APPLE TREE GROWTH AND YIELD
IN ALTERNATIVE GROUND MANAGEMENT SYSTEMS

by

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FOREWORD

This thesis is submitted in the form of original papers suitable for journal publications. Chapter 2 is a literature review presenting previous work done which is relevant to the experiments undertaken for this thesis. Chapters 3 and 4 are presented in manuscript form. Chapter 5 is an overall discussion of the results from these experiments and a summary of the conclusions and contributions to knowledge. Chapter 6 is a list of suggestions for future research.

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The work presented here was the responsibility of the candidate (except as stated in the prefaces to chapters 3 and 4). The project was supervised by Dr. D.J. Buszard, Department of Plant Science, McGill University. The two manuscripts are co-authored by S.S. Salmins, D.J. Buszard, A.F. MacKenzie, and B.D. Walsh. For consistency and convenience the manuscripts follow the same format, however, when submitted for publication, they will follow the requirements of the journal. Both manuscripts will be sent to the journal, HortScience.

GENERAL ABSTRACT

Dwarf apple tree growth and yield under several non-herbicidal ground management systems were compared. Six ground cover systems were established in two newly planted orchards. After two growing seasons, trees in the straw mulch and geotextile mulch treatments had larger trunk cross-sectional areas and more shoot growth than trees in the red fescue and insectary plant cover treatments. Growth of trees under the manure mulch and cultivation treatments was intermediate. When four of the systems were established along rows of five-year old trees in an existing orchard, the increase in trunk cross-sectional area over two growing seasons was greatest for trees in the manure mulch and straw mulch followed by tose in geotextile mulch, trees in the red fescue grew least. The use of a mulch, such as straw or geotextile, has a favourable effect on growth and has potential for use in organic orchards.

RÉSUMÉ

La croissance et le rendement de pommiers nains ont été comparés sous plusiers systèmes de gestion de sol sans herbicide. Six traitements ont été mis en place dans deux vergers nouvellement plantés, et, quatre d'entre eux seulement, dans un verger âgé de cinq ans. Les résultats après deux ans montrent que dans les vergers nouvellement plantés, les pommiers dont le sol était recouvert de paille ou d'un géotextile avaient une surface de la section transversale du tronc plus large et des tiges plus longues que ceux des pommiers dont le sol était recouvert de la fétuque rouge ou de la culture de couverture de plantes mixtes. Les pommiers ayant reçu comme traitement le paillis de fumier ou le sarclage obtenaient une croissance intermédiaire. Dans le verger mature, les résultats après deux ans indiquent une plus grande surface transversale de la section du tronc pour les arbres ayant reçu le paillis de fumier et le paillis de paille suivis du paillis de géotextile. La fétuque rouge a eu comme effet de reduire la croissance des pommiers. L'utilisation de paillis comme la paille ou le géotextile produit un effet favorable sur la croissance des pommiers et offre un potentiel pour les vergers organiques.

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CHAPTER 1

INTRODUCTION

Apples are the most widely produced and consumed fruit in North America. The establishment of an apple orchard requires a large initial capital investment. Furthermore, it takes at least five years to begin to realize a return on this investment, with dwarf trees beginning to bear three to five years after planting (Guy Jalbert, J.C. Spenard, personal communication). To minimize this time, by promoting early, vigorous growth and precocious, heavy yielding trees, good soil management is critical. Many apple growers rely on herbicides along the tree row to reduce competition for moisture and nutrients from unwanted vegetation; however, concern for the environment, soil degradation and pollution of groundwater associated with long-term chemical use, has led some researchers to search for alternatives to herbicides for orchard soil management.

Cultivation is one method used by orchardists' to control weeds (Westwood, 1978). Results from Shribbs and Skroch's (1986a) study, found growth and yield of trees under cultivation to be comparable with that of those under bare ground maintained by herbicides. However, a major concern with this practice is the detrimental effect it has on the soil over the long term. Cultivation has been found to decrease soil stability and organic matter levels (Hipps et al., 1990; Jordan and Jordan, 1984; Wooldridge and Harris, 1989), and to lead to increased soil erosion (Jordan and Jordan, 1984). These factors may in turn lead to decreased productivity.

Straw mulch is another option currently used for weed control in some orchards (LISA, 1990) and has been found to stimulate tree growth and promote high yields (Baxter, 1970; Shribbs and Skroch, 1986a). It also provides organic matter and nutrients to the soil (Haynes, 1980; White and Holloway, 1967) and has been found to decrease soil temperature fluctuations (Baxter, 1970), conserve soil moisture (Skroch and Shribbs, 1986), and overall, to help maintain good soil structural stability (Hipps et al, 1990).

Various grasses have also been studied for their suitability as in-row cover for orchards and are used by some growers (member of COG, personal communication; Shribbs and Skroch, 1986a). Grass sod helps to improve soil structural stability, aeration, and friability (Jordan and Jordan, 1984; Skroch and Shribbs, 1986), and to make conditions favourable for soil biological activity (Haynes, 1980). However, researchers have overwhelmingly found tree growth to be inhibited, and yields to be decreased under this type of management system (Johnson and Samuelson, 1990; Shribbs and Skroch, 1986a).

One of the newest techniques being investigated for orchard use, is that of woven polypropylene geotextiles. This fabric-like material allows the soil to "breathe", while protecting it from erosion and conserving soil moisture. The use of this type of cover should be expected to favour tree growth as it blocks most weeds, thus reducing their competitive effect. It is an expensive material; however, should it be proven effective, as we move to higher density orchards, and if its cost is amortized over a lifespan of at least five years (Alain Chaisse, Materiaux Technique Cote, Boucherville, Quebec, personal communication), and possibly even eight years (E.J. Hogue, Agriculture Canada, Summerland, B.C., personal communication), it may become an economically viable and interesting option.

Two other covers investigated in this study are manure mulch and a living cover comprised of plants favouring beneficial insect activity. We can expect the manure mulch to provide the benefits of an organic mulch (ie., soil moisture conservation, improved soil structural stability, addition of organic matter and nutrients, and decreased erosion); however, its effect on growth and yield compared with the other systems is unknown. The effect of a plant cover should be expected to benefit soil structural stability and both soil and above-ground biological activity; however, due to its competitive effect, it is reasonable to expect that tree growth may be inhibited under this system,.

The goal of this study is to examine several soil management systems in the context of organically managed apple orchards, to find the best program to enhance the orchard environment, while at the same time promoting growth and high yields. One experiment compares the effects on the growth of newly planted apple trees on dwarf rootstocks, of cultivation, straw mulch, geotextile, manure mulch, red fescue cover (*Festuca rubra*), and an insectary plant cover consisting of a mix of lupin (*Lupinus albus*) and wild carrot (*Daucus carota*). The second experiment investigates the effects on growth and yield of mature, bearing, dwarf trees, of four of these treatments, including red fescue cover, straw mulch, geotextile, and manure mulch, applied five year's after planting, subsequent to conventional weed control with herbicides.

CHAPTER 2

GENERAL LITERATURE REVIEW

2.1 Cultivation

The manual removal of weeds and use of cultivating machinery to disturb weeds and germinating weed seeds has been, and still is, widely used in agriculture. According to Jordan and Jordan (1984), the practice of cultivating in orchards should help to break surface crusts, allowing better water penetration and aeration, facilitate irrigation, pest control, and harvesting, and is easy to perform with equipment generally being readily available. In reviewing the studies that have been done to assess the effectiveness of cultivation in orchards, although some found an advantage to cultivation, many found the practice to be detrimental to the soil, and to the growth of the tree and its ultimate productivity.

Of primary concern worldwide is the loss of soil to wind and water erosion. Soils left bare by cultivation will be far more susceptible to erosion, which may increase the likelihood of the tree roots near the surface being exposed and potentially damaged by cultivation equipment (Baxter, 1970; Haynes, 1980; Hipps et al, 1990; Jordan and Jordan, 1984; Lord and Vlach, 1973). Even without erosion playing a part, Greenham and White (1968), Shribbs and Skroch (1986a), and White and Holloway (1967) state that cultivation machinery may cut surface roots, and, according to Haynes (1980), this may be an important cause of dieback in apple trees. The damage to surface roots will reduce the amount of nutrients taken from the upper portion of the soil. These damaged roots will also be more susceptible to insect and disease attack (Jordan and Jordan, 1984). White and Holloway (1967) found that apple trees in completely cultivated areas had the fewest roots near the trunk, and the roots were shorter when compared to those in mulch, sod, and simazine treatments. Also, tillage equipment may break branches and damage the trunk, permitting insects and disease to invade the broken bark (Jordan and Jordan, 1984).

2.1.1 Effects on growth and yield

To date, most studies measuring performance of fruit trees under different soil management regimes, have compared cultivation with herbicide, sod, and cover crop (generally legume) treatments. When compared with these programs Wooldridge and Harris (1989) found that, over a two year study, mechanical cultivation using discing and rotovating tended to decrease stem circumferences by approximately 16% annually relative to herbicide treatments. However, Lord and Vlach (1973) found that the growth and yield of peach trees under cultivation were comparable to those in the herbicide treatment. Bollard (1957), found that yields of apple trees under clean cultivation were always higher than under grass.

Trunk girth increase of apple trees, over a three year period, was found to be greatest under cultivation when compared with cover crops of grass, clover, alfalfa, and weeds (Rogers and Raptopoulos, 1945). Rogers and Raptopoulos (1945) also found that the trees under cultivation had the most new wood each year compared with other treatments.

Blossoming was found to be earliest under cultivation compared with cover crops of grass, alfalfa, and weeds (Rogers and Raptopoulos, 1945), and in comparison with straw mulch and sod treatments (Greenham and White, 1968).

2.1.2 Effects on soil

In his review, Haynes (1980) observes that cultivation has been found to promote good aeration, which increases biological activity and organic matter decomposition. Cultivation redistributes the organic matter down the soil profile resulting in a lower concentration in the surface layers and higher concentrations in lower levels. However, Greenham and White (1968) and Rogers et al (1948), report that cultivation tends to destroy soil structure. In the short term, bulk density may be reduced and porosity increased. Infiltration capacity was increased compared with grassed and herbicide treatments (Haynes, 1980). Over the long term, however, many researchers found that both soil aggregation and organic matter levels were decreased (Haynes, 1980; Haynes, 1981; Hipps et al, 1990; Jordan and Jordan, 1984; Rogers and

Raptopoulos, 1945). Thus, Haynes (1980), Jordan and Jordan (1984), Rogers and Raptopoulos (1945), Rogers et al (1948), and Wooldridge and Harris (1989), found that cultivated soils had a smaller percentage of organic matter than zero-till and sod treatments; and Wooldridge and Harris (1989) found that mechanical cultivation led to a 13% decrease in organic matter, and a decrease in the cation exchange capacity of the soil.

Cultivation was found to lead to crust formation, decreasing water infiltration and impeding aeration, leading to surface runoff (Haynes, 1980; Haynes, 1981; Jordan and Jordan, 1984), promoting compacted layers (Jordan and Jordan, 1984), and ultimately reducing the amount of water available to the trees (Jordan and Jordan, 1984).

2.1.3 Effects on leaf nutrients

Potassium (K) concentration in leaves was often found to be lower in cultivated treatments. Lord and Vlach (1973), found K content to be lower in the cultivated treatment when compared with herbicide, hay mulch, and frequently mowed sod treatments. Similarly, K content in apple leaves was lowest in the cultivated treatment when compared with straw mulch and sod treatments (Greenham and White, 1968), and with herbicide and sod (Haynes and Goh, 1980).

According to Rogers and Raptopoulos (1945), the highest incidence of interveinal leaf scorch, a result of magnesium deficiency, was found in clean cultivated plots.

2.1.4 Effects on arthropods and earthworms

Cultivation may have the advantage of destroying soil arthropod pests by mechanical injury or exposure (Haynes, 1980); however, this mechanical disturbance will also kill larger soil animals (Haynes, 1980) and has been found to reduce earthworm (*Lumbricus* spp.) populations (Haynes, 1981). This decline in earthworm activity may cause a lowering of soil pH which has been found to lead to Mg toxicity in the tree, affecting storage potential of the fruit and making the tree more susceptible to diseases such as bark measles (Haynes, 1981).

Beneficial arthropods may be killed by the inert dusts, produced by repeated cultivation, through enhanced dessication (Jordan and Jordan, 1984). Dust on the leaves has also been found to inhibit the activity of beneficials (Jordan and Jordan, 1984; William, 1981). A higher level of dust tends to increase the populations of destructive arthropods, including mites (*Tetranychus* spp.), scale (*Quadraspidiotus perniciosus* Comstock and *Lepidosaphes ulmi* L.), mealybugs (*Pseudococcus comstocki* Comstock) and aphids (*Aphis pomi* DeGeer, *Dysaphis plantaginea* Passerini, and *Erisoma lanigerum* Hausmann) (Haynes, 1980; Jordan and Jordan, 1984; William, 1981), thus increasing the severity of leaf damage. According to William (1981), a bare soil background acts as a cue and may actually attract certain species of aphids.

Greater fluctuations in temperature and moisture found under cultivated conditions may create a harsh environment and reduce the growth and survival of permanent soil fauna (Haynes, 1980; Haynes, 1981). Furthermore, the lack of any cover plants may destroy habitats, overwintering refuges, and alternate host food sources of natural enemies and beneficials (Haynes, 1980).

2.1.5 Effects on diseases

Cultivated, bare soil may increase the risk of infection of the fruit or tree to rots caused by the fungus, *Phytopthora cactorum*, if either becomes contaminated with the soil (Bollard, 1957, Haynes, 1980).

2.1.6 Effects on vertebrate pests

Cultivation may have the advantage of reducing vole (*Microtus* spp.) and other rodent populations by destroying the surface runway system, reducing food supply, and destroying some surface nesting sites (Curtis and Merwin, 1991).

2.1.7 Effects on weeds

Timing of cultivation can determine whether it increases or decreases weed problems, and it may result in a shift from annual weeds to a stand of perennials, which are more difficult to control (Jordan and Jordan, 1984). In one study, tillage increased weed populations by more than 50% over a no-till area and increased the weed biomass to almost double (Putnam et al, 1983).

2.2 Straw Mulch

Straw mulch remains a popular method to suppress weeds in orchards. It is particularly popular with organic growers and thus warrants careful examination in this study. As one of the more established soil management systems, much scientific literature exists on this subject.

2.2.1 Effects on growth and yield

Many researchers have found that straw mulch has a favourable effect on growth and yield of apple trees (Baxter, 1970; Boynton and Anderson, 1956; Fisher et al, 1961; Greenham and White, 1968; White and Holloway, 1967). When compared to 8 other treatments over 8 years, tree growth was found to be fastest under the straw mulch (Fisher et al, 1961). Trunk girth increment was found to be greater in these treatments than in sod and crown vetch (*Coronilla varia* L.) treatments (Merwin, 1991), and over ryegrass (*Lolium perenne* L.) and cultivation treatments (Greenham and White, 1968). Judkins and Rollins (1943) found that when a straw mulch was used on top of sod, the trunk girth increment was greater over the first 3 years of establishment than for those under sod with no mulch layer. Peach and apple trees were found to grow faster, having larger trunk girth increments and more vegetative growth, than trees under permanent pasture (Baxter, 1970) and herbicide (Baxter, 1970; Lord and Vlach, 1973).

Annual shoot growth of apple trees under hay mulch was greater than for trees under seaweed, sawdust, and sod treatments (Latimer and Percival, 1947). Similarly, Shribbs and Skroch (1986a) found trees in a 10 cm rye-straw mulch to have greater shoot lengths than trees in legume and orchard grass treatments. Total leaf area of trees under straw mulch was found to be greater than for trees under herbicide, sod, and cultivation treatments (White and Holloway, 1967).

Fruit yields of mulched apple and peach trees were found to be consistently higher than under other treatments. Apple yield per tree in the first harvest was higher for mulched trees than for sod and crown vetch (Merwin, 1991) and sod and herbicide (Baxter, 1970) treatments. Shribbs and Skroch (1986a) found that in the first year of bearing, trees in a rye-straw mulch had 10 fruit per tree while those in other treatments were virtually unfruitful. In the second year, these trees had more than 40 fruit per tree while trees in an orchard grass (*Dactylis glomerata*) treatment had no fruit. In a peach trial, trees under straw mulch had higher yields over two years of study, compared to both herbicide and cultivation treatments (Baxter, 1970). Baxter (1970) found peach trees under straw mulch to yield almost twice the weight of fruit as those under sod treatments. In an older, 4 year study of standard apple trees, hay mulched trees yielded comparably to seaweed treatments but both were more productive than trees in the sawdust and sod treatments (Latimer and Percival, 1947).

Flower bud formation was greater under straw mulch (Baxter, 1970; Haynes, 1980) and even after heavy yields, mulched trees had higher bloom densities in the following year than trees where cultivation was practised (Baxter, 1970; Latimer and Percival, 1947).

Many authors agree that root growth near the soil surface is encouraged under a straw mulch (Baxter, 1970; Greenham and White, 1968; Haynes, 1980; Latimer and Percival, 1947; White and Holloway, 1967). White and Holloway (1967) found that under straw mulch, apple tree roots were larger and more numerous compared with those in the simazine, cultivation, and sod treatments.

2.2.2 Effects on soil

It is widely accepted that adding a layer of straw is of benefit to the soil. Straw mulch has been found to reduce erosion (Haynes, 1980; Hipps et al, 1990; Skroch and Shribbs, 1986). By absorbing the impact of rain, velocity of the surface flow is reduced and soil particles are not as likely to be washed away (Hipps et al, 1990). Slaking and sealing of the surface is slowed down, thus helping to maintain soil structural stability (Haynes, 1980; Hipps et al, 1990). The layer of straw has been found to help conserve soil moisture and decrease soil evaporation by protecting the soil from sun and wind (Baxter, 1970; Boynton and Anderson, 1956; Greenham and White, 1968; Haynes, 1980; Skroch and Shribbs, 1986; Tukey and Schoff, 1963; White and Holloway, 1967). According to Skroch and Shribbs (1986) and Tukey and Schoff (1963), water infiltration rates were also increased.

Soil temperature fluctuations were found to be smaller under the protective layer (Baxter, 1970; Haynes, 1980) and according to Baxter (1970), Haynes (1980), and Tukey and Schoff (1963), overall soil temperatures have been found to decrease, thus protecting the roots from dessication.

Straw mulch has been found to add nutrients and organic matter to the soil (Haynes, 1980; Latimer and Percival, 1947; White and Holloway, 1967). Latimer and Percival (1947) found that the lower two inches of a hay mulch consisted of highly broken down organic matter of which much had become admixed with the top 2 cm of soil. Haynes (1980) suggests that a higher level of microbial activity occurs under a straw mulch.

Increased amounts of available forms of nutrients including nitrogen, phosphorus, potassium, and magnesium were found under straw mulch (Latimer and Percival, 1947; Tukey and Schoff, 1963). Soil nitrate content was found to be higher in straw mulch treatments compared with cultivation (Latimer and Percival, 1947; Shribbs and Skroch, 1986b).

2.2.3 Effects on leaf nutrients

In general, leaves of trees under straw mulch were found to have higher than normal levels of nitrogen and potassium, with phosphorus in a normal range (Shribbs and Skroch, 1986b). Tukey and Schoff (1963) speculated that increased amounts of available nutrients including nitrogen, phosphorus, potassium, and magnesium are to be found in soils under decomposable mulches.

Over two years, Shribbs and Skroch (1986b) found trees in rye-straw mulch had higher nitrogen (N) contents than orchard grass treatments. Similarly, over 4 years of study, mulch treatment tended to increase leaf N (Boynton and Anderson, 1956). Mulched trees were found to have more pre-harvest drop of fruit compared to cultivation and sod treatments (Greenham and White, 1968). Boynton and Anderson (1956) also found mulched trees dropped their fruit earlier and attributed it to the elevated levels of nitrogen. Baxter (1970) and Haynes (1980) speculate that under a straw mulch, shoot growth may continue longer into the fall, for the same reason, thus increasing the risk of frost damage to the trees. The increased nitrogen concentrations may also induce earlier flowering and again increase the risk of frost damage in the spring (Baxter, 1970; Haynes, 1980); however, Greenham and White (1968) found that mulched trees blossomed later than those in sod and cultivation treatments, possibly due to the lower soil temperatures under the mulch and slower warming of the soil in the spring.

Leaf potassium concentrations were found to be higher under mulch than under sod or cultivation (Greenham and White, 1968; White and Holloway, 1967), and compared with various other treatments (Boynton and Anderson, 1956). This was found to be true for peach trees as well (Baxter, 1970; Lord and Vlach, 1973).

2.2.4 Effects on arthropods and earthworms

The stable soil environment created by a mulch layer and the presence of organic matter from the decomposing straw, tends to favour arthropod and earthworm activity (Haynes, 1980)

2.2.5 Effects on diseases

Recently, Merwin (1992) found that trees in straw mulch treatments had higher susceptibility to crown or root rots caused by *Phytopthora cactorum*. These rots developed on 35% of the trees in the straw mulch treatments compared to an incidence of only 0 - 6% in five other treatments, including crown vetch, close mowed sod, chemically growth regulated sod, herbicide, and cultivated.

2.2.6 Effects on vertebrate pests

Straw mulch provides an ideal habitat for rodents. Rodent populations and activity have been found to increase in areas of straw mulch, thus increasing the risk of damage to trees (Haynes, 1980; Curtis and Merwin, 1991).Curtis and Merwin (1991) found damage to be greatest in straw mulch treatments over 7 other ground cover systems.

2.2.7 Effects on weeds

Many researchers claim that straw mulch has been found to be an efficient method of weed control in orchards, decreasing the competition between tree roots and weeds for moisture and nutrients (Baxter, 1970; Greenham and White, 1968; Haynes, 1980; Latimer and Percival, 1947). Some researchers looked at the possibility that residues from straw may have an allelopathic effect on weeds. It was found that, upon breakdown, mature straw from cereal grains released a variety of alipathic and phenolic acids which may inhibit weed growth (Putnam et al, 1983). In greenhouse experiments, Putnam et al (1983) found that the percentage of 4 weed species emerged was reduced by 43 - 100% under surface residues of rye-straw. They also found that weed densities under rye, wheat, and barley straw residues we reduced by close to 90% over conventionally tilled areas.

2.2.8 Effects on fruit size and quality

Average fruit size was found to be larger in straw mulch treatments than in others (Baxter, 1970; Boynton and Anderson, 1956; Fisher et al, 1961; Greenham and White, 1968). Peaches from mulched trees were also found to be larger (Baxter, 1970). Latimer and Percival (1947) found that in years of higher yields, fruit size of mulched trees was similar to other trees; however, in years of lower average yields, fruit size in hay mulch and seaweed treatments was larger than for sod and sawdust treatments.

Boynton and Anderson (1956), Greenham and White (1968), and Latimer and Percival (1947) claim that red colour development on the fruit surface was reduced by mulch treatments; whereas, Fisher et al (1961) found it to be similar to other treatments. According to Engel (1974), the incidence of bitter pit was increased in apples from mulch treated plots, presumably due to the higher potassium content of these apples.

2.3 Geotextile

Over the last 10 - 15 years, fabric-like "geotextiles", most often made of polypropylene (a polymerized petroleum byproduct), have been developed for use in horticultural practice as an aid in controlling weeds. To date, they have most often been used in landscaping and are most suitable in plantations where they will not be disturbed for approximately

3 to 5 years. Very little scientific documentation, particularly as pertains to orchard management, is available; therefore, this section presents a very general view of the properties of the fabric, its advantages and disadvantages, in an effort to help understand its potential for use in the establishment years of an orchard.

Briefly, installation involves laying out sheets of the geotextile over the area where weed control is needed, allowing for holes where the desired plants are to be grown. Once installed, the fabric should last 3 to 5 years.

Geotextiles are porous, thus they allow rain through and allow gas exchange in the soil. According to Lytton (1990), they help to insulate the ground and minimize temperature fluctuations. They are said to block the majority of weeds; however, Lytton (1990) and Appleton and Derr (1990) state that perennial weeds such as nutsedge, crabgrass and Bermuda grass will often grow through the geotextile. Weed seeds also germinate in the layers above the fabric and must be pulled out early. If they have time to anchor in the fabric they will tear it when pulled (Lytton, 1990). This obviously increases the amount of time needed to manage the area, in terms of vigilance and labour. Herbicide application before installation is recommended (Lytton, 1990); however, this practice is in direct conflict with the goals of organic agriculture.

Installation, as described earlier, is time consuming and labour intensive, as specific machinery for geotextile installation in orchards has not yet been developed and the procedure needs the precision of human hands. The cost of the fabric itself is quite high at approximetely $3.00 per square metre, although this cost and the initial cost of installation can be spread over the length of time of its effectiveness (ie. approximetely 3 to 5 years).

2.4 Manure mulch

No specific references to the use of farmyard manure as a mulch for apple trees and its effect on growth and yield of the trees were found. The large amounts required for a commercial orchard, applied as a weed controlling mulch to a depth of approximately 15 cm., extending to a radius of roughly 1 metre from the tree, may be difficult to obtain and expensive to apply. Another drawback is that air-borne weed seeds and any not killed in the composting process find the manure an ideal place to root and grow.

2.4.1 Effects on growth and yield

Trials involving a cover crop of soybean in combination with poultry manure provide some information. Standard trees under this treatment grew faster in the first eight years compared to seven other treatments (Fisher et al, 1961).

These trees also had the highest cumulative yield over sixteen years (Fisher et al, 1961).

According to Haynes (1980) this layer of mulch could be expected to encourage root growth near the surface of the soil.

2.4.2 Effects on soil

As a mulch, this layer may have many beneficial effects on the soil which may ultimately have an effect on the growth and yield of the trees. Mulch layers have been found to help absorb the impact of rain, thereby helping to maintain soil structural stability, retarding the slaking and sealing of the surface and thus decreasing erosion (Haynes, 1980) while promoting water infiltration rates (Skroch and Shribbs, 1986). Mulches have also been found to help reduce evaporation by protecting the soil from sun and wind, while helping to keep the soil moist (Haynes, 1980; Skroch and Shribbs, 1986).

Soil under mulches was found to stay at a more uniform temperature with increased protection from freezing damage (Haynes, 1980). However, high nitrogen levels late in the season may delay hardening of the tree and increase the risk of winter damage (Haynes, 1980). By using this type of mulch, organic matter is added to the soil (Rogers and Raptopoulos, 1945) with the upper few centimetres of soil tending to become richer in organic matter (Haynes, 1980).

2.4.3 Effects on arthropods and earthworms

The environment created by a mulch, ie., more stable moisture levels and temperatures, as well as higher levels of organic matter and increased soil structural stability contribute to greater arthropod and earthworm activity (Haynes, 1980).

2.4.4 Effects on fruit quality

Too much nitrogen during ripening has been found to reduce fruit colouring and fruit quality (Fisher et al, 1961, Haynes, 1980).

2.5 Red fescue cover

The use of various species of grass to form a sod is a well-established cultural practice in many orchards. One of the primary reasons for the development of this system is that it is better for traffic, making it easier to access the orchard for operations such as harvesting, pruning, and irrigation.

2.5.1 Effects on growth and yield

It is well documented that a major problem in using a complete sod cover in the establishment years of an orchard is the competition between trees and grass for water (Greenham and White, 1968; Skroch and Shribbs, 1986; Stott et al, 1977; White and Holloway, 1967) and nutrients (Baxter, 1970; Bould et al, 1972; Greenham and White, 1968; Haynes and Goh, 1980; Johnson and Samuelson, 1990; Jordan and Jordan, 1984; Shribbs and Skroch, 1986a; Stott, 1976). Johnson and Samuelson (1990) speculate that trees on dwarf rootstocks, in more intensive plantings might suffer even more from competition with grass than more widely spaced, deeper rooted standard trees. An overwhelming majority of researchers found tree growth to be inhibited under sod cover compared to other treatments tested (Bould et al, 1972; Bould and Jarrett, 1962; Fisher et al, 1961; Greenham and White, 1968; Haynes, 1980; Johnson and Samuelson, 1990; Latimer and Percival, 1947; Rogers et al, 1948; Shribbs and Skroch, 1986a; Stott, 1976; White and Holloway, 1967).

White and Holloway (1967) concluded that moisture stress, especially in dry years, was the main cause of growth depression under sod. Greenham and White (1968), Skroch and Shribbs (1986), and Stott et al (1977) found that the sod tended to deplete the available water within the root zone to depths of about 50 cm.

Others found the competition for nitrogen to be severely limiting (Bould et al, 1972; Bould and Jarrett, 1962; Greenham and White, 1968; Johnson and Samuelson, 1990; Latimer and Percival, 1947; Shribbs and Skroch, 1986b; Stott, 1976; Rogers and Raptopoulos, 1945; Rogers et al, 1948). Concentrations of leaf nitrogen in trees under sod were reduced when compared with trials using herbicide (Stott, 1976) (in peach, Lord and

Vlach, 1973), mulch and cultivation (Shribbs and Skroch, 1986b) (in peach, Lord and Vlach, 1973) and bare ground (Bould et al, 1972; Greenham and White, 1968; Johnson and Samuelson, 1990). Some researchers found that adding nitrogen can overcome sod competition (Bollard, 1957; Greenham and White, 1968) while others argue that it does not (Atkinson and Lipecki, 1980; Shribbs and Skroch, 1986b).

Research overwhelmingly indicates that apple tree growth is inhibited under grass covers. These trees tended to be less vigorous, have smaller trunk growth increments, and lower yields of fruit (Atkinson and Lipecki, 1980; Bould et al, 1972; Fisher et al, 1961; Greenham and White, 1968; Johnson and Samuelson, 1990; Latimer and Percival, 1947; Rogers et al, 1948; Stott, 1976). Peach trees in grass were also found to grow less and produce fewer fruit than those in herbicide, hay mulch, and cultivation treatments (Lord and Vlach, 1973). In 1964 and 1965, Cox's Orange Pippin trees under grass cover had yields reduced by 56% and 43% respectively, compared to other treatments (Bould et al, 1972). Stott (1976) found that yields of Golden Delicious and Cox on MM106 rootstock were smaller under grass treatment than under both uncut clover and herbicide treatments. In elaborate studies measuring tree roots, White and Holloway (1967) found that the total weight of roots was less under grassed down areas than under herbicided, straw mulched or cultivated areas. Wooldridge and

Harris (1989) speculate that grassing down may reduce the number of root laterals and the degree of mycorrhization.

2.5.2 Effects on soil

A sod cover helps to control erosion (Bollard, 1957; Skroch and Shribbs, 1986) and improve water retention and infiltration rates (Haynes, 1980; Haynes, 1981; Jordan and Jordan, 1984; Merwin, 1991). Merwin (1991) measured water infiltration rates and found them to be higher under vegetative covers including grass sod and crown vetch when compared to bare soil.

Soil compaction at depths of 2 - 10 cm was found to be lower in the grass treatment compared to herbicided areas (Haynes, 1980; Haynes, 1981; Merwin, 1991b). The grass roots themselves provide large amounts of dry matter for slow, steady decomposition, increasing the level of organic matter (Haynes, 1980; Haynes, 1981; Jordan and Jordan, 1984; Rogers and Raptopoulos, 1945; Skroch and Shribbs, 1986). According to Haynes (1980), this supplies an energy source to soil microflora in the rhizosphere, encourages earthworm activity, and improves the growth of fungal and actinomycete hyphae. Hence, soil structural stability, aeration, and friability are all improved (Haynes, 1980; Haynes, 1981; Jordan and Jordan, 1984; Skroch and Shribbs, 1986). Under these conditions, roots are encouraged to branch and form more fibrous systems at all depths, enabling them to exploit a greater soil volume than trees under cultivation (Haynes, 1980).

According to Jordan and Jordan (1984), the cover may restrict heat radiation from the soil thus increasing the risk of frost damage while Skroch and Shribbs (1986) claim that the cover will limit extremes of climatic conditions thus favouring growth.

2.5.3 Effects on cree nutrients

Visual examination showed that leaves of trees under sod were paler, showing signs of nitrogen deficiency (Latimer and Percival, 1947; Rogers and Raptopoulos, 1945; Rogers et al, 1948). Shribbs and Skroch (1986b) measured nutrient levels in apple twigs and again found the nitrogen concentration to be lower. Haynes (1980) and Skroch and Shribbs (1986) speculate that a foliar spray to the trees may be able to compensate for the use of nitrogen by the sod.

Studies examining leaf and twig concentrations of potassium (K) and phosphorus (P) indicate that levels of these nutrients in leaves of trees under sod treatments are higher than under various other treatments including mulch, herbicide, and clean cultivation, (Bould et al, 1972; Greenham and White, 1968; Johnson and Samuelson, 1990; Shribbs and Skroch, 1986b). Stott (1976) found increased P levels while K levels were similar to those in herbicide treatments. Shribbs and Skroch (1986b) found this for both leaves and twigs, and speculate that the high levels may be due to a concentration of P and K as a result of poor growth related to N deficiency. Johnson and Samuelson (1990), on the other hand, believe that the grass cover may encourage endogenous mycorrhizae populations and in this way help the tree to take up more phosphorous and potassium. Bould et al (1972) found that P and K levels dropped initially, and only later (approximately 6 years) began to increase. It is suggested that P and K gradually became mobilized and released over time.

2.5.4 Effects on arthropods and earthworms

Grass cover reduces dust and according to William (1981), this should have the effect of decreasing mite infestations as well as other arthropod pests of apple orchards.

As mentioned earlier (see above, sect., 3.5.2), the stable soil environment and slow, steady decomposition of grass roots encourages soil micro-arthropod and earthworm activity (Haynes, 1980).

2.5.5 Effects on vertebrate pests

Grass cover provides protection for rodents which can increase the risk of damage to trees grown in this type of environment (Curtis and Merwin, 1991; Jordan and Jordan, 1984).

2.5.6 Effects on fruit and tree characteristics

Fruit of trees under grassed areas has generally been found to be smaller (Fisher et al, 1961; Greenham and White, 1968) but more highly coloured (Greenham and White, 1968; Latimer and Percival, 1947; Rogers and Raptopoulos, 1945; Rogers et al, 1948; Stott, 1976) than that of trees under other management systems, with the exception of Fisher et al (1961), who found fruit colour to be the same as under different treatments.

Trees under sod tended to retain their fruit longer when compared with mulch and cultivation (Greenham and White, 1968; Rogers et al, 1948). Haynes (1980) states that these trees have a reduced tendency to biennial bearing and usually form fruit spurs more easily. According to Rogers and Raptopoulos (1945), trees tended to blossom later under sod treatments compared to clean cultivation. Delver (1974) warns that the incidence of bitter pit may be increased in fruit of trees under sod due to the higher concentration of potassium.

2.6 Insectary plant cover

The data obtained from the effects of a lupin (*Lupinus albus*)/wild carrot (*Daucus carota*) cover crop on apple tree growth are likely to be original in nature. In reviewing the literature I have, therefore, considered the effects of other leguminous plants in cropping systems in order to extrapolate the effects *Lupinus albus* may have on soil properties and apple tree growth and have made some notes on general attributes of *Daucus carota*. Lupin species are used as food for livestock and as green manures. Wild carrot is considered a noxious weed in Canada.

2.6.1 Effects on growth and yield

Bould and Jarrett (1962) found that trunk girth increments of apple trees were higher under a wild white clover (*Trifolium repens*) cover crop treatment than under both timothy (*Phleum pratense*) and perennial ryegrass (*Lolium perenne*) treatments. Furthermore, bloom density and yields of Cox's Orange Pippin were also higher under the clover treatment (Bould and Jarrett, 1962). These trees were found to bloom earlier, possibly due to a higher leaf nitrogen content (Bould and Jarrett, 1962).

In a three year study by Shribbs and Skroch (1986), trunk diameters of apple trees increased dramatically after the legume plots were tilled in and then kept bare.

According to Jordan and Jordan (1984), the deep taproot of leguminous plants is more competitive with the tree than fibrous-rooted grasses. Bould and Jarrett (1962), Haynes (1980), Jordan and Jordan (1984), and Skroch and Shribbs (1986) agree that competition with fruit trees for water is increased in the presence of a leguminous cover crop.

Finally, in studies of allelopathy, Haynes (1980) cites Bergamini's greenhouse trials in which legume (clover and alfalfa) roots seemed to be exerting some form of biological antagonism, inhibiting the growth of young peach trees.

2.6.2 Effects on soil

Leguminous cover crops have been shown to maintain soil structural stability and to reduce erosion (Haynes, 1980; Jordan and Jordan, 1984; Skroch and Shribbs, 1986) while also retarding the leaching of nutrients (Skroch and Shribbs, 1986). According to Skroch and Shribbs (1986), cover crops have been shown to accelerate the recycling of nutrients. They also increase the level of organic matter (Jordan and Jordan, 1984; Rogers and Raptopoulos, 1945; Skroch and Shribbs, 1986) while controlling the rate of its decomposition (Skroch and Shribbs, 1986).

It is well known that leguminous plants fix nitrogen and provide extra nitrogen to the soil; however, Jordan and Jordan (1984), Rogers et al (1945), and Rogers and Raptopoulos (1948) found that a legume crop seldom produced enough nitrogen for itself and the fruit trees.

2.6.3 Effects on arthropods

The presence of the cover crop near the tree may increase shelter sites for insects and help to attract beneficial insect predators and parasites (William, 1981), creating a balance and allowing better natural control of pest insects in orchards. According to William (1981), wildflowers and especially *Daucus carota* in an abandoned orchard were attractive to several parasitic wasps and parasitization of codling moth and tent caterpillar were increased. The lower level of dust, achieved by a cover crop, also tended to decrease mite infestation (William, 1981).

2.6.4 Effects on diseases

In studies of host plants of tomato ringspot virus (which can affect apple trees), Powell et al (1984) found *Daucus carota* to be a good host.

2.6.5 Effects on vertebrate pests

The presence of the cover crop near the tree may serve as shelter, encouraging rodent activity, and increasing the likelihood of damage to the trees (Curtis and Merwin, 1991; Jordan and Jordan, 1984).

2.6.6 Effects on weeds

Leguminous crops tend to favour the development of weeds. According to Bould et al (1972), Jordan and Jordan (1984), and Shribbs and Skroch (1986), grasses may invade legumes within a short time.

Preface to Chapter 3

The data on soil volumetric water content and soil nitrate and ammonium were collected and analyzed by B.D. Walsh and is provided in this chapter to show how trends in tree growth compare with those of soil characteristics. Similarly, it was hoped to present leaf nutrient analyses; however, this data was not yet available. Observations on weed growth and arthropods, and data collection and analysis of tree growth measurements were carried out by S.S. Salmins. All literature cited in this chapter is listed in chapter 7 of this thesis.

CHAPTER 3

APPLE TREE ESTABLISHMENT IN SIX GROUND MANAGEMENT SYSTEMS IN TWO ORGANIC ORCHARDS

3.1 Abstract

In the spring of 1991, six ground management systems were established in two newly planted apple orchards. At the end of two growing seasons, trees under geotextile and straw mulch treatments showed the most vigorous growth. In orchard 1, trees in straw mulch, geotextile, and cultivation had the greatest increments in trunk cross-sectional area; while in orchard 2, trees in straw mulch, geotextile, and manure mulch were found to have the greatest increments. Trees in the red fescue and insectary plant treatments showed the least growth compared to trees in all other treatments.

3.2 Introduction

The production of apples in North America currently depends on large amounts of chemical inputs including herbicides, insecticides, and fungicides. However, current public concern about chemical use, in terms of individual health and the global environment has led to an increased interest in developing sustainable techniques in agriculture (MacRae et al, 1990). Producers are being asked to maintain the quality and quantity of fruit produced while, at the same time, decreasing the amount of chemicals used (Merwin 1991).

With the use of dwarf rootstocks, apple trees come into bearing only three to five years after planting. However, their small root systems are sensitive to competition for water and nutrients from ground vegetation. Stronger, better nourished trees bear fruit earlier in their life and have higher yields than weaker trees. Thus, the control of weeds is an important aspect of orchard management in establishment years to insure that tree growth is not inhibited.

Increasing land, labour, and capital costs, and the decreasing availability of labour, means that growers have to become more and more efficient to stay in business (Autio et al 1991). One response has been to search for a management system that encourages tree growth and promotes early production. This includes finding a ground cover management system that is economically feasible, is beneficial to the long-term stability of the soil and the above-ground environment, eliminates chemical inputs, and yet does not inhibit tree growth.

This study compares the effects on growth of newly planted dwarf apple trees of a straw mulch, cultivation, red fescue cover, an insectary plant cover of lupin and wild carrot, geotextile, or a manure mulch.

3.3 Materials and Methods

Two experimental orchards were established at the Horticultural Research Center of Macdonald Campus, McGill University in Ste. Anne de Bellevue, Quebec.

Orchard 1, covering an area 31.5m x 60m consisted of 300 trees (30 trees/row x 10 rows) on M.9 rootstocks, planted on a mixed Chateauguay clay loam/St. Bernard loam in October 1990. Five scab-resistant cultivars were selected and arranged north to south in paired rows, 3.0 metres apart, with 2 metres between trees. The five outer trees at the ends of each row, one tree between each treatment along the row, and the two rows of the cultivar "Novamac", along the east side of the orchard, served as guard trees. The 144 experimental trees comprised the cultivars "Brightgold", "Freedom", "Liberty", and "Murray" arranged from west to east in that order.

Orchard 2, covering an area 52 metres x 85 metres, consisted of 304 trees (16 trees/row x 19 rows) on M.26 rootstock, planted on a St. Bernard clay loam in May 1991. Rows, running north to south, were 3.5 metres apart, with 3.0 metres between trees. The 144 experimental trees, arranged in paired rows, were all of the scab-resistant cultivar "Macfree". Tree rows, between each pair of experimental tree rows, and the outermost rows of the orchard (1 row on the west, south, and east sides, and 2 rows on the north side) pollinator trees, serving also as guard rows, were used.

These comprised the scab-resistant cultivars "Liberty", "Moira", "637", "Rouville", "Richelieu", and "Olympic". Along each row of experimental trees, one "Macfree" served as a guard tree between each treatment plot of six trees.

Each orchard had 24 plots of six trees, arranged in a randomized complete block design, with the six treatments replicated 4 times. The four inner trees of each plot were considered an experimental unit and average measurements were taken, in order to compensate for differences in vigour between trees.

Management of both orchards was identical. Fertilizers, which complied with organic standards, including feathermeal, blood meal, fish emulsion, and compost (details in Appendix 1) were applied around the base of each tree. Pest insects were controlled using rotenone, Safer's soap, pyrethrum, and *Bacillus thuringiensis* (Appendix 2). Alleys were sown with a mixture of ryegrass (*Lollium perenne* L.) and red fescue (*Festuca rubra*) in the spring of 1991 and mown as required (2-4 times) throughout each summer. Sprinkler irrigation was provided to supplement natural rainfall to provide, on average 2.5 cm/week. In 1991, extension growth from the bud was kept to a single shoot, while in late spring of 1992, side shoots at and below 40 cm were removed once, after which remaining shoots and new seasonal growth was left intact.

Ground management treatments

The six ground management treatments were established in both orchards in the spring of 1991 and maintained and/or reapplied as necessary (details in Table 3.1). Each treatment was applied as a 1 metre wide strip along the length of the 6 tree plot, and extended to 1 metre beyond the end trees.

Growth measurements and data analysis

Mid-terminal leaves were sampled in mid-July in 1991 and 1992. Leaves were measured using a Paton electronic planimeter to determine average leaf area. In October 1991, trunk diameter was measured at 30 cm from the soil surface and subsequently converted into trunk cross-sectional area (TCSA in square centimetres) before analysis. The length of the single extension shoot was measured from the point of the grafted bud to the tip of the shoot in October 1991. In October 1992, trunk diameter was again measured. In addition, the number of shoots per tree were counted and their lengths measured.

Data were analysed using the Analysis of Variance procedure of the SAS PC 6.04 software package (SAS Institute, Cary, N.C.). When the ANOVA was significant, differences between means were compared using Duncan's new multiple range test using SAS software (as above).

Table 3.1 Methods of establishment and maintenance of treatments

Ground cover treatment	Establishment and maintenance
1 Cultivation	Tilled at initiation and throughout summers 1991 and 1992 as needed (4-6 times) using 'Gravely' cultivator, to depth of about 5-10cm. At 0.3 metre radius around trees, weeds were removed manually and using hand-held hoe.
2 Geotextile mulch	1991: 'Amoco' woven polypropylene landscape fabric applied. 1992: 'Amoco' deteriorated; removed and replaced with 'Exxon Sunbelt', UV resistant woven polypropylene geotextile to last 5 years.
3 Straw mulch	15 cm layer (approx. 2.5 kg/square metre) applied at initiation. Same amount reapplied spring 1992.
4 Manure mulch	15 cm layer (Orchard 1, 0.28 cubic metres/treatment; Orchard 2, 0.5 cubic metres/treatment) of semi-composted manure applied at initiation. 0.23 and 0.4 cubic metres/treatment, to orchards 1 and 2 respectively, applied spring 1992 to re-establish 15 cm layer.
5 Red fescue cover	Seed sown spring 1991 (36 grams/square metre). Mowed as needed; 2-4 times per year.
6 Insectary plant cover	Mixture of *Lupinus albus*/*Daucus carota* sowed spring 1991 at rates of 26 g/sq. metre and 1 g/sq. metre respectively. Cut down at end of season. *Lupinus albus* resown spring 1992.

3.4 Results and Discussion

Weed control

Based on visual examination, weed growth was best controlled under the geotextile and straw mulch treatments.

Some weeds did emerge where the geotextile (Treatment 2) was cut around the tree base, however, these were easily removed manually. Along the outer edge of the geotextile, there was also some weed growth, with dandelion (*Taraxacum officinale* Weber) being particularly predominant.

One month after initial application, the straw (Treatment 3) had matted considerably with very little weed emergence, however, some viable oat seed in the straw produced some seedlings which were easily removed by hand as they were only loosely rooted in the straw.

In the earlier part of the 1991 growing season, weeds were scarce in the cultivated areas (Treatment 1), as it had been very dry. However, later in the season, redroot pigweed (*Amaranthus retroflexus* L.), dandelion, pineappleweed (*Matricaria matricarioides* Less.), lamb's-quarter's (*Chenopodium album* L.), quack grass (*Agropyron repens* L.), and red clover (*Trifolium pratense* L.) were present. In 1992, repeated shallow cultivation kept most species under control, however, quack grass, which spreads by rhizomes, did not respond well to this treatment and re-emerged on a regular basis.

The manure mulch (Treatment 4) was not fully composted and harboured many viable weed seeds. In 1991, lush growth of lamb's-quarter's, redroot pigweed, and dandelion was particularly predominant at all sites. In 1992, common mallow (*Malva neglecta* Wallr.) predominated. It was allowed to grow to a height of approximately one metre and was then chopped with a bush scythe and left in place to help suppress new growth with reasonable success.

The red fescue cover (Treatment 5) was relatively free of weeds, although some dandelion, lamb's-quarter's, and redroot pigweed were present. Regular mowing kept these plants from going to seed.

In 1991, the insectary plant cover (Treatment 6) grew as tall as the trees (approximetely 0.5m to 0.75m). In both years these plots were characterized by the presence of quack grass, dandelion, broad-leaved plantain (*Plantago major* L.), lamb's-quarter's, and red clover.

Arthropods

In 1991, the predominant arthropod pests in the two orchards were those associated with very young trees in a nursery. Apple aphid (*Aphis pomi*) was observed to be evenly distributed at both sites; however, where escaped buckwheat was growing in the alleys, it served as an alternative food source and fewer aphids were present on the trees. Tent caterpillar (*Malacosoma americanum*), obliquebanded leafroller

(*Choristoneura rosaceana*), and green fruitworm (*Lithophane antennata*) were also observed but not at high enough densities to cause serious damage. Among beneficials, lady beetle (*Hippodamia convergens*) and lady beetle larvae were present throughout, and were observed to be feeding on the aphids. Overall, there seemed to be more general insect activity in the areas of the insectary plant and the manure mulch treatments. In 1992, apple aphids were again present but at a lower density than in 1991. Redbanded leafroller (*Archips argyrospilus*) was the most serious pest in both orchards in 1992.

Tree growth

In both orchards 1 and 2 (Tables 3.2 and 3.3, respectively), trees under straw mulch and geotextile showed the greatest increases in trunk cross-sectional area (TCSA) over the two first seasons of growth. In orchard 1, TCSA of trees under cultivation compared favourably with those in other treatments, however, in orchard 2, trees in geotextile grew more in 1992 than those under cultivation. Trees in the red fescue and insectary plant treatments consistently showed the least amount of trunk radial growth.

In 1991, shoot growth in orchard 1 (Table 3.2), was greater on trees under geotextile, straw mulch, and manure mulch treatments, than on those in the red fescue and insectary plant treatments, although there was no difference

Table 3.2. Effects of soil management treatments on the growth of 'Liberty', 'Freedom', 'Murray', and 'Brightgold' apple trees on M.9 rootstock planted in fall 1990 (Orchard 1)^~. TCSA, Shoot growth, and Shoots/Tree measured at end of each growing season. Average Leaf Area sampling taken mid-July each year.

TREATMENT	TCSA (cm^2)		Shoot growth (cm)		Average Leaf Area (cm^2)		Shoots/Tree (#)
	1991*	1992*	1991*	1992*	1991ns	1992*	1992*
Cultivation	0 468 ab	1 088 abc	74 25 ab	231 3 bc	24 05	31 13 ab	7 2 bc
Geotextile	0 617 a	1 714 ab	89 00 a	462 3 a	26 43	29 52 abc	11 1 a
Straw Mulch	0.620 a	1 974 a	78 50 a	398 0 ab	23 55	35 65 a	8 9 ab
Manure Mulch	0 472 ab	0 770 bc	78 00 a	180 0 bc	27 24	31 00 ab	5 4 c
Red Fescue Cover	0 350 b	0 714 bc	53 25 b	151 8 c	22 67	26 41 bc	6 7 bc
Insectary Plant Cover	0 329 b	0 579 c	54 25 b	119 0 c	21 47	22 06 c	6 3 bc

^ Means are of 24 observations
~ Mean separation within columns by Duncan's new multiple range test
ns, *, nonsignificant, or significant at $p = 0.05$

Table 3.3. Effects of soil management treatments on the growth of 'Macfree'/M26 apple trees planted in spring 1991 (Orchard 2)^~. TCSA, Shoot growth, and Shoots/Tree measured at end of each growing season. Average Leaf Area sampling taken mid-July each year.

TREATMENT	TCSA (cm^2)		Shoot growth (cm)		Average Leaf Area (cm^2)		Shoots/Tree (#)
	1991ns	1992***	1991ns	1992***	1991ns	1992**	1992ns
Cultivation	0 279	0 560 b	74 82	221 8 b	23 43	23 10 a	8.1
Geotextile	0.275	0 815 a	79.89	315 5 a	21 62	23 23 a	8.2
Straw Mulch	0 322	0 712 ab	80.22	284.0 ab	18.85	23.62 a	7.8
Manure Mulch	0 221	0 585 ab	73.54	250 0 b	20 54	23 52 a	7.3
Red Fescue Cover	0 181	0 280 c	59.52	113 8 c	20.46	18 23 b	6.0
Insectary Plant Cover	0 199	0 226 c	53 74	92.3 c	19 49	17 51 b	5.3

^ Means are of 24 observations

~ Mean separation within columns by Duncan's new multiple range test

ns, *,**,*** nonsignificant, or significant at $p = 0.05$, 0.01, 0.001 respectively compared with those under cultivation. In orchard 2 (Table 3.3), although not significantly different at p=0.05, shoot growth followed a similar trend, wherein trees in the red fescue and insectary plant treatments showed the least amount of growth compared with those in the other four treatments.

In the second year of the experiment, in orchards 1 and 2 (Tables 3.2 and 3.3), the geotextile and straw mulch treatments continued to stimulate increased growth. At both sites, shoot growth of trees in the straw mulch did not differ significantly from that of those under cultivation and manure mulch treatments; however, trees under geotextile and straw mulch did have significantly more shoot growth per tree than trees in the red fescue and insectary plant treatments. In 1992, shoot growth of trees under geotextile was significantly greater than for those under cultivation.

In 1992, shoot number per tree was determined. In orchard 1 (Table 3.2), trees in the geotextile and straw mulch treatments produced the greatest number of shoots, averaging 11.1 and 8.9 shoots per tree respectively. Trees under geotextile had significantly more shoots per tree than those under cultivation which averaged only 7.1 shoots per tree. Trees in the other four treatments produced somewhat fewer shoots on average. In orchard 2 (Table 3.3), trees averaged 7.1 shoots per tree and although there were no significant differences at p=0.05, trees in the red fescue and insectary plant treatments again produced fewer shoots per tree, 6.0 and 5.3 respectively, than trees in the other four treatments.

In 1991, no significant differences in average leaf area were found at either site but leaves of trees in the red fescue, insectary plant, and straw mulch treatments were found to be slightly smaller than those of trees under cultivation, geotextile, and manure mulch. However, in 1992, leaves on trees in straw mulch were found to be the largest compared with those from trees in all other treatments in both orchards (Tables 3.2 and 3.3). In 1992, trees under cultivation, geotextile, straw mulch, and manure mulch, in both orchards, all produced leaves of similar size. However, in orchard 2, average leaf area was found to be significantly lower for trees in the red fescue and mixed flora treatments compared to the other four treatments.

Soil water content

In July 1992, data on soil volumetric water content at a depth of O-Ah (Table 3.4), indicate that in orchard 1, at distances of both 10 and 50 cm from the tree, the % water content of soils under the straw mulch was significantly higher than for soil under the cultivation, red fescue grass, and insectary plant treatments, although not different from that in the manure and geotextile treatments. In orchard 2, soil in the straw, geotextile, and manure mulch treatments had the highest % volumetric water content, although not

Table 3.4. Effects of soil management treatments on soil volumetric water content at depth 0-Ah in orchards 1 and 2; Soils sampled July 1992, 10 and 50 centimetres from the tree.^*

	Volumetric Water Content (%)			
	Orchard 1		Orchard 2	
	Location from tree (cm)			
TREATMENT	10	50	10	50
Cultivation	11 bc	12 bc	11 ab	12 ab
Geotextile	12 abc	12 ab	12 a	12 ab
Straw Mulch	14 a	15 a	13 a	13 a
Manure Mulch	12 ab	13 ab	12 a	11 ab
Red Fescue	10 bc	12 bc	10 b	11 ab
Insectary Plants	9.5 c	10 c	10 b	10 b

^ Means within each orchard and location sharing a common letter are not significantly different at $p = 0.05$ according to Tukey's multiple comparison test.

* Means are of 24 observations and are antilogs of transformed data

significantly greater than that under cultivation, it was higher than for soil in the red fescue grass and insectary plant treatments. In September 1992, there were no significant differences in soil volumetric water content in either orchard at this depth (data not shown). At a depth of Ah-30 cm, soil volumetric water content was similar at all sampling locations and dates (data not shown).

Soil nitrate and ammonium content

Soil nitrate content in both orchards, at all sampling dates, locations, and depths was almost always found to be highest under the manure mulch treatment, although in most cases it was not significantly different from that under the straw mulch, geotextile, and cultivation treatments, which consistently had levels similar to each other (see Tables 3.5 to 3.8). Soil under the red fescue grass and insectary plant treatments was found to have the lowest soil nitrate content which was frequently significantly lower than that under the manure mulch treatment.

Soil ammonium content, measured in 1992, was found to be very similar among all treatments (data not shown); only one significant difference in ammonium levels was found. In orchard 1, in July, 50 cm from the tree, at soil depth Ah-30 cm, soil in the manure mulch treatment was found to have significantly higher ammonium levels, at 1.3 kg/ha, than that under the red fescue grass treatment which had 0.51 kg/ha.

Table 3.5. Effects of soil management treatments on soil nitrate levels at depth 0-Ah in orchard 1; Soils sampled July and September 1992, 10 and 50 centimetres from the tree.^*

	Nitrate Level (kg/ha)			
	July 1992		September 1992	
	Location from tree (cm)			
TREATMENT	10	50	10	50
Cultivation	33 a	16 ab	18.0 ab	25.0 a
Geotextile	34 a	23 ab	33.0 a	15.0 a
Straw Mulch	37 a	18 ab	26.0 a	13.0 ab
Manure Mulch	62 a	30 a	36.0 a	32.0 a
Red Fescue	14 b	13 b	6.2 b	4.4 b
Insectary Plants	15 b	15 ab	11.0 ab	14.0 a

^ Means within each date and location sharing a common letter are not significantly different at $p = 0.05$ according to Tukey's multiple comparison test.

* Means are of 24 observations and are antilogs of transformed data

Table 3.6. Effects of soil management treatments on soil nitrate levels at depth Ah-30 in orchard 1; Soils sampled July and September 1992, 10 and 50 centimetres from the tree.^*

	Nitrate Level (kg/ha)			
	July 1992		September 1992	
	Location from tree (cm)			
TREATMENT	10	50	10 ns	50 ns
Cultivation	7.6 bc	7.3 b	3.0	4.6
Geotextile	8.0 bc	7.5 b	4.1	6.9
Straw Mulch	10.0 ab	5.4 b	4.2	4.1
Manure Mulch	29.0 a	43.0 a	14.0	14.0
Red Fescue	2.8 cd	2.2 bc	1.4	2.4
Insectary Plants	2.0 d	1.5 c	1.4	2.1

^ Means within each date and location sharing a common letter are not significantly different at p = 0.05 according to Tukey's multiple comparison test.

ns non-significant at p=0.05

* Means are of 24 observations and are antilogs of transformed data

Table 3.7. Effects of soil management treatments on soil nitrate levels at depth 0-Ah in orchard 2; Soils sampled July and September 1992, 10 and 50 centimetres from the tree.^*

	Nitrate Level (kg/ha)			
	July 1992		September 1992	
	Location from tree (cm)			
TREATMENT	10	50	10	50
Cultivation	18 ab	15 c	31 abc	26 abc
Geotextile	36 ab	32 ab	76 a	45 ab
Straw Mulch	41 ab	20 bc	21 bc	25 bc
Manure Mulch	56 a	42 a	54 ab	73 a
Red Fescue	13 b	12 c	24 bc	12 c
Insectary Plants	16 ab	11 c	14 c	22 bc

^ Means within each date and location sharing a common letter are not significantly different at $p = 0.05$ according to Tukey's multiple comparison test.

* Means are of 24 observations and are antilogs of transformed data

Table 3.8. Effects of soil management treatments on soil nitrate levels at depth Ah-30 cm in orchard 2; Soils sampled July and September 1992, 10 and 50 centimetres from the tree.^*

	Nitrate Level (kg/ha)			
	July 1992		September 1992	
	Location from tree (cm)			
TREATMENT	10	50	10 ns	50 ns
Cultivation	7.3 b	5.4 ab	8.0	7.7
Geotextile	7.3 b	8.3 ab	11.0	14.0
Straw Mulch	8.3 b	8.4 ab	3.0	2.8
Manure Mulch	34.0 a	19.0 a	20.0	20.0
Red Fescue	4.1 b	2.9 b	4.1	2.6
Insectary Plants	3.8 b	3.9 b	4.0	5.1

^ Means within each date and location sharing a common letter are not significantly different at p = 0.05 according to Tukey's multiple comparison test.

ns non-significant at p=0.05

* Means are of 24 observations and are antilogs of transformed data

Summary

The effects of geotextile on apple tree growth have not previously been documented; however, early results of this experiment concur with work being done at Agriculture Canada's Summerland Research Station, B.C., (E.J. Hogue, personal communication), which indicates that the use of geotextiles promotes growth of apple trees. Preliminary results from this experiment suggest that the use of geotextile promotes more vigorous early tree growth than cultivation, as seen by the significantly greater TCSA in orchard 2 in 1992, greater shoot growth per tree in both orchards in 1992, and a greater number of shoots per tree recorded in orchard 1 in 1992, for trees in the geotextile treatment (Tables 3.2 and 3.3).

Results from this trial are similar to those reported by other researchers, in which the use of a hay or straw mulch around apple trees has been found to result in more vigorous growth and greater trunk girth increases when compared with trees under sod (Baxter, 1970; Merwin, 1991), crown vetch (Merwin, 1991), ryegrass, and cultivation treatments (Greenham and White, 1968). Over the first two years of this experiment, trees in the straw mulch showed slightly more vigorous growth than trees under cultivation, however, the difference was not significant at this stage.

Although the initial cost of materials and installation of a geotextile or a straw mulch is high, they require less work to maintain throughout the season than does cultivation.

Weed growth was also found to be better controlled in the geotextile and straw mulch treatments than through cultivation. A consideration of the relative advantages and disadvantages of these systems is also important, especially in the realm of sustainable agriculture, where long-term stability of the soil and the above-ground environment must be considered alongside short-term production efficiency.

Findings in this experiment show soil under the straw mulch treatment to have the highest soil volumetric water content among treatments (Table 3.4). This is supported by other studies which have found hay and straw mulches to conserve soil moisture and to reduce evaporation (Baxter, 1970; Boynton and Anderson, 1956; Greenham and White, 1968; Haynes, 1980; Skroch and Shribbs, 1986; Tukey and Schoff, 1963; White and Holloway, 1967). Previous research has also found straw mulches to add nutrients and organic matter to the soil as the mulch breaks down (Haynes, 1980; Latimer and Percival, 1947; White and Holloway, 1967), to reduce erosion, by protecting the soil surface (Haynes, 1980; Hipps et al, 1990; Skroch and Shribbs, 1986), and to increase water infiltration rates (Skroch and Shribbs, 1986; Tukey and Schoff, 1963). Latimer and Percival (1947) and Tukey and Schoff (1963) also found increased amounts of available nutrients, including nitrogen, phosphorus, potassium, and magnesium under straw mulches.

The use of a geotextile over the soil surface can be expected to protect the soil and to conserve soil moisture, and indeed, soil under it was found to have one of the greatest soil volumetric water contents, similar to straw mulch, cultivation and manure mulch treatments. One of the most serious drawbacks in consideration of long-term sustainability of the soil, is that this treatment does not add organic matter or nutrients to the soil. The difficulty of proper disposal of the product, after its removal, must also be weighed in evaluation of its overall environmental effects.

Repeated cultivation is considered to be detrimental to the soil. It has been found to increase susceptibility of the soil to erosion, to decrease soil aggregation, organic matter levels, and water infiltration, to impede aeration, and to promote the development of compacted layers (Jordan and Jordan, 1984). It has also been found to reduce the diversity and density of microarthropod populations (Wallwork, 1976).

In terms of growth, trees in the geotextile treatment followed by those in the straw mulch and cultivation treatments are most vigorous at this stage. Continued monitoring in these two orchards, over the next years, will provide data on long term tree growth, as well as information on precocity of bearing, yield, and return bloom. These results, along with the findings from the soil and leaf analyses, and soil microarthropod studies from the other areas being investigated in this multi-disciplinary project, will aid in forming a sound ground management system for organic orchards.

Preface to Chapter 4

Results from the experiments reported in Chapter 3, which examined the effects on tree growth of various ground management treatments on newly planted trees, could help to plan the management practices employed in newly established organic orchards. The next experiment (Chapter 4), was initiated to assess how a change from conventional weed control using herbicides in the first five growing seasons, to various non-herbicide ground management systems, will affect tree growth in subsequent years. It is hoped that results from this trial will provide a sound basis for deciding on a new management strategy, particularly for orchardists considering a transition from conventional to organic management in an existing orchard.

Data on soil water content and soil nitrate and ammonium levels were collected and analyzed by B. Walsh. All other work was carried out by S.S. Salmins. All literature cited in this chapter is listed in Chapter 7 of this thesis.

CHAPTER 4

GROWTH AND YIELD OF BEARING 'SPARTAN'/M.9 APPLE TREES IN FOUR GROUND MANAGEMENT SYSTEMS

4.1 Abstract

In the spring of 1991, four ground management systems were established in an orchard planted in 1987. Trees in manure mulch and straw mulch, followed by those in the geotextile mulch grew most vigorously in the first two seasons of growth. Trees in the red fescue cover grew less than those in manure or straw mulch. Average leaf areas of trees in all treatments were similar. Yield and percent fruit set data indicate that the use of geotextile or straw mulch along tree rows may have a beneficial effect, resulting in increased fruit set and higher yields.

4.2 Introduction

With the growing demand in North America for organic produce, and a shift in aproach to agriculture, where long-term stability of the overall environment is considered important, many apple growers are making, or are considering making, a transition from conventional (predominantly chemical dependent) practices, to more sustainable (ie. less chemically dependent) approaches. One way to reduce chemical use in orchards, is to eliminate the use of herbicides, and to employ a different strategy for weed control. However, this decision is accompanied by a very real concern, as to how this practice will affect production. Production capacity of apple trees is dependent on the health and vigour of the tree, and is directly proportional to the size of the tree trunk (Westwood, 1978); thus, if management practices promote the growth of healthy trees which grow quickly, high yields should be expected.

In the orchard used for this study, tree rows had been treated with herbicides for weed control since their establishment in 1987. In 1991, four alternative in-row treatments were applied to determine their effects on soil quality (moisture, temperature, nutrient levels, organic matter, bulk density), and tree growth and yield. In this paper, the effects on tree growth and yield, of the four systems, including straw mulch, polypropylene geotextile mulch, manure mulch, and a red fescue cover, are examined.

4.2 Materials and Methods

In 1991, four rows of 19 'Spartan'/M.9 apple trees were selected within an orchard planted in a St. Bernard clay loam in 1987 at the Horticultural Research Center of Macdonald Campus, McGill University in Ste. Anne de Bellevue, Quebec. Tree rows were 3.5 metres apart with 2 metres between trees within rows. Two trees at each end of the rows, and one tree between each treatment along the row, served as untreated guard trees. The experiment was arranged in a randomized complete block design with 8 plots of 7 trees, where the 4 treatments were each replicated 2 times. An experimental unit was considered the average of measurements taken from the five inner trees of each treatment.

The orchard was managed according to conventional practice, using chemical fungicides, insecticides, and fertilizers (see Appendix 3), herbicides, fungicides, insecticides, and miticides (Appendix 4). During the experiment, Paraquat was applied as a strip along tree rows in non-experimental areas within the orchard; however, no herbicide was used within the experimental area. Well established alleys, comprised of a mixture of perennial red fescue and several colonized native weed species were mown as required throughout each summer (approximately 2-4 times). No supplimental irrigation was supplied in 1991 or 1992. Trees were trained to the central leader system.

Ground management treatments

Four ground management treatments were established in spring 1991, and maintained and/or reapplied as necessary (Table 4.1). Each treatment was applied as a 1 metre wide strip along the length of 7 trees and extended to 1 metre beyond the end trees.

Table 4.1. Methods of establishment and maintenance of treatments

Ground cover treatment	Establishment and maintenance
1 Geotextile mulch	1991: 'Amoco' woven polypropylene landscape fabric applied. 1992: 'Amoco' deteriorated; removed and replaced with 'Exxon Sunbelt' UV resistant woven polypropylene geotextile to last 5 years.
2 Straw mulch	15 cm layer (approximately 2.5 kg/square metre) applied at initiation. Same amount reapplied spring 1992.
3 Manure mulch	15 cm layer (0.33 cubic metres /treatment) of semi-composted manure applied at initiation. 0.27 cubic metres/treatment applied spring 1992 to re-establish 15 cm layer.
4 Red fescue cover	Seed sown spring 1991 (36 grams/square metre). Mowed as needed; 2-4 times per year.

Apple growth measurements and data analysis

Leaves were sampled in mid-July in 1991 and 1992. Seven mid-terminal leaves were taken from each of the five inner trees of each treatment and were then measured using a Paton electronic planimeter to determine average leaf area. At the beginning of the experiment, ie. June 1991, trunk diameter, 35 cm from the soil surface, was measured using calipers, and then converted into trunk cross-sectional area (TCSA cm), before analysis, to determine whether there were any initial differences in trunk girth. Trunk girth was then measured at the end of two growing seasons, ie. in October 1992, and again converted into trunk cross-sectional area before analysis. In October 1991, fruit on the tree and fruit which had fallen were harvested to determine yield in kilograms. In the spring of 1992, percent fruit set was determined (number of fruitlets set/total number of blossoms x 100%). In October 1992, yield and fruit size was determined. In addition, in 1992, fruit were graded by hand into four size categories (under 4 cm, 4 - 6 cm, 6 - 8cm, and over 8 cm diameter).

With the exception of size grouping, data were analysed using the Analysis of Variance procedure of the SAS PC 6.04 software package (SAS Institute, Cary, N.C.). When the ANOVA was significant, differences between means were compared using Duncan's new multiple range test using SAS software (as above). Fruit yield in 1992 was very low, therefore the sample size for purposes of grading the fruit into four size categories was too small for statistical analysis. This information is presented only to show the possibility of an emerging trend.

Results and Discussion

At the outset of the experiment it was determined that there were no significant differences in trunk girths of experimental trees. However, after two growing seasons, trees in the manure mulch and straw mulch treatments had greater trunk girths than those in the red fescue treatment (Table 4.2). It is widely accepted that favourable moisture and nutrient conditions (particularly the availability of nitrogen) favour apple tree growth (Bould and Jarrett, 1962; Shribbs and Skroch, 1986b; Stott, 1976; Westwood, 1978). In this experiment, 1992 data reveal no significant differences among all treatments, in either soil volumetric water content (Table 4.3) or soil nitrate levels (Table 4.4); albeit nitrate levels were found to be somewhat higher under the geotextile and manure mulch treatments. Latimer and Percival (1947) and Tukey and Schoff (1963) speculated that the presence of a straw mulch may make nutrients more available for tree uptake, and found increased amounts of available forms of nutrients, including nitrogen, under straw mulch treatments. This may be attributed to greater soil biological activity associated with decomposing organic mulches (Haynes, 1980; Seastedt, 1984), which, in turn, might help to explain the vigorous growth of

Table 4.2. Effects of soil management treatments on the growth, yield, and percent fruit set of 'Spartan'/M.9 apple trees planted in 1987^~

	TCSA (cm^2) initial	TCSA (cm^2) increase	Average Leaf Area (cm^2)		Yield (kg/5 trees)		Fruit Set (%)
TREATMENT	1991ns	1992*	1991ns	1992ns	1991ns	1992ns	1992ns
Red fescue	5 761	1 080 b	29 94	25 24	40 8	2.4	8 8
Geotextile	6 557	1 597 ab	31 36	25 71	43 1	5 6	12 2
Straw Mulch	6 503	1 998 a	28 89	25 00	41 2	3 6	15.1
Manure Mulch	6.251	2 069 a	28 79	25 51	36.0	2 8	9.9

^ Means are of 8 observations

~ Mean separation within columns by Duncan's new multiple range test

ns, * non-significant or significant at p=0.05 respectively

Table 4.3. Effects of soil management treatments on soil volumetric water content, at depth 0-Ah; 10, 50, and 100 centimetres from the tree.^*

	Volumetric Water Content (%)					
	July 1992			September 1992		
	Location from tree (cm)					
TREATMENT	10	50	100	10	50	100
Red Fescue	16	16	17	12	15	13
Geotextile	17	19	19	14	13	13
Straw Mulch	19	21	20	16	14	13
Manure Mulch	17	18	17	14	13	15

^ Means within each date and location are not significantly different at $p = 0.05$ according to Tukey's multiple comparison test.

* Means are of 8 observations and are antilogs of transformed data

Table 4.4. Effects of soil management treatments on soil nitrate levels at depth 0-Ah; Soils sampled July and September 1992, 10 and 50 centimetres from the tree.^*

	Nitrate Level (kg/ha)			
	July 1992		September 1992	
	Location from tree (cm)			
TREATMENT	10	50	10	50
Red fescue	22	22	42	39
Geotextile	74	64	120	220
Straw Mulch	25	30	34	21
Manure Mulch	32	50	65	96

^ Means within each date and location are not significantly different at p = 0.05 according to Tukey's multiple comparison test.

* Means are of 8 observations and are antilogs of transformed data

trees in the straw mulch treatment. One might also extrapolate from this that a similar process occured under the manure mulch. Trees in the geotextile treatment, while comparable to those in the straw and manure mulch treatments, had slightly smaller girth increments, and, although not significant, soil nitrate levels were highest under this treatment (Table 4.4). As mentioned earlier, soil water content was very similar among treatments (Table 4.3). Thus, we might speculate that the inorganic nature of this 'mulch' may not stimulate soil biological activity, and therefore not increase amounts of available forms of nutrients to these trees. Further studies are needed to support this hypothesis. The red fescue, although considered among the less competitive grasses, obviously exerted some competition with the trees for nutrients and/or moisture, thus inhibiting their growth compared with that of trees in the other treatments.

No significant differences in average leaf area, fruit yield, or percent fruit set were found (Table 4.2).

Interestingly, in 1992, when fruit was graded into four size groups (Table 4.5), it was found that trees in the manure mulch, straw mulch, and geotextile treatments produced the highest proportion (approximately 50%) of fruit in the 6-8 cm range; while trees in the red fescue treatment produced 77% of fruit in the smaller, 4-6 cm range, with very few fruit in the two larger size groups. Furthermore, while trees in straw and manure mulch, produced some fruit in the > 8 cm group (23% and

Table 4.5. Percent harvest by size groups (in diameter) of 'Spartan'/M.9 apples in 1992

Treatment	< 4 cm	4 - 6 cm	6 - 8 cm	> 8 cm
Red fescue	14 %	77 %	10 %	0
Geotextile	9 %	40 %	45 %	6 %
Straw mulch	2 %	25 %	50 %	23 %
Manure mulch	22 %	9 %	56 %	13 %

13% respectively), those in grass produced no fruit of this size category. Although inconclusive at this stage, this trend concurs with the findings of other researchers, that fruit size tended to be greater under mulches than under other treatments including grass (Baxter, 1970; Boynton and Anderson, 1956; Fisher et al, 1961; Greenham and White, 1968).

A red fescue sod should not be used if promoting vigorous growth is the only goal. However, from the standpoint of increasing soil biological activity and improving soil quality in the long-term, as well as in terms of the low costs associated with the establishment and maintenance of a sod, the use of red fescue grass could be a good choice and of interest to organic growers seeking a low input-low output system and a good, stable soil environment.

In this study, manure mulch was found to be difficult to use. Its application was not only slow, but also a large population of weed species became established quickly and grew very vigorously, complicating maintenance of the orchard. Trees grew well in this treatment, however, a very serious risk is that its use may lead to excessive nitrogen levels which has been found to be detrimental to apple production, promoting fruit drop and decreasing storage quality of the apples (Westwood, 1978).

It is reasonable to expect a geotextile mulch to encourage tree growth and promote high yields by eliminating competition from weeds; however, although an alternative to herbicide use, polypropylene geotextiles do not add organic matter to the soil. In this respect it not is likely to be of interest to growers who want to improve soil structure and develop long-term biological stability of the soil environment.

When considering the many effects of a ground management system, the best choice from the four systems investigated here, for a grower making a transition to organic practices, might be that of straw mulch. Straw mulches have consistently been found to promote vigorous apple tree growth (Baxter, 1970; Greenham and White, 1968;) and also benefit long-term soil stability, both in terms of promoting soil biological activity (Haynes, 1980), and improving soil structure (Haynes, 1980; Hipps et al, 1990). From a management perspective, it is easy to maintain, although requiring periodic reapplication as it decomposes. Tree guards must be used to prevent rodent damage, however, this is standard practice in the majority of North American orchards, regardless of the ground management system used.

Early results indicate that the straw mulch, manure mulch, and the geotextile mulch treatments resulted in the greatest increases in girth of established apple trees when compared with red fescue sod. Continued observation in this orchard will provide more conclusive results on growth and yield of these trees, and the effects of the four treatments on bloom density, fruit set, and fruit size, to help determine which treatment, if any, will best promote tree growth and fruit yields in the long term.

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

Much previous research work has assessed ground management systems for apple orchards, however, the emphasis has been primarily on finding ways to maximize production. The goal of this multi-disciplinary study was broader, and stemmed from a need to evaluate the impact of several organic ground management systems for orchards not only on production efficiency, but also on the soil environment, in terms of soil structure and nutrient content, and soil fauna activity, and thus, overall stability, and therefore sustainability, of the system. Some apple growers already practice organic methods of production but there is a growing need for scientific evaluation of these systems and investigation of new ones, so that sound management decisions, which take into consideration as many factors as possible, can be made. Although the focus of the work in this thesis has been to evaluate the effects of ground management systems on tree growth and yield, it is important that discussion of these results be considered within the context of the greater scope of the aims of the overall project.

After only two years of observation, trends in tree growth and vigour under the ground management systems investigated have emerged. Results indicate that tree growth is inhibited under the red fescue and insectary plant treatments, while that in the geotextile and straw mulch treatments is most vigorous. Based on previous work, this was to be expected, as the use of in-row living covers (various grass, broadleaf, and leguminous species) has repeatedly been found to result in slower growth and lower yields of apple trees when compared with bare ground and mulch systems (Bould et al, 1972; Bould and Jarrett, 1962; Fisher et al, 1961; Greenham and White, 1968; Johnson and Samuelson, 1990; Latimer and Percival, 1947; Rogers et al, 1948; Shribbs and Skroch, 1986a; Stott, 1976; White and Holloway, 1967). Fisher et al (1961) and Greenham and White (1968) found fruit of trees under grass treatment to be smaller than those under other management systems and, although it is still too early in this trial for definitive conclusions on differences in fruit size, preliminary observation found fruit of the 'Spartan'/M.9 trees under the red fescue treatment to be somewhat smaller overall, when compared with those from trees under the manure mulch, straw mulch and geotextile mulch treatments. It has been suggested that, due to lower tree nitrogen levels, fruit retention by the tree may be better and, that fruit quality, in terms of colour development, taste, and texture, is improved under systems of grass cover compared with mulch and cultivation treatments (Greenham and White, 1968; Rogers it al, 1948). The importance of consideration of a red fescue or an insectary plant cover system is largely based on their beneficial influence on the stability of the soil environment.

Both of these treatments provide cover for the soil, thus reducing erosion (Bollard, 1957; Skroch and Shribbs, 1986), and, have been found to improve soil structure over the long term (Haynes, 1981; Jordan and Jordan, 1984; Skroch and Shribbs, 1986). Organic matter is provided by the grass roots and clippings, encouraging earthworm and other soil fauna activity, and improving the growth of fungal and actinomycete hyphae (Haynes, 1980).

In measurements of growth, the trees in the cultivation and manure mulch treatments fell in the mid-range, although we cannot be sure whether this trend will continue or, over time, their growth rates will increase or decrease compared with those of trees in the other treatments. Growth data concur with those of other studies in which cultivation was found to promote more vigorous tree growth than that of trees under living plant covers, including grass and various legumes (Bollard, 1957; Rogers and Raptopoulos, 1945). Past research also found that trees under cultivation grew more slowly than those under a straw mulch system (Greenham and White, 1968), and while no significant differences between the cultivation and straw mulch treatments were found in the first two establishment years of the newly planted trees (orchards 1 and 2), trees under cultivation consistently had smaller trunk girths and less shoot growth than those under straw mulch. Repeated cultivation tends to be detrimental to soil structure in the long term (Greenham and White, 1968; Rogers et al,

1948) and has been found to contribute to soil compaction and erosion (Jordan and Jordan, 1984). The surface tends to form a crust which impedes water infiltration and forces water to runoff. In 1992, a very noticeable crust did form in the cultivation treatment, and although water infiltration rates were not measured, in orchard 1, in July, soil under the cultivation treatment, at depth 0-Ah, did have a significantly lower volumetric water content than that under the straw mulch. The samples at other dates and locations did not differ significantly, however, soil volumetric water content was consistently lower under the cultivation treatment compared with the straw mulch. It might be expected that the long-term effects of compaction and reduced water availability may further inhibit growth of trees under cultivation over time. Cultivation machinery can damage tree roots and/or the trunk and branches, leading to a greater risk of insect and disease invasion (Jordan and Jordan, 1984). Damage to surface roots will also reduce nutrient uptake from the upper portion of the soil (Haynes, 1980). Similarly, cultivation machinery can kill both beneficial and harmful arthropods and earthworms, thus upsetting the natural populations and balance of the system. Increased levels of dust associated with this practice has been found to favour population growth of destructive arthropod pests in orchards, and, to inhibit the activity of beneficials (Jordan and Jordan, 1984; William, 1981). In 1992, weed species in the cultivated plots shifted from mixed annual and some perennial species to an increasing population of hard to control perennial plants, with quack grass being particularly predominant, this is in agreement with the findings of Jordan and Jordan (1984).

Manure mulch, on the other hand, adds organic matter and provides a protective layer to the soil which helps to reduce erosion and to conserve soil moisture (Haynes, 1980). Soil volumetric water content under manure mulch in 1992 did not differ significantly from that under the straw mulch, which consistently provided the highest water level of all treatments. Unfortunately, this type of mulch is likely to contain viable weed seeds if not composted properly and/or can provide an ideal growth medium for arriving weed seeds. In this study these plots were characterized by heavy stands of mixed weed species which flourished abundantly and thus required extra vigilance and time to prevent their reseeding themselves. From this perspective, it is unlikely that a grower would be interested in this type of system; which would involve more complex management and thus more time and money. Another consideration is the risk of supplying too much nitrogen. In this study, nitrate levels were found to be highest under the manure mulch treatment. Excessive amounts of nitrogen applied to apple trees will have adverse effects, since too much nitrogen has been found to increase pre-harvest drop (Greenham and White, 1968), reduce fruit colouring and fruit quality (Fisher et al, 1961; Haynes, 1980), and delay hardening (Westwood, 1978).

While it is possible that trees in the geotextile and/or the straw mulch treatments will bear fruit earlier and produce higher yields than trees in the other treatments, geotextile mulch, although it does help to reduce erosion, does not add any organic matter to the soil. Results from this study concur with work currently being done at Agriculture Canada's Summerland research station in British Columbia in which they are finding that trees under geotextile mulch grow vigorously. In this experiment, the growth of newly established trees (orchards 1 and 2) under geotextile mulch did not differ from that of those under straw mulch. Trees in both these treatments were characterized by large radial growth and vigorous shoot growth. In the established, 'Spartan'/M.9 orchard, the results were slightly different; trunk growth of trees under geotextile was similar, although somewhat less than that of trees under manure mulch and straw mulch. Although results indicate that trees in both geotextile and straw mulch compare favourably in terms of growth, geotextiles must be further evaluated from the perspective of long-term sustainability of the environment and their ecological effects. It is not yet known how their use will affect soil quality and soil fauna activity. Another consideration is that of their proper disposal after their useful life. These factors must be evaluated in the context of the goals of organic agriculture.

It is impossible at this stage to state which system is best in the long-term, since the evaluation involves so many complex factors, including the means, and the philosophy and ideals of the individual grower, the location, the soil, and the topography. However, when taking into consideration the aspects which have been evaluated in this experiment, from the perspective of growing apples organically, the use of a straw mulch seems to come closest to the ideal. Straw mulches add nutrients and organic matter to the soil (Haynes, 1980; Latimer and Percival, 1947; White and Holloway, 1967), and have been found to improve soil structure (Haynes, 1980; Hipps et al, 1990). Their use helps to reduce erosion (Hipps et al, 1990; Skroch and Shribbs, 1986), and to conserve soil moisture (Baxter, 1970; Greenham and White, 1968; Skroch and Shribbs, 1986). This stable environment and the availability of organic matter has also been found to favour arthropod and earthworm activity (Haynes, 1980). In addition to the merits of a straw mulch to the system as a whole, as mentioned earlier, it was found that trees in the straw mulch were the most vigorous, along with those in the geotextile mulch. These results concur with previous work in which the use of a straw mulch was consistently found to promote tree growth (Baxter, 1970; Boynton and Anderson, 1956; Fisher et al, 1961; Greenham and White, 1968; White and Holloway, 1967). Should this trend continue, and follow that of other studies, it can be expected that trees in the straw mulch will begin to bear fruit earlier and have higher yields than those in the cultivation, manure mulch, red fescue, and insectary plant treatments. Visual observation throughout this study indicated that straw mulches provide good weed control in agreement with the findings of Baxter (1970) and Greenham and White (1968). There are however several drawbacks to the use of a straw mulch. Among them is the increased risk of infection of trees in this type of system to crown or root rots caused by *Phytopthora cactorum* (Merwin, 1992), presumably because of increased humidity around the tree. Also, this habitat is conducive to increased vole activity and is ideal for vole nesting (Merwin, 1991), which may put the trees in greater danger of being damaged by winter bark feeding. This problem is usually alleviated by the use of distasteful paint and/or tree guards on the trunk, which is standard practice for young trees in most North American orchards under all types of ground management systems. Another concern is that elevated levels of nitrogen have been found in trees under straw mulch and are implicated in increasing pre-harvest drop.

At this stage, results from this study would be of most use to a grower eatablishing a new orchard, as data from the established orchard revealed very little difference among the four treatments evaluated there. An organic grower planting an orchard on dwarf rootstock, might consider using a straw mulch, geotextile mulch, or cultivation as in-row ground management. These treatments all promoted tree growth, and, depending on the means and objectives of the grower, can be considered realistic methods of organic orchard ground management.

CHAPTER 6

SUGGESTIONS FOR FUTURE RESEARCH

1. Precocity of bearing, percent fruit set, and yields of the newly established trees need to be investigated.

2. Time of blossoming and thus risk of spring frost damage and the potential effects on yields should be evaluated.

3. The tendency of trees, under the different treatments, to pre-harvest drop should be studied.

4. The tendency to biennial bearing might also be investigated in each system.

5. Hardening off in the fall needs to be evaluated, as some treatments may stimulate late growth and increase the risk of cold injury.

6. Fruit quality, in terms of size, colouring, and taste should be evaluted.

7. Susceptibility of fruit grown under different treatments, to diseases in storage and overall storage quality need to be determined.

CHAPTER 7

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Appendix 1. Fertilizers used in management of orchards 1 and 2, 1991 and 1992

Fertilizer	Maker	Rate applied	Composition
feathermeal	Floradale Ltd.	150g/tree 1 appl. May 1991	11N 0P 0K
blood meal	McGinnis	100g/tree 1 appl. May 1992	12.5N 0P 0K
fish emulsion	Wilson	3 litres/tree May 1991 May 1992	5N 1P 1K
compost	Macdonald Campus, dairy division	500g/tree 1 appl. May 1991	12.6N 7.3P 5.2K*

* compost analyzed as parts per million

Appendix 2. Organic pest controls used in management of orchards 1 and 2, 1991 and 1992

Product	Maker	Rate applied	Composition
rotenone	Wilson	30ml/3l water sprayed to wet leaf surface as required	1% rotenone extracted from roots of tropical plant species
Safer's soap	Safer's Ltd.	1 part:50 parts water sprayed to wet leaf surface as required	potassium salts of fatty acids 50.50%
pyrethrum	Wilson	sprayed as needed to wet leaf surface	0.02% pyrethrins 0.20% piperonyl butoxide
Dipel	Abbott Laboratories	sprayed as needed to wet leaf surface	*Bacillus thuringiensis* 16,000 I.U. potency per mg.

Appendix 3. Fertilizers used in 'Spartan'/M.9 orchard planted in 1987

Year	Supplier	Rate* (grams/tree)	Composition
1990	CIL	60	34-0-0
1990	CIL	100	0-20-20-3Mg
1991	CIL	120	34-0-0
1991	CIL	100	0-20-20-3Mg
1992	CIL	150	34-0-0
1992	CIL	150	0-20-20-3Mg

* 1 application per season, applied in May of given year

Appendix 4. Pesticides used in 'Spartan'/M.9 orchard planted in 1987

Product	Chemical name	Supplier	Rate*
Roundup~	glyphosate	Monsanto	1kg/ha
Gramoxone~	paraquat	Chipman	1kg/ha
Equal^	dodine	Chipman	1.75kg/ha
Captan80W^	captan	Chipman	2.25kg/ha
Guthion+	azinphosmethyl	Chipman	2kg/ha-0
Imidan+	phosmet	Chipman	5kg/ha
CarsolSP**	formetanate hydrochloride	Nor-PM	1kg/ha

* Rate as wettable powder in 1000 litres water per hectare
~ Herbicide
^ Fungicide
\+ Insecticide
** Miticide