AN ABSTRACT OF THE THESIS OF

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Title: Chemical suppression of a perennial ryegrass (Lolium perenne) living mulch and influence of ground cover management on growth of 'Chardonnay' wine grapes (Vitis vinifera) and Douglas fir (Pseudotsuga menziesii) Christmas trees.

Abstract approved: [signature]
Garvin Crabtree

A grass living mulch may reduce erosion, suppress weeds, improve trafficability, and maintain soil tilth in perennial cropping systems. Competition for water and nutrients limits the use of grass living mulches in many crops. Reducing grass growth may decrease the competitive effects of the grass. Studies were conducted to determine sublethal rates of postemergence herbicides for grass growth suppression, and to evaluate the growth of wine grapes (*Vitis vinifera* L. 'Chardonnay') or Douglas fir Christmas trees (*Pseudotsuga menziesii* (Mir.) Franco.) grown with various ground cover treatments.

In field studies in 1983 to 1984, 'Manhattan II' perennial ryegrass (*Lolium perenne* L.) was treated with low rates of fluazifop {(±)-butyl-2-(4-{[5-(trifluoromethyl-2-pyridinyl]oxy}phenoxy)propanoate}, fluazifop-P-butyl {(R)-butyl-2-(4-{[5-(trifluoromethyl-2-pyridinyl]oxy}phenoxy)propanoate}, sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one}, or glyphosate {*N*-(phosphonomethyl)glycine}. Compared to an untreated grass, a single, sublethal treatment of herbicide reduced grass growth for 5 to 7 weeks. Duration of grass growth suppression was shorter in spring compared to fall applications. Fall treatments caused greater grass injury. Adjuvants improved grass suppression activity of fluazifop and sethoxydim.

From 1984 to 1986, in 2 separate but identical experiments, grapevines or Christmas trees were grown in 6 ground cover management treatments (bare ground, mowed grass aisles, chemically suppressed grass aisles (fluazifop-P-butyl or sethoxydim), and 100% grass cover chemically suppressed (fluazifop-P-butyl or sethoxydim). In either crop, chemical suppression reduced grass growth more than mowing during a 5 to 7 week chemical suppression period.

Mowed or chemically suppressed grass aisle treatments reduced total vine length and cane pruning weights compared to grapes grown in bare ground. Grapevines grown in the chemically suppressed, 100% grass cover plots were stunted and chlorotic; pruning weights were 40 times lower than grapes grown in bare ground.

In 1985, ground cover management had no significant effect on Christmas tree growth. In 1986, canopy volume and terminal shoot growth of trees grown in mowed or chemically suppressed grass aisle treatments did not differ from measurements of trees in bare ground plots, but trunk caliper growth was greatest for trees in bare ground. Trees in the chemically suppressed 100% grass cover plots were stunted and chlorotic.

# Chemical suppression of a perennial ryegrass (Lolium perenne) living mulch and influence of ground cover management on growth of 'Chardonnay' wine grapes (Vitis vinifera) and Douglas fir Christmas trees (Pseudotsuga menziesii)

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Typed by Loretta K. Brenner and David C. Smith for Loretta K. Brenner

This thesis is dedicated to my mom,

Elizabeth Pauline Rogalewski

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# Chapter 1

## INTRODUCTION

Using clean cultivation or herbicides to eliminate all ground vegetation maximizes crop growth and yield, but also increases soil erosion, decreases organic matter, and deteriorates soil structure, ultimately decreasing crop production (4,18,32,59,91,114,130, 135,187). Cover crops, grass or legume sods, and natural vegetation are types of living mulches that have been used in ground cover management systems to enhance soil tilth, improve trafficability, and augment pest management practices (4,6,7,59,91,92,114,128,141, 142,172,181,187,188,224,228). The growth of any ground cover or living mulch must be carefully managed to reduce competition with the crop for soil moisture and nutrients.

The benefits and disadvantages of ground cover management techniques have been extensively studied in many tree fruit production systems (12,19,63,91,153,158,185,186,187,197, 207,221,222,223). Traditionally in orchards, trees are grown in bare ground rows, with perennial grass sods grown in the orchard aisles; growth of the grass sods is managed by mowing.

Chemical suppression or chemical mowing is the application of sublethal rates of herbicides or plant growth regulators to suppress the growth of the ground cover or living mulch, potentially reducing the competitive effects of the mulch. Chemical suppression of grass sods has been studied in perennial and annual cropping systems (12,15,16,46,58,69,88,90,108,149,176,1195,196,197,215,216,226,227), in pasture management (82,89,182), and as a substitute for mowing of turfgrasses on golf courses or along highways (52,64,71,113,183,192).

Crop growth with chemically suppressed living mulches can be comparable to crop growth and production with mowing or bare ground management, if the living mulch growth is sufficiently suppressed (15,46,69,90,149,197,200). The use of plant growth regulators or herbicides as chemical suppressants of living mulches is limited by potentially negative effects of some chemicals on crop growth and development, lack of commercial registration of these chemicals for food crops, and cost. Selective, postemergence grass herbicides provide grass weed control in many perennial crops without crop injury, but little is known about their grass suppression ability at sublethal rates.

In Oregon's Willamette Valley, wine grapes and Christmas trees are often grown on steep slopes with little or no ground vegetation, increasing the potential for erosion and runoff. Wine grape and Christmas tree growers are interested in adapting ground cover management strategies from other crops to improve their crop production systems. In the Willamette Valley, using perennial ryegrass as a living mulch is appealing because it establishes quickly, suppresses weed growth, has fair to good wear tolerance, is a bunch grass that does not encroach into the crop row, and is readily available (57).

The potential of sublethal herbicide rates for suppressing perennial ryegrass growth was evaluated by determining herbicide rates for grass suppression, length of suppression, seasonal differences in suppression activity, grass recovery, and seed head suppression. Fluazifop and sethoxydim, two postemergence selective grass herbicides, and glyphosate, a broad spectrum postemergence herbicide, were evaluated. The effects of adjuvants on the suppression activity of fluazifop and sethoxydim were also evaluated. The results of these trials were used to establish herbicide rates for chemical suppression treatments in perennial ryegrass living mulch experiments.

In two separate studies, the effect of various ground cover management systems on growth of newly established 'Chardonnay' wine grapes or Douglas fir Christmas trees was determined. Grapevines or trees were grown in bare ground, in bare rows with grassed aisles managed by mowing or chemical suppression, and in 100% grass cover, managed by chemical suppression. Differences in growth between mowed and chemically suppressed 'Manhattan II' perennial ryegrass were also evaluated.

# Chapter 2

# REVIEW OF THE LITERATURE

## I. Ground Cover Management in Perennial Cropping Systems

Ground cover management in perennial crop plantings can be accomplished through cultivation, mulching, herbicide treatment, cover cropping, or through a combination of these methods. Cultivation can eliminate weeds and incorporate cover crops and is an important alternative to herbicides. Cultivation can also damage the shallow feeder roots of trees and other perennial crops, destroy soil structure, increase erosion, and limit field traffic when the soil is wet; cultivation is also energy consumptive (91,181,187).

Mulches of straw and other organic and synthetic materials act as barriers to weed development, conserve soil moisture, prevent compaction, moderate soil temperatures, reduce erosion, improve soil tilth and organic matter. Improved yields and growth of crops grown with mulches in or between the crop rows have been reported for tree fruits (91,187); grapes (29,162,190); and conifers (188). Disadvantages to mulching include reduction in available nitrogen (from organic materials with high carbon to nitrogen ratios), increased tree damage from mice, voles, and gophers (62), and higher potential for frost damage in tree and vine crops (91); mulches may also be cost-prohibitive.

Many growers adopted total ground cover elimination with the advent of herbicides in the 1940's and 1950's (18,187,197,200). Herbicide management can maximize crop growth and yields by eliminating ground cover competition primarily for available soil moisture and nutrients (18,91,187,197). Root distribution of apple trees grown in overall herbicide treated plots is more uniform and extends over a greater area than for trees grown with a cover crop or with permanent sod aisles, improving nutrient and water uptake (18,19). Overall herbicide management is considered less labor intensive than other ground cover management systems, but both water and wind erosion can be more destructive to soils devoid of ground cover (20,30,79,200). When the ground is bare, trafficability is restricted during wet field conditions (20) and splashing soil can reduce crop value and spread diseases (91). Other drawbacks to complete herbicide management are: increased soil compaction, reduced water infiltration, increased bulk density, soil acidification, and lower soil organic matter (18,83,91,130,142). Reliance on specific herbicides may increase the population of resistant weed biotypes or create weed shifts to other undesirable weed species (43,129).

Management of grass and legume cover crops and permanent or perennial sods, once a common practice in orchards and vineyards (114,139,141,148,172,181) is again being studied and recommended in crop production systems (30,44,79,91,138,143,162,185,187,207,218, 219,223). Cover cropping usually refers to a ground cover that is grown and incorporated into the soil before a crop is planted or initiates growth. When annual or perennial ground covers are managed between the crop rows, during the period when the crop is growing, they are often referred to as living mulches. Benefits of cover crops and living mulches include: reduced runoff and soil erosion, reduced wind injury (154), improved water infiltration, increased soil organic matter, improved physical condition of the soil, soil nutrient replenishment and reclamation, suppression of weed germination and growth (212), and enhanced habitat for beneficial microbes, insects, arthropods, and earthworms (7,79,91,138,167,187, 228).

Cover crops and living mulches are usually grown in the aisle between the crop rows, but may also be grown over the entire planting area. Living mulches, because they are growing with the crop, must be carefully managed to avoid interference with crop growth and yields due to competition for soil moisture and nutrients, allelopathy, and shading. In addition to reducing crop growth and yields, other drawbacks to living mulch and cover crop management are: improved habitat for crop pests, diseases, weeds, and rodents; greater danger of frost damage due to cooler radiative temperatures; and reduced area for crop rooting (19,79,91,187,228).

Many types of cover crops and living mulch systems exist including: annual winter covers, self-reseeding annuals, natural vegetation and weeds, and permanent, perennial grass or legume sods. Annual winter covers, or green manures, are grasses or legumes, or combinations of the two, that are usually seeded in late summer or early fall, grown over the winter, then disked-in or cultivated in early spring to minimize cover crop use of soil moisture (79). Other winter covers may die naturally from frost, requiring minimal incorporation (30). Green manures can also be grown in the early spring then plowed under to provide organic matter and nutrients before planting the crop.

Self-reseeding annuals, such as 'Blando' bromegrass (*Bromus mollis*) and annual bluegrass (*Poa annua* L.), are planted once, grow in the fall and winter, then set seed and senesce in summer until fall rains stimulate seed germination and the cycle is repeated (79).

Many perennial grasses and legumes have been studied and recommended as perennial living mulches, but most common in orchards are perennial grass sods. Growth of the grass is usually managed by infrequent mowing or flailing during the growing season; using plant growth regulators or herbicides to reduce sod growth have also been studied and will be discussed later (30,79,223,229).

Non-traditional ground covers, using weeds or natural vegetation, may also be managed as a living mulch, with growth controlled by mowing or flailing, or with chemicals. Hazelnut growers in the Pacific Northwest use this technique, and researchers are studying the use of less competitive weedy ground covers such as the native grass nimblewill (*Mulenbergia schreberi* J.F.Gmel), or blackberry (*Rubus* spp.), to replace grass sods in North Carolina apple (*Malus domestica Borkh.*) orchards and in conifer plantings (185,186,188).

Combining ground cover and herbicide management is a common practice both in tree fruit and grape production systems, offering the benefits of both management systems. Weeds and other vegetation in the tree row are eliminated with pre- and postemergence herbicides, and a living mulch (typically a perennial grass sod) is grown in the aisle between the tree rows. In orchard production, this technique is referred to as herbicide strip, grass aisle, permanent sod, or living mulch management. This system can reduce the amount of herbicides used in the planting while benefiting the soil and ultimately the crop.

Herbicide strip management reduces ground cover competition for water and nutrients, but does not necessarily eliminate it. To minimize competition and interference, and to maintain crop growth and yields, a sufficient bare ground area must be maintained in the crop row, and the living mulch in the aisles must be managed by mowing, flailing, herbicides, growth regulators, or other means.

Despite the disadvantages, cover crops and living mulches offer substantial benefits in both annual and perennial cropping systems. Refining living mulch management techniques will enable growers to produce healthy and productive crops while sustaining and replenishing the soil.

## II. Soil Factors Affected by Living Mulch Management

Compared to grass sod, bulk density of the soil increases with overall herbicide management (91), with the greatest effect in the surface soil, (18,142). Conversely, cultivated soils have decreased bulk density, at least initially (91). Soil porosity is higher in cultivated soils, but overall herbicide managed soils may have been found to have both lower (91,92) and higher porosity (18,20) than soils under grass sod aisles. Soil crusting tends to be greater in the surface soils of cultivated and herbicide managed orchards, decreasing water infiltration and subsequently increasing runoff and erosion (4,5,91,142). Generally, the long term affect of grass sod is improved soil structure, infiltration, and aeration due to microbial chemical activity, earthworm tunnels, and plant roots (91). Welker and Glenn (222), investigated soil factors under a killed tall fescue sod in a peach orchard. With the killed sod they report increased water infiltration, macroporosity, and microbial respiration rates compared to cultivation and herbicide treatments.

Soil organic matter improves soil structure, fertility, and water holding capacity (91). Permanent grass sods increase the amount and stability of soil organic matter compared to herbicide treated or cultivated soil (20,91,222). Proebsting (167), however, found no increase in organic matter or water holding capacity with 25 years of cover cropping, probably due to rapid oxidation of the organic matter under high temperatures and inadequate soil moisture; soil structure and water infiltration did improve. Cultivation tends to redistribute the organic matter, and levels may be lower in the surface, but higher in the subsurface soil profile (91). Aggregate stability, a component of soil structure, is higher with a grass sod than cultivated, herbicide treated (91,92), or killed sod (222).

Results of a grower survey by Atkinson and White (17) indicated that less than half of the apple growers who switched to overall herbicide management (bare ground) had difficulties driving in the orchard. Growers who did have difficulty reported problems at harvest, usually in wet years. Sod covers may permit machinery operations under wet soil conditions, but soil compaction can be as severe with sod management as with overall herbicide management. In one study, soil under permanent grass had greater compaction, partially due to the increased traffic in orchard from mowing (130).

In herbicide treated soil, acidification occurs resulting in a lower pH than soil under a grass sod aisle (20,91,94,130). This decrease in pH is a result of leaching of the exchangeable bases from the topsoil (91). Lipecki et al. (130) reported a higher pH in compacted soils managed with either herbicide or grass sod.

When grassed sod aisles are managed by mowing and clippings are left to decompose, cycling of nutrients, especially phosphorus (P) and potassium (K), can occur (96). Phosphorus and potassium levels are highest in herbicide treated surface soils, intermediate in grassed strips, and lowest in cultivated soils, a result of soil compaction (96) and low water infiltration (91). In an apple orchard, Atkinson and White (20), found an increase in P concentrations only in soil from herbicide treated plots. Soil nitrate nitrogen and sulfate were lower with grassed as compared to cultivated or herbicide treated apple plots, but calcium (Ca) and magnesium (Mg) levels were higher, probably due to nutrient cycling (96).

## III. Effect of Ground Cover Management on Crop Growth

### 1. Shoot growth

Ground cover management in perennial crops has been most widely studied in tree fruit production systems. Less information is available about ground cover management in vineyards or in conifer plantings, but specific references for these crops will be included whenever possible.

Interference from unchecked growth of grass, legume, and natural or native ground covers reduces growth and yields in fruit tree, conifer, and grape plantings, usually through competition for water and nutrients. Several reviews describe the effects of ground covers and management on annual and perennial crop growth (18,58,65,91,107,154,156,187,204,227,228,233). Negative effects of ground covers on tree and vine growth are reported as tree mortality and reductions in: tree height, vine length, stem or trunk diameter or circumference, shoot elongation, branches per node, and terminal extension, dry weight, root growth, and total biomass in conifers (54,61,127,188,219), grapes (65,147,162,190,204,205,232,233), and tree fruits (123,133,185).

Typically, tree growth increases as the bare ground area in the tree row increases (12,13,18,153,178,185,197,200,221,229). In planting conifers for forestry purposes, scalping (mechanically removing) the existing vegetation and soil provides a vegetation-free area for seedling establishment thereby increasing seedling survival and growth (39,131,191). Kittams and Ryker (117) report 30% more growth in Douglas fir (*Pseudotsuga menziesii* (Mir.) Franco.) seedlings on scalped compared to unscalped plots, but scalping can also reduce tree growth by removing nutrients when the top soil is removed (24). Site preparation is essential to survival and growth of newly planted seedlings for reforestation; other methods of site preparation include: burning brush and weeds before replanting (25), cultivating before and after planting, and herbicide treatment with pre- and postemergence sprays (24,55,56,230). Reducing weedy ground vegetation using herbicides improves tree survival and increases height, shoot growth, and stem diameter in conifer stands (24,53,66,165,191,225). Herbicides must be used judiciously; both timing of application and herbicide rate influenced the degree of phytotoxicity observed in plantings of Norway spruce (*Picea abies* (L.) Karst.), Fraser fir (*Abies fraseri* (Pursh) Poir.), and Canadian hemlock (*Tsuga canadensis* (L.) Carriere) treated with glyphosate (151).

Cultivation is generally thought to be injurious to surface roots of fruit trees (178,209), but several authors found tree growth in cultivated treatments equalled growth in herbicide treatments and increased growth compared to treatments with ground vegetation, especially in young tree fruit plantings (123,133,144,185,222).

The greatest reductions in growth occur when the ground cover is growing up to the base of the tree trunk, such as apple trees planted in pasture (26) or overall grass (34,86,144,200). Similar reductions in tree height, volume, shoot growth, and trunk diameter are reported for sugar maple (*Acer saccharum*), black walnut (*Juglans nigra*), ornamental tree species (152,208,235), and in fir, spruce, and pine (*Pinus* spp.) (54,164,219,225). Eastern hemlock (*Tsuga canadensis* L.) are shorter, with smaller stem diameter when grown in orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.), and Kentucky bluegrass (*Poa pratensis* L.) compared to mulched, cultivated, and bareground treatments (188). Eastern white pine (*Pinus strobus* L.) responded similarly to the grass treatments, but white pine height was not significantly different with cultivation compared to Kentucky bluegrass treatments (188). Tree height in conifers may not be as sensitive to ground cover effects as trunk or stem diameter (219).

Studies by Lewis (124) and Lewis, et al.(126) indicate that slash pine (*Pinus elliotii* Engelm.) may be successfully grown in bermudagrass (*Cynodon dactylon* (L.) Pers.) pastures, when the pasture is mowed for hay and fertilized regularly. The slash pines in pasture produce more wood than trees in native unfertilized vegetation and cattle can graze on the land, providing the landowner income until the pines mature (125).

Organic mulch in the tree row increases tree growth of grapes, fruit trees and conifers compared to bare ground or ground covers (29,133,162,185,188). Black plastic mulch increases growth of slash pine or Douglas fir in the first and second year after planting (127,210). Grapes grown with black plastic mulch or with glyphosate treatments had higher grape yields in the first 2 years of production compared to grapes grown in grass sod (190).

Peach (*Prunus persica* (L.) Batsch.) trees had the greatest growth and fruit yield when grown in a killed tall fescue sod, compared to cultivated, herbicide treated, or mowed sod (221,222,223). Heidmann (100) reported increased Ponderosa pine (*Pinus ponderosa* Dougl.) survival when grown in a dead grass mulch; soil moisture was also higher.

Moss growing in herbicide treated bare ground plots had no deleterious effects on apple tree growth, and provided good conditions for machinery passage (178), and prevented weed establishment and soil erosion (178,200).

The optimum width of the bare ground strip when crops are grown with a living mulch appears to be crop and ground cover specific. Elimination of a minimum of two-thirds of the total grass and weed cover within 6 ft of young apple trees to allow optimal tree growth has been suggested by Stiles (193); Atkinson and White (18,19) suggest in many soils a herbicide strip 2 M wide will provide all the nutrients required by newly planted trees for several years. Peaches grown for 4 years in an unirrigated, mowed tall fescue sod in vegetation-free squares ranging in size from 0.36 to 13.0 $m^2$, had increased tree growth, leaf nitrogen, and fruit yield as the size of the bare ground area increased (223). The greatest increases in yield and growth occurs with a bare ground area from 0.36 to 9.0 $m^2$ (0.6 to 3.0 m wide strip), with growth increases levelling off after 9.0 $m^2$. Newly planted peach trees also had greater tree height, canopy width, and trunk diameter as the bare ground area increased (221,222).

Height and dry weight of eastern white pine are no different in 100% bare ground (herbicide managed) from trees grown in a 3 ft. wide herbicide strip, but Scotch pine (*Pinus sylvestris*) growth is better in the herbicide strip treatment (101). Maximum stem diameter of Norway spruce occurs with a bare tree row, regardless of interrow ground cover (different combinations of grasses and forbs), but Fraser fir achieves maximum stem diameter with complete ground cover elimination using herbicides (219). Methodologies for studying interference and competition of ground vegetation with forest tree species have been suggested for determining the optimum level of vegetation management necessary for optimum tree growth (140,171).

## 2. Root growth

Another consequence of herbicide strip management is limitation of tree root growth and mineral nutrient uptake to the herbicide strip area (18,19,158,197,223). With young apple trees, 70% of the new root occurs in the herbicide strip area, and roots growing in the grass strip grow deeper than roots in the herbicide strip (10). Roots of grapes (*Vitis vinifera*) (132,147) and conifers (219) are also more prevalent in the herbicide strip, and root growth is deeper under grass than under bare ground. In a greenhouse study, root initiation of uncallused grapevine cuttings was inhibited by perennial ryegrass, possibly due to allelopathy (65).

Under the grass strip, apple tree root weight and density is reduced, and rooting depth is increased (10,13,18,19). Density of apple tree roots is 1 to 20 $cm/cm^2$, compared to grass roots that have roots density values up to 5000 $cm/cm^2$, which may help account for the competitive advantage of many grasses (13). With apple tree roots, grass competition increases the ratio of lateral roots (short length, short-lived roots) to extension roots (longer, permanent roots) (13). Grasses can reduce permanent root length of apple trees, but the total apple root length can be higher under grass than with overall herbicides, due to increases in the lateral roots.

Sycamores (*Acer pseudoplatanus*) grown with perennial ryegrass

(*Lolium perenne* L.) have decreased root growth rate, shortened period of active growth, reduced density of root hairs, and restriction of rooting depth and lateral spread (175). Grass roots start growing 3 weeks earlier than tree roots, and have greater surface area for nutrient and water absorption (175).

Young apple trees initiate root growth earlier in the season under bare ground than under grass (10).

Studies with Ponderosa pine seedlings reported grass roots growing 50 times faster, with greater dry weight, and faster drought recovery than pine roots (121). With Norway spruce and Fraser fir, tree roots are confined to the bare row when a cover is present; maximum tree root growth of both tree species occurs with a bare row, regardless of the ground cover in the interrow (219).

### 3. Crop yield and quality

Ground cover management also affects crop yield and quality. Fruit trees grown with total grass cover usually have lower yields than cultivated orchards (33,34,60,95,123), trees grown in herbicide strips (26,83,111,133,144,197,200,221,222,223), or overall herbicide managed orchards (18,197,200). Robinson and O'Kennedy (178) report lower fruit yields in grassed apple plots compared to overall herbicide treated plots, but higher yields compared to trees grown in cultivated plots. Atkinson and White (18) report than a change from a wide herbicide strip to overall herbicide management increased apple yields by 32%. Grass ground covers reduce fruit tree yields more than trees grown in white or strawberry clovers (34,197,200).

Fruit yield and quality are influenced by many factors, and effects on crop yield due to ground cover effects can be inconsistent from year to year (87,111,144,158,159,178,197).

In overall herbicide treated orchards, early vigorous tree growth establishes strong limb structure and fruiting wood thus increasing fruit yields (197). Trees may never recover from effects of early competition; fruit yields in older trees may continue to be depressed after the ground cover is eliminated, or after reductions in trunk diameter cease (32,178,197). Fruit quality in apples was still affected by ground covers, though to a lesser degree, after 15 years of the study (87). In another study, however, pears (*Pyrus communis* L.) grown with an alfalfa (*Medicago sativa* L.) sod had lower yields than trees in cultivated plots for the first 12 years, but after that the trees in the sod plots had higher yields and were larger than the cultivated trees; bluegrass sod had replaced the alfalfa 6 years after the initial seeding suggesting increased soil moisture conservation with the bluegrass sod compared to alfalfa (209).

Ground cover management also affects fruit quality. Apples grown in overall grass or grass strip plots are generally smaller and more highly colored (redder), an effect of decreased nitrogen (N) and increased potassium levels in the fruit and foliage (34,95,111,144,153,197,200). Fruit size is reduced by weed, grass, and clover covers compared to cultivated treatments; ryegrass plots have smallest fruit with best color, fruit from clover plots has high nitrogen levels, largest fruit, and worst color, and weeds were intermediate (34). Although fruit quality may be diminished in overall weed-free (herbicide) treatments, increases in total yield offset the increase in culls, providing a higher good fruit percentage than in grassed plots (197).

Increased levels of K and Ca, and reduced levels of N in fruit grown with overall grass or grass strip management, can increase fruit firmness and prolong storage life (153,200). Johnson and Johnson (111), however, found greater senescence and low temperature breakdown in fruits from overall grass with low calcium (Ca). Due to higher percent of soluble solids and a higher titratable acidity, fruit from grassed plots are of higher eating quality (87,95). Although Johnson and Johnson (111) found incidence of bitter pit reduced in fruit in herbicide strip management or with increased N applications, other authors report no interaction between ground cover treatments and bitter pit (200), or increases in storage disorders with high fruit nitrogen levels (197). Ground cover treatments did not influence peach yields or quality in the first 5 years of fruiting, except in the second year cultivated trees produced larger fruit than sod cover (123).

Effects of ground cover treatments on apple fruit set are variable. Robinson and O'Kennedy (178) report fruit set is highest in grass plots and lowest with overall herbicides, herbicide strips, and cultivation, but fruit set in overall herbicide plots varied from low to high in different years. Baxter and Newman (26) and Stinchcombe and Stott (197) found increased fruit set with overall herbicide treatments versus overall grass or grass strips.

Grass living mulches may compete for late season nitrogen and soil moisture thus improving grapevine maturation (1). Lombard,et al. (132) reported that grape shoot growth, vine yields, and cluster numbers were reduced by a perennial ryegrass ground cover compared to bare ground. Grass slightly reduced grape leaf and petiole nitrogen, but grass species may determine the relative influence. Grass cover had no affect on berry composition including, Brix, titratable acid, pH, and anthocyanin content (132,233). Irrigating grapevines decreased Brix, phenolics, and anthocyanin pigments, and increased acidity in the berries, with or without a grass living mulch (233). Tan and Crabtree (205) reported reductions in grape leaf nitrogen, iron, sulfur, calcium, boron, and manganese with a perennial ryegrass living mulch; mowing the grass did not alleviate these reductions. Soluble solids in grapes were increased by an unmowed perennial ryegrass living mulch (204).

## 4. Water use

Living mulches may increase water infiltration and decrease runoff, but living mulches can deplete soil moisture reserves, reducing the amount of water available for crop growth. Skroch and Shribbs (187), state that mulching provides the greatest soil moisture availabilty, followed by bare soil, minimal cultivation, grass cover, legume cover, and continuous cultivation. Shribbs and Skroch (185) studied the effects of 12 ground cover systems on young apple tree growth, and found best growth with mulching, bare ground, or cultivation. Stott (200), reported best apple tree growth with bare ground, but found that tree growth in unmowed 'Kent' wild white clover (*Trifolium repens* L.) plots sometimes equalled that of trees grown in bare ground, and concluded that water competition was not as critical as nutrient competition, except on drier sites. Soil moisture deficits between an overall ground cover of strawberry clover (*Trifolium fragiferum* L.) or white clover were not significantly different from a mowed or chemically suppressed grass sod aisle; clover plots yielded more apples, but fruit was small and green (203).

Grass living mulches can reduce tree performance, but competition for water is decreased with frequent mowing or use of plant growth regulators (PGRs) to suppress ground cover growth (12, 14,17,18,86,180).

Depletion of available soil moisture in herbicide strip systems is greater and occurs earlier in the season than with overall herbicide management (bare ground) (11,21,19,233). Available soil water was completely depleted (at 25 cm) in mid-July in a grass sod aisle, at the end of the season in the herbicide strip, and never in the overall herbicide plots; early season soil moisture deficits were two times greater with grass than overall herbicide management (11).

Growth and yield of peach trees was better in a killed tall fescue sod, than trees grown with overall herbicide, cultivation, or mowed sod, due to increased water infiltration rate, more organic matter, improved aggregate stability, and moisture conservation (83,222).

Soil moisture in a grapevine row was not reduced by perennial ryegrass sod aisles in mid-July compared to overall bareground, but soil moisture measured in late July and September in the row aisles was significantly decreased by grass sod compared to bare ground (204). Irrigation increased grape shoot growth and vine pruning weights with or without a perennial ryegrass sod, but grape shoot growth was less when grown with the grass sod (233). Wilson (233) found the maximum difference in water use of the grass strip and bare ground occurred by July, when water was still plentiful in the soil. Greater soil moisture depletion occurred in the inter-row versus the in-row area of the overall herbicide plots late in the season, possibly due to differential soil heating of the inter-row area, or to renewed grape root development in the inter-row area (233). Kobayashi,et al (118) reported that the lower the soil moisture level, the greater the reduction in grapevine shoot elongation, vine weight, bloom, fruit set, and fruit size.

Information on ground cover competition for soil moisture in conifer plantings parallels information on ground covers competition in orchards (67,149,165,188,219).

In plantations of firs, spruce, and pine, grasses have been implicated as severe competitors for soil moisture (24,61,66,99,102,103,165,206). Soil moisture in dead brush (herbicide treated) plots and clear cut plots was similar and adequate throughout the season, but in living brush plots soil moisture loss was two times greater at a soil depth of 10 to 14 inches, and three times greater at 20 to 24 inches, than the non-vegetated plots (206). Increases in conifer survival with herbicide management may be due to reductions in moisture stress (24,66,165,170), or increased nutrient availability (53,66). Eissenstat and Mitchell (67) concluded that water was not the only, nor the primary limiting factor in their study of Douglas fir seedling growth. They suggest that nutrient and water interactions, allelopathy, or cold injury is more limiting, at least in the early years after tree planting.

Other researchers have found no significant differences in conifer growth due to ground cover management. Growth of Scotch or white pine in herbicide strips with grass aisles was not significantly different from trees grown with overall herbicide management (101). Similarly, Murray (149) reported no differences in first year growth among Douglas firs grown in herbicide strips with mowed, chemically suppressed, or unsuppressed grass aisles, and herbicide treated bare ground plots, but bareground plots and suppressed grasses used 61% and 9% less water than unsuppressed grasses, respectively.

**5. Nutritional factors**

Ground cover management systems affect nutrient availability and content in the soil, and consequently the nutrient status of the tree or vine. Soil nutrient effects have been previously discussed, therefore this section will focus on crop nutrient responses. Nutritional effects of ground covers on crops have been reviewed for tree fruit (63,65,91,187,233), grapes (65,233,204), and conifers (149,150,188,217,218).

Crop responses to ground cover nutrient competition is variable and difficult to study due to different nutrient and moisture requirements of ground covers, changes in ground cover biomass and composition, seasonal responses, nutrient cycling, and a host of other biotic and abiotic factors. The need to study nutritional changes over several years, and with different ground covers is emphasized by Goh and Haynes (84), Perring (158,159), Shribbs and Skroch (186), and Warren, et al. (217,218).

The most consistent effect of grass ground covers on tree fruit nutrition is a reduction in leaf N levels (12,36,34,33,91,95,153, 186,200,221), shoots (186), and fruit (91,95,200). Conifers and deciduous trees exhibit a decrease in nitrogen in needles or leaves with ground cover competition (54,72,150,152,188,217,218). Grape leaf and petiole N can also be reduced with grass competition (1,132,205). The effect of ground covers on the N levels in conifers and grapes can be inconsistent from year to year (132,164,188,217).

Reductions in growth and yield of the crop usually accompanies decreased N levels in tree fruits. With conifers and other forest trees reductions in growth may (72,150,152,164,188,217) or may not be (188) associated with low N; grape response is also varied (132,190,232,233). Even with herbicide strip management, grass growth needs to be managed to reduce competition for N with fruit trees and conifers. Apple tree root growth and nutrient uptake occurs mainly in the bare ground strip in the tree row (12,18,19,21), with the area of nutrient uptake increasing as the bare ground area increases (10). In high-density apple plantings, nutrient uptake under the grass strip is increased relative to nutrient uptake from within the tree row (12,13). Roots of fruit trees (10,13) and grapevines (132,147) grow deeper under grass sods, influencing the soil area available for nutrient and water uptake. Roots of Fraser fir are confined to the herbicide strip when vegetation is in the aisle, also affecting the area of nutrient uptake (217).

Frequent and close mowing of the grass aisles may reduce grass N use thereby decreasing competition with the crop (60,85,180), but other authors report that even frequent mowing may not compensate for grass N use (26,144). Tan (204) found that both mowed or unmowed perennial ryegrass sod decreased grape leaf N, but a high rate of N fertilizer compensated for the reduction in N caused by sod competition. Apple trees grown with chemically suppressed or mowed grass had higher N levels than unmowed grass, but lower N levels than trees grown in overall herbicide plots (197,199,200). Grass or weed ground covers can indirectly decrease N uptake in conifers by decreasing soil moisture content, thus limiting the movement and uptake of mobile ions (150). Crop moisture stress induced by grass competition may also reduce N uptake by the tree crop (188,197).

Although grass competition for N produces negative effects on crop growth, apple fruit quality may be enhanced, mainly from improved skin color and increased firmness (111,153,197,200). High juice N levels in apples grown in bare ground or clover plots reduces cider quality (200). Unirrigated 'Pinot Noir' wine grapes grown with a perennial ryegrass sod strip had lower yields and cluster weights but improved berry quality than irrigated grapes without grass

(232,233). Lombard, et al.,(132) reported no improvement in berry quality factors (soluble solids, titratable acid, pH, and anthocyanin content) of winegrapes grown in a perennial ryegrass sod, although yields were reduced by 16%. They suggested that a wider grass strip or more competitive grass species might have more influence on berry quality. Juice and winegrapes in eastern Washington are grown with grass cover crops or permanent sods. The grass covers compete with the vines for N and water in mid-August, improving vine maturity and cold hardiness (1). Conifers are usually chlorotic and stunted with deficiencies of N, which reducing market quality (150,188).

Trees or vines grown with grass ground covers may need supplemental N, but the amount of additional N required varies with the crop and ground cover system. Apples grown with overall herbicide management, with no addition of N fertilizers, used large amounts of N (up to 360 kg/ha/yr) with development of only a slight N deficiency (18).

Bould and Ingram (33) report that Nitro-Chalk fertilizer applied at 750 kg/ha almost compensated for N competition from a grass sod in a plum orchard, and Baxter and Newman (26) reported that 400 kg/ha of N would be needed to overcome yield reductions from N deficiency of apple trees grown in a grass pasture. Tan (204) found that a high rate of urea (274 kg N/ha) compensated for N reduction in grape leaves caused by grass competition. Additions of N fertilizer may actually increase grass growth and N use at the expense of tree growth (26,54,152,204). Satisfactory production of 'Elberta' peaches was attained by adding 1 kg N/tree to trees growing in a permanent orchardgrass sod (166).

Neilsen, et al.,(153), reports that N nutrition is affected more by vegetation management than by N fertilizer applied to 'Golden Delicious' apples grown in permanent grass sod, bare ground, or with a temporary grass cover crop. Although trees grown in bare ground maintained adequate leaf N (greater than 2%) and best growth with only 30 kg N/ha, trees in sod plots required 180 kg N/ha to maintain adequate leaf N, with no increase in tree growth. Trunk diameter did not increase consistently with high rates of N fertilization for any treatment.

Similarly, Miller (144) reported that neither rate nor source of N fertilizers influenced growth or yield efficiency of 'Topred Delicious' apples grown in a mowed tall fescue sod, herbicide strip or cultivated plots. No differences in growth were observed the first year of planting, suggesting that tree vigor and N reserves in the planted tree affect initial tree growth. After the initial year of planting, however, N fertilizer did increase growth of trees grown in the sod plots, but not of trees grown in herbicide strips or with cultivation. Trunk diameter and terminal growth was lowest in the sod plots, but in the fourth and fifth years after planting terminal growth was not different among treatments.

Cluster and pruning weights of irrigated 'Foch' grapes were reduced by grass sod compared to overall herbicide and plastic mulch, but N fertilizer treatments had no measurable effects on the grapevines (190).

Applications of N fertilizer to black walnut grown in a bluegrass sod increased growth in the first and second years by 57% compared to unfertilized sod (152). Nitrogen fertilizer combined with an application of glyphosate at the base of the trees increased growth by 92% and 77% in the first and second years, respectively. Although N was applied at 300 kg N/ha (250 lbs/A), the authors speculate that half that amount was used by the grass.

Most often tree nutrient studies demonstrate the effect of grass ground covers on tree nutrient uptake, but the effects of non-grass ground covers have also been evaluated. Stott (200), evaluated apple tree nutrition in overall clover management, overall grass, herbicide strip, and bare ground. Trees grown in white clover had higher N, P, and K leaf concentrations than grass sod, and only slightly lower growth and yields than trees grown in bare ground, even in a dry year. Bould and Jarrett (34) found trees grown in clover had higher leaf N and P levels, but lower K.

Shribbs and Skroch (186), studied the effect of 12 different ground cover systems on growth and nutrition of 'Smoothee Golden Delicious' apple trees, and found N competition from grasses and tall broadleaves a major factor in tree growth and nutrition. Leaf N levels were higher in trees grown in mulch, bare ground, cultivated, legume, and blackberry treatments, than trees grown in bluegrass, tall fescue, orchardgrass, wheat (*Triticum aestivum* L.), and tall broadleaves. Trees grown with red sorrel (*Rumex acetosella* L., a low-growing broadleaf) and nimblewill (a native grass) covers had intermediate leaf N levels.

Beattie (29) found that mulching 'Concord' grapes with straw increased N in the leaf petioles by 30% compared to grapes grown with a cover crop and cultivation; yields and cane pruning weights were also higher.

Skroch, et al. (188) evaluated growth and market value of eastern hemlock and eastern white pine when grown in 10 different ground cover systems. Nitrogen concentration in eastern hemlock was correlated with tree height, and was greater in straw mulch and bare ground, than in orchardgrass or tall fescue plots. With eastern white pine, N concentration was not significantly different among the treatments, although mulched white pine had greater height, stem diameter, and market value than trees in tall fescue.

Unlike N, levels of phosphorus (P) and potassium (K) in tree leaves usually increase with increasing grass competition (33,36,84,91,153,159,186,187). With a N deficiency, tree leaf growth is reduced, causing relative increases in levels of other nutrients such as P and K, creating a concentration effect (34,91,186). Shribbs and Skroch (186) found that, although apple trees grown in mulch, bare ground, and blackberrry plots had higher leaf concentrations of N, and lower leaf concentrations of P and K than trees grown in grass or tall broadleaf plots, twig concentrations of N, P, and K were all lower in the grass and tall broadleaf plots.

Increased soil moisture competition induced a concentration effect with P and K in needles of eastern white pine and eastern hemlock or tree fruits grown in grass (91,188). Increases in leaf P and K in trees grown in sod may also be due to cycling of these elements from grass clippings, which reduces nutrient leaching and keeps the elements in available form (35,84,91). Goh and Haynes (84), found that grass clippings constitute two-thirds of the N and K reserves in an apple orchard.

Shribbs and Skroch (186) suggest that high leaf P concentrations and good tree growth of apple trees grown with red sorrel indicate possible mycorrhizal associations. Reich (173) found at high fertility levels, perennial ryegrass increased leaf P concentration in potted apples trees in the presence of mycorrhizae, but at low fertility levels the grass affect was negligible.

Ground cover effects on tree nutrition are more variable with nutrients other than N. Stinchcombe and Stott (197) found no difference in N or K levels of apple trees grown in overall grass (mowed), herbicide strip (grass chemically suppressed), overall white clover, overall weed-free, but P was higher with grass and clover treatments. Bould and Jarrett (34) found increased levels of leaf N and P in apples grown in white clover, but lower K than in grass plots. In apples, leaf N was decreased with grass, K concentration was higher, and P and other nutrient levels were not affected (18).

Perring (159) found higher levels of P in apple fruit grown in wide herbicide strips. Best P uptake occurs in surface soils, but tree roots grow deeper under grassed aisles limiting P uptake. In a ten-year study of apple tree nutrition, levels of fruit P were reduced with high rates of N, increased with grass cover, and reduced in some years by overall herbicide management (159). Similarly, herbicide management and N fertilization improved N uptake, but decreased P levels in apple leaves (111). Grass had no effect on total leaf P of apple rootstocks grown in pot culture, contrary to results of field studies (35).

Straw mulched 'Concord' grapes had higher concentrations of N, P, K, and manganese (Mn), and lower levels of calcium (Ca) and magnesium (Mg), compared to cover crop and cultivated treatments (29). Pool et al. (162) also reported higher concentrations of K and deficient levels of Mg in mulched 'Concord' grapes, compared to sod, cultivation, or herbicide treatments. No differences in K or Mg levels were found among the sod, cultivation, herbicide treatments.

Warren, et al. (217) evaluated nutrients concentrations and seasonal nutrient patterns of Fraser fir and Norway spruce grown in 7 different management systems (100% grass to bare ground). Nitrogen levels in both conifer species, during active conifer growth, is positively correlated with ground cover biomass, but during conifer dormancy N is negatively correlated with amount of ground cover biomass. This suggests that N uptake does not keep up with tree growth, presumably because of N competition from the grass cover.

In grass plots, levels of Ca in the leaves and fruit of trees were higher (96,158), lower (111) or not different (153,186) than bare ground plots. Shribbs and Skroch (186) found leaf N negatively correlated with leaf P and K, and positively correlated with Ca, Mg, copper (Cu), and zinc (Zn) concentrations.

Decreased levels of Ca and Mg could pose physiological problems for fruit trees (93,94). Trees grown in grass produced low Ca fruits, and were more susceptible to senescence and temperature breakdown (111). Bitter pit was decreased with N fertilizers and in herbicide plots. (111). With grass sod, increased fruit Ca was associated with smaller fruit in two years (153).

Although Haynes found higher levels of Mg and Ca in the soil of grassed plots due to less leaching (93,94,96), Shribbs and Skroch (186) found no difference in soil levels of P, Ca, Mg, Mn, Zn, or Cu among 12 different ground cover systems.

## IV. Grass Living Mulches

### 1. Turfgrass growth and development

Many turfgrasses are well-suited for use as living mulches, especially when a perennial mulch is desired. Turfgrasses are referred to as being either cool-season or warm-season grasses; optimum temperature for growth of warm season turfgrasses is between 27 to 35 degrees C, and for cool-season turfgrasses from 15 to 20 degrees C (27). Cool-season grasses thrive in the Willamette Valley, where as warm-season grasses do not. Perennial ryegrass, tall fescue, red fescue (*Festuca rubra* L.), hard fescue (*Festuca ovina* var. *duriuscula* L. Koch), chewings fescue (*Festuca rubra* var. *commutata* Gaud.), sheep fescue (*Festuca ovina* L.), colonial bentgrass (*Agrostis tenuis* Sibth.), and annual bluegrass are cool-season grasses that grow well in the Willamette Valley climate and are readily available (30,57). The characteristics and management of these and other grasses have been reviewed by several authors (27,30,44,57,65).

Perennial ryegrass has characteristics favoring its use as a living mulch. It is quick to establish, can germinate within 5 to 8 days, and forms a dense cover (57). Rapid growth enables perennial ryegrass to effectively compete with certain weeds, particularly annual weeds (57). Perennial ryegrass grows as a noncreeping bunchgrass, meaning it grows in clumps and does not spread by stolons or rhizomes. Bunch type grasses do not invade into the rows of the primary crop, and are easier than creeping grasses to maintain as living mulch aisles (57). Although wear tolerance of perennial ryegrass is good compared to other cool-season grasses, it has poor recuperative ability because it is a bunchgrass and cannot spread to bare areas by rhizomes or stolons. The wear tolerance of cool-season grasses is variable, but in one study 'Manhattan' perennial ryegrass was the most tolerant (44).

Heat and cold tolerance varies widely among grass species and cultivars. Perennial ryegrass is the least cold tolerant of any of the cool-season grasses, and can be injured where winters are severe; this is usually not a problem in the Willamette Valley (27,57). 'Manhattan' perennial ryegrass is hardy to -20 C, but other cultivars range in hardiness from -26 to -12 C (44). Drought tolerance of perennial ryegrass has been described as very poor (27), but Cook (57) states that drought tolerance of perennial ryegrass is as good or better than other grasses. Butler (44) reports varying degrees of perennial ryegrass drought resistance from fair to good, and in one study, perennial ryegrass had greater drought tolerance than Kentucky bluegrass and several fine fescues (146). In another study, perennial ryegrass grew well under a wide range of soil moisture conditions, from water-logged to dry (179). Perennial ryegrass is described as a short-lived perennial, (27), but can be managed for several years if not subjected to the stresses of heat, cold, and excessive wear and traffic (57).

Perennial ryegrass has a high fertilizer requirement; low fertility can cause thinning out of the grass stand. Low nutritional status and reduced grass vigor can reduce competitive ability (136) allowing undesirable, perennial weeds to become established. Perennial ryegrass responds quickly to additions of N fertilizers, but with low soil moisture and temperatures, additions of fertilizer decreases grass growth (22,23). Grasses grown with high rates of nitrogen fertility are less able to withstand soil drought and cold temperatures (48).

Perennial ryegrass can be seeded at anytime of the year, even during droughty periods on unirrigated sites (27). In the Willamette Valley perennial ryegrass for turf is often seeded in the late summer or early fall before fall rains begin, and will germinate and become established over the fall and winter.

Perennial, cool-season grasses initiate growth in the late winter and early spring, usually before active crop growth commences. In the Willamette Valley summers are usually dry, and in unirrigated situations grasses will undergo a period of dormancy in response to reduced moisture levels (48,57,65,104). Buds in the crowns, stolons, or rhizomes of dormant grasses can survive drought, and if water is supplied during this dormant period, grass growth will resume (27). Summer dormancy of grass may be advantageous if the grass is used as a living mulch, because the crop can grow without competition from the grass after the grass is dormant (65,149,233).

Allelopathic compounds produced by perennial ryegrass and other grasses may impair weed germination and growth (125,168,169). Unfortunately, allelopathy has also been implicated in the reduction of crop growth and development (65,208). Doty (65) found that established perennial ryegrass inhibited callus formation and rooting of grapevine cuttings. Fales and Wakefield (75) found that root leachates from perennial ryegrass, inhibited shoot and root growth of forsythia (*Forsythia intermedia* Spaeth.). The actual impact of allelopathy from grass living mulches on crop production is a controversial topic, necessitating more research on allelopathy as a management tool in crop production and living mulch management.

## 2. Water use of grasses

Early season depletion of soil water by perennial grasses grown as living mulches can be a limiting factor in crop production. Grass growth usually starts and peaks earlier than crop growth, thus depleting available moisture reserves before crop water demand is greatest. Perennial ryegrass grown between rows of 'Pinot Noir' grapevines had the greatest amount of moisture depletion by early July when soil water was plentiful and before the grass went dormant (232,233). Tan (204) found that soil moisture in the grape row was not reduced by a perennial ryegrass sod in mid-July, but by late July and September soil moisture between the grape rows was reduced by the grass. A high positive correlation between depth of soil water depletion and grass root density indicates that maximum grass water use occurs in the upper layers of the soil profile (0 to 100 cm) (65,182,232,233,234). Wine grape roots will grow below the area of maximum grass rooting, where water reserves have not been depleted, and draw heavily upon those reserves (233). Although water may be available at deeper soil depths, the loss of water from early season grass competition may be enough to decrease grape vine growth and development.

The water use rate of a grass is influenced by the evapotranspiration rate, length of the growing season, growth rate of the plant, turfgrass species or cultivar, intensity of culture, traffic, soil type, rainfall, and soil moisture (27). Evapotranspiration (ET) is a measure of the loss of water from the soil by evaporation, and the loss of plant water by transpiration (27,44). With grasses most soil water depletion can be attributed to evapotranspiration (27,44). Soil moisture deficits are higher under a grass living mulch than under bare ground (18,24,27,44,65,67, 100,103,132,149,165,204,232,233). In late summer, however, evaporation from bare ground can exceed ET from dormant grasses (65, 233).

Comparative studies of grass species and cultivars have found wide variation in water use. Over a growing season, 'Ensylva' creeping red fescue used 54mm of water compared to 124mm for 'Derby' perennial ryegrass (65,132). Smooth bromegrass (*Bromus inermis* Leyss.), quackgrass (*Agropyron repens* (L.) Beauv.), and reed canarygrass (*Phalaris arundinacea* L.) transpire large amounts of water and root deeply enough to reach moisture reserves unavailable to other grass species; redtop (*Agrostis alba*), Kentucky bluegrass, and fine fescues transpire high amounts of water, but are not deep-rooted (157). Tall fescue has better high temperature and drought tolerance compared to other cool-season grasses, related to deep and prolific roots (119). Aronson et al. (9) found that chewings fescue and hard fescue are more drought tolerant that perennial ryegrass or Kentucky bluegrass.

Warm season grasses usually have lower ET rates than cool-season grasses (27,31,44,116). Grasses with lower ET rates have high shoot density, horizontal leaf orientation, low leaf area, and narrow leaves (116). In another study, growth rate of the cool season and warm-season grasses was similar, but water consumption by the cool-season grasses was higher (31). Evapotranspiration of turfgrass is greater with sandy loam compared to loam soils (211).

### 3. Management of grass living mulches

Management of grass living mulches can be accomplished by cultivation, mowing or flailing, or chemical suppression. Cultivation destroys the ground cover and is not recommended for management of perennial living mulches, but could be used in management of annual living mulches (57). Shallow cultivation can also be used to control weed growth in the crop aisles without damamging crop roots (133).

Mowing has traditionally been used to manage grass growth in orchard aisles and turfgrass operations. Flail mowing cuts the grass closer to the ground, leaving only the crown and very little shoot tissue. Flailing is practiced in hazelnut production where a smooth, clean ground surface is necessary for nut harvest. At lower cutting heights, turfgrass wear tolerance is decreased (27). The amount of grass regrowth is positively correlated with the cutting height and raising the cutting height from 3 to 6 cm for a 6 week period led to increased vigor in all grasses (31). Beard (27) states that mowing decreases: carbohydrate synthesis and storage, leaf width, root growth rate, total root production, and rhizome growth, and increases shoot growth, shoot density, leaf succulence, and chlorophyll content. Mowing can also reduce grass water use (17,149,203), but mowing must be done frequently in order to reduce grass competition with the crop for water (85). Kentucky bluegrass mowed at 5 cm used 15% more water than grass mowed at 2 cm (76). Crop growth and yield may still be decreased by mowed grass swards in comparison to crops grown in bare ground (83,101,133,144,178,221,222,223).

Chemical suppression of turfgrass with sublethal rates of herbicides or growth regulators has been studied for turfgrass, pasture, and living mulch systems, and is thoroughly discussed in the following section. Less is known about the effect of chemical suppression on grass moisture use. Chemical suppression with sub-lethal herbicide rates reduces evapotranspiration of the grass (28). Chemical suppression, compared to unsuppressed sod, reduces grass water use (12,13,14,16,17,149), but water use of chemically suppressed or mowed grass are similar (17,149,202,203). Chemical suppression reduced the competitive ability of the grass grown as a living mulch with cabbage *(Brassica oleracea)* and, when water was not limiting, the plots with suppressed living mulch yielded as well as bare ground plots (88).

Planting genetically dwarf turfgrasses such as 'Elka' perennial ryegrass and 'Pomar' orchardgrass may be another approach to living mulch management. These grasses provide acceptable ground cover, have reduced height and require less mowing than standard cultivars (57,193), but water use may not be less than with standard cultivars (65). Studies of grass water use will help determine which grasses are least competitive in cropping systems (65,234). Self-seeding annual grasses such as annual bluegrass or annual fescue have potential in certain cropping situations, for reducing competition with the crop for soil moisture (57,79). Living mulch systems for annual crops are also being researched and may provide information useful in perennial crop production (3,7,47,58,88,108,155, 160,176,226,227).

## V. Chemical Suppression of Ground Covers

Using herbicides or plant growth regulators to reduce growth and development of ground covers is termed chemical suppression, chemical retardation, or chemical mowing. Chemical suppression of turfgrasses is used as substitute for mowing, especially in areas where frequent mowings are required such as highway roadsides, golf courses, and orchard aisles. Ideally, the chemical suppressant should reduce the growth rate of the ground cover without killing it, thus reducing mowing requirements and maintaining the ground cover.

Chemical suppression of grasses has been accomplished with plant growth regulators (PGRs) and herbicides (51,64,68,77,78,109, 113,137,163,183). Many different chemicals, alone and in combination have been studied, as chemical suppressants.

Kaufmann (113) categorizes turfgrass suppressants by their effect on grass growth or development. Growth is defined as an "irreversible enlargement in size", whereas development is the "transformation of apparently identical cells into diversified cells and plant organs" (113). In the case of chemical suppression of grasses, development usually refers to seedhead production. Kaufmann describes type I suppressants as PGRs that inhibit both growth and development of turfgrasses. Type I suppressants include: amidochlor {N-[(acetylamino)methyl]-2-chloro-*N*-(2,6-diethylphenyl) acetamide}, mefluidide {N-[2,4-dimethyl-5-[[(triflurometh yl) sulfonyl] amino] phenyl] acetamide}, chlorflurenol {methyl 2-chloro-9-hydroxyfluorene-9-carboxylate}, and maleic hydrazide {1,2-dihydro-3,6-pyridazinedione}.

Type II suppressants inhibit both growth and development, with high rates killing the grass. This group includes: non-selective herbicides, such as glyphosate {*N*-(phosphonomethyl) glycine} or paraquat {1,1'-dimethyl-4,4'-bipyridinium ion}; selective grass herbicides, fluazifop {(±-butyl-2-(4-{[5-(trifluoromethyl-2-pyridinyl]oxy}phenoxy)propanoate} and sethoxydim {2-[1-(ethoxyimino)-butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one}; and selective broadleaf herbicides such as the sulfonyl ureas.

Type III suppressants are PGRs that control plant growth, but not development and include paclobutrazol {B-[(4-chlorophenyl) methyl]-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol} and flurprimidol {α-(1-methylethyl)-α-[4-(trifluoromethoxy)phenyl]-5-pyrimidinemethanol}.

Plant growth suppressants are either foliar or root active, or both. Foliar applied suppressants include herbicides, and the PGRs mefluidide, maleic hydrazide, and chlorflurenol. Root active suppressants include paclobutrazol, flurprimidol, and amidochlor. Timing of application of root active PGRs such as paclobutrazol is not as critical as with foliar applied chemicals. Suppression is slower with paclobutrazol than with foliar active PGRs and herbicides; suppression may not be apparent for 10 to 20 days after treatment (183).

### 1. Herbicides

Broadspectrum herbicides such as paraquat and glyphosate suppress the growth not only of grasses, but the growth of broadleaved groundcovers as well. Tall fescue sod treated with glyphosate or paraquat was suppressed enough to permit the establishment of more alfalfa seedlings in the established sod than in the untreated control (74). Glyphosate caused severe injury to the tall fescue allowing the establishment of crabgrass (*Digitaria sanguinalis*), a weed highly competitive with alfalfa seedlings. Paraquat, a contact herbicide, did not completely kill the tall fescue and the live sod offered some competition to weed emergence. Atrazine {2-chloro-4-ethylamino-6-isopropylamino-*s*-triazine} reduced the growth of a fescue sod, allowing for production of corn for grain and silage in the suppressed sod (189).

Selective grass herbicides are useful for suppression of grass in plantings of broadleaved crops that might be unintentionally injured by broad spectrum herbicides. Sethoxydim and fluazifop, two selective grass herbicides, have been used as grass suppressants in experiments with Douglas fir Christmas trees (149), crucifers (88,226,227), dry beans (*Phaseolus vulgaris*) (105); snap beans and cabbage (*Brassica oleracea*) (176).

Grass species vary in their sensitivity to sethoxydim and fluazifop. Hinton and Minotti (106) found that tall fescue and two varieties of perennial ryegrass were severely injured by all rates of sethoxydim, but only slightly injured by fluazifop; bentgrass showed greater susceptibility to fluazifop than to sethoxydim; red fescue and annual bluegrass were only slightly suppressed by either herbicide.

## 2. Plant growth regulators

The response of grass and broadleaf groundcovers to plant growth regulator treatments has been studied extensively. Suppression of shoot and root growth, and suppression of seedhead development have been the effects most frequently reported (77,98, 113,183). Elkins et al. (71) treated tall fescue and Kentucky bluegrass with 19 different growth retardants and concluded that most PGRs that reduce shoot growth also reduce root growth, root spread, root volume, grass tiller number, and bluegrass rhizome development. Plant growth regulators affect gibberellin and auxin production in grass (110), disrupting normal apical dominance in the shoot causing increased tillering (81). Maleic hydrazide acts by inhibiting cell division, restricting stem and leaf growth and by impairing flowering (27). Wiles (226) found that chemical suppression with fluazifop decreased total dry weight of perennial ryegrass more than mowed grass or unsuppressed grass. Fluazifop reduced both shoot and root growth of the grass, but root growth was less affected.

Maleic hydrazide is one of the first chemicals used in chemical suppression of turfgrasses (77,183). Maleic hydrazide reduces clipping weight of Kentucky bluegrass by 70 to 90%, depending on the cultivar and chemical rate (70). Mefluidide suppresses tall fescue shoot growth for 6 to 8 weeks after treatment (82), and a perennial ryegrass and white clover pasture has a 29% growth reduction for 3 to 4 weeks after treatment (38). Cycocel {2-chloroethyl trimethl ammonium chloride + choline chloride} applied to smooth bromegrass, tall fescue, and Kentucky bluegrass virtually stops grass growth for up to 100 days (137).

Grass species and cultivar differences can affect the degree of suppression obtained (49,52,68,70,163,183). Treatments of bermudagrass by flurprimidol reduced cumulative grass height by up to 83%, but mefluidide and amidochlor did not provide long term height suppression at any rate (64). Mefluidide reduced shoot growth of Kentucky bluegrass, but ethephon did not; neither ethephon or mefluidide inhibited root organic matter production or rhizome weight of bluegrass (51). Mefluidide reduced growth of fine-leaved grasses or annual grasses more than coarse leaved or perennial grasses (89).

High rates of several chemicals cause severe stand reduction, color loss, and weed infestations in grass plots (70). The discoloration caused by maleic hydrazide applications to grass and unreliable growth suppression limits its use as a universal suppressant (77). Creeping red fescue treated with paclobutrazol shows reduced growth comparable to mefluidide treated fescue, but results in "thatchy" turf appearance (49). Mefluidide, maleic hydrazide, and ethephon {(2-chloroethyl)phosphonic acid}, alone and in combination with broadleaf herbicides, fungicides, and surfactants, were evaluated on 4 cool-season grasses. All materials caused some degree of injury or discoloration (109). Paclobutrazol decreases grass growth, and reduces the appearance of the grass sward (183).

Perennial ryegrass treated with the an experimental PGR had reduced growth and produced many tillers with small leaves creating a prostrate, rosette form of grass growth (81). Foreman (81) observed that the prostrate growth habit of the treated ryegrass prevented invasion by other weed species, helping to retain the purity of the sown stand; increased tiller density helps establish a full ground cover earlier in the life of the sward. Elkins et al. (71) concluded that reduction of grass growth rate and spread due to chemical suppression could be problematic for long term pure sward maintenance. In another study, higher rates of PGRs resulted in serious stand reductions and subsequent weed infestations (70). Results of a 15 year study of changes in sward composition indicate that maleic hydrazide rapidly reduces tufted grasses and promotes creeping red fescue (231). Murray (149) suggests that populations of perennial broadleaf weeds could increase in chemically suppressed perennial ryegrass due to decreased competitive ability of the grass.

Combinations of herbicides with PGRs are also effective in suppressing grass growth (109,192). A sod predominantly of red fescue was suppressed with treatments of mefluidide alone, or in mixtures with several broadleaf herbicides (192). Not only did the treatments reduce vegetative and seedhead growth, but weeds in the turf were eliminated, fewer mowings were required, and the appearance of the turf was enhanced. Combinations of herbicides and PGRs did not reduce the effectiveness of mefluidide or maleic hydrazide in suppressing growth of Kentucky bluegrass, red fescue, colonial bentgrass, and perennial ryegrass (109).

A mixed spray of maleic hydrazide + 2,4-D {(2,4-dichlorophenoxy)acetic acid} produced a short, non-flowering grassy sward dominated by Kentucky bluegrass with most broadleaved plants reduced or eliminated (231).

### 3. Length of growth suppression

Length of chemical grass suppression is dependent on several factors: type and rate of chemical applied, age and species of the grass, growth stage at time of application, nutritional status of the plant, and environmental factors.

Kaufmann (113) suggests that foliar growth and development suppressants and inhibitors are most effective in suppressing grass for 5 to 6 weeks when applied when grass is just starting to grow.

Root-active PGRs provide longer control of vegetative growth, but should be applied in the fall or when grass starts to green-up. Foliar PGRs applied after seedhead development or when grass starts senescing, usually provide short growth inhibition, severe loss of turfgrass, and rapid growth of escaped tillers not affected by the product. The root active PGRs are more effective in spring applications when a fertilizer treatment is made with the PGR treatment; suppression can then last longer than 5 to 6 weeks (113). Suppression effects may last several weeks with paclobutrazol and activity will last through successive mowings (183). Most grass suppressants are more effective when grass is actively growing and unstressed; inconsistent results are achieved with stressed plants (77).

Mefluidide has been shown to suppress grass growth of perennial ryegrass, Kentucky bluegrass, tall fescue, red fescue, and colonial bentgrass for 6 to 8 weeks (77,78,82,109). Brookes and Holmes (38) found that perennial ryegrass and white clover pastures treated with mefluidide had growth depressed by 29% for 3 to 4 weeks. Other work indicates that mefluidide has little to no effect on some species, and timing of application affects suppression (51,89). Haggar and Standell (89) report that the effect of mefluidide was greater on grasses with vertical growth habit than species with finer-leaved more prostrate growth; this effect may be due to better chemical coverage on the upright grass.

Maleic hydrazide has suppressed growth of Kentucky bluegrass, tall fescue, red fescue, colonial bentgrass, and perennial ryegrass for 6 weeks (68,70,71,109). Ethephon applied to Kentucky bluegrass demonstrated a delayed suppression; grass treated on July 2nd did not show suppression for 3 weeks and suppression lasted only 2 weeks (51).

In general, paclobutrazol provides longer grass growth control than foliar applied treatments and is less affected by environmental fluctuations (15,196).

Herbicide suppressants produce a similar suppression effect. Rates of fluazifop, sethoxydim, and glyphosate at 5 to 20% of full-strength rates, suppressed a cool-season mixed grass pasture for 4 weeks after treatment (174). Two warm-season grasses, bermudagrass and bahiagrass, were both suppressed for 6 to 8 weeks by fluazifop-p, sethoxydim, and sulfometuron (163). Sub-lethal rates of fluazifop suppressed perennial ryegrass for 4 weeks (226).

4. Timing of application

Several authors note that timing of application is critical in achieving optimum grass and seedhead suppression. Cool-season grasses can exhibit up to 50% of their total annual vertical growth during a six week period from April through June; therefore spring is the usual time for chemical suppression treatments to reduce grass growth and mowing (113). Kentucky bluegrass treated with mefluidide in 2 different years showed greater suppression when applied in mid-May than at the beginning of July (51). Grass was suppressed for 7 weeks when mefluidide was applied in May, and suppression was noted for 1 week only when treatment was in July. Cool-season grasses will go dormant in the warmer summer months under conditions of low moisture, and chemical treatments will be less effective at those times.

Fall applications of grass suppressants can also be effective in limiting grass growth; cool-season and warm-season grasses treated with several different PGRs during September were still suppressed 6 months after chemical application (70). Residual chemical retarding effects were noted in fall-treated grass plots when evaluated in spring, but not in fall evaluated spring-treated plots (70). Kauffman (113) reports that grass growth in the fall is more horizontal due to short days and cool temperatures, and grass growth results in tiller and rhizome development which improves the density of the sod. Grass suppressants applied in the fall may decrease or stop the growth of the grass during a time when the grass needs to recuperate.

Grass in turf settings is often mowed before or after suppression treatments to improve the appearance and uniformity of the stand. Timing of chemical application after mowing also affects growth suppression. Mefluidide was made unavailable to ryegrass shoots and roots as a result of mowing two days before or after spraying (78). Mowing the grass increased the amount of mefluidide necessary for growth reduction. Field and Whitford (78) suggest that mowing grass to 5 cm, 4 to 5 days before chemical application, allows for visible regrowth and is the best pre-spray treatment.

Not all mowing treatments reduce the effectiveness of PGRs. Mowing 1 week after maleic hydrazide treatment did not reduce the growth suppression of Kentucky bluegrass, red fescue, colonial bentgrass, and perennial ryegrass (109). The mowing treatment was reported was "trim mowing", which may have removed less leaf area than in the previous work describe with mefluidide.

Activity of soil-applied paclobutrazol is not diminished with successive mowings (183). Sheaffer and Marten (182) report no reduction of suppression of cool-season grasses when cut 1 week before treatment with mefluidide.

5. Seedhead reduction

Grass seedhead development is also affected by many chemical suppressants. Mefluidide and maleic hydrazide reduced production in Kentucky bluegrass, red fescue, colonial bentgrass, perennial ryegrass, and annual bluegrass (51,109). In another study, mefluidide insignificantly decreased seed head numbers in perennial ryegrass (89). Seedhead production in creeping red fescue treated with ethephon was not decreased, but seedhead sizes were (49). Timing of chemical suppressant application also affects the amount of seedhead suppression obtained. Haggar and Standell (89) compared several grass species and timing of mefluidide application and noted that, in general, the earlier the spray application, the greater the suppression of seedheads. Plant growth regulators applied during vegetative dormancy of the grass usually provides less suppression than applications at the early vegetative growth stage; applications after seedheads are visible in the rolled sheaths will not control those seedheads, but will control subsequent seedhead growth (113).

Timings based on calendar days or grass appearance alone often give inconsistent results and are not generally applicable to different regions and grass species. Timing based on growing degree days (GDD) may provide more consistent results. Branham and Danneberger (37) applied mefluidide and amidochlor to Kentucky bluegrass between 25 and 125 GDD and reported 86% seedhead suppression. Applications after 150 GDD gave less than 30% suppression. Clipping weights were not significantly different with applications at different GDD, indicating that timing for vegetative control was not as critical for Kentucky bluegrass, at least not between 20 to 150 GDD.

Paclobutrazol does not provide consistent seedhead suppression. Seedheads are delayed in emergence, shortened, and reduced in number, and control is poor (183). Paclobutrazol may actually increase perennial ryegrass seed production by shortening the internode length of the grass and reducing lodging, improving conditions for pollen shed and pollination and thereby increasing seed set and development (98).

The seedhead suppressing effect of maleic hydrazide and mefluidide lacks persistence through successive mowings; paclobutrazol is more persistent, but decreases quality and appearance of grass, therefore Shearing and Batch (183) suggest the 'ideal' grass suppressant may be a combination of paclobutrazol and mefluidide or maleic hydrazide.

## 6. Injury, color, and wear tolerance

Phytotoxicity of plant growth regulators and herbicides to grasses has been widely reported (64,68,161,183). Maleic hydrazide, mefluidide and other PGRs have been reported to cause color loss and serious stand reductions when applied at higher rates or with sensitive species (70,109), making it difficult to establish general recommendations for chemical suppression.

Due to the potential for turf injury, some chemical suppressants are better suited for use in rough turf areas such as roadsides, hillsides, and orchards where appearance is not critical; other suppressants are recommended for use when visual quality is a priority. Mefluidide may be more appropriate in semi-rough and rough turf, because phytotoxicity has been observed in fine-leaved grasses (77).

Chemically suppressed ground covers may have decreased wear tolerance and recovery ability. Tiller mortality and reduced tiller development increases stand thinning, and may lead to invasion by undesirable weeds and reduced grass vigor (77). Elkins et al. (71) reports that maleic hydrazide reduced not only shoot growth and root growth of Kentucky bluegrass, but decreased root spread and volume, grass tiller number, and rhizome development, factors which could be problems in maintaining a pure grass stand.

## 7. Regrowth

Grasses treated with chemical suppressants are initially reduced in growth compared to untreated checks, but after the suppression effects wear off they may grow as well or better than untreated grass.

Tall fescue treated with mefluidide was suppressed for 6 to 8 weeks after treatment, but subsequent stimulation of grass growth produced dry matter yields 23% higher than untreated plots (82). Cycocel applied to smooth bromegrass, tall fescue, and Kentucky bluegrass suppressed growth of the grass for up to 100 days, followed by a period of stimulated growth by the grasses (137). Haggar and Standell (89), however, found variation in regrowth characteristics depending on grass species, and early application of mefluidide resulted in reduced total clipping yield of most grasses.

Warm-season grasses treated with fluazifop, sethoxydim, and sulfometuron had reduced growth for 4 to 6 weeks and reduced seedhead formation; after recovery, dry matter production was greater than in the untreated plots (163). Amidochlor suppressed bermudagrass by 50 to 55% (height reduction) for three weeks, after which the bermudagrass grew more than the untreated control (64).

Other studies indicate no stimulation in regrowth (compared to untreated grass) with cool-season grasses. Acceptable grass growth was maintained following the suppression period (49,89,174,182,189).

## 8. Fertilizer and grass suppressants

Nitrogen fertilizer can stimulate the growth of chemically suppressed grass (64,82). Tall fescue treated with mefluidide and fertilized with nitrogen fertilizer grew more than the mefluidide treated, unfertilized grass (82). Bermudagrass treated with flurprimidol had reduced growth, but nitrogen fertilizer applications reduced the effectiveness of the treatment (64). When grass competition is not a concern, the stimulation of grass growth may help maintain the vigor of the suppressed grass.

Timing of fertilizer application may also be important in recovery of grass after suppression. Sheaffer and Martin (182) found that a cool-season grass pasture treated with mefluidide did not show the compensatory grass regrowth expected with mefluidide treatments. The authors suggest that a single nitrogen application in April did not supply enough nitrogen at the end of the suppression period to stimulate grass growth. They suggested that a split application of nitrogen once in early spring and once after first harvest might provide more nitrogen to stimulate grass regrowth.

Phytotoxicity from the chemical suppressants, as expressed by lighter grass color grass, can sometimes be overcome with nitrogen fertilizer applications. Bermudagrass treated with flurprimidol exhibited leaf tip dieback and discoloration, but turf discoloration was reduced with increased nitrogen levels (64).

### 9. Water use of suppressed grasses

Grasses treated with PGRs for growth suppression have been shown to use less water, but reductions may be slight. Bermudagrass treated with several different PGRs and nitrogen levels had water consumption reduced by as much as 27% for the no nitrogen, high flurprimidol rate (64). Atkinson (12) found that early season water use by timothy (*Phleum pratense* L.) was decreased with mefluidide and paclobutrazol, but overall, PGRs did not have a major effect on regulation of water use. Although Atkinson et al. (16) reported that reduced water competition with mefluidide may be due to a change in grass root distribution and density, in a later study mefluidide had little effect on grass root growth (12). Paclobutrazol reduced both transpiration and flux through the grass root system, decreasing competition for water, but absolute length of grass roots may be so great that PGRs may not be able to have much impact on total root growth (14).

In a study of the effect of PGRs on yield and water use of three cool-season grasses, water use was found to be highly correlated with the amount of shoot growth (137). They concluded that ET would decrease as plant size decreased. Doty (65) also found strong correlation between soil water depletion and root density for four unirrigated cool-season grasses. Although cool-season grasses were competitive with grapes vines for soil water, the competition was reduced by grass dormancy with dry summers.

Perennial ryegrass chemically suppressed with fluazifop-p used 9% less water than untreated ryegrass (149). Water use of the chemically suppressed grass was not different from mowed perennial ryegrass. Atkinson and Vokes (17) found lower soil water deficits with a chemically suppressed orchard sward, but the grass stand was invaded by broadleaved weeds.

## 10. Chemical suppression in perennial cropping systems

Chemical suppression has been used successfully in orchards to reduce the number of mowings required during the growing season (15,134,145,196,197,198,220). Paclobutrazol persisted for a season after the last of a series of annual applications in an apple orchard (15). Miller and Eldridge (145) suppressed established sod driveways in an apple orchard with several PGRs eliminating 1 to 3 mowings. Other reports have indicated that 2 applications of maleic hydrazide + 2,4-D have replaced mowing the orchard sward 6 to 10 times per year (134); mefluidide applied 2 times to tall fescue reduced the number of mowings from 11 to 2 per year (220); and paclobutrazol reduced mowing of perennial ryegrass and bentgrass to a single maintenance cut (15). Cost of maleic hydrazide treatment was cheaper than mowing in one orchard (145), but maleic hydrazide + 2,4-D was not less expensive than monthly mowing (201).

Apple tree growth and yield in a chemically suppressed grass sod is usually intermediate between growth and yield of trees in 100% grass cover or bare ground, and similar to growth and yield in a mowed sod (194,195,197,200,201). Chemical suppression of a grass sod growing up to the base of the trees did not decrease the competitive effects of the sod for moisture and nutrients (200). Murray (149) found no difference in first year growth of Douglas fir seedlings grown in overall herbicide, native ground vegetation, or in a mowed or chemically suppressed perennial ryegrass living mulch. Chemical suppression has been more widely studied in annual cropping systems, but results of these studies may be adaptable to perennial crops (3,58,69,88,90,105,112,160,176,213,214,215,216,226,227).

Living mulch management can enhance the productivity and sustainability of a crop production system. Living mulches must be managed avoid excessive competition with the primary crop for water and nutrients. Chemical suppression may be a substitute for mowing in areas where mowing a living mulch is difficult or impossible. If chemical suppression treatments can eliminate or reduce the number of mowings necessary to maintain a ground cover without decreasing crop quality, chemical suppression may be a cost effective management tool.

# Chapter 3

# MATERIALS AND METHODS

## I. Chemical suppression studies 1983 and 1984

Studies were conducted in 1983 and 1984 at the Oregon State University Lewis Brown Horticulture Farm in Corvallis, Oregon. Experimental plots were established on a Chehalis silty clay loam. The experimental site was plowed then leveled with a spring-tooth harrow.

Three varieties, representing different growth habits of turf-type perennial ryegrass (*Lolium perenne* L.), were planted June 6, 1983. 'Elka' is a dwarf perennial ryegrass, 'Manhattan II' is an intermediate type perennial ryegrass, and 'Derby' is a vigorous turf-type perennial ryegrass. A separate plot of 'Manhattan II' perennial ryegrass was also established. The grasses were planted at 22.4 kg/ha with a Brillion seeder. Plots were irrigated at planting and after grass emergence, as needed, to prevent drought stress and to maintain the grass stand. After planting, plots were fertilized with 26 kg N/ha of urea. Broadleaf weeds were treated with 4.7 l product/ha Trimec herbicide a commercial mixture of: [0.26 kg ai/l 2,4-D {(2,4-dichlorophenoxy)acetic acid}; 0.13 kg ai/l mecoprop {2-(4-chloro-*o*-tolyl)oxylpropionic acid}; and 0.03 kg ai/l dicamba {3,6-dichloro-*o*-anisic acid}] on July 8, 1983, with a $CO_2$ compressed air bicycle sprayer delivering 309 l/ha at 242 kPa.

1. **Preliminary rate trial - summer 1983**

Grass plots, 1.5 by 23 m, were mowed at 2.5 cm with a gas-powered rotary lawn mower on August 24. Treatments were replicated over the 3 perennial grass cultivars previously described. Three herbicides and 2 plant growth regulators were applied with a $CO_2$ compressed air logarithmic sprayer (R & D Sprayers, Incorporated, Steady Dilution Sprayer) on August 25. Initial concentrations of the chemical treatments were: 1.1 kg ai/ha fluazifop {(±)-butyl-2-(4-{[5-(trifluoromethyl-2-pyridinyl]oxy}phenoxy)propanoate}; 1.1 kg ai/ha sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one}; 2.4 kg ai/ha glyphosate {[N-(phosphonomethyl)glycine}; 3.2 kg ai/ha mefluidide {N-[2,4-dimethyl-5-[[(trifluoromethyl)-sulfonyl]amino]-phenyl]acetamide}; 2.0 kg ai/ha paclobutrazol {*B*-[(4-chlorophenyl)-methyl]-*α*-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol}. Spray concentrations were determined at approximately 7, 21, 36, 50, 64, 78, 92, and 100% of the total distance sprayed in each plot, using the formula:

$$\log C = \log C_o - (v/r) \log e$$

where:

C = concentration of the spray after flow of volume v

$C_o$ = initial concentration of v = 0 (2 liters)

r = volume of concentration chamber

e = Naperian base

or:

$$\log C = 2 - (v/0.51)*0.4343$$

Grasses were rated 21 and 42 days after treatment (DAT), between designated concentration points, for percent stand, broadleaf and grass weed density, color, and growth (cm). Results of this trial were used to determine herbicide rates for future grass suppression rate trials (data not presented).

**2. Suppression trial - fall 1983**

Grass plots, 1.5 by 2 m, were established in 'Manhattan II ' perennial ryegrass, with 3 replicates arranged in a randomized complete block design. Grass plots were mowed at a height of 4.5 cm, 5 days before herbicide applications.

Fluazifop at 0.12, 0.31, 0.52, and 0.9 kg a.i./ha; sethoxydim at 0.02, 0.04, 0.1, and 0.13 kg a.i./ha; and glyphosate at 0.12, 0.31, 0.51 and 0.77 kg/ha were applied on October 16, with a $CO_2$ backpack sprayer delivering 702 l/ha at 207 kPa. All herbicide treatments except glyphosate contained Moract 1% (v/v) crop oil concentrate (COC). Treatments included an untreated check plot and a COC check plot treated with 1% COC in a water carrier.

Grass growth was determined by mowing a 51 cm wide strip of grass in each plot at the original mowing height of 4.5 cm, then measuring the difference in height (growth) between the mowed and unmowed grass. Treatments were evaluated at 25, 36 and 81 DAT until grass suppression was no longer observed in a majority of the plots.

**3. Suppression trial - spring 1984**

'Manhattan II' perennial ryegrass at 44.8 kg/ha was planted on

September 15, 1983 with a Brillion seeder. Trimec herbicide at 4.7 l/ha was applied on March 8 with a tractor-mounted sprayer calibrated to apply 561 l/ha of water at 207 kPa. Grass was fertilized with 9.5 kg N/ha ammonium sulfate on April 17 May 17; urea was applied at 21 kg N/ha on June 29. Plots were irrigated as necessary to maintain grass vigor.

Experimental plots measured 3 by 3 m, and treatments were replicated 3 times in a randomized complete block design. Plots were mowed at 4.0 cm, 6 days before herbicide application. Herbicides were applied on May 29 with a $CO_2$ pressurized backpack sprayer delivering 374 l/ha at 241 kPa. Treatments included: fluazifop at 0.11, 0.28, and 0.45 kg ai/ha; fluazifop-P-butyl {(R)-butyl-2-(4-{[5-(trifluoromethyl-2-pyridinyl]oxy}phenoxy)propanoate} at 0.06, 0.13, and 0.22 kg ai/ha; glyphosate at 0.17, 0.28, and 0.39 kg ai/ha; and sethoxydim at 0.01, 0.02, and 0.04 kg ai/ha. All herbicide treatments except glyphosate included a 1 % (v/v) COC. Treatments included an untreated control plot and a plot treated only with a 1% (v/v) COC treatment.

Grass growth at 25 and 36 DAT was determined by subtracting the base mowing height of the grass (4.0 cm) from direct height measurements. Seedhead suppression was determined by counting seedheads in a randomly placed 0.09 $m^2$ frame. The experiment was concluded when grass suppression subsided.

### 4. Adjuvant trial 1984

Plot preparation was identical to procedures in the 1984 spring herbicide rate trial. Plots measured 1.5 by 2 m, and were replicated 3 times in a randomized complete block design. Herbicides were applied on May 29 with a $CO_2$ pressurized backpack sprayer delivering 374 l/ha at 241 kPa. Treatments were: fluazifop at 0.11 kg ai/ha, and sethoxydim at 0.02 or 0.04 kg ai/ha applied alone, or in combination with a 1% (v/v) COC or with a 0.1% (v/v) surfactant (X-77 Spreader). Controls included an untreated plot, a plot treated only with 1.0% (v/v) COC, and a plot treated only with 0.1% (v/v) surfactant (X-77 Spreader). Growth determinations were identical to those described for the spring 1984 grass suppression treatments.

## II. Living Mulch Suppression Trials in Wine Grapes 1984, 1985, 1986

Grass suppression trials were conducted as the management component of a living mulch trial in a planting of 'Chardonnay' wine grapes at the Oregon State University Vegetable Farm, in Corvallis, Oregon. Plots were established on a Newburg loam which was plowed then leveled with a spring toothed harrow. 'Manhattan II' perennial ryegrass was planted at 44.8 kg/ha with a Brillion seeder, on September 15, 1983. Ammonium sulfate was applied at 9.5 kg N/ha in April 17 and May 17, 1984; urea was applied at 21 kg N/ha on June 29. Trimec herbicide at 4.7 l/ha was applied on March 8 with a tractor mounted sprayer delivering 561 l/ha at 207 kPa. Plots were irrigated as necessary to maintain grass vigor.

Rooted cuttings of 'Chardonnay' wine grapes were planted into the perennial ryegrass plot in March. Individual 3 by 5.5 m plots were established for each treatment. Five grapevines spaced 1 m apart in the vine row, with 3.5 m between rows, were planted in each plot. A 0.5 m grass border separated the plots.

Ground cover management treatments were established in June. Treatments were replicated 5 times in a randomized complete block design. Treatments were blocked based on visual plot ratings of percent grass cover at time of tree or vine planting, using a scale of 95 to 85%, 85 to 80%, 80 to 75%, 75 to 65%, and 65 to 55%. Grass stand was not uniform due to effects of residual soil herbicides applied in previous farm experiments unrelated to this study. In 1985, grass was seeded by hand to fill in areas of poor stand.

In June 1984, bare ground areas were established in some plots according to treatment. Sethoxydim at 0.56 kg ai/ha + 1% COC was applied with a $CO_2$ backpack sprayer delivering 299 l/ha at 207 kPa. Summer weed control was maintained by hand hoeing in the bare ground areas.

Wine grapes were grown in the following six ground cover management treatments from 1984 to 1987:

1. Bare Vine Row + Bare Aisles (Bare Ground)
2. Bare Vine Row + Grassed Aisles - Grassed Mowed
3. Bare Vine Row + Grassed Aisles - Chemical Suppression with fluazifop-P-butyl 0.22 kg ai/ha.
4. Bare Vine Row + Grassed Aisles - Chemical Suppression with sethoxydim 0.044 kg ai/ha.
5. Grassed Row + Grassed Aisles (100% Grass Cover) - Chemical Suppression with fluazifop-P-butyl 0.22 kg ai/ha.
6. Grassed Row + Grassed Aisles (100% Grass Cover) - Chemical Suppression with sethoxydim 0.044 kg ai/ha.

1. Living mulch trials - 1984

After establishing the ground cover management plots, all grassed plots were mowed to a uniform height of 7.6 cm on July 10, 1984, and clippings were removed. Chemical suppression treatments were applied on July 11 and 12, to treatments 3,4,5,and 6. Fluazifop-P-butyl or sethoxydim were applied with a $CO_2$ pressurized backpack sprayer delivering 374 l/ha at 207 kPa. A 1% COC was added to the spray solution of each herbicide. Grass in treatment 2 (mowed grassed aisles) was mowed at 2 week intervals during the 6 week chemical suppression period, clippings were collected, and fresh and dry weights determined. Clipping weights of the mowed plots are the cumulative weights of clippings collected during the 6 week suppression period. Mowed and chemically suppressed grass plots were mowed on August 30, 1984 to 7.6 cm, clippings were collected, and fresh and dry weights of the grass were determined. Grass dry weights were standardized to $g/m^2$, and also reported as g/plot (16.5 $m^2$).

2. Living mulch trials - 1985

All plots were fertilized with 26 kg N/ha of urea in April and August. Bare ground areas of the plots were treated on April 26 with a tank mixture of 3.36 kg ai/ha napropamide {2-(*a*-naphthoxyl)- -N,N-diethylpropionamide} and 3.36 kg ai/ha of oryzalin {3,5-dinitro$N^4$,$N^4$-dipropylsulfanilamide} applied with a $CO_2$ pressurized backpack sprayer delivering 38 l/ha at 194 kPa on the plots with a 1 m wide bare ground area, and delivering 49 l/ha at 194 kPa on the plots with a 3 m wide bare ground area. Sethoxydim, for grass weed control, was applied 0.28 kg ai/ha on May 5 with a $CO_2$ pressurized backpack sprayer delivering 28.5 l/ha at 194 kPa, and again on July 3 at 0.45 kg ai/ha with a $CO_2$ pressurized backpack sprayer delivering 229 l/ha at 207 kPa. A 2% glyphosate solution was applied on August 20 to individual weeds in the bare ground areas. Weeds were hoed as needed in both the grassed and bare ground plot areas.

All grass plots were mowed at 5.1 cm on May 24. Chemical suppression treatments were applied on May 27. Chemical suppression treatments (fluazifop-P-butyl or sethoxydim) were applied to grass treatments 3, 4, 5, and 6 using a $CO_2$ pressurized backpack sprayer delivering 243 l/ha at 207 kPa. Grassed aisles in treatment 2 plots were mowed at 2 week intervals during the 6 week chemical suppression period. No grass data were collected during this suppression period.

All grass plots were mowed at 7.6 cm on August 20, 3 days before treatment. Chemical suppression treatments were repeated on August 23. Application rates and methods were the same as on May 27. Mowed treatments were mowed to 7.6 cm every 2 weeks during the 6 week suppression. Clipping weight determinations were made as in 1984.

### 3. Living mulch trials - 1986

Grass suppression trials were continued. Weed control in grassed and bare ground areas was obtained by hoeing, and spot applications of a 33% solution of glyphosate were made with a hand held spray bottle on March 21. On March 23, bare ground areas were treated with a mixture of 4.48 kg ai/ha napropamide and 4.48 kg ai/ha diuron {3-(3,4-dichlorophenyl)-1,1-dimethylurea} applied with a $CO_2$ pressurized backpack sprayer delivering 299 l/ha at 207 kPa, for residual weed control. All grassed plots were mowed at 6.4 cm on March 20. Grass was chemically suppressed on March 25, with either fluazifop-P-butyl or sethoxydim, applied with a $CO_2$ pressurized backpack sprayer delivering 271 l/ha at 207 kPa. Grass in the mowed treatments was mowed to 6.4 cm every 2 weeks during the chemical suppression period for a total of 3 mowings. Grass growth measurements were the same as in 1984 and 1985.

### 4. Wine grape growth - 1985 and 1986

From 1984 to 1986 'Chardonnay' wine grapes were grown in 6 ground cover management treatments. The treatments were: bare ground, mowed grassed aisles, chemically suppressed grassed aisles, and chemically suppressed 100% grass cover. Details of these treatments are discussed in previous sections. Vine growth was assessed by weighing cane prunings (g fresh weight/vine) and measuring total vine length in the 1985 and 1986 dormant seasons.

## III. Living Mulch Suppression Trials in Christmas Trees - 1984, 1985, 1986

Establishment and management of ground cover treatments for Douglas fir seedlings (2-0 stock), and measurement of grass growth suppression was identical to treatments and measurements described for the living mulch in wine grape trials. Initial Christmas tree growth measurements of height (cm) and canopy volume ($cm^3$) were made the dormant season of 1984. Height was measured from the base of the trunk to the leader apex. Canopy volume was determined by measuring across the widest part of the canopy (D1), and measuring perpendicular to D1 (D2). Canopy volume was calculated using the formula of a cone:

$$V = (pi*r2*h)/3$$

V = canopy volume (CV)

r = the radius of the canopy = (D1 + D2)/4

h = tree height

pi = 3.14.

Trunk caliper (diameter in mm) was initially measured in 1985, from the bottom of a paint mark 10 cm above the soil surface. In 1986 trunk caliper growth was determined during the dormant season.

Measurements of tree height, canopy volume, and trunk caliper are not reported as absolute values, but represent relative growth calculated by subtracting measurements in the previous season from current season measurements.

Mean separations were made using Duncan's multiple test at $P = 0.05$.

# Chapter 4

# RESULTS AND DISCUSSION

## I. Chemical Suppression of Perennial Ryegrass

### 1. Suppression trials - 1983 and 1984

Twenty-two and 36 days after treatment (DAT) in the 1983 trial, all herbicide treatments, except the lowest rate of sethoxydim, suppressed grass growth (Table 1). The lack of suppression with the lowest rate of sethoxydim is unexpected, because this rate did suppress perennial ryegrass in preliminary trials.

At 22 DAT, grass growth was suppressed 52% to 69% compared to untreated grass. At 36 DAT, grass suppression ranged from 42% to 88%. After 81 days, the highest rate of fluazifop, the 3 highest rates of sethoxydim, and the 2 highest rates of glyphosate had killed the grass. Fluazifop at 0.31 and 0.52 kg $ha^{-1}$; and glyphosate at 0.31 kg $ha^{-1}$, continued to suppress grass regrowth by at least 45%. Fluazifop and glyphosate, at their lowest rate, were still suppressing grass growth by 33%, but this reduction was not significantly different from untreated grass. Grass suppression was rate dependent, with suppression and injury increasing with increasing herbicide rates.

Grass quality ratings for all herbicide treated plots were lower than the control, 22 and 36 DAT (Table 2). Grass treated with the 2 highest rates of fluazifop, the 3 highest rates of sethoxydim, or the 3 highest rates of glyphosate, had quality ratings of 2 or

less, indicating chlorosis and necrosis of leaves.
After 81 days, grass treated with the low rate of fluazifop, sethoxydim, or glyphosate, had quality ratings equal to those of untreated grass.

Grass treated with glyphosate at 0.31 kg $ha^{-1}$ also had a quality rating of 5, but the grass stand was reduced (Table 3). Grass stand was at least 75% with the lowest rate of each herbicide, but grass stand was 52% or less with all other herbicide rates.

Overall, in fall 1983, fluazifop and glyphosate at 0.12 kg $ha^{-1}$ provided the best grass suppression with the least reduction in grass quality.

In 1984, herbicide rates provided less suppression, for a shorter duration, compared to the 1983 treatments. Herbicide treatments in 1984 were applied in late spring, and fall applied in 1983. Apparently the more vigorous grass growth in the spring decreased herbicide effectiveness, or grass was more sensitive to herbicide treatments in the fall.

At 25 DAT, best grass suppression was achieved with all rates of fluazifop, fluazifop-P-butyl at 0.13 and 0.22 kg $ha^{-1}$, and sethoxydim at 0.04 kg $ha^{-1}$ (Table 4); suppression ranged from 48 to 68%. Although not significantly different from the growth of untreated grass, lower rates fluazifop-P-butyl and sethoxydim, and all rates of glyphosate provided less than 32% suppression. The suppression activity of glyphosate, at such low rates, may have been improved by the addition of a surfactant.

At 36 DAT, no significant grass suppression occurred with any herbicide, although the highest rate of fluazifop or fluazifop-P-butyl suppressed grass growth by 33% and 43%, respectively. Grass growth suppression was less than 24% with sethoxydim and glyphosate, but again these growth reductions were not significant.

Healthy, vigorous grass regrowth was observed in all plots 7 weeks after treatment, except grass treated with glyphosate at 0.39 kg $ha^{-1}$, which had yellowed leaves.

Grass seedhead production was reduced 62 to 95% with all rates of fluazifop, fluazifop-P-butyl, and sethoxydim, and the mid rate of glyphosate, compared to untreated grass (Table 4). Other herbicide rates also reduced seedhead production, but these reductions did not differ significantly from the untreated grass. There was no effect from COC, applied in a water carrier, on grass growth or seedhead suppression compared to untreated grass.

Results of these rate studies were used to identify rates of fluazifop, fluazifop-P-butyl, sethoxydim, and glyphosate that effectively suppressed perennial ryegrass without injury, so chemical suppression treatments could be evaluated in future living mulch studies in annual and perennial crops.

## 2. Adjuvant trial - 1984

The addition of either crop oil concentrate (COC) or surfactant to fluazifop, enhanced grass suppression 25 DAT compared to untreated grass (Table 5). Grass was suppressed 42% with fluazifop + COC, and 52% with fluazifop + surfactant. Fluazifop alone did not suppress grass growth. Fluazifop-P-butyl was not included in this experiment.

Crop oil concentrate + sethoxydim at either rate enhanced grass suppression more than surfactant + sethoxydim or sethoxydim alone. Grass growth was suppressed 34% with the low rate of sethoxydim + COC, and 58% with the high rate compared to untreated grass. Grass suppression with sethoxydim + surfactant did not differ significantly from the untreated grass, but the lower rate of sethoxydim + surfactant suppressed the grass more than the higher rate contrary to results from other studies (50,115).

No significant grass suppression occurred with any herbicide treatment at 36 DAT; this agrees with results from the other 1984 rate trial previously discussed. After 7 weeks, ryegrass was green and growing vigorously in all plots.

Reductions in seedhead production were observed in all treatments, but not all results were significantly different from the untreated check (Table 5). Adding COC or surfactant to fluazifop caused greater seedhead reductions than fluazifop alone.

Adding COC to both rates of sethoxydim also significantly decreased seedhead production. The addition of surfactant, however, only decreased seedhead production with sethoxydim at the lower rate. The lack of grass and seedhead suppression with the high rate of sethoxydim is unexpected, because it conflicts with research indicating increasing grass control with increasing rates of sethoxydim with or without the addition of adjuvants (50). Uniform application of the herbicide solution is probably a factor in achieving consistent suppression with fluazifop and sethoxydim, especially at sub-lethal rates, because site of application has been shown to influence grass weed control (42).

In this experiment, neither COC or surfactant, applied in a water carrier, had any effect on grass suppression or seedhead production compared to untreated grass.

Results of these studies indicate that fluazifop, sethoxydim, and glyphosate have potential as chemical suppressants for living mulches. Fluazifop and sethoxydim may be more desirable than glyphosate because they are selective grass herbicides and can be safely applied in conifer and broadleaved crops (2,97,120). The use of glyphosate, however, may be advantageous where suppression of both broadleaved and grass ground vegetation is desired (73).

Grass regrowth was vigorous and healthy after suppression with sub-lethal rates of sethoxydim, fluazifop, fluazifop-P-butyl, and glyphosate, but further studies should investigate the impact of long-term chemical suppression on grass stand and wear tolerance. Caution should be used with herbicides used as chemical suppressants, because they appear to have a narrow margin of safety, and slight overdoses could kill the grass.

In this study, both crop oil concentrate or surfactant improved suppression activity of fluazifop and sethoxydim, although suppression with sethoxydim + surfactant was not consistent. Additions of adjuvants to postemergence herbicides are commonly recommended to improve activity (43). Fluazifop and sethoxydim provide better grass weed control with additions of crop oil concentrate or surfactants (41,50).

Higher herbicide rates were needed in the 1984 summer trial, than in the fall, 1983 trial, to provide acceptable suppression. The activity of postemergence grass herbicides varies in response to plant growth stage (8,50,115), herbicide carrier volume (41), temperature and moisture (41,42,45,50,115), and grass species (45,106). The impact of these effects on chemical suppression need to be determined before consistent, effective herbicide recommendations can be made.

## II. Living Mulch Suppression

### 1. Suppression of perennial ryegrass in wine grapes - 1984,1985,1986

In all years, plots chemically suppressed with either fluazifop-P-butyl or sethoxydim had lower perennial ryegrass clipping weights 7 weeks after treatment, than plots mowed every 2 weeks (Table 6). The reduction in clipping weight with chemical suppression occurred regardless of whether the treatments were made in summer, fall, or spring, although overall ryegrass growth was greatest in the spring, 1986 trial, and lowest in the fall, 1985 trial, following the normal pattern of grass growth. In summer, 1984 grass growth was suppressed 41 to 46% with fluazifop-P-butyl, and 25 to 62% with sethoxydim, compared to growth of mowed grass. In fall, 1985, grass growth was suppressed 56 to 76% with fluazifop, and 58 to 62% with sethoxydim. Fluazifop suppressed grass growth 50 to 69%, and sethoxydim 41 to 51%, in spring, 1986.

Fluazifop and sethoxydim were comparable at suppressing grass growth based on clipping weight, but based on field observations grass growth suppression lasted longer with fluazifop-P-butyl than sethoxydim. Grass regrowth was observed 1 to 2 weeks earlier in the sethoxydim plots. All chemical suppression treatments caused slight discoloration (chlorosis) of the grass. Duration of chemical grass suppression with both herbicides was shorter (5 weeks) in August, 1985 and March, 1986, than in June, 1984 (7 weeks). Initial grass regrowth was spotty and uneven, but within 7 to 9 weeks after treatment all the grass plots were relatively uniform.

The yield of grass clippings per total plot area (g/plot) was lowest with the chemically suppressed grassed aisle plots, but these yields were not always significantly less than chemically suppressed plots with 100% grass cover (Table 6). Mowed grass aisles produced the greatest cumulative clipping yield, except in 1984 when clipping yields in the 100% grass cover plots, chemically suppressed with sethoxydim, were 14% greater than mowed plot.

**2. Suppression of perennial ryegrass in Christmas trees - 1984, 1985,1986**

Results of suppressing growth of a perennial ryegrass living mulch in Douglas fir Christmas trees are analogous to the results of grass suppression in wine grape plantings. In 1985 and 1986, clipping yields of chemically suppressed grass were significantly less than mowed grass, but in 1984 only sethoxydim treated grassed aisles had significantly lower clipping weights than mowed aisles (Table 7). Compared to mowed grass, clipping yields were reduced 42 and 48% with fluazifop, and 29 and 54% with sethoxydim, in summer, 1984. In fall, 1985, fluazifop reduced clipping yields 63 and 71%, and sethoxydim 59 and 64%. In spring, 1986, fluazifop reduced clipping yields 54 and 64%, and sethoxydim reduced clipping yields 43 and 53%. Grass suppression was comparable with fluazifop or sethoxydim. Other comparisons and qualitative observations were consistent between the wine grape and Christmas tree trials.

The yield of grass clippings per total plot area (g/plot) was lowest with the grassed aisle plots treated with either fluazifop or sethoxydim, but these yields were not always significantly less than the chemically suppressed plots with 100% grass cover (Table 7). Mowed grass aisles produced the greatest clipping yield per plot area, except in 1984 when clipping yields in the 100% grass cover plot, chemically suppressed with sethoxydim, were 22% greater.

In both the wine grape and Christmas tree study, the 100% grass cover plots had one-third more plot area planted to grass than the grassed aisle plots, but total grass clipping weights (g/plot) in the mowed grassed aisle plots were usually higher. Clipping weights in the chemically suppressed grassed aisle plots were usually lower or equal to weights in the chemically suppressed 100% grass cover plots. The reason for the production of more grass from a smaller grassed area is unclear, but the grassed aisle plots do have more bare ground area than the 100% grass cover plots, possibly providing the grass with a better environment for growth, due to less inter- and intraspecific competition from the grapes or trees and the grass for water and nutrients. This pattern of improved growth along a bare ground and grass interface is referred to as an edge effect.

Chemical suppression of grass living mulches decreased grass growth more than mowing during the 6 week suppression period, which agrees with results from other chemical suppression studies (12,15,16,134,194,195,196). Although Wiles (226,227) found no difference in dry weight between mowed and chemically suppressed grasses in field trials, in greenhouse studies chemically suppressed grass yielded less than mowed.

Beard (27) states that frequent and low mowing of turfgrasses decreases growth and water use rate compared to uncut grass. Graham (88) and Murray (149), however, found that water use between infrequently mowed and uncut grass is similar. Chemical suppression also decreases soil moisture depletion compared to uncut grass (12,16,28,88,149). In three studies, no statistical differences in water use were found between mowed and chemically suppressed grass, but the chemically suppressed grass tended to use less water than mowed (16,88,149). The reduction in grass growth with chemical suppression compared to mowing, and the trend for decreased water use warrants further studies on the potential of chemical suppression as a method of decreasing water use and competitiveness of living mulches.

Both herbicides in this study provided acceptable suppression, without grass injury, but sethoxydim provided effective grass suppression at lower rates than fluazifop-P-butyl. Fluazifop-P-butyl, however, provided slightly longer grass suppression than sethoxydim.

## III. Effects of Living Mulch on Crop Growth

### 1. Wine grape growth - 1985 and 1986

In 1985, the second year after planting, vine growth of grapes in the bare ground and mowed grassed aisle treatments was greater than growth in the chemically suppressed grassed aisle, or the chemically suppressed 100% grass cover plots; differences in grape growth between bare ground and mowed aisles were not significant (Table 8). Pruning weights of vines grown in chemically suppressed aisles were 8 to 10 times greater than vines in chemically suppressed, 100% grass cover plots, but these differences were not statistically significant. Total cane length was, however, significantly greater for vines grown in chemically suppressed grassed aisle plots. Grapes plants grown in the 100% grass cover treatments were stunted and chlorotic, indicating moisture and nitrogen deficiencies, and possibly allelopathic effects from the perennial ryegrass (65,75,80,168,169).

In 1986, vine growth was greatest in the bare ground treatment (Table 8). Significant growth differences found among the treatments are ranked as follows: bare ground > mowed grassed aisles > chemically suppressed grassed aisles > 100% grass cover, chemically suppressed. Grapes grown in the 100% grass cover plots, chemically suppressed were again stunted and chlorotic; these vines were at least 40 times smaller than vines grown in bare ground, based on cane pruning weights. In both 1985 and 1986, grape response was similar in chemically suppressed plots treated with either fluazifop-P-butyl or sethoxydim.

Growing newly established grapes vines in bare ground rows with grassed aisles could help reduce erosion and improve trafficability in the vineyard, but results of this study indicated that growing vines in a 1 M wide bare ground strip, with mowed or chemically suppressed grassed aisles, reduced grape vine growth even in a new planting. These data support results from other research showing decreased growth and production of crops grown in a bare row + grassed interrow system for grapes (190,204,233); peaches (123,221,222,223); and apples (12,178,185,187,197,200). Increasing the width of the bare ground strip can increase crop growth in a bare row + grassed aisle system (193,223).

On sites where a living mulch is desired, the optimum width of the bare ground strip needs to be determined. Suggested width of the bare ground strip has been reported as one-half to two-thirds or more of the planting area (18,19,111,193,221,222,223).

Mowing or chemical suppression of grassed aisles did not eliminate interference with grape growth, but both of these ground cover management techniques were improvements over 100% grass cover, illustrating the importance of a eliminating weeds or other ground covers from the crop row in young vineyards.

The differences in vine growth between the mowed and chemically suppressed grassed aisle treatments were somewhat unexpected because grass clipping yields in the chemically suppressed plots were 40 to 55% lower than in the mowed plots. Research indicates ground covers competition for water and nutrients increases with increasing ground cover vigor (88,144,149,153,185,186,197,204,205,221,223,226,227,233). Understanding of results in this study would have been improved by monitoring soil moisture, grass growth, and weed populations over the entire growing season, but without this information, several possible explanations can be offered for the decrease of vine growth in the chemically suppressed grassed aisle plots.

Beardmore and Linscott (28) found that grass suppressed with fluazifop or sethoxydim continues to transpire but at a decreased rate, depending on herbicide rate. They suggest that fluazifop and sethoxydim disrupt the cellular tissue in and around the xylem and phloem in meristematic regions of the grass, interfering with water transport.

Clipping weight of oat treated with sethoxydim at 0.07 kg $ha^{-1}$ was 44% of untreated grass, but transpiration rate and soil matric potential was not significantly different from untreated oat (28). Devitt and Morris (64) also showed reduced transpiration with chemically suppressed compared to mowed grass, but again at lower suppression rates grass growth was decreased but evapotranspiration was not. Mowing initially decreases grass water use by decreasing transpiration and leaf area index, with transpiration gradually increasing as leaf area index increases with grass regrowth (27). In this study, 3 mowings in a 7 week period may have decreased water use more than one chemical suppression treatment, during a period of active grass growth, decreasing potential soil moisture deficits for the grapevines.

Attempts were made to control broadleaf weeds in the grassed aisles, but field bindweed, Canada thistle, and other broadleaf weeds persisted in the plots. The grass herbicides, fluazifop-P-butyl and sethoxydim, used as chemical suppressants in this experiment, are not consistently phytotoxic to broadleaf species (43). Chemical suppression may curtail the competitive advantage of perennial ryegrass against weed establishment. Increased populations of undesirable broadleaf weeds in chemically suppressed grass have been reported (88,134,149,177). Broadleaf weeds in the chemically suppressed plots may increase total water use, because these plants are actively growing during the grass suppression phase.

Certain plant growth regulators (e.g. mefluidide, flurprimidol, and Cycocel), after the initial period of growth suppression, stimulate grass growth above that of untreated grass, potentially increasing grass water use (64,82,137). Although fluazifop-P-butyl and sethoxydim affect meristematic activity and seedhead production of grasses, no literature indicates a stimulating effect of these chemicals on grass growth. In this study, grass growth was not measured after the effects of chemical suppression subsided, so any growth stimulating effect of sub-lethal rates of fluazifop and sethoxydim are unknown.

The land used for this experiment had been treated with several residual soil herbicides in a previous study; due to detrimental effects of these residual herbicides, within plot variation of crop growth may have confounded treatment effects.

Fluazifop-P-butyl and sethoxydim have shown no phytotoxicity to wine grapes (97), but variety sensitivity has not been reported.

Mowing and chemical suppression treatments were applied only once in the spring of 1985 and 1986. Visual observations indicated that the perennial ryegrass continued growing vigorously after the effects of suppression subsided, and grass did not go dormant until July, when soil moisture was reduced. The effectiveness of chemical suppression might be improved if spring treatments are repeated until summer grass dormancy occurs; 2 to 3 treatments from March until June could be necessary, depending on seasonal variations.

2. Christmas tree growth - 1985 and 1986

In 1985, the second year after planting, there were no differences in either terminal shoot growth or canopy volume of Douglas fir among the ground cover treatments (Table 9).

In 1986, there were no differences in either terminal shoot growth or canopy volume between bare ground plots and the mowed or chemically suppressed grassed aisle plots. Trees grown in a chemically suppressed 100% grass cover, were significantly smaller than in the bare ground treatment. In early summer, trees grown in 100% grass cover appeared to be nitrogen and water deficient, because they were distinctly more chlorotic than trees in the other treatments.

Trunk caliper measurements, in 1986, were largest with trees grown in bare ground, and smallest with trees in the chemically suppressed 100% grassed cover plots. No difference in trunk caliper was detected among the grassed aisle treatments (mowed or chemically suppressed), but trunk caliper was significantly greater than caliper of trees in the 100% grassed cover plots, chemically suppressed. Again trees in the 100% grass cover plots were smaller and more chlorotic than trees in other treatments.

The deleterious effect of 100% grass cover on conifer and landscape tree growth has been well documented, and was demonstrated in this trial, even with chemical suppression or mowing (24,39,53,67,100,127,152,164,165,170,188,219).

In this study, Douglas fir Christmas tree growth was negatively affected by ground cover management, but appears to better tolerate grass interference than wine grapes grown with the same management system, at least in the first 3 years after planting. Allelopathic effects of the perennial ryegrass on the grapes but not the Christmas trees may offer a partial explanation for this result (65). Grass may have less affect on Christmas tree than grape growth due to the fact that Douglas fir terminates growth in early July, at a time when soil moisture is still available. Grape vine shoot growth continues through the summer at a time when grass growth has already depleted soil moisture reserves.

Research shows that growing conifers grown in bare rows with grassed aisles reduces the competitive effects of the grass, at least in the early years of growth compared to overall sod (40,101,124,188,219). Murray (149) found no differences in growth of young Douglas fir planted in: bare ground, fluazifop suppressed grass aisles, infrequently mowed grass aisles, or mowed indigenous vegetation. Skroch et al.(188) found that grasses, more than broadleaved ground covers, inhibit growth of hemlock and pine.

Continuing this study until the trees reached a marketable size would help determine the overall effect of growing trees with a perennial ryegrass living mulch.

As with grapes, extending the length of time grass growth is suppressed in spring, and increasing the bare ground area of the tree row, could further decrease competition of mowed or chemically suppressed grassed aisles.

Table 1. Growth of chemically suppressed 'Manhattan II' perennial ryegrass; Fall treatment, November, 1983.

| Treatment | (kg ai/ha) | Grass Regrowth (cm)[1] | | |
|---|---|---|---|---|
| | | 22 DAT | 36 DAT | 81DAT |
| Fluazifop[2] | | | | |
| | 0.12 | 1.3 b[3] | 1.7 cd | 1.5 bc |
| | 0.31 | 1.1 b | 1.2 cde | 1.3 c |
| | 0.52 | 1.4 b | 1.3 cde | 0.6 c |
| | 0.9 | 0.9 b | 0.7 de | ---[4] |
| Sethoxydim[2] | | | | |
| | 0.02 | 2.5a | 2.7ab | 2.6a |
| | 0.04 | 1.1 b | 0.7 de | --- |
| | 0.1 | 1.2 b | 1.1 cde | --- |
| | 0.13 | 1.1 b | 0.4 e | --- |
| Glyphosate | | | | |
| | 0.12 | 1.4 b | 1.9 bc | 1.6abc |
| | 0.31 | 1.3 b | 1.2 cde | 1.1 c |
| | 0.51 | 0.9 b | 0.7 de | --- |
| | 0.77 | 1.2 b | 0.5 e | --- |
| Untreated Check | | 2.9a | 3.3a | 2.4ab |

[1]Height of grass measured from base mowing height of 4.5 cm.
[2]Crop oil concentrate (1% v/v) added to fluazifop and sethoxydim treatments.
[3]Mean separation within columns by Duncan's multiple range test, P = 0.05.
[4]Grass dead by this date.

Table 2. Quality of chemically suppressed 'Manhattan II' perennial ryegrass; Fall treatment, November, 1983[1].

| | | Grass Quality Rating[2] | | |
|---|---|---|---|---|
| | | 22 DAT | 36 DAT | 81 DAT |
| Treatment | (kg ai/ha) | | | |
| Fluazifop[3] | | | | |
| | 0.12 | 3.5 | 3 | 5 |
| | 0.31 | 4 | 3 | 2 |
| | 0.52 | 3 | 2 | 2 |
| | 0.9 | 2 | 1.5 | 0 |
| Sethoxydim[3] | | | | |
| | 0.02 | 4 | 3 | 5 |
| | 0.04 | 2 | 2 | 1 |
| | 0.1 | 1 | 1 | 0 |
| | 0.13 | 1 | 1 | 0 |
| Glyphosate | | | | |
| | 0.12 | 3.5 | 2.5 | 5 |
| | 0.31 | 2 | 2 | 5 |
| | 0.51 | 1 | 1 | 1 |
| | 0.77 | 1 | 1 | 1 |
| Untreated Check | | 5 | 4.5 | 5 |

[1]Table of means, not statistically analyzed.
[2]Grass quality based on visual leaf color rating; 0 = brown, necrotic, dead; 5 = dark green, healthy.
[3]Crop oil concentrate (1% v/v) added to fluazifop and sethoxydim.

Table 3. Percent stand of chemically suppressed 'Manhattan II' perennial ryegrass; Fall treatment, November, 1983[1].

| Treatment | (kg ai/ha) | Percent Grass Stand[2] 81 DAT |
|---|---|---|
| Fluazifop[3] | | |
| | 0.12 | 85 |
| | 0.31 | 47 |
| | 0.52 | 35 |
| | 0.9 | 0 |
| Sethoxydim[3] | | |
| | 0.02 | 80 |
| | 0.04 | 17 |
| | 0.10 | 0 |
| | 0.13 | 0 |
| Glyphosate | | |
| | 0.12 | 78 |
| | 0.31 | 52 |
| | 0.51 | 10 |
| | 0.77 | 10 |
| Untreated Check | | 92 |

[1]Table of means from 3 plots, not statistically analyzed.
[2]Percent of plot area with established grass stand.
[3]Crop oil concentrate (1% v/v) added to fluazifop and sethoxydim.

Table 4. Growth and seed head production of chemically suppressed 'Manhattan II' perennial ryegrass; Spring treatment; May, 1984.

| | | Grass Growth[1] (cm) 1984 | | Seed Heads/ 0.09 $m^2$ |
|---|---|---|---|---|
| | | 25 DAT | 36 DAT | 36 DAT |
| Treatment | (kg ai/ha) | | | |
| Fluazifop[2] | | | | |
| | 0.11 | 1.8 cd[3] | 6.1 abc | 23 bcd |
| | 0.28 | 1.7 cd | 6.6 abc | 24 bcd |
| | 0.45 | 1.4 cd | 5.6 bc | 6 d |
| Fluazifop-P-butyl[2] | | | | |
| | 0.06 | 2.8 abc | 7.5 ab | 17 bcd |
| | 0.13 | 1.1 d | 6.6 abc | 11 d |
| | 0.22 | 1.8 cd | 4.8 c | 6 d |
| Sethoxydim[2] | | | | |
| | 0.01 | 2.3 bcd | 6.7 abc | 28 bcd |
| | 0.02 | 2.5 abcd | 6.6 abc | 4 d |
| | 0.04 | 1.8 cd | 6.5 abc | 17 cd |
| Glyphosate | | | | |
| | 0.17 | 2.4 abcd | 6.8 abc | 48 abc |
| | 0.28 | 2.7 abcd | 6.2 abc | 31 bcd |
| | 0.39 | 2.7 abcd | 6.6 abc | 48 ab |
| Untreated Check | | 3.4 ab | 8.3 a | 73 a |
| COC[2] check | | 3.9 a | 6.7 abc | 64 a |

[1]Height of grass measured from base mowing height of 4.0 cm.
[2]Crop oil concentrate (COC) 1 % (v/v) added to fluazifop, fluazifop-P-butyl, sethoxydim, and COC check.
[3]Mean separation within columns by Duncan's multiple range test, P = 0.05.

Table 5. Effect of adjuvants on grass suppression activity of fluazifop and sethoxydim. Spring treatment; May,1984.

| | | Grass Growth[1] (cm) 1984 | | Seed Heads/ 0.09 $m^2$ |
|---|---|---|---|---|
| Treatment | (kg ai/ha) | 25 DAT | 36 DAT | 36 DAT |
| Fluazifop | 0.11 | | | |
| | alone | 5.4 abc[4] | 9.8 ab | 41 bcd |
| | + oil[2] | 2.9 def | 8.5 ab | 12 def |
| | + surfactant[3] | 2.4 ef | 8.0 b | 3 ef |
| Sethoxydim | 0.02 | | | |
| | alone | 4.6 abcd | 8.9 ab | 58 abc |
| | + oil | 3.3 def | 7.8 b | 8 def |
| | + surfactant | 3.8 cdef | 7.8 b | 34 cdef |
| Sethoxydim | 0.04 | | | |
| | alone | 4.0 bcd | 9.2 ab | 37 cde |
| | + oil | 2.1 f | 7.1 b | 1 f |
| | + surfactant | 5.7 ab | 9.6 ab | 62 abc |
| Untreated check | | 5.0 abc | 8.8 ab | 75 ab |
| COC check | | 4.7 abcd | 9.5 ab | 88 a |
| Surfactant check | | 6.2 a | 10.8 a | 86 a |

[1]Height of grass measured from base mowing height of 4.0 cm.
[2]Crop oil concentrate (COC) (1% v/v) added to fluazifop, sethoxydim, and COC check.
[3]Surfactant (0.1% v/v) added to fluazifop, sethoxydim, and surfactant check.
[4]Mean separation within columns by Duncan's multiple range test, P = 0.05.

Table 6. Clipping weight of mowed and chemically suppressed perennial ryegrass in a wine grape planting.

| | Clipping Dry Weight ($g/m^2$) | | | Clipping Dry Weight (g/plot)[1] | | |
|---|---|---|---|---|---|---|
| Grass Treatment | 1984 50 DAT[2] | 1985 47 DAT | 1986 47 DAT | 1984 50 DAT | 1985 47 DAT | 1986 47 DAT |
| Grassed Aisles + Bare Row | | | | | | |
| Mowed Aisles | 81a[5] | 50a | 117a | 886ab | 547a | 1282a |
| Chem. Supp. Fluazifop-P[3] | 48 b | 22 b | 58 b | 526 bc | 247 b | 638 c |
| Chem. Supp. Sethoxydim[4] | 31 b | 19 b | 69 b | 328 c | 204 b | 764 bc |
| 100% Grass Cover (Aisle + Row) | | | | | | |
| Chem. Supp. Fluazifop-P | 44 b | 12 b | 36 c | 725abc | 198 b | 509 c |
| Chem. Supp. Sethoxydim | 61ab | 21 b | 57 b | 1011a | 343 b | 927 b |

[1]Grass clipping weight from the entire plot area (16.5 $m^2$).
[2]DAT = Days after treatment.
[3]Fluazifop-P-butyl 0.22 kg ai/ha + 1% (v/v) crop oil concentrate applied to grass.
[4]Sethoxydim 0.044 kg ai/kg + 1% (v/v) crop oil concentrate applied to grass.
[5]Mean separation within columns by Duncan's multiple range test, P = 0.05.

Table 7. Clipping weight of mowed and chemically suppressed perennial ryegrass in a Douglas fir Christmas tree planting.

| | Clipping Dry Weight ($g/m^2$) | | | Clipping Dry Weight (g/plot)[1] | | |
|---|---|---|---|---|---|---|
| Grass Treatment | 1984 50 DAT[2] | 1985 47 DAT | 1986 47 DAT | 1984 50 DAT | 1985 47 DAT | 1986 47 DAT |
| Grassed Aisles + Bare Row | | | | | | |
| Mowed Aisles | 90a[5] | 49a | 116a | 985ab | 540a | 1275a |
| Chem. Supp. Fluazifop-P[3] | 52ab | 18 b | 53 bc | 576 b | 193 c | 578 c |
| Chem. Supp. Sethoxydim[4] | 41 b | 16 b | 66 b | 454 b | 180 c | 729 bc |
| 100% Grass Cover (Aisle + Row) | | | | | | |
| Chem. Supp. Fluazifop-P | 47ab | 14 b | 42 c | 779ab | 283 bc | 688 bc |
| Chem. Supp. Sethoxydim | 73ab | 20 b | 54 bc | 1203a | 335 b | 891 b |

[1]Grass clipping weight from the entire plot area (16.5 $m^2$).
[2]DAT = Days after treatment.
[3]Fluazifop-P-butyl 0.22 kg ai/ha + 1% (v/v) crop oil concentrate applied to grass.
[4]Sethoxydim 0.044 kg ai/kg + 1% (v/v) crop oil concentrate applied to grass.
[5]Mean separation within columns by Duncan's multiple range test, P = 0.05.

Table 8. Cane pruning weight and vine length of 'Chardonnay' grapevines grown with various ground cover management treatments.

| | 1985 | | 1986 | |
|---|---|---|---|---|
| | Cane Pruning Fresh Weight (g/vine) | Total Vine Length (cm/vine) | Cane Pruning Fresh Weight (g/vine) | Total Vine Length (cm/vine) |
| Ground Cover Treatment | | | | |
| Bare Row + Bare Aisles | 90 a[1] | 81 a | 910 a | 1701 a |
| Bare Row + Grassed Aisles | | | | |
| Mowed Aisles | 100 a | 84 a | 542 b | 1415 b |
| Chem. Supp. Fluazifop-P[2] | 40 b | 51 b | 304 c | 768 c |
| Chem. Supp. Sethoxydim[3] | 31 b | 49 b | 308 c | 788 c |
| Grassed Row + Grassed Aisles | | | | |
| Chem. Supp. Fluazifop-P | 5 b | 16 c | 23 d | 132 d |
| Chem. Supp. Sethoxydim | 4 b | 13 c | 14 d | 96 d |

[1]Mean separation within columns by Duncan's multiple range test, P = 0.05.
[2]Chemical suppression with fluazifop-P-butyl 0.22 kg ai/ha + 1% crop oil concentrate.
[3]Chemical suppression with sethoxydim 0.044 kg ai/ha + 1% crop oil concentrate.

Table 9. Growth of Douglas Fir Christmas trees grown with various ground cover management treatments.[1]

| Treatment | 1985 Terminal Shoot Growth (cm) | 1985 Canopy Volume Growth ($cm^3$) | 1986 Terminal Shoot Growth (cm) | 1986 Canopy Volume Growth ($cm^3$) | 1986 Trunk Caliper Growth (mm) |
|---|---|---|---|---|---|
| Bare Row + Bare Aisles | 31 | 86,000 | 81 a | 456,000 a | 24 a |
| Bare Row + Grassed Aisles | | | | | |
| Mowed Aisles | 28 | 75,300 | 72 a | 354,400 ab | 20 b |
| Chem. Supp. Fluazifop-P[2] | 37 | 101,900 | 82 a | 480,900 a | 20 b |
| Chem. Supp. Sethoxydim[3] | 36 | 86,900 | 68 ab | 386,600 ab | 20 b |
| Grassed Row + Grassed Aisles | | | | | |
| Chem. Supp. Fluazifop-P[2] | 29 | 86,800 | 49 c | 196,400 c | 13 c |
| Chem. Supp. Sethoxydim[3] | 30 | 74,800 | 56 bc | 296,700 bc | 14 c |

[1]Mean separation within columns by Duncan's multiple range test, P = 0.05; lack of separation indicates nonsignificance.
[2]Chemical suppression with fluazifop-P-butyl 0.22 kg ai/ha + 1% crop oil concentrate.
[3]Chemical suppression with sethoxydim 0.044 kg ai/ha + 1% crop oil concentrate.

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