

**MULCH MANAGEMENT SYSTEMS IN ORGANIC DWARF APPLE ORCHARDS
AND THEIR EFFECTS ON SOIL PHYSICAL PROPERTIES, SOIL
NUTRIENT AVAILABILITY, AND TREE NUTRITION**

By

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Forward

This thesis is comprised of nine chapters. Chapters 1 and 2 are an abstract and introduction respectively. The third chapter is a review of literature which was utilized to generate thesis hypotheses and objectives. Chapters 4 through 6 are submitted in the form of three original papers, prepared for submission for publication. Chapter 4 discusses mulch effects on soil physical properties, Chapter 5 examines mulch effects on soil nutrient availability. The influence of mulches on tree nutrient uptake are discussed in Chapter 6. Overall conclusions are presented in Chapter 7 while Chapter 8 provides a list of literature cited. Chapter 9 contains appendices.

The format of this thesis has been approved by the Faculty of Graduate Studies and Research of McGill University as per "Guidelines Concerning Thesis Preparation". The conditions are as follows:

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This research was supervised by Prof. A.F. MacKenzie, professor of soil science, Department of Natural Resource Sciences in collaboration with Prof. D.J. Buszard, Department of Plant Science. The papers in this thesis are co-authored by Professors A.F. MacKenzie and D.J. Buszard.

Chapter 1

Abstract

An alternative to herbicides in dwarf apple orchards (*Malus pumila* Mill.) is the use of mulches. Research objectives were to compare several mulch systems (*Festuca rubra* L., *Lupinus albus* L. plus *Daucus carota* L.; straw, manure compost, geotextile) with soil cultivation as to soil physical properties and plant nutrient levels in soils, leaves and fruit. Studies carried out in 1992 and 1993 on three dwarf apple orchards on the Macdonald Campus of McGill University showed that straw mulch increased soil water contents and exchangeable K, but reduced exchangeable Mg compared to *Festuca* mulch. Straw mulch reduced soil temperatures in summer relative to geotextile or cultivation. *Festuca* reduced leaf N contents but increased leaf P contents relative to geotextile treatments. Soil nitrate N contents were correlated with soil water contents, and the ratios N/Ca and K/Ca in the fruit were unaffected by treatment. Straw and geotextile mulches increased soil water content and nitrate-N levels during peak growing periods and thus were the superior treatments.

Chapitre 1

Résumé

Les mauvaises herbes dans les vergers de pommiers nains (*Malus pumila* Mill.) peuvent réduire la croissance des arbres et le rendement des fruits. Les herbicides peuvent être substitués par des matériaux de paillis. L'objectif de ces recherches fut de comparer plusieurs types de matériaux de paillis, de plantes de couverture et la cultivation du sol. Leurs effets sur les propriétés physiques du sol et le contenu en éléments nutritifs des sols, feuilles et fruits furent déterminés. Les plantes de couverture furent *Festuca rubra* L. et un mélange de *Lupinus albus* L. et *Daucus carota* L.. Les matériaux de paillis comprenaient de la paille, du compost de fumier de vaches, et un matériel de plastique (geotextile). Les essais de 1992 et 1993 au Campus Macdonald de l'Université McGill sur deux nouveaux vergers et un verger déjà établi ont démontré les résultats suivants: La paille a produit dans le sol des quantités d'eau et de K échangeable plus élevées que le *Festuca*, mais les quantités de Mg échangeable furent moins élevées. La paille a produit une température plus basse en été que le geotextile ou la cultivation. Le *Festuca* a réduit le contenu des feuilles en N et augmenté le contenu en P en rapport avec le geotextile. Pour tous les traitements, le contenu en eau et en $\text{NO}_3\text{-N}$ du sol fut corrélé. Le rapport N/Ca ou K/Ca dans les fruits ne fut pas affecté par les traitements. Les paillis et le geotextile ont augmenté le contenu d'eau et de nitrate dans le sol pendant les périodes de croissance et par conséquent furent les meilleurs traitements.

Chapter 2

Introduction

Dwarf apple trees will produce fruit three to five years after planting and thus have economic advantages over conventional standard trees. Dwarf trees, however, suffer from certain management restrictions. With shallow root systems, growth can be significantly reduced by weed competition especially when trees are young (Haynes and Goh, 1980). Traditional management practices have involved elimination of weeds with herbicide treatments along tree rows and mown grass alleys between the rows (Haynes and Goh, 1980; Johnson and Samuelson, 1990; Lord and Vlach, 1973). Complete orchard herbicide use has also been recommended (Atkinson and White, 1976).

Growing public health and environmental concerns (Hill, 1988; Hill, et.al. 1989; Tamburro, 1992), however, over the use of herbicides, and increased interest in sustainable soil resource management (Eisenberg, 1989; MacRae, et.al. 1990) has led to the desire to find alternative strategies to manage orchards without herbicides.

An alternative to herbicides is the use of mulches. The idea and practice of mulching is perhaps as old as agriculture itself (Jacks, et.al. 1955). The English word is derived from the German word *molsch* meaning "soft and beginning to decay", and since 1802 the action of spreading materials over the soil surface has been referred to in English as "mulching" (Jacks, et.al. 1955).

A mulch can be defined as any protective covering of the soil near growing plants (Swenson, 1973), to prevent loss of water (Jacks, et.al. 1955), and discourage and stop the growth of weeds (Alth, 1978).

From this definition, a mulch could be a variety of materials. A mulch might be a living plant cover such as grass sod or some other mixed flora cover crop. Mulches could be decomposable organic materials such as straw or composts, or synthetic materials such as woven permeable geotextile landscape fabric.

There are numerous benefits of mulching. Mulches suffocate weeds, thus reducing competition for water and nutrients (Call and Sewell, 1917; Alth, 1978). Mulches help soil maintain a high water content by reducing evaporation of water from the soil surface (Black and Greb, 1962; Bristow, 1988). Mulches moderate temperature fluctuations by acting as insulators so that soil temperatures stay warmer at night and into the fall (Appleton, et.al. 1990). Depending on the material, mulches may add nutrients and organic matter to the soil as they decompose (Jacks et.al. 1955). Mulches may decrease nutrient losses by reducing leaching and soil loss through erosion. Some mulching materials provide habitat for beneficial organisms such as earthworms and other predators of crop pests (Haley and Hogue, 1990; Mba, 1978). Therefore, it seemed pertinent to study mulch effects in new and established orchards.

Chapter 3

Literature Review

Mulch Effects on Soil Physical Properties

Mulches such as straw and manure act as insulators (Watson, 1988) lowering soil temperatures (Gupta, 1989; Greb, et.al. 1970) and reducing soil temperature fluctuations (Shribbs and Skroch, 1986; Baxter, 1970). In contrast, soils with cultivation and synthetic ground covers experienced higher temperatures with more variability (Shaw and Southwick, 1936; Jacks, et.al. 1955). Grass sod in apple orchards appears to be intermediate between mulch ground cover and bare ground cultivation (Watson, 1988).

Neilsen et.al. (1986) established that the largest daily and seasonal soil temperature fluctuations occurred under black plastic mulch while total vegetation cover had the coolest temperatures. Mage (1982) found that soil temperature from May to August at a depth of 20 cm was approximately 3°C higher under plastic mulch compared to cultivated soil or grass sod. Fear and Nonnecke (1989) measured soil temperatures 4°C warmer under plastic mulch compared to straw. Lower temperatures under straw mulch have also been reported by Dancer, (1964); Wilhelm et.al. (1989); and Merwin, et.al. (1992). According to Tukey and Schoff (1963) lower temperatures under mulches such as straw are advantageous, allowing tree roots to

develop in a micro-environment protected from desiccation and air temperature extremes. Grass sod has been found to reduce soil temperatures compared to cultivated soil (Newenhouse and Dana, 1989; Hedrick, 1914).

Mulches are thought to influence moisture availability primarily by affecting the rate of water infiltration and the ability of the soil to conserve absorbed moisture, and by reducing the extent of moisture competition from other plants (Haynes, 1980; Kenworthy, 1953).

In general, mulching materials such as straw and manure have beneficial effects on available soil moisture. Adams et.al. (1976) and Anderson and Russell (1964) established that soil water content was higher under mulched soil predominately because of reductions in evaporation. Baver et.al. (1972) and Skroch and Shribbs (1986) concluded that mulches reduced moisture evaporation, increased water infiltration, and significantly increased the capacity of soil to store water. The propitious effects of mulch on water infiltration found by Hulugalle, et.al. (1990) resulted from mulching material protecting surface soils from direct rainfall impact, preventing formation of surface seals. Unger (1976); Shaw and Southwick (1936); Merwin et.al. (1992); Latimer and Percival (1947); and Baxter (1970) have established that augmented soil water storage occurred with increased amounts of residues on the soil surface. Cover crops and grass sod tend to have detrimental effects on soil moisture availability. Haynes and Goh (1980) established that particularly when trees were young, grass swards compete for moisture. Similar conclusions were made by Goode and Hyrycz (1976). Reduced moisture restricted tree growth (Hardisty, 1966),

and resulted in fruit size reductions (Goode et.al. 1978).

Mage (1982) found that grassed plots used more water than those under either cultivation or geotextile treatments. Moisture content under geotextile fabric was highest of all treatments at all recorded dates. White and Holloway (1967) found drying conditions in the top 15 cm of soil under grass management. Rogers et.al. (1948) discovered that soil under grass management systems began losing water 15 to 30 days earlier in the spring compared to cultivated soil.

In contrast, experiments by Haynes (1981) established that grassed soil contained higher water contents than non-grassed treatments in the top 10 cm. Haynes concluded that this greater water holding capacity resulted from high organic matter levels under grass management treatments compared to cultivation treatments. Hamblin and Davies (1977) demonstrated a positive correlation between organic matter content and soil moisture retention capability.

Cultivation management systems tend to diminish soil aggregate stability (Graecen, 1958) and increase erosion losses (Lord and Valch, 1973). Judkins and Rollins (1947) concluded that cultivation practices in orchards increased soil erosion.

Mulching tends to reduce erosion losses (Shaw and Southwick, 1936; Burrows and Larson, 1962) especially in newly planted orchards where erosion is a significant problem (Atkinson and White, 1977). Hipps, et.al. (1990) found that straw mulch was highly effective in reducing soil erosion by as much as 30% compared to bare soil. Mulches reduce soil erosion by protecting soil aggregates from direct raindrop impact and wind abrasion. Direct impact of dry aggregates by rainfall causes rapid ped

disintegration (Hillel, 1980) and can be a destructive force especially in dry summer months.

Orchard grass and other mixed flora have positive influences on aggregate stability. Rogers et.al. (1948) recognized that grass sward management promoted stable soil aggregates through a continually dying and replaced fibrous grass root system. The roots themselves stabilize the soil by the exudation of mucigel which binds aggregates (Russell, 1973) and by pushing soil particles together (Haynes, 1980). The grass rhizosphere supports a large microbial population whose polysaccharide gums stabilize soil aggregates (Haynes, 1980).

There is little information on the effects of orchard soil management systems on bulk density. Haynes (1981) found that bulk density of soil under grassed treatments was intermediate to both cultivated and herbicide treated plots. Merwin et.al. (1992) established that soil bulk density was lowest under vegetative ground covers compared to herbicide treatments. In contrast, a study by Newenhouse and Dana (1989) established that soil under grass was less compacted compared to cultivated soil.

Mulch Affects on Nutrient Availability

There is evidence that orchard trees compete with grass for mineral N (Haynes, 1980; Perring, 1975; Johnson and Samuelson, 1990). Haynes and Goh (1980) established that in the top 0-10 cm of soil, grassed plots contained less soil NO_3^- -N

than clean cultivation plots. Haynes (1981a) found that percolates from soils with grass had significantly lower NO_3^- -N concentrations than percolates from soil with no grass. Judkins and Rollins (1943) noted that soil NO_3^- -N under a cultivation-cover crop management system were higher than under orchard grass. Komosa (1990) found at a soil depth of 0-20 cm, concentrations of NO_3^- -N and NH_4^+ -N under grass sward strips decreased during the vegetative period. Lyon and Bizzell (1913) have found that grasses strongly depress NO_3^- -N formation. Baxter and Newman (1971) estimated that approximately $300 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ would be required to overcome the competitive effects of grass sod on apple trees. Bould et.al. (1972) found that 52 Kg N ha^{-1} applied annually was inadequate to counteract the competitive effects of orchard grass.

Latimer and Percival (1947) found that NO_3^- -N was much higher under hay mulch than sod, sawdust or seaweed treatments. The authors concluded that this resulted from hay mulch suppressing grass growth thereby eliminating competition between grass and tree roots for nutrients such as N. This effect of mulches has been supported by Tukey and Schoff (1963).

Soil NO_3^- -N has been found to be higher under straw mulch compared to cultivation management (Shribbs and Skroch, 1986). Shaw and Southwick (1936), using low grade hay mulch, obtained soil NO_3^- -N values over 200% higher than with cultivation treatments.

Bould et.al. (1972), found that in the first few growing seasons following grass establishment in orchards, low soil levels of P, K and other cations may occur

because of grass/tree competition. Haynes (1980), established that pasture plants such as orchard grasses absorb P and K. Johnson and Samuelson (1990) found that grass cover was competitive to Ca uptake by trees.

In contrast, many studies have demonstrated the benefits of grass management to nutrient availability. The use of grass strips in soil orchard management is thought to increase the available form of nutrients (primarily cations) by decreasing losses by leaching (Haynes, 1983; Haynes, 1980; Johnson and Samuelson, 1990), and by cycling of nutrients through herbage returns following mowing (Haynes and Goh, 1980; White, 1971; Bould et.al 1972; Stott, 1976). Evidence of P cycling by increased mobilization exists (Bould et.al. 1954).

Atkinson and White (1976), found that soil pH was lower in non-grassed plots compared to grassed plots. Baeumer and Bakermans (1973) concluded that pH decreases resulted from leaching of cations from non-grassed plots. The higher concentrations of K and Mg in comparison to NO_3^- -N and P under grass management systems were thought to have resulted from the higher sorption capacity of soil under grass sward strips (Komosa, 1990). Komosa (1990) concluded that leaching of cations from soil under grass management was significantly lower than herbicide or cultivation systems. Haynes (1983) established that leaching of Ca and Mg was approximately 3.5 times lower under grass strips, and Lowe and Armitage (1970) found that pasture reduced levels of Ca, Mg, K, and P in leachate samples compared to cultivation. Haynes (1981a) also found that percolates from grassed treatments contained significantly lower Ca and Mg than percolates from cultivated plots.

Hulugalle et.al. (1990) found that exchangeable Ca, Mg, and K were higher under mulched treatments. Latimer and Percival (1947) established that available soil P, K, and Mg were highest under hay mulch compared to sawdust or sod treatments. Merwin et.al. (1992) found that extractable soil K concentrations were approximately 2.5 times higher under straw than sod or cultivation treatments.

Mulch Affects on Nutrient Cycling, Tree Uptake, and Fruit

Quality

The impact of mulching on nutrient cycling is of importance as cycling will relate directly to nutrition and thus production of the tree. In terms of fruit quality, Ca content of fruit will be the controlling factor (Wiersum, 1979), since low levels of fruit Ca have been associated with bitter pit development (De Long, 1937). Generally, (depending on apple variety), Ca levels above 5 mg 100 g⁻¹ (or 0.05 mg g⁻¹) are requisite for maintenance of fruit quality, depending on variety (Waller, 1980).

Mulches will directly influence nutrient cycling if they are in themselves nutrient sources. Any mulch that directly increases the soil pool of a particular nutrient will encourage uptake of that nutrient by the plant. For example, Claassen and Wilcox (1974) found that plant uptake of both Ca and Mg was directly related to the level of exchangeable Ca and Mg in the soil. Positive correlations have been found between NO₃⁻-N concentrations in soil and apple yields (Hudska, 1990).

Living mulches will directly influence nutrient cycling and tree uptake through

nutrient competition with the tree. Johnson and Samuelson (1990) found reduced leaf N contents when orchard management was changed from herbicide strip to complete grass cover. Similar results are reported by Shribbs and Skroch (1986a); Estabrooks and Ghanem (1990); and Haynes and Goh (1980). Grass mulch has been found to have comparable competitive effects on leaf N in the mandarin (Mustaffa, 1988) and grape (Tan and Crabtree, 1990).

Living mulches of grass sod have also been found to be competitive to Ca uptake (Johnson and Samuelson, 1990; Tan and Crabtree, 1990). In contrast, Haynes (1980) found high leaf levels of Ca from grass treatments, possibly a result of cycling of Ca in mown grassed treatments (Haynes and Goh, 1980).

Increasing the level of a particular nutrient will also result in interactive influences with other nutrients. For example, plants nourished with high NO_3^- -N will have a corresponding increase in inorganic cations such as Ca, Mg, and K (Blair et.al. 1970; Haynes, 1980). It has also been suggested that N uptake by trees is antagonistic to uptake of P (Johnson and Samuelson, 1990). This is supported by Shribbs and Skroch (1986a) who found the level of leaf N negatively correlated with leaf P.

High levels of soil NO_3^- -N have been shown to be negatively correlated with fruit quality (Terblanche, et.al. 1980; Lewis, et.al. 1977). Elevated soil NO_3^- -N stimulates vegetative growth, decreases fruit number and size, and leads to increased fruit N. This can result in fruit low in Ca (Shear, 1980; Van Schreven, 1980). Shear (1974) demonstrated that the incidence of bitter pit and cork spot in fruit was higher in fruit with elevated N/Ca ratios.

Both Ca and Mg will compete with K for entry into plants (York et.al. 1953; Al-Kanani, et.al. 1989). Thus the availability of K is more dependant on its concentration in the soil pool relative to that of Ca and Mg than the total quantity of K itself (Lahav, 1978). According to Ashley and Stewart (1969) and Gross and Jung (1978), plant deficiencies of Mg can occur in soils with high levels of Ca. The activity of phosphorus will also be lower in soils saturated with Ca (Westermann, 1992).

Calcium uptake by plants is depressed by high soil levels of $\text{NH}_4^+\text{-N}$, K, Mg and Ca absorption is increased when plants are supplied with more $\text{NO}_3^-\text{-N}$ (Marti and Mills, 1991).

High levels of soil K can interfere with Mg uptake, sometimes to the point of deficiency (Claassen and Wilcox, 1974; Adams and Henderson, 1962; Walsh and O'Donohoe, 1945). Elevated soil K levels have been found to interfere with nitrification by blocking the release of fixed NH_4^+ in clay minerals (Welch and Scott, 1960)

High levels of soil K can also affect fruit quality by inhibiting Ca absorption into fruit (Sharples, 1973). Ludders (1973) showed that high soil K levels throughout the growing season increased the amount of fruit K at the expense of Ca. High K/Ca ratios in fruit have been related with fruit quality disorders (Faust and Shear, 1968). Holland (1980) stated that fruit K/Ca could be used to rank orchards according to their capacity for producing bitter pit.

Mulches can indirectly affect nutrient cycling by influencing other soil properties such as temperature and water content.

A mulch layer that does not allow soil temperatures to rise significantly over the growing season will decrease the absorption of solutes by roots (Clarkson, et.al. 1992). Ching and Barber (1979) found that K influx into roots at 15°C was one-half that at 29°C. Low soil temperatures also reduce diffusion rates (direct effect of P movement).

Mulches that allow for temperature increases (for example geotextile absorbing radiant energy) influence both biological and chemical processes. Burns and Barber (1961) found with higher temperatures, a greater release of nonexchangeable K. Power et.al, (1964) found that increased soil temperature may raise the level of soil P by increasing the rate of mineralization of organic P. In the same paper, however, the authors stated that rising soil temperatures might lead to reduced P solubility by increasing the rate of mobilization or chemical fixation of soil P. This process was supported by Beaton, et.al. (1965). Li, et.al. (1990) suggested that most factors regulating soil P supply were temperature dependent.

Mulching increases soil moisture levels by reducing moisture competition from other vegetation and by forming a protective layer over the soil, thus reducing evaporation of water. Moisture supply will have profound affects on availability and uptake of nutrients (Flocker and Nielsen, 1962). For example, Stanford and Epstein (1974) found a near linear relationship between the amount of N mineralization and soil water contents. Phosphorus diffusion rates increased as soil moisture increased (Olsen, et.al. 1962; Hira and Singh, 1977). Both Burns and Barber (1961) and Mederski and Wilson (1960) have shown increased K uptake from soil with increased

moisture content. Wade, et.al. (1992) found that K, Ca, and Mg accumulated in soil as water potentials increased.

Hypotheses

As a result of this review, several hypotheses have been developed:

1. Root systems of living mulches should increase soil aggregate stability relative to cultivation due to root exudates and root physical activity.
2. Grass and mixed flora mulch treatments will be competitive with trees for water while straw, manure, and geotextile will promote high soil water content by covering and protecting the soil surface thus reducing evaporation.
3. The highest daytime soil temperatures should be in cultivation treatments because soil will be exposed to direct solar radiation. Mulching should moderate temperature fluctuations in other treatments possibly because of maintenance of high water content.
4. Living mulches of grass and mixed flora should decrease soil levels of NO_3^- -N relative to those levels under other mulch treatments resulting in lower levels of leaf N.
5. Soil nutrient levels in any mulch treatment will be higher 0.1 m from the tree compared to 0.5 m from the tree because spring fertilization occurs near the tree. Therefore, leaf nutrient contents should be more highly correlated with soil nutrient levels at the 0.10 m sampling location.

6. High levels of soil K under manure and straw mulches should increase leaf K and reduce Mg and Ca relative to other mulch treatments due to cation competition.
7. Both apple N/Ca and K/Ca ratios will indicate which mulch treatments have the potential to promote bitter-pit in fruit.

Objectives

To compare effects of soil cultivation and various mulch management systems on soil physical properties, extractable soil nutrients and nutrient uptake in two newly established and one existing organic dwarf apple orchards in Québec, Canada.

Chapter 4

Mulch management systems in organic dwarf apple orchards and their effects on soil aggregate stability, bulk density, temperature and volumetric water content.

Abstract

With growing pressure to reduce pesticide use, fruit growers require an alternative to herbicidal control of weeds. One option is the use of mulches. This study was conducted to examine the effects of cultivation, straw mulch, geotextile mulch, composted manure mulch, grass sod (*Festuca rubra*) and a cover crop mixture of lupin (*Lupinus albus*) and wild carrot (*Daucus carota*) on soil aggregate stability, bulk density, temperature, and volumetric water content. Two newly established dwarf apple (*Malus pumila* Mill.) orchards in Québec were used. Straw and geotextile mulches, by covering and protecting the soil surface, resulted in higher soil water contents relative to soil under the living mulches. Living mulches maintained soil aggregate stability. Soil temperatures were highest under cultivation and geotextile treatments in spring and summer months. Straw mulch buffered soil from temperature variation particularly in 1992. Little effect of mulch treatments on soil bulk density was observed. Given that soil water content is the primary factor related to optimum orchard production, mulches such as straw and geotextile which promote soil water retention could be superior management options for growers.

Introduction

Dwarf apple trees are preferred by producers because trees come into bearing three to five years after planting, and therefore provide an income more rapidly than standard trees. Dwarf and semi-dwarf fruit trees, however, have shallow root systems and competition from weeds for moisture and nutrients can significantly restrict growth (Haynes and Goh, 1980) and fruit production (Goode, et.al. 1978). Weed control has been primarily by herbicides, but alternative methods of weed control are needed in light of a new environmental consciousness (MacRae, et.al. 1990), and concern about possible effects of herbicides on human health (Johnson, 1992). An alternative to herbicides is the use of mulches.

Swenson (1973), defines a mulch as any protective covering over the soil surface. Mulches control weeds primarily by smothering plants and preventing seeds from becoming established in soil.

The effect of a mulch management system for weed control on soil physical properties will vary depending on the mulch utilized. A mulch that promotes an optimum soil physical environment for the least cost and labour will be beneficial to fruit growers (Autio, et.al. 1991). Soil physical properties such as moisture content, temperature, texture, bulk density, and aggregate stability are important in determining crop productivity.

Soil temperature extremes can be detrimental to tree growth (Kozlowski, 1983). Decomposable mulches such as straw and manure are generally beneficial

management options since these materials act as insulators (Watson, 1988), maintaining a more constant, lower, soil temperature than non-mulched soils (Baxter, 1970; Greb, et.al. 1970). Tukey and Schoff (1963) concluded that lower soil temperatures under mulches protect tree roots from desiccation and air temperature extremes. Soil temperatures under cultivation and geotextile fabric management tend to be higher and have more temporal variability (Mage, 1982; Fear and Nonnecke, 1989). Elevated soil temperatures during the growing season may be beneficial to tree growth because of increased mineralization of soil nutrients (Tisdale, et.al. 1985). High soil temperatures, however, may increase soil desiccation and create moisture stress in trees. Living mulches (ground covers comprised of viable vegetation) should have soil temperatures intermediate between those of decomposable mulch cover and geotextile fabric (Watson, 1988; Newenhouse and Dana, 1989).

In general, soil water retention is elevated with increasing amounts of decomposable residues on the soil surface (Unger, 1976; Baxter, 1970), primarily from reduction in evaporation (Baver, et.al. 1972; Shroch and Shribbs, 1986). Living mulches may adversely affect tree growth (Hardisty, 1966) by competing for moisture (Haynes and Goh, 1980) especially in the top 0.15 m of soil (White and Holloway, 1967). In contrast, Haynes (1981) concluded that grass mulch might be beneficial to tree growth through increased water storage resulting from higher organic matter levels compared with cultivated soils.

Cultivation is detrimental to soil aggregate stability (Graecen, 1958) usually resulting in increased soil erosion (Lord and Valch, 1973; Judkins and Rollins, 1947).

Soil erosion in newly planted orchards can be a serious problem (Atkinson and White, 1977). Mulches tend to reduce erosion losses (Burrows and Larson, 1962; Hipps et.al. 1990) by protecting soil aggregates from direct raindrop impact and wind erosion and thereby increasing stability of the soil (Ghaw and Southwick, 1936). The fibrous root systems of living mulches promote stable soil aggregates (Rogers, et.al. 1948) by the cementing effects of mucigels (Russell, 1973), and the pushing together of soil particles (Haynes, 1980).

Objectives were to evaluate the effects of soil mulch systems on aggregate stability, bulk density, soil temperature, and volumetric water content, in two newly established dwarf apple orchards.

Materials and Methods

Experimental Design

All experiments were conducted in orchards at the Horticultural Research Centre of Macdonald Campus of McGill University in Ste. Anne de Bellevue, Québec, Canada (45° latitude, 74° longitude). In May 1991, 300 scab (*Ventivea inaequalis*) resistant apple trees (*Malus pumila* Mill.) of the cultivars #637, Liberty, Olympic, Moira, Macfree, Richelieu, and Rouville on M26 rootstock were planted in nineteen rows, 4.5 meters apart, of sixteen trees each, 3.5 meters apart within the row, on a St. Bernard sandy loam soil (Orthic Melanic Brunisol) (Lajoie, 1960) . This orchard is

referred to as Orchard 1.

In October 1990, 300 trees of the scab resistant cultivars Liberty, Murray, Freedom, Britegold, and Novamac on M9 rootstock were planted in ten rows, 4.5 meters apart, of thirty trees each, 3 meters apart within the row, on a St. Bernard sandy clay loam soil (Orthic Melanic Brunisol) (Lajoie, 1960). This orchard is referred to as Orchard 2.

In the spring of 1991, the following soil management treatments were applied in a randomized complete block design with four replications; 1) cultivation, 2) straw mulch, 3) geotextile fabric, 4) composted manure mulch, 5) cover crop mixture of lupin (*Lupinus albus*) and wild carrot (*Daucus carota*), and 6) grass sod (*Festuca rubra*). Treatments were established as 1 meter wide strips extending along six trees to 1 meter beyond each of the end trees (Table 4.1). Information on organic fertilizers and pest controls applied to all treatments can be found in Appendices 1 and 3.

Sampling Protocol

A soil sample was taken from each plot in the Ah horizon for measurement of aggregate stability during July 1992 and 1993. The Ah horizon was defined as the topmost mineral horizon with accumulation of humified organic matter. Aggregate stability was determined by dry (White, 1993) and wet sieving (Angers and Mehuys, 1993).

Bulk density was determined on soils sampled in July and September 1992 and

Table 4.1 Mode of establishment and maintenance of mulch treatments[^].

Mulch Treatment	Establishment and Maintenance
Cultivation	1991: Cultivated at commencement. 1991, 1992, 1993: Maintained throughout summers as needed depending on weed growth (approximately every two weeks) using "Graveley" Rotovator (Graveley International Inc., Clemmons, NC) to a depth of approximately 0.05 to 0.10 m. Weeds near trees were removed by hand.
Geotextile	1991: "Amoco" woven polypropylene landscape fabric applied. 1992: "Amoco" fabric removed and replaced with "Exxon Sunbelt", UV resistant woven polypropylene geotextile. 1993: No maintenance.
Grass	1991: Red Fescue (<i>Festuca rubra</i>) seed sown at rate of 36 g m ⁻² . 1992, 1993: Mowed as needed approximately 4-5 times per year.
Manure	1991: 0.28 and 0.5 m ³ of semi-composted manure per treatment in West and Middle Orchards respectively. 1992: 0.23 and 0.4 m ³ reapplied in West and Middle Orchards respectively to re-establish 0.1 to 0.15 m layer. 1993: No application.
Mixed Flora	1991: Mixture of <i>Lupinus albus</i> and <i>Daucus carota</i> sowed at rates of 26 and 1 g m ⁻² respectively. 1992: <i>Lupinus albus</i> resown. 1993: Lupin and wild carrot allowed to reseed.
Straw	1991: 0.1 to 0.15 m layer applied. 1992 and 1993: Straw reapplied as needed to patch holes caused by decomposition.

[^] Modified from Salmins, S. Apple Tree Growth and Yield in Alternative Ground

Management Systems. M.Sc. Thesis, Faculty of Graduate Studies and Research. pg.

38.

1993. In July 1992, soils were sampled beneath two trees in each replicate at two locations (0.10 m and 0.50 m) from the tree trunks. Each sample was divided into two depths, the depth of the Ah horizon and below the Ah horizon to 0.30 m depth.

It was found through statistical analysis that there was no difference in initial soil bulk density between trees. Thus results from July 1992 were combined. Soils were sampled beneath one tree in July 1993 and September 1992 and 1993 at distances 0.10 m and 0.50 m from the tree. Samples were again divided into two depths as in July 1992.

Bulk density of soil was determined by weighing the mass of wet soil from a soil core (7 cm. in diameter) obtained with a hydraulic soil corer machine (Giddings, Fort Collins, CO) and dividing by the volume of the cylinder. The wet bulk density value was corrected for moisture content by drying a subsample at 65°C for 48 hours.

Soil temperatures were taken with a Weston Dial Reading 0-50°C probe thermometer (Arthur H. Thomas Co. Philadelphia, PA.) at a soil depth of 0.10 m. A reading was taken from each plot in the two orchards at the beginning of each month from May through October, 1992 and 1993.

In 1993, soil volumetric water content was measured in the field using a Trase System 6050X1 soil moisture measuring instrument (Soil Moisture Equipment Corp. Santa Barbara, CA) which utilizes time domain reflectometry (TDR) technology. A reading at 0.15 m depth from each plot in each of the two orchards was taken at the beginning of each month from May through October, 1993.

Bartlett's test for homogeneity of variance was performed on all measurements

from each orchard. Results for bulk density and aggregate stability required a log transformation prior to analysis of variance.

Analyses of Results

Results were analyzed using GLM procedure of SAS (SAS, 1988). Since there were only two levels of each repeated measure (sampling distance: 0.10 and 0.50 m; depth: Ah and Ah to 0.30 m) the H-F condition (Huynh and Feldt, 1970) automatically held (Littell, 1989; Fernandez, 1991) and 1992/1993 bulk density results within each orchard/depth combination were analyzed as split-plots with mulch treatment as the main plot and sampling distance from tree the subplot. Temperature (1992 and 1993) and volumetric water content (1993) results were analyzed as repeated measures. Aggregate stability results (1992 and 1993) were analyzed as a randomized complete block. Multiple comparison of treatment effects were determined using Tukey's multiple comparison test (Tukey, 1953).

Results

Soil Aggregate Stability

Although there were considerable differences in soil aggregate stability between orchards, treatments produced similar effects (Table 4.2). In 1992, grass and

mixed flora treatments in both Orchards lead to greater soil aggregate stability than soil under straw mulch in Orchard 1 and geotextile and straw mulches in Orchard 2. In 1993, there were no differences among treatments in Orchard 1. In Orchard 2, aggregate stability was greater under grass and mixed flora mulches than geotextile mulch.

Soil Bulk Density

There was little effect of mulch treatments on soil bulk density. The only significant difference occurred in July 1992 in Orchard 2 in the Ah horizon where soil under straw mulch had a higher bulk density than soil under mixed flora mulch. Bulk density values ranged from 1.0 to 1.1 and 1.2 to 1.3 Mg m⁻³ for orchards 1 and 2 respectively in the Ah horizon. Below the Ah horizon to 0.30 m depth, bulk density varied from 1.3 to 1.4 and 1.2 to 1.4 Mg m⁻³ for orchards 1 and 2 respectively.

Soil Temperatures

In both orchards in 1992, May, June, July, and August soil temperatures under cultivation and geotextile were higher than those under manure or straw mulches (Table 4.3) except in Orchard 1 in May 1992 where soil temperatures under geotextile and manure mulches were similar. Grass and mixed flora mulches resulted in intermediate soil temperatures. The same trends occurred in 1993 in May, July and

August, although soil temperatures were somewhat higher (Table 4.4). In June 1993 in Orchard 1, cultivation treatment resulted in soil temperatures higher than those under both straw and manure mulches while geotextile mulch resulted in soil temperatures higher than those under straw but not manure mulch. In Orchard 2 in June 1993, soil temperatures under geotextile mulch were higher than those under straw and manure mulches while the cultivation treatment resulted in similar soil temperatures as those under straw and manure mulches.

In September 1992 in both orchards, soil temperatures under geotextile mulch were higher than those under manure and straw mulch. In 1993 in both orchards, geotextile mulch resulted in soil temperature higher than straw mulch.

In October 1992, the trend in soil temperature reversed as soil under straw and manure mulches resulted in soil temperatures higher than those in all other treatments in Orchard 1 and than cultivation and mixed flora treatments in Orchard 2.

In October 1993, soil temperatures were warmer than 1992. In Orchard 1, soil temperatures under grass, mixed flora, and manure were lower than those under cultivation. No differences were observed in Orchard 2 for October 1993.

Soil Volumetric Water Contents

In May, soil water content was higher under geotextile and straw mulches than under grass mulch in Orchard 1, and both grass and cultivation treatments in

Orchard 2 (Table 4.5). In Orchard 2, straw mulch also resulted in higher soil water contents than those under mixed flora mulch.

In June, in Orchard 1 soil water content was higher under geotextile mulch than manure, grass, and mixed flora mulches. In Orchard 2, soil water contents under straw and geotextile mulches were higher than all other treatments except manure.

During the relatively dry summer month of July, straw mulch in both orchards resulted in the highest soil water contents, greater than those under all other treatments except geotextile in Orchard 1. In both orchards, soil under cultivation and geotextile treatments also had higher water contents than soil under grass or mixed flora mulches.

Soil under grass and mixed flora mulches had lower water contents than all other treatments in August in Orchard 1. In Orchard 2, straw mulch resulted in higher soil water content compared to all other treatments except geotextile. Living grass mulch had the lowest soil water content.

In September and October, there were fewer differences in soil water content among treatments. In September in Orchard 1, only soil under geotextile mulch had a higher water content than under grass mulch and in October there were no significant differences. In Orchard 2 in September, cultivation, straw, and geotextile treatments resulted in soil water contents higher than those under grass mulch while in October, grass and manure mulches resulted in lower soil water contents than soil under straw mulch.

Discussion

Living mulches promoted soil aggregate stability. This was likely a result of the roots systems acting to bind soil peds through root pressure and the cementing action of mucigels (Russell, 1973) and polysaccharide gums (Haynes, 1980). The vegetative cover would have also protected soil from direct rainfall impact and prevented the formation of surface seals (Hulugalle, et.al. 1990). In Orchard 1, higher aggregate stability values under living mulches relative to other mulch treatments in 1992 were not observed in 1993. The reason for the reduced aggregate stability in 1993 was not apparent.

The benefits of straw mulch on aggregate stability found by Hipps, et.al. (1990) were not observed in this study. Low aggregate stability values under straw particularly in 1992 in Orchard 1 might be related to high soil water contents. It is to be expected that soil particles within peds would be less stable as the water content of soil increased and swelling of clays occurred (Rasiah, et.al. 1992).

In Orchard 2, low aggregate stability values for soil under geotextile mulch might be related to lack of weed growth in these plots. With no living vegetation, the benefits of root systems in strengthening soil peds as observed in living mulch plots would not have occurred. Also, the high water content of soils under geotextile would have similar influences on soil stability as observed in soils under straw mulch. Low aggregate stability values might also be related to limited organic matter additions in geotextile plots and the resulting reduction of microbial populations

(Yokoyama, et.al. 1991) which would diminish the benefits of polysaccharide gums and mucigels on soil stability.

The detrimental effects of cultivating soil on aggregate stability found in many studies (Lord and Valch, 1973) were not observed in either orchard. Weed growth following cultivation could have provided results as observed in grass and mixed flora treatments.

If soil is susceptible to erosion, a living mulch would be the best management choice. If the orchard is planted on an inherently stable soil, however, then other mulches could be as effective as a living mulch in promoting soil aggregate stability.

In terms of soil water content, mulch treatments exhibited their greatest differences in July and August when air and soil temperatures were high and plant demand for water was likely at its greatest. During this time, straw and geotextile mulches maintained high soil water contents and were most beneficial to water availability to the tree. These mulches may have acted as barriers and reduced evaporation of stored water from the soil surface while not hindering precipitation inputs, an outcome observed by others (Skroch and Shribbs, 1986). This is also supported by the fact that cultivated soil without mulch protection generally had lower soil water levels. Because straw and geotextile mulches limited weed growth, water loss via plant transpiration could have been reduced relative to living mulch plots.

It was expected that manure compost mulch would have similar influences on soil water content as straw and geotextile mulches, since compost may act as a

barrier to moisture evaporation. Soil moisture availability is, however, also a function of water competition from other growing plants (Haynes, 1980). Thus it is speculated that soil under manure had low soil moisture levels because roots from weeds growing within the manure compost penetrated the soil in 1993.

Living mulches generally resulted in the lowest soil water contents. Thus root systems of the living mulches could have been competing with trees for water as noted by Haynes and Goh (1980). Water utilized by living mulches was therefore not available to young trees which require large amounts of water for tissue hydration and nutrient uptake (Manru, et.al. 1990). The consequence for growers would be trees which take longer to reach fruit bearing age. Water competition will also be pernicious during the reproductive phase of the trees development. During fruit development, demand for water is large. Thus plant competition for water will reduce fruit size, which is supported by Salmins (1993) who found fruit size to be larger from trees with straw and geotextile mulches relative to grass mulch.

Soil water content appears to be the primary factor that requires management for optimum orchard production (Guilivo, 1990). These results indicated that any mulch that covers and protects the soil such as straw and geotextile will be beneficial to soil water content provided these materials also control weed growth. In areas of limited rainfall, grass and mixed flora mulches which diminish water reserves should be avoided. If in an area with adequate precipitation, cultivation would also be an acceptable option in relation to soil water contents.

Soil temperature variability was a function of the depth of material covering

the soil. Thus, soil under mulches of straw and manure, had the lowest seasonal temperature variability, a result supported by Stribbs and Skroch (1988). Mulch materials like straw buffer soil temperature extremes by trapping air and creating an insulation effect (Watson, 1988). In addition, straw mulch promoted high soil water content relative to cultivation, increasing the specific heat of the soil water mixture and reducing temperature changes per unit heat absorbed or lost.

As long as materials such as straw and manure allow temperatures to increase to an adequate level for microbial activity they are a benefit because a constant, lower soil temperature reduces evaporation, and is favourable for optimal tree growth (Kozłowski, 1983).

In contrast, soils with no protection (cultivation) or a relatively thin covering (geotextile mulch) had more extreme ranges of temperature. There are both positive and negative impacts of high soil temperatures. High soil temperatures increase microbial mineralization of organic nutrients. Thus higher temperatures in soil under cultivation management might give trees an early advantage in terms of N, P, or S acquisition. On the negative side, high soil temperatures will promote soil desiccation and reduce tree growth particularly in soils already subject to moisture problems.

Table 4.2 Aggregate stability of soils in the Ah horizon in Orchards 1 and 2 in 1992 and 1993.

Treatment	1992		1993	
	Orchard 1	Orchard 2	Orchard 1	Orchard 2
	-----%			
Cultivation	57 ^{ab} (1.2)	18 ^{abc} (1.3)	50 ^a (1.2)	15 ^{ab} (1.2)
Grass	75 ^a (1.1)	32 ^a (1.1)	61 ^a (1.1)	49 ^a (1.2)
Mixed Flora	82 ^a (1.1)	23 ^{ab} (1.3)	60 ^a (1.0)	43 ^a (1.0)
Straw	41 ^b (1.1)	10 ^{bc} (1.2)	45 ^a (1.3)	20 ^{ab} (1.8)
Manure	61 ^{ab} (1.1)	19 ^{abc} (1.1)	66 ^a (1.1)	17 ^{ab} (1.2)
Geotextile	70 ^{ab} (1.1)	10 ^c (1.2)	46 ^a (1.2)	5.7 ^b (1.4)

Values are antilogs of log transformed data.

Means within each sampling season and orchard with the same letter are not significantly different at 0.05 level of probability according to Tukeys multiple comparison test.

() standard error of means (n=4).

Ah denotes soil layer to bottom of Ah horizon.

Table 4.3 Soil temperatures in Orchards 1 and 2 at soil depth of 0.10 m in 1992.

Treatment	May	June	July	August	September	October
Orchard 1	°C					
Cultivation	12 ^a (0.55)	15 ^a (0.41)	17 ^a (0.18)	17 ^b (0.25)	16 ^b (0.22)	5.6 ^c (0.24)
Geotextile	12 ^{abc} (0.23)	15 ^a (0.24)	18 ^a (0.40)	19 ^a (0.16)	17 ^a (0.18)	6.9 ^b (0.12)
Grass	12 ^{ab} (0.41)	15 ^{ab} (0.46)	16 ^b (0.24)	17 ^{bc} (0.08)	15 ^c (0.16)	6.4 ^b (0.28)
Mixed Flora	12 ^{bc} (0.27)	14 ^b (0.16)	16 ^{bc} (0.05)	16 ^{cd} (0.10)	15 ^c (0.11)	6.2 ^{bc} (0.10)
Straw	9.2 ^d (0.49)	12 ^c (0.11)	15 ^d (0.09)	16 ^d (0.15)	15 ^c (0.08)	8.2 ^a (0.18)
Manure	11 ^c (0.17)	12 ^c (0.06)	15 ^{cd} (0.08)	16 ^{cd} (0.18)	16 ^{bc} (0.11)	7.6 ^a (0.12)
Orchard 2						
Cultivation	19 ^a (0.82)	16 ^a (0.30)	17 ^{ab} (0.30)	17 ^{ab} (0.30)	16 ^b (0.33)	5.4 ^c (0.50)
Geotextile	16 ^b (0.57)	16 ^{ab} (0.19)	17 ^a (0.09)	18 ^a (0.33)	17 ^a (0.14)	6.6 ^{ab} (0.12)
Grass	17 ^{ab} (0.63)	16 ^a (0.09)	16 ^{bc} (0.21)	17 ^{bc} (0.10)	16 ^{bc} (0.11)	6.5 ^{ab} (0.23)
Mixed Flora	16 ^b (0.47)	15 ^b (0.22)	15 ^{cd} (0.22)	16 ^{cd} (0.14)	15 ^d (0.11)	5.9 ^{bc} (0.12)
Straw	11 ^d (0.40)	12 ^d (0.15)	15 ^d (0.22)	16 ^d (0.26)	15 ^{cd} (0.11)	7.4 ^a (0.12)
Manure	13 ^c (0.33)	15 ^c (0.12)	16 ^{cd} (0.14)	16 ^{cd} (0.06)	15 ^{bcd} (0.11)	7.3 ^a (0.21)

Means within each month and orchard with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.
() standard error of means (n=4).

Table 4.4 Soil temperatures in Orchards 1 and 2 at soil depth of 0.10 m in 1993.

Treatment	May	June	July	August	September	October
Orchard 1	°C					
Cultivation	15 ^a (0.46)	13 ^a (0.83)	23 ^a (0.53)	21 ^a (0.23)	16 ^{ab} (0.19)	9.8 ^a (0.21)
Geotextile	15 ^a (0.16)	13 ^{ab} (0.92)	23 ^a (0.43)	21 ^a (0.23)	17 ^a (0.06)	9.4 ^{abc} (0.19)
Grass	12 ^b (0.20)	12 ^{abc} (0.42)	21 ^b (0.20)	18 ^{bc} (0.18)	16 ^{ab} (0.26)	8.8 ^{bc} (0.16)
Mixed Flora	13 ^b (0.44)	12 ^{abc} (0.58)	20 ^b (0.28)	18 ^b (0.18)	15 ^{ab} (0.37)	8.9 ^{bc} (0.16)
Straw	10 ^c (0.51)	11 ^c (0.21)	18 ^c (0.23)	17 ^c (0.24)	14 ^b (1.2)	9.6 ^{ab} (0.28)
Manure	11 ^{bc} (0.41)	11 ^{bc} (0.27)	19 ^{bc} (0.40)	17 ^c (0.12)	16 ^{ab} (0.10)	8.6 ^c (0.07)
Orchard 2						
Cultivation	14 ^a (0.12)	12 ^{ab} (0.16)	28 ^a (0.50)	21 ^a (0.21)	20 ^a (0.27)	9.2 ^a (0.44)
Geotextile	14 ^{ab} (0.22)	14 ^a (0.76)	25 ^b (0.59)	22 ^a (0.33)	20 ^a (0.37)	9.6 ^a (0.37)
Grass	13 ^b (0.34)	13 ^{ab} (0.90)	23 ^c (0.30)	20 ^b (0.37)	20 ^a (0.68)	9.2 ^a (0.21)
Mixed Flora	13 ^b (0.41)	12 ^b (0.22)	22 ^{cd} (0.60)	20 ^b (0.26)	19 ^{ab} (0.16)	8.8 ^a (0.26)
Straw	9.1 ^d (0.07)	11 ^b (0.59)	20 ^c (0.28)	19 ^b (0.10)	18 ^b (0.31)	9.4 ^a (0.21)
Manure	11 ^c (0.10)	11 ^b (0.12)	21 ^{de} (0.44)	20 ^b (0.31)	19 ^{ab} (0.16)	8.8 ^a (0.56)

Means within each month and orchard with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.
() standard error of means (n=4).

Table 4.5 Soil volumetric water content in Orchards 1 and 2 in the Ah horizon in 1993.

Treatment	May	June	July	August	September	October
Orchard 1	mL L ⁻¹					
Cultivation	250 ^{ab} (21)	260 ^{abc} (9.8)	230 ^b (10)	210 ^a (11)	210 ^b (5.3)	290 ^a (6.5)
Geotextile	290 ^a (5.3)	300 ^a (6.5)	240 ^{ab} (8.7)	250 ^a (10)	280 ^a (8.2)	320 ^a (6.0)
Grass	210 ^b (20)	200 ^c (13)	130 ^c (8.0)	130 ^b (7.3)	160 ^b (15)	280 ^a (2.8)
Mixed Flora	260 ^{ab} (16)	200 ^c (13)	120 ^c (9.0)	120 ^b (6.4)	180 ^b (9.6)	300 ^a (6.2)
Straw	280 ^a (6.6)	300 ^{ab} (19)	280 ^a (9.7)	220 ^a (12)	210 ^b (16)	290 ^a (15)
Manure	270 ^{ab} (11)	210 ^{bc} (37)	150 ^c (16)	210 ^a (9.0)	160 ^b (1.0)	290 ^a (9.9)
Orchard 2						
Cultivation	290 ^c (14)	270 ^{bc} (6.7)	240 ^c (7.8)	300 ^{bc} (8.0)	290 ^a (5.4)	430 ^{ab} (14)
Geotextile	330 ^{ab} (5.7)	340 ^a (5.9)	280 ^b (7.6)	330 ^{ab} (8.9)	310 ^a (5.3)	440 ^{ab} (19)
Grass	290 ^c (5.0)	270 ^{bc} (7.0)	130 ^a (0.30)	280 ^c (11)	210 ^b (35)	420 ^b (26)
Mixed Flora	310 ^{bc} (22)	250 ^c (11)	170 ^{ab} (16)	300 ^{bc} (3.7)	250 ^{ab} (15)	440 ^{ab} (17)
Straw	350 ^a (3.4)	340 ^a (25)	340 ^a (9.6)	360 ^a (7.2)	310 ^a (17)	520 ^a (26)
Manure	330 ^{ab} (5.6)	310 ^{abc} (12)	200 ^{cd} (13)	300 ^{bc} (6.1)	240 ^{ab} (6.2)	410 ^b (18)

Means within each month, do not, and orchard with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.
() standard error of means (n=4).

Connecting Paragraph

It was important to begin with the affects that mulches have on soil physical properties as the soil physical environment determines potential tree growth, and consequently nutrient demand. Thus the next step is to examine the effects of mulches on soil-extractable plant nutrient levels.

Chapter 5

Mulch management systems in organic dwarf apple orchards and their effects on soil extractable NO_3^- -N, NH_4^+ -N, P, K, Ca, and Mg.

Abstract

Mulches are an alternative to herbicidal control of weeds in orchards. Mulches may affect soil nutrient levels and consequently alter tree growth, fruit yield, and quality. The objective of this study was to determine the effects that cultivation, straw mulch, geotextile mulch, grass sod (*Festuca rubra*), a cover crop mixture of lupin (*Lupinus albus*) and wild carrot (*Daucus carota*), and composted manure mulch would have on extractable soil nutrients in two newly established dwarf apple (*Malus pumila* Mill.) orchards in Québec. In 1992, manure compost and straw mulches resulted in higher soil NO_3^- -N and K relative to those levels under living mulches. Levels of soil NO_3^- -N were logarithmically related to soil water content under any particular mulch. Straw mulch resulted in high July NO_3^- -N levels and low September levels of soil NO_3^- -N in comparison to geotextile and cultivation treatments which resulted in higher September NO_3^- -N levels relative to July. Soil under manure mulch tended to have higher P levels than soil under other treatments. There was little effect of mulch treatments on extractable levels of soil NH_4^+ -N, Ca, or Mg. Fertilization of trees resulted in different soil nutrient values depending on soil sample location.

Introduction

Weed control is important in newly established orchards since weed competition with young apple trees can reduce tree growth (Haynes and Goh, 1980) and delay fruit production. In the past, fruit producers have utilized herbicides in orchard weed management (Atkinson and White, 1976). Growers, however, to qualify for sale of "organic" fruit, must find methods of weed control that do not utilize chemicals, while still maintaining quantity and quality of fruit (Merwin, 1991). One weed management alternative to herbicides is the use of mulches.

Broadly defined, a mulch is any protective covering of the soil (Swenson, 1973). The effect of mulches on extractable soil nutrient levels will depend on the type of mulch (Shribbs and Skroch, 1986).

Many orchards use grass as a mulch. It is well established that trees and grass mulches compete for NO_3^- -N (Komosa, 1990; Haynes, 1980). The effect of grass mulch on P, K, Ca, and Mg is less obvious. Bould et.al. (1972) found that grass competed with apple trees for P and K. Johnson and Samuelson (1990) established that a living grass cover was competitive with apple trees for Ca uptake. Other studies have shown however that grass mulches increase available forms of P, K, and other cations by decreasing leaching losses (Haynes, 1983), and increased cycling of nutrients through leaf and stem returns following mowing (White, 1971; Stott, 1976).

Decomposable materials used as mulch include straw and composted manure. It is generally found that soil NO_3^- -N levels under straw cover are higher compared

to cultivation and living mulches (Shribbs and Skroch, 1986), sometimes as much as 200 percent greater (Shaw and Southwick, 1936). Mulching appears to increase soil P and exchangeable cations (Tukey and Schoff, 1963). Hulugalle, et.al. (1990) and Merwin, et.al. (1992) found elevated levels of exchangeable Ca, Mg, and K under mulched soil.

It would be expected that soil nutrient levels under organic mulches such as composted manure would be higher than soil under cultivation or grass management. This is primarily because organic materials contain nutrients and may add nutrients to the soil upon decomposition and mineralization.

Polyethylene geotextile plastic has become an orchard management option (Lytton, 1990). Most geotextiles are woven polypropylene fabrics that allow air and water to reach the soil. Nutrient levels in soil under this material may be higher than soil under straw and grass mulches due to elevated soil temperatures which would stimulate microbial activity and mineralization of nutrients from organic matter.

Cultivation of soil for weed control is well established in fruit production (Haynes and Goh, 1980; Lord and Vlach, 1973). Cultivation of soils generally results in more mineral N in the 0 to 0.10 m depth compared to soil under grass (Judkins and Rollins, 1943; Haynes and Goh, 1980). In contrast, cultivated soils are more likely to experience leaching of K, Ca, and Mg compared to soil under grass (Komosa, 1990; Haynes, 1981a).

Objectives were to evaluate in two newly established organic dwarf apple orchards the effects of six soil mulch management systems on extractable soil NO_3^- -N,

NH₄⁺-N, P, K, Ca, and Mg.

Materials and Methods

Experimental Design

All experiments were conducted in orchards at the Horticultural Research Center of Macdonald Campus of McGill University in Ste. Anne de Bellevue, Québec, Canada (45° latitude, 74° longitude). In May 1991, 300 scab (*Ventivea inaequalis*) resistant apple trees (*Malus pumila* Mill.) of the cultivars #637, Liberty, Olympic, Moira, Macfree, Richelieu, and Rouville on M26 rootstock were planted in nineteen rows, 4.5 meters apart, of sixteen trees each, 3.5 meters apart within the row, on a St. Bernard sandy loam soil (Orthic Melanic Brunisol) (Lajoie, 1960). This orchard is referred to as Orchard 1.

In October 1990, 300 trees of the scab resistant cultivars Liberty, Murray, Freedom, Britegold, and Novamac on M9 rootstock were planted in ten rows, 4.5 meters apart, of thirty trees each, 3 meters apart within the row, on a St. Bernard sandy clay loam soil (Orthic Melanic Brunisol) (Lajoie, 1960). This orchard is referred to as Orchard 2.

Management of both orchards was conducted within standards related to "organic" certification. Fertilizers and soil amendments included fish emulsion, feathermeal, compost, and bloodmeal. When required, insects were controlled with

rotenone, Safer's soap, pyrethrum, and/or *Bacillus thuringiensis* (Appendices 1 and 3).

In the spring of 1991, the following treatments were established in a randomized complete block design with four replications; 1) cultivation, 2) straw mulch, 3) geotextile fabric, 4) composted manure mulch, 5) cover crop mixture of lupin (*Lupinus albus*) and wild carrot (*Daucus carota*), and 6) grass mulch (*Festuca rubra*). The treatments were established as 1 meter wide strips extending along six trees to 1 meter beyond each of the end trees (Table 4.1).

Sampling Protocol and Chemical Analyses

Soil samples were taken in mid-July and late September of 1992 and 1993 using a hydraulic corer machine (Giddings, Fort Collins, CO). In July 1992, soils were sampled beneath two trees in each replicate at two locations (0.10 m and 0.50 m) from the tree trunks. Each sample was divided into two depths, the depth of the Ah horizon and below the Ah horizon to 0.30 m depth. The Ah horizon was defined as the topmost mineral horizon with accumulation of humified organic matter. The Ah horizons were somewhat variable in depth.

There was no difference between sample locations from tree to tree on nutrient levels, thus results from the two tree locations in July 1992 were combined. In September 1992 and 1993 and July 1993, soils were sampled beneath one tree, again at 0.10 m and 0.50 m from the tree trunk. Samples were divided into two depths as

in July 1992.

Extractable NO_3^- -N and NH_4^+ -N was determined by the method described by Keeney and Nelson (1982). Ten to 15 g of wet soil and 100 mL of 1.0 M KCl solution was shaken for 1 hour and the suspension was filtered through #5 Whatman filter paper. July 1992 and 1993 and September 1993 extracts were analyzed for NO_3^- -N and NH_4^+ -N on a Technicon Auto Analyzer (Technicon Instruments Corporation, Chauncey, NY) while September 1992 extracts were analyzed on a Lachat Instruments Quick Chem AE (Lachat Instruments, Milwaukee, WI).

Soil samples were oven dried at 70 °C for 24 hours then ground to pass a 2 mm sieve. Analysis for extractable P, K, Ca, and Mg used the method described by Mehlich (1984). Extracts in 1992 were analyzed for P by colorimetric analysis, and K by flame photometry using a Technicon Auto Analyzer (Technicon Instruments Corporation, Chauncey, NY) and in 1993 were analyzed on a Lachat Instruments Quick Chem AE (Lachat Instruments, Milwaukee, WI).

Mehlich extracts were diluted 100 fold using Mehlich III solution and 0.1 ml of 100 000 ppm $\text{LaCl}_2 \cdot 7\text{H}_2\text{O}$ was added to every 10 ml of diluted filtrate. Extracts were then analyzed for Ca and Mg using an Atomic Absorption Spectrometer, Perkin Elmer model 3100 (Perkin-Elmer Corporation, Norwalk, CT).

Values of NO_3^- -N, NH_4^+ -N, P, K, Ca, and Mg were converted to kg ha^{-1} using soil bulk density values.

For analyses of the nutrient contents of mulches and plant materials, tissue samples were oven dried at 105 °C for forty-eight hours then ground to pass a 0.5

mm sieve. Tissue was digested using concentrated H_2SO_4 and 30% H_2O_2 following the procedure of Thomas, et.al. (1967). Total N and P were determined using colorimetric analysis and K by flame photometry. Amounts of N, P, and K in samples were analyzed on a Lachat Instruments Quick Chem AE. Samples were analyzed for total Ca and Mg using an Atomic Absorption Spectrometer, Perkin Elmer model 3100.

Analyses of Results

Extraneous values were deleted from each data (Dixon, 1986). Statistical analyses were conducted on log transformed data.

Although these results were obtained from samples with a repeated measures experimental design, (i.e. repeated locations and repeated depths within each experimental unit), because there were only two levels of each repeated measure, the H-F (Huynh-Feldt, 1970) condition held automatically. Results were thus analyzed as univariate split-plots (Littell, 1989; Fernandez, 1991) with mulch treatment as the main plot and sampling location from tree the subplot using procedure GLM of the SAS statistical package (SAS, 1988). Significant treatment and location main effects were determined using Tukey's multiple comparison test (Tukey, 1953). Regressions were performed using procedure REG of the SAS statistical package (SAS, 1988).

Results

Direct Mulch Effects Via Nutrient Addition or Removal

In Orchard 1, in July 1992, manure, straw and geotextile mulches resulted in higher soil NO_3^- -N levels in the Ah horizon than those levels under the living mulches (Table 5.1). Soil NO_3^- -N levels under manure and geotextile mulches were also higher than those levels under cultivation treatment. Similar trends occurred in Orchard 2 in July 1992 as soil NO_3^- -N levels in the Ah horizon under the living mulches were lower than those levels under manure, straw and geotextile mulches (Table 5.2). Manure mulch also resulted in higher soil NO_3^- -N levels than those levels found in soils under cultivation management.

In Orchard 1 in September 1992, manure mulch resulted in higher soil NO_3^- -N levels in the Ah horizon than all other treatments except geotextile mulch. In Orchard 2 in September 1992 in the Ah horizon, manure, geotextile, cultivation, and straw treatments resulted in higher soil NO_3^- -N than those levels found under grass mulch. Soil NO_3^- -N levels under manure mulch were also higher than those levels under straw and mixed flora mulches.

In Orchard 1 in the soil depth below the Ah horizon, manure mulch resulted in higher soil NO_3^- -N than those levels under all other treatments in July 1992, and grass, mixed flora, and straw mulches in September 1992. In Orchard 2, at the lower soil depth, manure mulch resulted in soil NO_3^- -N levels higher than those levels

under all other treatments for both sampling dates.

The results for soil NO_3^- -N in 1993 differed from 1992 results. In Orchard 1 in July 1993 in the Ah horizon, geotextile, cultivation, and straw treatments resulted in higher soil NO_3^- -N levels than those levels under composted manure and the living mulches (Table 5.3). In Orchard 2 in July 1993 in the Ah horizon, NO_3^- -N levels under cultivation, straw, and geotextile treatments were higher than those levels under the living mulch treatments (Table 5.4). The cultivation treatment also resulted in higher soil NO_3^- -N levels than those levels under manure mulch.

In both orchards in September 1993, cultivation and geotextile treatments resulted in higher soil NO_3^- -N levels in the Ah horizon than those levels under all other treatments. Also, soil NO_3^- -N levels under straw mulch in both orchards were higher than those levels under the living mulches.

At soil depth below the Ah horizon in Orchard 1 in 1993, cultivation treatments resulted in higher soil NO_3^- -N levels than those levels under all other treatments except geotextile for both sampling dates. In Orchard 2 below the Ah horizon soil NO_3^- -N levels under cultivation treatments were higher than those levels from all other treatments except straw and geotextile for the July sampling and geotextile mulch for the September sampling.

In both orchards in 1992 and 1993, manure mulch resulted in higher soil P levels in the Ah horizon than those levels under all other treatments (Tables 5.5, 5.6) except in Orchard 1 in 1992 in which there were no treatment differences, and in Orchard 2 in 1993 in which mixed flora resulted in similar soil P levels.

Soil K levels were affected by mulch treatments. In Orchard 1 in 1992 in the Ah horizon, soil under manure and straw had K levels higher than those levels under all other treatments. Soil under grass mulch had the lowest K level. There were no differences in soil K levels among treatments in 1993.

In Orchard 2 in 1992 in the Ah horizon, soil K under manure mulch was higher than levels under all other treatments. Straw mulch resulted in soil K levels higher than those levels under grass, mixed flora, and geotextile treatments. In 1993 soil K levels under manure mulch were higher than those levels under all other treatments with the exception of straw. In 1993, soil K levels under straw were only higher than K levels under geotextile mulch.

There was little affect of mulch treatments on soil extractable $\text{NH}_4^+\text{-N}$, Ca, or Mg in the Ah horizon. The only differences obtained were for soil $\text{NH}_4^+\text{-N}$ levels in September 1993 in Orchard 2, in which $\text{NH}_4^+\text{-N}$ levels under straw and geotextile mulches were higher than those levels under manure and cultivation treatments. There was also a treatment difference detected for Mg in July 1993 in Orchard 2. Soil under manure mulch had Mg levels higher than soil under straw and geotextile mulches.

Indirect Mulch Effects Via Influences on Soil Water Content and Temperature

An initial multiple regression analysis (data not shown) revealed that soil temperature had no effect on soil $\text{NO}_3^-\text{-N}$ levels ($p=0.9323$) while soil moisture

content was found to be highly significant ($p=0.0154$).

Temperature data were dropped from the model and soil NO_3^- -N levels were regressed against the log of soil water contents for each mulch treatment. In both orchards, soil NO_3^- -N levels were found to be a function of the log of the soil water content at 0.10 level of probability (Figure 5.1). The relationship between soil NO_3^- -N and water content was stronger in Orchard 1 with an R^2 value of 0.84 ($p=0.0103$) compared to 0.58 in Orchard 2 ($p=0.0764$).

Sampling Location Effects on Nutrient Levels

Sampling location (0.10 m and 0.50 m from the tree trunk) had affects on nutrient levels in both orchards in 1992 (Table 5.7). In both orchards, soil NO_3^- -N was higher at the 0.10 location. In Orchard 2, soil P was also highest at the 0.10 location and in Orchard 1, soil K was higher at the 0.50 m location.

In 1993, both soil NO_3^- -N and K were higher at the 0.10 sampling location compared to the 0.50 m location in Orchard 1. In Orchard 2, soil levels of P, K, Ca, and Mg were higher at the 0.10 sampling location.

Discussion

The use of manure compost as a mulch increased soil NO_3^- -N levels in 1992. This result indicated manure compost was a direct source of N (Table 5.8). Results

obtained in 1992, however, were not duplicated in 1993. After the 1992 season, there was still a 5 to 7 cm. layer of manure compost remaining on the plots thus manure compost was not applied in 1993. In 1993, however, it was observed that roots of weeds growing within the compost penetrated the soil. Thus low soil NO_3^- -N in 1993 relative to 1992 might have resulted from nutrient extraction by weeds growing mostly within the compost. These results appear to indicate that for manure compost to maintain high soil NO_3^- -N levels, the mulch needs to be applied yearly.

Grass and mixed flora mulches relative to other mulch treatments reduced soil NO_3^- -N levels and were probably competitive with trees for soil NO_3^- -N (Johnson and Samuelson, 1990). Nitrogen reduction is detrimental when trees are young since rapid vegetative growth is required for tree establishment and vigour. Nutrient and moisture competition (Chapter 4) with living mulches could result in reduced tree size compared with trees under other mulch treatments (Salmins, 1993).

High levels of Ah horizon NO_3^- -N can lead to leaching into the Ah to 0.30 m soil horizon (Angle, et.al. 1993). Manure mulch in 1992 and cultivation treatment in 1993 resulted in the highest NO_3^- -N levels in both the Ah and Ah-0.30 m horizons, probably indicating some leaching. In contrast, living mulches resulted in the lowest levels of soil NO_3^- -N in the Ah-0.30 m horizon signifying that there was little NO_3^- -N in the Ah horizon available for leaching or that NO_3^- -N in the Ah-0.30 m horizon was taken up by the trees. Leaching is a concern since this leads to NO_3^- -N losses and inefficient fertilizer usage.

Mulch treatments were also expected to have indirect consequences on soil

NO_3^- -N by influencing soil biochemical processes via affects on soil temperature and water content. Results show that soil water content was the primary factor in controlling soil NO_3^- -N levels. Thus mulches such as straw and geotextile which maintained high soil water contents resulted in higher soil NO_3^- -N relative to mulches such as grass and mixed flora which reduced levels of available soil water.

This outcome demonstrates the importance of mulches that maintain soil water content at a high level since mulches which reduce soil water will also reduce soil NO_3^- -N levels. This indicates that soil water, microbial activity and NO_3^- -N movement are intimately related. If living mulches are used in orchards, growers could require supplementary irrigation and N fertilization. Mulches which maintain and prevent soil moisture loss such as straw or geotextile mulches would require less supplementary N and water.

In terms of orchard soil N management, straw mulch appears to be satisfying two important requirements. Firstly, straw mulch resulted in high soil NO_3^- -N levels during the growing season, similar to those levels under cultivation and geotextile treatments. Unlike cultivation and geotextile treatments, however, straw mulch also resulted in reduced NO_3^- -N levels in September sampled soils. This is important in terms of reducing leaching losses and lessening the risk that trees will not harden off. This observed outcome might be the result of rapid mineralization due to increased moisture content, then N immobilization as straw, with a high C/N ratio is decomposed later in the season.

Cultivation also appeared to be an adequate management choice in terms of

July soil NO_3^- -N levels. The relatively high levels of soil NO_3^- -N were probably related to high soil temperatures which would tend to increase the rate of soil N mineralization.

Increased levels of soil P under most mulch treatments in 1993 relative to 1992 probably resulted from the application of phosphate rock in the spring of 1993.

Higher levels of soil Mehlich III P under manure mulch and soil K under both manure and straw mulches indicated that P and K were relatively available from these materials and leached into the soil from these mulches. These materials must therefore be considered in any nutrient management system. Absorption of soil P and K by grass mulch and the probable resulting competition with orchard trees was similar to that found by Bould et.al. (1972). The minimal effect of mulch treatments on soil levels of Ca and Mg was probably related to the relatively high levels of these nutrients in these soils.

The higher soil nutrient levels generally found at the 0.10 m sampling location were probably related to spring fertilizer which was spread in circles around the trees within a radius of 0.075 m. This would have increased the level of available nutrients relative to the 0.50 m location. Growers who take soil samples for nutrient analysis must take this variability into account.

Table 5.1 Soil NO_3^- -N and NH_4^+ -N levels in Orchard 1, in the Ah horizon and below the Ah horizon to 0.3 m depth in July and September in 1992.

Treatment	NO_3^- -N				NH_4^+ -N			
	July		September		July		September	
	Ah	Ah-0.3	Ah	Ah-0.3	Ah	Ah-0.3	Ah	Ah-0.3
	kg ha ⁻¹							
Cultivation	16 ^{bc} (1.1)	5.3 ^{bc} (1.2)	28 ^b (1.2)	7.9 ^{ab} (1.1)	3.1 ^a (1.1)	0.95 ^a (1.2)	1.3 ^a (1.1)	0.68 ^a (1.2)
Grass	12 ^c (1.1)	3.4 ^c (1.1)	17 ^b (1.2)	3.1 ^b (1.3)	3.7 ^a (1.1)	0.97 ^a (1.2)	1.7 ^a (1.1)	0.87 ^a (1.4)
Mixed Flora	13 ^c (1.1)	3.9 ^c (1.1)	18 ^b (1.2)	4.5 ^b (1.3)	2.4 ^a (1.3)	0.87 ^a (1.2)	1.4 ^a (1.2)	0.51 ^a (1.2)
Manure	47 ^a (1.2)	24 ^a (1.4)	58 ^a (1.2)	20 ^a (1.3)	2.4 ^a (1.3)	1.2 ^a (1.4)	1.4 ^a (1.3)	0.68 ^a (1.1)
Straw	29 ^{ab} (1.3)	8.4 ^b (1.1)	21 ^b (1.2)	2.9 ^b (1.2)	2.3 ^a (1.2)	0.80 ^a (1.2)	1.4 ^a (1.1)	0.49 ^a (1.3)
Geotextile	34 ^a (1.2)	7.8 ^b (1.1)	57 ^a (1.1)	12 ^{ab} (1.1)	1.4 ^a (1.2)	0.55 ^a (1.3)	1.6 ^a (1.1)	0.40 ^a (1.3)

Values are antilogs of log transformed data.

Means within each nutrient, sampling date, and sampling depth with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.

() standard error of means (n=8).

Ah denotes soil layer to bottom of Ah horizon.

Ah-0.30 m denotes soil layer from bottom of Ah horizon to 0.30 m depth.

Table 5.2 Soil NO_3^- -N and NH_4^+ -N levels in Orchard 2, in the Ah horizon and below the Ah horizon to 0.3 m depth in July and September in 1992.

Treatment	NO_3^- -N				NH_4^+ -N			
	July		September		July		September	
	Ah	Ah-0.3	Ah	Ah-0.3	Ah	Ah-0.3	Ah	Ah-0.3
	kg ha ⁻¹							
Cultivation	23 ^{bc} (1.2)	7.5 ^b (1.2)	21 ^{ab} (1.1)	3.8 ^{bcd} (1.2)	3.1 ^a (1.2)	1.1 ^{ab} (1.1)	1.9 ^a (1.1)	0.67 ^a (1.1)
Grass	14 ^c (1.1)	2.5 ^c (1.2)	5.2 ^c (1.2)	1.8 ^d (1.2)	3.9 ^a (1.2)	0.58 ^c (1.2)	2.1 ^a (1.1)	0.71 ^a (1.3)
Mixed Flora	15 ^c (1.1)	1.7 ^c (1.2)	12 ^b (1.1)	1.9 ^{cd} (1.3)	3.8 ^a (1.1)	0.63 ^{bc} (1.2)	2.5 ^a (1.1)	0.67 ^a (1.1)
Manure	45 ^a (1.2)	36 ^a (1.2)	34 ^a (1.3)	14 ^a (1.6)	2.9 ^a (1.1)	1.3 ^a (1.2)	1.6 ^a (1.1)	0.68 ^a (1.1)
Straw	26 ^b (1.2)	7.5 ^b (1.2)	18 ^b (1.2)	4.2 ^{bcd} (1.2)	3.2 ^a (1.1)	0.98 ^{abc} (1.1)	1.7 ^a (1.1)	0.72 ^a (1.2)
Geotextile	28 ^{ab} (1.1)	7.7 ^b (1.1)	22 ^{ab} (1.2)	5.3 ^b (1.2)	2.9 ^a (1.1)	1.0 ^{abc} (1.1)	1.4 ^a (1.1)	0.79 ^a (1.2)

Values are antilogs of log transformed data.

Means within each nutrient, sampling date, and sampling depth with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.

() standard error of means (n=8).

Ah denotes soil layer to bottom of Ah horizon.

Ah-0.30 m denotes soil layer from bottom of Ah horizon to 0.30 m depth.

Table 5.3 Soil NO_3^- -N and NH_4^+ -N levels in Orchard 1, in the Ah horizon and below the Ah horizon to 0.3 m depth in July and September in 1993.

Treatment	NO_3^- -N				NH_4^+ -N			
	July		September		July		September	
	Ah	Ah-0.3	Ah	Ah-0.3	Ah	Ah-0.3	Ah	Ah-0.3
	kg ha ⁻¹							
Cultivation	38 ^a (1.2)	9.6 ^a (1.2)	46 ^a (1.1)	10 ^a (1.2)	5.7 ^a (1.1)	2.6 ^a (1.2)	3.1 ^a (1.2)	0.63 ^a (1.3)
Grass	4.7 ^b (1.5)	0.73 ^c (1.7)	4.0 ^{cd} (1.5)	1.0 ^{cd} (1.5)	4.5 ^a (1.1)	1.1 ^{bc} (1.4)	3.0 ^a (1.1)	0.54 ^a (1.2)
Mixed Flora	3.8 ^b (1.3)	3.1 ^b (1.2)	3.2 ^d (1.2)	0.82 ^d (1.6)	5.7 ^a (1.1)	1.6 ^b (1.2)	2.7 ^a (1.1)	0.49 ^a (1.3)
Manure	3.9 ^b (1.3)	1.0 ^c (1.2)	7.5 ^{bc} (1.3)	2.5 ^b (1.8)	4.1 ^a (1.1)	1.6 ^b (1.3)	2.6 ^a (1.2)	1.4 ^a (1.3)
Straw	29 ^a (1.3)	3.6 ^b (1.5)	11 ^b (1.3)	2.2 ^{bc} (1.4)	4.4 ^a (1.1)	1.1 ^{bc} (1.2)	2.8 ^a (1.1)	0.70 ^a (1.1)
Geotextile	35 ^a (1.2)	4.8 ^{ab} (1.2)	27 ^a (1.2)	9.5 ^a (1.2)	4.8 ^a (1.2)	0.78 ^c (1.1)	2.4 ^a (1.1)	0.46 ^a (1.2)

Values are antilogs of log transformed data.

Means within each nutrient, sampling date, and sampling depth with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.

() standard error of means (n=8).

Ah denotes soil layer to bottom of Ah horizon.

Ah-0.30 m denotes soil layer from bottom of Ah horizon to 0.30 m depth.

Table 5.4 Soil NO_3^- -N and NH_4^+ -N levels Orchard 2, in the Ah horizon and below the Ah horizon to 0.3 m depth in July and September in 1993.

Treatment	NO_3^- -N				NH_4^+ -N			
	July		September		July		September	
	Ah	Ah-0.3	Ah	Ah-0.3	Ah	Ah-0.3	Ah	Ah-0.3
	kg ha ⁻¹							
Cultivation	39 ^a (1.2)	7.6 ^a (1.2)	29 ^a (1.1)	20 ^a (1.3)	3.5 ^a (1.2)	1.7 ^a (1.2)	1.7 ^c (1.1)	0.68 ^a (1.3)
Grass	4.1 ^{cd} (1.2)	0.44 ^d (1.5)	0.90 ^c (1.4)	0.60 ^c (1.5)	4.1 ^a (1.1)	0.70 ^b (1.1)	4.8 ^{ab} (1.3)	0.69 ^a (1.2)
Mixed Flora	3.2 ^d (1.4)	0.76 ^{cd} (1.3)	1.6 ^c (1.2)	0.56 ^c (1.2)	3.8 ^a (1.1)	0.61 ^b (1.1)	2.8 ^{abc} (1.3)	0.57 ^a (1.1)
Manure	11 ^{bc} (1.2)	1.5 ^{bc} (1.2)	8.2 ^b (1.4)	1.5 ^{bc} (1.8)	3.5 ^a (1.1)	1.5 ^a (1.2)	2.0 ^{bc} (1.1)	1.0 ^a (1.3)
Straw	29 ^{ab} (1.3)	3.8 ^{ab} (1.3)	6.6 ^b (1.3)	2.1 ^{bc} (1.6)	3.3 ^a (1.1)	1.2 ^{ab} (1.2)	6.0 ^a (1.2)	0.75 ^a (1.1)
Geotextile	21 ^{ab} (1.1)	3.6 ^{ab} (1.3)	51 ^a (1.3)	5.6 ^{ab} (1.1)	3.1 ^a (1.1)	1.5 ^a (1.2)	5.1 ^a (1.4)	1.4 ^a (1.4)

Values are antilogs of log transformed data.

Means within each nutrient, sampling date, and sampling depth with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.

() standard error of means (n=8).

Ah denotes soil layer to bottom of Ah horizon.

Ah-0.30 m denotes soil layer from bottom of Ah horizon to 0.30 m depth.

Table 5.5 Soil P, K, Ca, and Mg levels in Orchard 1 in the Ah horizon in July in 1992 and 1993.

Treatment	1992				1993			
	P	K	Ca	Mg	P	K	Ca	Mg
	kg ha ⁻¹							
Cultivation	260 ^a (1.2)	400 ^b (1.2)	3700 ^a (1.1)	580 ^a (1.1)	250 ^{bc} (1.1)	430 ^a (1.1)	4600 ^a (1.2)	630 ^a (1.2)
Grass	210 ^a (1.2)	240 ^c (1.1)	4300 ^a (1.1)	590 ^a (1.1)	320 ^b (1.1)	540 ^a (1.1)	5300 ^a (1.1)	810 ^a (1.2)
Mixed Flora	210 ^a (1.1)	290 ^{bc} (1.1)	3600 ^a (1.1)	540 ^a (1.2)	260 ^{bc} (1.2)	390 ^a (1.2)	5000 ^a (1.1)	750 ^a (1.1)
Manure	400 ^a (1.2)	770 ^a (1.2)	3500 ^a (1.0)	610 ^a (1.1)	490 ^a (1.1)	580 ^a (1.2)	3800 ^a (1.2)	520 ^a (1.2)
Straw	260 ^a (1.2)	640 ^a (1.1)	3100 ^a (1.1)	490 ^a (1.1)	310 ^{bc} (1.1)	470 ^a (1.2)	4000 ^a (1.1)	510 ^a (1.3)
Geotextile	210 ^a (1.1)	280 ^{bc} (1.1)	3400 ^a (1.1)	440 ^a (1.2)	210 ^c (1.0)	300 ^a (1.3)	4200 ^a (1.2)	360 ^a (1.4)

Values are antilogs of log transformed data

Means within each sampling date and nutrient with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.

() standard error of means (n=8).

Ah denotes soil layer to bottom of Ah horizon.

Table 5.6 Soil P, K, Ca, and Mg levels in Orchard 2 in the Ah horizon in July in 1992 and 1993.

Treatment	1992				1993			
	P	K	Ca	Mg	P	K	Ca	Mg
	kg ha ⁻¹							
Cultivation	360 ^b (1.1)	490 ^{bc} (1.1)	4400 ^a (1.1)	690 ^a (1.1)	380 ^b (1.2)	350 ^{bc} (1.2)	7400 ^a (1.0)	1200 ^{ab} (1.1)
Grass	360 ^b (1.2)	390 ^c (1.2)	5200 ^a (1.1)	750 ^a (1.1)	540 ^b (1.2)	380 ^{bc} (1.2)	7300 ^a (1.1)	1100 ^{ab} (1.1)
Mixed Flora	420 ^b (1.2)	430 ^c (1.1)	5100 ^a (1.1)	750 ^a (1.1)	600 ^{ab} (1.3)	350 ^{bc} (1.2)	7400 ^a (1.0)	1100 ^{ab} (1.1)
Manure	750 ^a (1.2)	1000 ^a (1.2)	4800 ^a (1.1)	900 ^a (1.1)	1100 ^a (1.2)	720 ^a (1.2)	7600 ^a (1.1)	1400 ^a (1.1)
Straw	350 ^b (1.2)	600 ^b (1.2)	5000 ^a (1.1)	750 ^a (1.1)	550 ^b (1.3)	470 ^{ab} (1.2)	7500 ^a (1.1)	1000 ^{bc} (1.1)
Geotextile	380 ^b (1.2)	390 ^c (1.2)	4900 ^a (1.1)	700 ^a (1.1)	440 ^b (1.3)	290 ^c (1.3)	5900 ^a (1.1)	820 ^c (1.1)

Values are antilogs of log transformed data.

Means within each sampling date and nutrient with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.

() standard error of means (n=8).

Ah denotes soil layer to bottom of Ah horizon.

Table 5.7 The effect of sample location from the tree on soil nutrients in Orchards 1 and 2 in the Ah horizon in July in 1992 and 1993.

Nutrient	1992			1993		
	Sampling Location		S	Sampling Location		S
	0.10	0.50		0.10	0.50	
Orchard 1	kg ha ⁻¹					
NO ₃ ⁻ -N	25 (1.2)	19 (1.1)	*	17 (1.2)	8.2 (1.3)	*
NH ₄ ⁺ -N	2.6 (1.1)	2.3 (1.1)	ns	4.4 (1.1)	5.2 (1.1)	ns
P	250 (1.1)	230 (1.1)	ns	290 (1.1)	300 (1.1)	ns
K	360 (1.1)	430 (1.1)	*	490 (1.1)	400 (1.1)	*
Ca	3700 (1.1)	3500 (1.1)	ns	4500 (1.1)	4500 (1.1)	ns
Mg	540 (1.1)	530 (1.1)	ns	630 (1.1)	530 (1.1)	ns
Orchard 2						
NO ₃ ⁻ -N	29 (1.1)	18 (1.1)	*	14 (1.2)	11 (1.3)	ns
NH ₄ ⁺ -N	3.3 (1.1)	3.2 (1.1)	ns	3.9 (1.1)	3.3 (1.0)	ns
P	470 (1.1)	380 (1.1)	*	660 (1.1)	490 (1.2)	*
K	500 (1.1)	540 (1.1)	ns	460 (1.1)	360 (1.1)	*
Ca	5100 (1.0)	4700 (1.1)	ns	7500 (1.0)	6800 (1.0)	*
Mg	780 (1.0)	730 (1.0)	ns	1200 (1.1)	1000 (1.0)	*

Values are antilogs of transformed data.

*, ns denotes significant and non-significant differences respectively at 0.05 level of probability between the two locations for each nutrient.

() standard error of means (n=24).

S denotes significance.

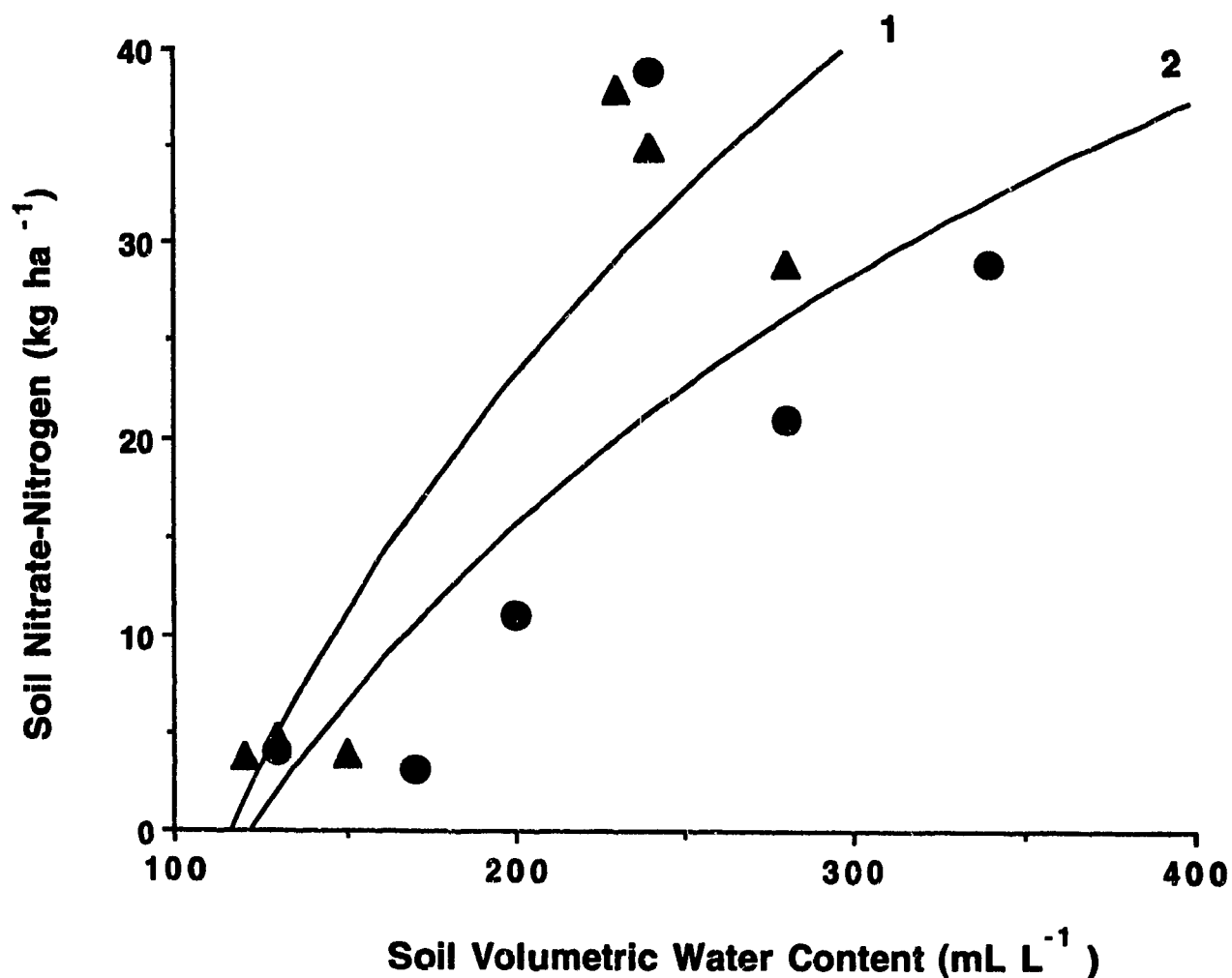
Ah denotes soil layer to bottom of Ah horizon.

Table 5.8 Nutrient contents of mulches and plant materials.

Mulch	N	P	K	Ca	Mg
	mg g ⁻¹				
Manure	12 (1.8)	4.9 (0.48)	5.9 (0.30)	35 (7.0)	12 (2.0)
Straw	11 (3.2)	1.0 (0.24)	15 (4.1)	3.1 (0.33)	1.2 (0.16)
Grass	17 (0.84)	3.2 (0.25)	26 (1.8)	6.1 (0.15)	1.8 (0.06)
Mixed Flora	14 (7.0)	1.6 (0.43)	24 (2.9)	8.8 (1.1)	2.5 (0.12)

() standard error of means (n=4).

Figure 5.1 Relationship between soil NO_3^- -N and soil volumetric water content in Orchards 1 and 2 in July 1993.



Regression Equations.

1 (Orchard 1) NO_3^- -N = -202.1 + 97.87 Log (Water) $R^2 = 0.84$

2 (Orchard 2) NO_3^- -N = -151.9 + 72.73 Log (Water) $R^2 = 0.58$

Parameter Estimate	S.E.	F-Value	Prob>F
x1 = 97.87	21.45	4.562	0.0103
x2 = 72.73	30.62	2.375	0.0764

Connecting Paragraph

The two previous chapters revealed that mulches affect soil physical properties and extractable soil nutrient levels. The next step is to examine how these affects influence the nutrient concentration of leaves and fruit.

Chapter 6

Mulch management systems in organic dwarf apple orchards and their effects on leaf and fruit nutrient contents.

Abstract

Weed control is vital in dwarf apple orchards, but an alternative to herbicides may be desirable for environmental and human health reasons. Mulches are considered to be an option for weed control. This study assessed the impact of cultivation, geotextile mulch, straw mulch, composted manure mulch, grass (*Festuca rubra*), and a cover crop mixture of lupin (*Lupinus albus*) and wild carrot (*Daucus carota*) on leaf and fruit nutrient levels in two newly established and one existing dwarf apple (*Malus pumila* Mill.) orchard in Québec. Leaf N and K contents were in some cases correlated with soil NO_3^- -N and K levels. Mulches had significant effects on leaf nutrient concentrations by indirectly affecting soil nutrient levels. Leaves from trees under straw mulch had high levels of K and low levels of Mg. Grass mulch resulted in low levels of leaf N, and K and high levels of leaf Mg. In 1993, grass mulch increased leaf P levels relative to leaves from geotextile plots. There were no mulch effects on fruit N/Ca or K/Ca ratios. Fruit Ca levels were sufficiently high to prevent bitter pit in all treatments. Soil nutrient levels are affected by mulches thus measures must be taken to ensure that trees do not suffer from nutrient imbalances.

Introduction

Because of their shallow rooting systems, dwarf apple trees can suffer from weed competition for water and nutrients. This can be a serious problem in young dwarf orchards resulting in tree growth reduction (Haynes and Goh, 1980) and decreased fruit yields (Goode, et.al. 1978).

While herbicides are frequently used to control unwanted vegetation (Johnson and Samuelson, 1990; Atkinson and White, 1976), mulching is an alternative for environmental reasons (MacRae, et.al. 1990) and as a system of sustainable soil management (Eisenberg, 1989).

A mulch can be defined as any protective covering of soil (Swenson, 1973), that prevents water loss and discourages growth of weeds (Alth, 1978). The action of distributing materials over the soil surface is perhaps as old as agriculture itself and since at least 1802 has been referred to as "mulching" (Jacks, et.al. 1955).

The effects of mulching on soil nutrient levels, tree uptake, and nutrient cycling are both direct and indirect. Mulches such as manure compost or straw may be nutrient sources. Plant uptake of NO_3^- -N (Hudska, 1990), Ca and Mg (Claassen and Wilcox, 1974) have been found to be correlated with the available amount of nutrients in soil.

Augmented amounts of nutrients in the soil may result in interactive effects with other nutrients. Soil K, Ca, and Mg may be absorbed in proportion to their content in the soil (Al-Kanani, et.al. 1989; York, et.al. 1953). Magnesium deficiencies

have been recorded in plants growing in soils high in K (Claassen and Wilcox, 1974; Adams and Henderson, 1962). Other examples include increased uptake K, Ca, and Mg in plants nourished with high levels of NO_3^- -N (Marti and Mills, 1991; Haynes, 1980). Elevated levels of soil N have been found to be negatively correlated with leaf P (Johnson and Samuelson, 1990; Shribbs and Skroch, 1986a). Phosphorus availability has also been found to be lower in soils saturated in Ca (Westermann, 1992).

Living mulches (ground covers comprised of viable vegetation) such as grass sod or mixed flora have the capacity to influence tree nutrient uptake through competition for nutrients and water. Grass sod has been found to reduce leaf N (Johnson and Samuelson, 1990; Shribbs and Skroch, 1986a; Estabrooks and Ghanem, 1990) and Ca (Tan and Crabtree, 1990) content in apple trees.

Calcium is the most crucial element in terms of fruit quality (Sharples, 1973). Many studies have shown that high levels of soil NO_3^- -N (Terblanche, et.al. 1980) or K (Faust and Shear, 1968) have negative effects of fruit quality by increasing N/Ca or K/Ca ratios in fruit leading to increased incidence in bitter pit (Shear, 1974). Since mulches are known to change levels of extractable soil nutrients (Chapter 5), it was suspected that fruit quality would also be a function of mulch choice.

Mulches can have indirect effects on tree nutrient uptake by influencing soil temperature and moisture. Burns and Barber (1961) found greater release of nonexchangeable K at higher temperatures. Potassium influx into roots was greater at 29°C than at 15°C (Ching and Barber, 1979). Li, et.al. (1990) suggested that P availability was most often temperature dependent. Near linear relationships have

been found between N mineralization rates and soil water contents (Stanford and Epstein, 1974). High water contents were found to increase soil levels of K, Ca, and Mg (Wade, et.al. 1992; Mederski and Wilson, 1960). Phosphorus diffusion rates increased as soil moisture increased (Hira and Singh, 1977; Olsen, et.al. 1962).

Concentrating fertilizer close to trees will generally result in higher levels of a particular nutrient in soil 0.10 m from the tree than at a 0.50 m sampling location. The question is does this higher soil nutrient level 0.10 m from the tree have any affect on tree nutrition? Analysis of the nutrient content of leaves in mid-summer can provide a measure of tree nutritional status by detecting possible nutrient deficiencies.

Objectives were to evaluate the effects of soil cultivation and mulch management systems on leaf and fruit nutrient contents and to determine the correlation between soil and leaf nutrient levels in organically managed dwarf apple orchards.

Materials and Methods

Experimental Design

All experiments were conducted in orchards at the Horticultural Research Center of the Macdonald Campus of McGill University in Ste. Anne de Bellevue, Quebec, Canada (45° latitude, 74° longitude). Experimental design was as described

in Chapter 4 with the addition of a more mature orchard (4 years old) for fruit quality data since trees in orchards 1 and 2 were not of fruit-bearing age.

In May 1991, four rows, 3.5 meters apart, of 19 trees each, 2 meters apart within the row, of the cultivar 'Spartan' on M9 rootstock were chosen within an orchard established in 1987 on a St. Bernard clay loam soil (Orthic Melanic Brunisol). (Lajoie, 1960). This orchard is referred to as Orchard 3. The following treatments were established in a randomized complete block design with two replications; 1) geotextile mulch, 2) living grass mulch (*Festuca rubra*), 3) composted manure mulch, and 4) straw mulch. Treatments were established as one meter wide strips extending along seven trees to one meter beyond the end trees (Table 4.1). Details on fertilizer and pest control methods can be found in Appendices 2 and 4.

Sampling Protocol and Chemical Analyses

Leaf samples from orchards 1 and 2 were taken from trees in each plot in July 1992 and 1993. Fruit samples from Orchard 3 were taken at harvesting in late September 1992 and 1993. Tissue samples were oven dried at 105 °C for forty-eight hours and then ground to pass a 0.5 mm sieve. Tissue was digested using concentrated H₂SO₄ and 30% H₂O₂ following the procedure of Thomas, et.al. (1967). Total N and P were determined using colorimetric analysis and K by flame photometry. Amounts of N, P, and K in samples were analyzed on a Lachat Instruments Quick Chem AE (Lachat Instruments, Milwaukee, WI). Samples were

analyzed for total Ca and Mg using an Atomic Absorption Spectrometer, Perkin Elmer model 3100 (Perkin-Elmer Corporation, Norwalk, CT).

Analyses of Results

Results were analyzed using the GLM procedure of SAS (SAS, 1988). Linear regression analyses were used to evaluate the relationship between soil nutrient levels and leaf nutrient contents. Leaf and apple nutrient content results were analyzed using a randomized complete block model. Significant treatment differences were determined using Tukey's multiple comparison test (Tukey, 1953).

Results

Relationships Among Soil and Leaf Nutrient Levels

In 1992 in Orchard 1, there was a correlation between soil NO_3^- -N and K levels and leaf total N and K contents at both sampling locations (0.10 m and 0.50 m from the tree trunk) (Table 6.1). For leaf N, the R^2 value was higher for the 0.50 m sampling location while for K, it was significantly higher for the 0.10 m location. Leaf N and K were also correlated with soil NO_3^- -N and K levels in Orchard 2. In this orchard the relationship only existed for the 0.10 m sampling location.

In 1993 in Orchard 1, leaf N, K, and Ca levels were found to be significantly

related to soil levels of NO_3^- -N, K, and Ca at the 0.50 m sampling location. No relationships were found between soil and leaf N, K, and Ca levels in Orchard 2.

Mulch Effects on Leaf Nutrient Levels

In 1992 in Orchard 1, leaves from trees under geotextile mulch had N contents higher than those from grass mulch (Table 6.2) while in Orchard 2, leaf N contents from trees under geotextile, manure, and straw mulches were higher than leaf N levels from living mulch treatments (Table 6.3). Cultivation treatments also resulted in leaf N contents higher than those from mixed flora mulch.

In 1993, no leaf N differences among treatments were detected in Orchard 1. In Orchard 2 in 1993, cultivation, geotextile, manure, and straw mulches resulted in leaf N contents higher than those levels from grass mulch.

In Orchard 1, no treatment differences were detected in relation to leaf P contents in either 1992 or 1993. In Orchard 2 in 1992, manure, straw, and geotextile mulches resulted in higher leaf P contents than those from the living mulches. Manure mulch also resulted in a higher leaf P content than those from cultivation treatments. In Orchard 2 in 1993 the results reverse somewhat as grass mulch resulted in a higher leaf P content than those levels from geotextile mulch.

In 1992 in both orchards, K content was higher in leaves from trees under manure and straw mulch compared with those from the living mulches. Geotextile and cultivation treatments resulted in leaf K contents similar to those contents found

for manure and straw mulch in Orchard 1, and manure mulch in Orchard 2.

In 1993 in Orchard 1, manure, straw and geotextile mulches resulted in similar leaf K contents. Leaves from manure mulch had higher K content than those from cultivation and living mulch treatments. In Orchard 2 in 1993, treatments had relatively similar impacts on leaf K contents except grass mulch resulted in higher leaf K levels than those from geotextile mulch.

In Orchard 1 in 1992, living mulches, manure and cultivation treatments had similar leaf Mg contents. Leaves from trees under grass mulch had higher leaf Mg levels than those from straw and geotextile mulches. In 1992 in Orchard 2, living mulches resulted in higher leaf Mg contents than those from only straw mulch.

In 1993 in both orchards, mixed flora, cultivation, and manure treatments resulted in higher leaf Mg levels than those from straw mulch. Mixed flora mulch in Orchard 1 and geotextile mulch in Orchard 2 also resulted in higher leaf Mg contents than those from straw mulch. There were no leaf Ca content differences among treatments in either orchard for both 1992 and 1993.

Mulch Affects on Fruit Nutrient Levels

In 1992 in Orchard 3, fruit from trees under geotextile treatments had N levels higher than those from straw mulch (Table 6.4). No other significant fruit nutrient differences among mulch treatments were detected in either 1992 or 1993. The highest K/Ca ratios obtained in fruit were 13 in 1992 and 7.1 in 1993.

Discussion

For the most part, only leaf N and K contents correlated with soil NO_3^- -N and K levels. There were no clear trends as leaf N and K were related in some cases to soil levels at the 0.10 m sampling location, in some instances to the 0.50 m location and in some cases to both sampling locations.

Thus it appears that leaf nutrient contents (i.e. nutritional status of the tree) were not highly correlated, as a result of fertilization, with soil nutrient levels close to the tree. While the pool of available soil nutrients can be important, other factors such as nutrient competition, soil temperature, water content, and root distribution have a significant role in nutrient movement and absorption by the tree. Thus analysis of soil may not provide an accurate depiction of tree productivity potential.

Living mulches of grass and mixed flora reduced soil levels of NO_3^- -N and K (Chapter 5). The consequence of this reduction was diminished levels of leaf N and K which could decrease tree growth and vigour leading to reduced fruit production (Salmins, 1993).

Of interest was the positive affect grass mulch had on leaf P levels in both young orchards in the 1993 season. High leaf P content from trees under grass mulch might be a consequence of reduced leaf and shoot growth (Salmins, 1993). Another explanation could be that root and microbial respiration increased CO_2 levels in soils under grass mulch (Barber and Martin, 1976) relative to geotextile mulch which could increase P mobilization by weathering calcium phosphate

minerals (Jurinak, et.al. 1986). Furthermore, VAM fungi have been associated with increased mobilization of mineral P (Knight, et.al. 1989) and Atkinson and White (1980) have suggested that grassed plots may increase the infection of apple roots with endogenous mycorrhizae.

Uptake of nutrients can be influenced by certain soil nutrient interactions. Nutrient competition among cations is well documented for K, Ca, and Mg (Claassen and Wilcox, 1974). This competition was observed as high K levels in soil under straw mulch translated into high leaf K contents at the expense of leaf Mg in comparison to grass mulch which resulted in low K and high Mg contents in leaves. It was expected that manure mulch would also result in lower leaf Mg levels because of the high levels of soil K under this mulch. This however did not happen perhaps since manure compost could be a source of Mg (Table 5.8) which would prevent a wide K/Mg ratio in soil. Competition between Ca and K (Al-Kanani, et.al. 1989) was not duplicated in this study.

In terms of practical consequences, growers should be aware of the importance of soil nutrient interactions. Continual additions of soil K via mulching materials like straw could lead to Mg and Ca deficiencies in trees having dramatic influences on tree nutrition and also on the quality of fruit (Wiersum, 1979).

In Orchard 3, although mulching materials did have effects on soil levels of NO_3^- -N and K, this did not translate into any significant differences in terms of N/Ca or K/Ca ratios in fruit. Also, for apples to have bitter pit risk, K/Ca ratios in fruit must exceed 19 and problems do not occur for most cultivars until the ratio exceeds

48 (Waller, 1980). The highest ratio obtained in this study was 13 so bitter pit should not have been a concern with these fruit.

Table 6.1 Significant relationships between leaf nutrient contents and soil nutrient levels in Orchards 1 and 2 at 0.10 and 0.50 m sampling locations from the tree in July 1992 and 1993.

Leaf Nutrient	Orchard	Year	Soil Sample Location	Regression Equation	S.E. of Estimate [*]	R ²
Nitrogen	1	1992	0.10 m	N=23+0.084(a)	0.023	0.77
	1	1992	0.50 m	N=23+0.13(a)	0.032	0.79
	1	1993	0.50 m	N=25+0.096(a)	0.030	0.72
	2	1992	0.10 m	N=19+0.090(a)	0.039	0.59
Potassium	1	1992	0.10 m	K=11+0.014(b)	0.0029	0.86
	1	1992	0.50 m	K=13+0.0065(b)	0.0026	0.60
	1	1993	0.50 m	K=10+0.014(b)	0.0051	0.65
	2	1992	0.10 m	K=7.4+0.014(b)	0.0064	0.55
Calcium	1	1993	0.50 m	Ca=7.4+0.00086(c)	0.00037	0.55

a, b, and c denotes soil NO₃⁻-N, K, and Ca respectively.

** estimate significant at 0.10 level of probability.*

Leaf and soil nutrient data are in units of mg g⁻¹ and kg ha⁻¹ respectively.

Table 6.2 Nitrogen, P, K, Ca, and Mg content of leaves in Orchard 1 in July in 1992 and 1993.

Treatment	N		P		K		Ca		Mg	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
	mg g ⁻¹									
Manure	27 ^{ab} (0.56)	26 ^a (1.8)	1.6 ^a (0.16)	2.3 ^a (0.33)	19 ^a (0.65)	20 ^a (0.38)	9.9 ^a (0.43)	11 ^a (0.34)	3.3 ^{ab} (0.22)	3.1 ^{ab} (0.08)
Straw	26 ^{ab} (1.4)	26 ^a (0.89)	1.4 ^a (0.04)	2.2 ^a (0.17)	19 ^a (0.59)	18 ^{ab} (1.6)	10 ^a (1.0)	11 ^a (0.67)	2.7 ^b (0.04)	2.6 ^c (0.09)
Grass	23 ^b (1.1)	25 ^a (1.1)	1.4 ^a (0.09)	3.6 ^a (0.52)	13 ^c (0.86)	15 ^{bc} (0.45)	9.4 ^a (0.61)	12 ^a (0.26)	3.9 ^a (0.41)	3.1 ^{bc} (0.22)
Mixed Flora	24 ^{ab} (0.53)	25 ^a (1.1)	1.3 ^a (0.14)	2.3 ^a (0.40)	14 ^{bc} (1.1)	14 ^c (0.63)	9.9 ^a (0.43)	12 ^a (0.73)	3.2 ^{ab} (0.09)	3.4 ^a (0.12)
Geotextile	27 ^a (0.72)	30 ^a (1.3)	1.5 ^a (0.07)	2.1 ^a (0.40)	17 ^{ab} (0.95)	16 ^{abc} (1.1)	8.2 ^a (0.27)	10 ^a (0.74)	2.7 ^b (0.15)	2.9 ^{bc} (0.06)
Cultivation	25 ^{ab} (0.62)	27 ^a (0.95)	1.5 ^a (0.05)	2.5 ^a (0.60)	16 ^{abc} (0.82)	14 ^{bc} (0.60)	8.3 ^a (0.37)	11 ^a (0.75)	3.0 ^{ab} (0.19)	3.2 ^{ab} (0.12)

Values are antilogs of log transformed data.

Means within each nutrient and year with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.

() standard error of means (n=4).

Table 6.3 Nitrogen, P, K, Ca, and Mg content of leaves in Orchard 2 in July in 1992 and 1993.

Treatment	N		P		K		Ca		Mg	
	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
	mg g ⁻¹									
Manure	23 ^a (1.2)	25 ^{ab} (1.3)	1.9 ^a (0.01)	2.4 ^{ab} (0.43)	18 ^{ab} (1.2)	17 ^{ab} (0.67)	9.9 ^a (0.90)	11 ^a (0.95)	3.1 ^{ab} (0.36)	3.2 ^a (0.31)
Straw	23 ^a (1.5)	24 ^{ab} (0.89)	1.8 ^{ab} (0.08)	2.6 ^{ab} (0.65)	21 ^a (1.2)	17 ^{ab} (1.0)	9.3 ^a (1.2)	9.7 ^a (0.85)	2.2 ^b (0.22)	2.4 ^c (0.17)
Grass	19 ^{bc} (1.7)	20 ^c (1.5)	1.5 ^c (0.05)	3.8 ^a (0.33)	12 ^c (2.1)	19 ^a (0.93)	11 ^a (0.30)	12 ^a (0.33)	3.2 ^a (0.17)	2.5 ^{bc} (0.14)
Mixed Flora	19 ^c (1.9)	22 ^{bc} (1.5)	1.4 ^c (0.09)	3.3 ^{ab} (0.37)	11 ^c (1.4)	17 ^{ab} (1.2)	10 ^a (0.41)	12 ^a (0.70)	3.6 ^a (0.11)	2.9 ^{abc} (0.22)
Geotextile	24 ^a (1.8)	25 ^{ab} (1.3)	1.8 ^{ab} (0.07)	1.6 ^b (0.26)	14 ^{bc} (2.1)	14 ^b (1.1)	9.9 ^a (0.92)	11 ^a (1.1)	3.0 ^{ab} (0.34)	3.0 ^{ab} (0.25)
Cultivation	22 ^{ab} (1.1)	25 ^a (1.2)	1.6 ^{bc} (0.13)	2.1 ^{ab} (0.20)	13 ^{bc} (1.1)	16 ^{ab} (0.60)	11 ^a (0.57)	11 ^a (0.55)	3.1 ^{ab} (0.21)	3.0 ^{ab} (0.10)

Values are antilogs of log transformed data.

Means within each nutrient and year with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.

() standard error of means (n=4).

Table 6.4 Nitrogen, P, K, Ca, and Mg content in fruit plus N/Ca and K/Ca ratios in Orchard 3 in July in 1992 and 1993.

Treatment	N	P	K	Ca	Mg	N/Ca	K/Ca
	mg g ⁻¹						
1992							
Grass	2.0 ^{ab} (0.88)	3.0 ^a (0.03)	9.7 ^a (0.72)	1.0 ^a (0.04)	0.35 ^a (0.02)	2.0 ^a (0.97)	9.8 ^a (0.33)
Geotextile	4.5 ^a (0.48)	3.0 ^a (0.31)	9.7 ^a (0.02)	1.1 ^a (0.02)	0.26 ^a (0.01)	4.2 ^a (0.37)	9.1 ^a (0.18)
Manure	2.3 ^{ab} (1.1)	3.1 ^a (0.005)	9.9 ^a (1.5)	0.87 ^a (0.26)	0.40 ^a (0.07)	3.4 ^a (2.2)	13 ^a (5.7)
Straw	1.3 ^b (0.02)	3.0 ^a (0.04)	12 ^a (0.55)	0.93 ^a (0.04)	0.32 ^a (0.02)	1.4 ^a (0.04)	13 ^a (1.2)
1993							
Grass	2.3 ^a (0.22)	0.77 ^a (0.10)	7.6 ^a (0.49)	1.2 ^a (0.32)	0.70 ^a (0.16)	1.9 ^a (0.32)	6.7 ^a (2.1)
Geotextile	2.4 ^a (0.23)	0.22 ^a (0.04)	7.2 ^a (0.76)	1.0 ^a (0.03)	0.64 ^a (0.05)	2.4 ^a (0.31)	7.1 ^a (0.51)
Manure	2.0 ^a (0.26)	0.38 ^a (0.36)	8.3 ^a (0.69)	1.2 ^a (0.17)	0.54 ^a (0.05)	1.7 ^a (0.03)	7.0 ^a (1.6)
Straw	1.8 ^a (0.13)	0.34 ^a (0.05)	6.4 ^a (0.13)	1.2 ^a (0.08)	0.53 ^a (0.005)	1.5 ^a (0.02)	5.4 ^a (0.46)

Means within each nutrient and season with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.
() standard error of means (n=2).

Required nutrient concentrations in fruit for long term storage: N: 0.5 - 0.7, P: > 0.11, K: 1.0 - 1.7, Ca: 0.04 - 0.05, Mg: > 0.05 mg g⁻¹, depending on cultivar (Waller, 1980).

Chapter 7

General Conclusions

When selecting a mulch for orchard weed management, mulch effects on soil/tree relationships must be considered. Since each mulch material has both positive and negative attributes, mulch assessments must be based on those attributes of most importance under various management systems.

Cultivation

In agricultural systems, cultivation of soil is a standard management practice for weed control. In these orchards, rapid growth and incorporation of weed vegetation into the soil, resulted in higher soil nutrient levels than those found under the living mulches. High soil temperatures could have also contributed to higher chemical activity or organic soil nutrient mineralization. On the negative side, cultivation resulted in greater loss of moisture than soil under straw and geotextile mulches.

Geotextile Mulch

Geotextile was beneficial in promoting high July levels of soil NO_3^- -N required

by young trees for rapid vegetative growth. However, soil NO_3^- -N levels were, in most cases, maintained into late September which could be detrimental due to increased risk of winter damage to less hardy shoot growth. Geotextile relative to other mulches had little effect on other soil nutrients except for reduced soil P, K, or Mg levels in some cases. Geotextile maintained soil water contents and increased soil temperatures both of which have positive influences on tree growth.

A disadvantage with geotextile mulch was limited organic matter addition to soil. This limited return in combination with high soil temperatures which would increase organic matter mineralization, could reduce soil organic matter levels. Low soil aggregate stability values found in orchard 2 were most likely related to high soil water contents and lack of root growth under geotextile mulch.

Grass Mulch

As expected, grass mulch reduced soil moisture and nutrient levels of particularly NO_3^- -N, and K relative to those levels under other treatments. This competition makes grass sod a poor choice in terms of promoting tree growth. Utilizing grass mulch when trees are young may require supplemental fertilization and water.

A grass mulch does, however, have a place in orchard management. Grass sod should certainly be utilized in the alleys between tree rows because of the positive effects grass mulch has on soil aggregate stability.

Composted Manure Mulch

Compost mulches are utilized as soil amendments because of their nutrient and organic matter value. In 1992, compost mulch increased soil nutrients levels, maintained soil moisture levels, and moderated soil temperature fluctuations relative to the living mulches and cultivation treatments. The one drawback was that it appeared that compost needed to be applied yearly to be effective as supported by the fact that the noted benefits of compost on the soil environment observed in 1992 were not repeated in 1993.

Mixed Flora Cover Crop

Utilizing mixed flora cover crops as mulches had similar detrimental results as grass sod in terms of nutrient and moisture competition. In some plots, lupin grew higher than the trees, thus the observed stunted growth of trees was not surprising. This mulch had positive influences on aggregate stability most likely a result of root growth and the action of microbes supported by the rhizosphere.

Straw Mulch

Straw mulch resulted in higher soil moisture levels relative to those levels under the living mulches and cultivation treatments. Straw mulch also resulted in

medium to high levels of soil nutrients particularly NO_3^- -N and K. Of interest was a trend observed for September soil NO_3^- -N levels to significantly decrease from July levels relative to other mulch treatments which would be beneficial in terms of reducing the risk of winter damage from trees not hardening off. Another benefit of straw was its ability to buffer soil temperature.

On the negative side, continued use of straw mulch increased soil K to levels where Mg uptake was reduced. This potential imbalance could be monitored with tissue analysis. Other than this potential problem, straw mulch had little negative impact on soil properties.

Chapter 8

Literature Cited

- Adams, J.E., G.F. Arkin, and J.T. Ritchie. 1976. Influences of row spacing and straw mulch on first stage drying. *Soil Sci. Soc. Am. J.* 40: 436-442.
- Adams, F., and J.B. Henderson. 1962. Magnesium availability as affected by deficient and adequate levels of potassium and lime. *Soil Sci. Soc. Am. Proc.* 26: 65-68.
- Al-Kanani, T., A.J. Hussien, and N.N. Barthakur. 1989. Potassium exchange equilibria in calcareous soils. *Soil Sci.* 128: 286-292.
- Alth, M. 1978. *How to farm your backyard the mulch-organic way.* McGraw-Hill Book Co. New York, N.Y.
- Anderson, D.T., and G.C. Russell. 1964. Effects of various quantities of straw mulch on the growth and yield of spring and winter wheat. *Can. J. Soil Sci.* 44: 109-118.
- Angers, D.A., and G.R. Mehuys. 1993. Aggregate stability to water. *In: Soil sampling and methods of analysis.* M.R. Carter (Ed.) Lewis Publishers. p. 651-657.

Angle, J.S., C.M. Gross, R.L. Hill, and M.S. McIntosh. 1993. Soil nitrate concentrations under corn as affected by tillage, manure, and fertilizer applications. *J. Environ. Qual.* 22: 141-147.

Appleton, B.E., J.F. Derr, and B.B. Ross. 1990. The effect of various landscape weed control measures on soil moisture and temperature and tree root growth. *J. Arboric.* 16: 264-268.

Ashley, D.L., and J.A. Stewart. 1969. Magnesium deficiency in tree fruits as related to leaf concentrations of Mg, K, and Ca. *J. Am. Soc. Hort. Soc.* 94: 310-313.

Atkinson, D., and G.C. White. 1980. Some effects of orchard soil management on the mineral nutrition of apple trees. *In: Mineral nutrition of fruit trees.* D. Atkinson, J.E. Jackson, R.O. Sharples, and W.M. Waller (Eds.) Butterworths, Sevenoaks, UK. p. 221-254.

Atkinson, D., and G.C. White. 1977. Overall herbicide soil management in top fruit-growers experience. Report of East Malling Research Station. p. 187-188.

Atkinson, D., and G.C. White. 1976. Soil management with herbicides. The response of soils and plants. *Proc. Br. Crop Protect. Conf.* p. 873-883.

Autio, W.R., D.W. Greene, D.R. Cooley, and J.R. Schupp. 1991. Improving the growth of newly planted apple trees. Hort. Sci. 26: 840-843.

Baeumer, K., and W.A.P. Bakermans. 1973. Zero tillage. Adv. Agron. 25: 77-123.

Barber, D.A., and J.K. Martin. 1976. The release of organic substances by cereal roots in soil. New Phytol. 76: 68-80.

Baver, L.D., W.H. Gardner, and W.R. Gardner. 1972. Soil physics. John Wiley and Sons. London.

Baxter, P. 1970. Effect of a weed-free or straw mulched strip on the growth and yield of young fruit trees. Aust. J. Exp. Agric. Anim. Husb. 10: 467-473.

Baxter, P., and B.J. Newman. 1971. Orchard soil management. 2. Effect of herbicides and nitrogen on growth and yield of young apple trees in permanent pasture. Aust. J. Exp. Agric. Anim. Husb. 11: 105-112.

Beaton, J.D., R.C. Speer, and G. Brown. 1965. Effect of soil temperature and length of reaction period on water solubility of phosphorus in soil fertilizer reaction zones. Soil Sci. Soc. Am. Proc. 29: 194-197.

- Black, A.L., and B.W. Greb. 1962. Nitrate accumulation in soils covered with plastic mulch. *Agron. J.* 54: 366.
- Blair, G.J., M.H. Miller, and W.A. Mitchell. 1970. Nitrate and ammonium as sources of nitrogen for corn and their influence on the uptake of other ions. *Agron. J.* 62: 530- 532.
- Bould, C., H.M. Hughes, and E. Gunn. 1972. Effects of soil management and NPK fertilizers on tree growth, yield and leaf nutrient composition of dessert apples. *Exp. Hort.* 24: 25-36.
- Bould, C., W.D.E. Thomas, and J.A.H. Tolhurst. 1954. Cover crops in relation to soil fertility and fruit tree nutrition: the effect of grass on the uptake of total and fertilizer phosphate by Malling I rootstocks. *J. Hort. Sci.* 29: 301-309.
- Bristow, K.L. 1988. The role of mulch and its architecture in modifying soil temperature. *Aust. J. Soil Res.* 26: 269-280.
- Burns, A.F., and S.A. Barber. 1961. The effect of temperature and moisture on exchangeable potassium. *Soil Sci. Soc. Am. Proc.* 25: 349-352.

Burrows, W.C., and W.E. Larson. 1962. Effect of amount of mulch on soil temperature and early growth of corn. *Agron. J.* 54: 19-23.

Call, L.E., and M.C. Sewell. 1917. The soil mulch. *Agron. J.* 9: 49-61.

Ching, P.C., and S.A. Barber. 1979. Evaluation of temperature effects on K uptake by corn. *Agron. J.* 71: 1040-1044.

Claassen, M.E., and G.E. Wilcox. 1974. Comparative reduction of Ca and Mg composition of corn tissue by NH_4^+ -N and K fertilizer. *Agron. J.* 66: 521-522.

Clarkson, D.T., L.H.P. Jones, and J.V. Purves. 1992. Absorption of nitrate and ammonium ions by *Lolium perenne* from flowing solution cultures at low root temperatures. *Plant Cell Environ.* 15: 99-106.

Dancer, J. 1964. The influence of soil moisture and temperature on the growth of apple trees. I. Some observations on moisture and temperature conditions under grass, arable and mulch. *Hort. Res.* 4: 3-13.

De Long, W.A. 1937. Calcium and boron related to blotch cork. *Pl. Physiol.* 2: 552-556.

Dixon, W.J. 1986. Extraneous values. *In: Methods of soil analysis, Part 1, Physical and mineralogical methods*. 2nd Ed. A. Klute (Ed). Amer. Soc. of Agron., Inc.-Soil Sci. Soc. of Amer., Inc., Madison, Wisconsin. p. 83-90.

Estabrooks, E.N., and I. Ghanem. 1990. Using leaf analysis results to manage McIntosh apple trees. *Acta Hort.* 274: 123-127.

Eisenberg, E. 1989. Back to Eden. *The Atlantic.* 264: 57-89.

Faust, M. and C.B. Shear. 1968. Corking disorders of apples: a physiological review. *Bot. Rev.* 34: 441-469.

Fear, C.D., and G.R. Nonnecke. 1989. Soil mulches influence reproductive and vegetative growth of "Fern" and "Tistar" day-neutral strawberries. *Hort. Sci.* 24: 912-913.

Fernandez, G.C.J. 1991. Repeated measure analysis of line-source sprinkler experiments. *Hort. Sci.* 26: 339-342.

Flocker, W.J., and D.R. Nielsen. 1962. The absorption of nutrient elements by tomatoes associated with levels of bulk density. *Soil Sci. Soc. Am. Proc.* 26: 183-186.

- Goode, J.E., K.H. Higgs, and K.J. Hyrycz. 1978. Nitrogen and water effects on the nutrition, growth, crop yield and fruit quality of orchard-grown Cox's Orange Pippin apple trees. *J. Hort. Sci.* 53: 295-306.
- Goode, J.E., and K.J. Hyrycz. 1976. The effect of nitrogen on young, newly planted, apple rootstocks in the presence and absence of grass competition. *J. Hort. Sci.* 51: 321-327.
- Greacen, E.L. 1958. The soil structure profile under pastures. *Aust. J. Agric. Res.* 9: 129-137.
- Greb, B.W., D.E. Smika, and A.L. Black. 1970. Water Conservation with stubble mulch fallow. *J. Soil Water Conserv.* 25: 58-62.
- Gross, C.F., and G.A. Jung. 1978. Magnesium, Ca, and K concentration in temperate-origin forage species as affected by temperature and Mg-fertilization. *Agron. J.* 70: 397-403.
- Guilivo, C. 1990. Interactions between mineral nutrition and tree and soil water status. *Acta Hort.* 274: 149-167.

Gupta, J.P. 1989. Integrated effect of water harvesting, manuring and mulching on soil properties, growth and yield of crops in pearl millet-mungbean rotation. Trop. Agric. 66: 233-239.

Haley, S. and E.J. Hogue. 1990. Ground cover influence on apple aphid, *Aphis pomi* DeGeer (Homoptera: *Aphididae*) and its predators in a young apple orchard. Crop Prot. 9: 225-230.

Hamblin, A.P., and D.B. Davies. 1977. Influence of organic matter on the physical properties of some East Anglian soils of high silt content. J. Soil Sci. 28: 11-22.

Hardisty, S.E. 1966. The elimination of cultivation in apple orchards- a new approach to orchard management. J. Agric.W. Aust. 7: 79-86.

Haynes, R.J. 1983. Some observations on surface soil pH, base saturation and leaching of cations under three contrasting orchard soil management practices. Plant Soil. 56: 429-438.

Haynes, R.J. 1981. Effects of soil management practices on soil physical properties, earthworm population and tree root distribution in a commercial apple orchard. Soil & Tillage Res. 1: 269-280.

Haynes, R.J. 1981a. Laboratory study of nutrient leaching from the surface of cultivated, grassed and herbicided orchard soil. *Soil & Tillage Res.* 1: 281-288.

Haynes, R.J. 1980. Influence of soil management practice on the orchard agro-ecosystem. *Agro-Ecosystems.* 6: 3-32.

Haynes, R.J., and K.M. Goh. 1980. Some effects of orchard soil management on sward composition, levels of available nutrients in the soil, and leaf nutrient content of mature 'Golden Delicious' apple trees. *Scientia Hort.* 13: 15-25.

Hedrick, U.P. 1914. A comparison of tillage and sod mulch in an apple orchard. New York agricultural experiment station. Bulletin no. 383. p. 249-281.

Hill, S.B. 1988. Soil, food, health, and values. *Humanist In Canada.* 84: 2-6.

Hill, R.H., T. To, J.S. Holler, D.M. Fast, S.J. Smith, L.L. Needham, and S. Binder. 1989. Residues of chlorinated phenols and phenoxy acid herbicides in the urine of Arkansas children. *Arch. Environ. Contam. Toxicol.* 18: 469-474.

Hillel, D. 1980. Fundamentals of soil physics. Academic Press. London.

Hipps, N.A., J. Hazelden, and G.B.N. Fairall. 1990. Control of erosion in a mature orchard. *Soil Use Manage.* 6: 32-35.

Hira, G.S., and N.T. Singh. 1977. Observed and predicted rates of P diffusion in soils of varying bulk density and water content. *Soil Sci. Soc. Am. J.* 41: 537-540.

Holland, D.A. 1980. The prediction of bitter pit. p. 380-381. *In: Mineral nutrition of fruit trees.* D. Atkinson, J.E. Jackson, R.O. Sharples, and W.M. Waller (Eds.) Butterworth, London.

Hudska, G. 1990. Determination of standard values of elements in the leaves of fruit species and their relation to the productivity of trees and soil management. *Acta Hort.* 274: 195-199.

Hulugalle, R., R. Lal, and M. Gichuru. 1990. Effect of five years of no-tillage and mulch on soil properties and tuber yield of cassava on an acid ultisol in southeastern Nigeria. *Exp. Agric.* 26: 235-240.

Huynh, H. and L.S. Feldt. 1970. Conditions under which mean square ratios in repeated measurements design have exact F-distributions. *J. Amer. Statist. Assn.* 65: 1582-1589.

- Jacks, G.V., W.D. Brind, and R. Smith. 1955. Mulching. Commonwealth Bureau of Soil Science, Tech. Comm. No. 49.
- Johnson, D.S., and T.J. Samuelson. 1990. Short-term effects of changes in soil management and nitrogen fertilizer application on 'Bramley's Seedling' apple trees. I. Effects on tree growth, yield and leaf nutrient composition. J. Hort. **3** 65: 489-494.
- Judkins, W.P., and H.A. Rollins. 1947. The effect of sod, cultivation and mulch treatments on the soil moisture, soil nitrates and tree growth in a young peach orchard. Proc. Am. Soc. Hort. Sci. **43**: 7-10.
- Jurinak, J.J., L.M. Dudley, M.F. Allen, and W.G. Knight. 1986. The role of calcium oxalate in the availability of phosphorus in soils of semi-arid regions: A thermodynamic study. Soil Sci. **142**: 255-261.
- Keeney, D.R., and D.W. Nelson. 1986. Nitrogen- Inorganic forms. *In*: Methods of soil analysis, Part 2, Chemical and microbiological properties, 2nd ed. A.L. Page, R.H. Miller, and D.R. Keeney (Eds.) Amer. Soc. of Agron., Inc.-Soil Sci. Soc. of Amer., Inc. Madison, Wisconsin. p. 643-698.

- Kenworthy, A.L. 1953. Moisture in orchard soils as influenced by age of sod and clean cultivation. Mich. Agric. Exp. Stn. Quart. Bull. 35: 454-459.
- Knight, W.G., M.F. Allen, J.J. Jurinak, and L.M. Dudley. 1989. Elevated carbon dioxide and solution phosphorus in soil with vesicular-arbuscular mycorrhizal Western wheatgrass. Soil Sci. Soc. Am. J. 53: 1075-1082.
- Komosa, A. 1990. Changes in some chemical properties of the soil under grass sward and herbicide strips in apple orchards. Acta Hort. 274: 223-230.
- Kozlowski, T.T. 1983. Reduction in yield of forest and fruit trees by water and temperature stress. *In*: Crop reductions to water and temperature stresses in humid, temperate climates. C.D. Raper, Jr., and P.J. Kramer (Eds.) p. 67-88.
- Lahav, E. 1978. The value of the K/Ca+Mg ratio for determination of the nutritional status of the banana sucker. Fruits. 33: 3-6.
- Lajoie, P.G. 1960. Soil survey of Argenteuil, Two Mountains and Terrebonne Counties, Québec. Research Branch Canada Department of Agriculture in co-operation with Québec Department of Agriculture and Macdonald College, McGill University. Cat. No. A57-215.

Latimer, L.P., and G.P. Percival. 1947. Comparative value of sawdust, hay, and seaweed as mulch for apple trees. *Proc. Am. Soc. Hort. Sci.* 50: 23-30.

Lewis, T.L., D. Martin, J. Cerny, and D.A. Ratkowsky. 1977. The effects of increasing the supply of nitrogen, phosphorus, calcium, and potassium to the roots of Merton Worcester apple trees on leaf and fruit composition and on the incidence of bitter pit at harvest. *J. Hort. Sci.* 52: 409-419.

Li, G.C., R.L. Mahler, and D.O. Everson. 1990. Effects of plant residues and environmental factors on phosphorus availability in soils. *Comm. in Soil Sci. Plant Anal.* 21: 471-491.

Littell, R.C. 1989. Statistical analysis of experiments with repeated measurements. *Hort. Sci.* 24: 37-40.

Lord, W.J., and E. Valch. 1973. Responses of peach trees to herbicides, mulch, mowing, and cultivation. *Weed Sci.* 21: 227-229.

Lowe, A.J., and E.R. Armitage. 1970. The composition of leachate through cropped and uncropped lysimeters compared with that of the rain. *Plant Soil.* 33: 393-411.

Ludders, P. 1973. Influence of seasonally varied potassium supply on apple trees. Proc. Int. Working Group on Soilless Culture. 1973: 21-31.

Lyon, T.L., and J.A. Bizzell. 1913. Some relations of certain higher plants to the formation of nitrates in soils. Cornell Exp. Sta. Memoir No. 1: 75-91.

Lytton, P. 1990. Miraculous textile mulch: A fabrication? Amer. Hort. 69: 8-9.

MacRae, R.J., S.B. Hill, G.R. Mehuys, and J. Henning. 1990. Farm-scale agronomic and economic conversion from conventional to sustainable agriculture. Adv. Agron. 43: 155-198.

Mage, F. 1982. Black plastic mulching, compared to other soil management methods. Scientia Hortic. 16: 131-136.

Manru, G., S. Huairui, S., and Z. Hongwei. 1990. A study of nitrogen nutrition of apple trees. Acta Hort. 274: 179-185.

Marti, H.R., and H.A. Mills. 1991. Calcium uptake and concentration in bell pepper plants as influenced by N form and stages of development. J. Plant Nutr. 14: 1177-1185.

- Mba, C.C. 1978. Influence of different mulch treatments on growth rate and activity of the earthworm *Eudrilus eugeniae* (Kinberg). [Contribution of individual earthworm species to soil fertility in Nigerian soils]. J. Plant Nutr. Soil Sci. **141**: 453-468.
- Mederski, H.G., and J.H. Wilson. 1960. Relation of soil moisture to ion absorption by corn plants. Soil Sci. Soc. Am. Proc. **24**: 149-152.
- Mehlich, A. 1984. Mehlich 3 test extractant: A modification of Mehlich 2 extractant. Comm. Soil Sci. Plant Anal. **15**: 1409-1416.
- Merwin, I.A. 1991. Orchard weed control: how much is enough. Proc. 53rd Ann. N.Y. State IPM Conf.
- Merwin, I.A., W.F. Wilcox, and W.C. Stiles. 1992. Influence of orchard ground cover management on the development of phytophthora crown and root rots of apple. Plant Dis. **76**: 199-205.
- Mustaffa, M.M. 1988. Effects of orchard management practices on yield, quality and leaf nutrient content of Coorg mandarin. J. Hort. Sci. **63**: 711-716.

Neilson, G.H., B.J. Hogue, and B.G. Drought. 1986. The effect of orchard soil management on soil temperature and apple tree nutrition. *Can. J. Soil Sci.* **66**: 701-711.

Newenhouse, A.C., and M.N. Dana. 1989. Grass living mulch for strawberries. *J. Am. Soc. Hort. Sci.* **114**: 859-862.

Olsen, S.R., W.D. Kemper, and R.D. Jackson. 1962. Phosphate diffusion to plant roots. *Soil Sci. Soc. Am. Proc.* **26**: 222-227.

Perring, M.A. 1975. The effect of orchard factors on the chemical composition of apples. IV. Some effects of soil management and NPK fertilizers. *J. Hort. Sci.* **50**: 425-533.

Power, J.F., D.L. Grunes, G.A. Reichman, and W.O. Willis. 1964. Soil temperature effects on phosphorus availability. *Agron. J.* **56**: 545-548.

Rasiah, V., B.D. Kay, and T. Martin. 1992. Variation of structural stability with water content: influence of selected soil properties. *Soil Sci. Soc. Am. J.* **56**: 1604-1609.

Rogers, W.S., T.H. Raptopoulos, and D.W.P. Greenham. 1948. Cover crops for fruit plantations. IV. Long-term leys and permanent swards. *J. Hort. Sci.* **24**: 228-270.

Russell, E.J. 1973. Soil conditions and plant growth. 10th ed. Longman, London.

Salmins, S. 1993. Apple tree growth and yield in alternative ground management systems. M.Sc. Thesis. Faculty of Graduate Studies and Research, McGill University, Montreal, Canada.

SAS. 1988. SAS/STAT (c) User's guide, Version 6, 4th ed. Vol. 2. SAS Institute Inc., Cary, N.C.

Sharples, R.O. 1973. Orchard and climatic factors, Part IV. p. 175-225. In: The biology of apple and pear storage. J.C. Fidler, B.G. Wilkinson, K.L. Edney, and R.O. Sharples (Eds.) Res. Rev. Commonw. Bur. Hort. Plant. Crops. No. 3.

Shaw, J.K., and L. Southwick. 1936. Heavy mulching in bearing apple orchards. Massachusetts agricultural experiment station. Bulletin no. 328. p. 3-15.

Shear, C.B. 1980. Interaction of nutrition and environment on mineral composition of fruits. p. 41-50. In: Mineral nutrition in fruit trees. D. Atkinson, J.E. Jackson, R.O. Sharples, and W.M. Waller (Eds.) Butterworth, London.

Shear, C.B. 1974. Interaction of calcium and nitrogen and time of calcium availability in relation to the development of apple disorders. Proc. 7th Int. Colloq. Pl. Analysis Fertil. Probl. Germ. Soc. Pl. Nutr. 1: 427-436.

Shribbs, J.M., and W.A., Skroch. 1986. Influence of 12 ground cover systems on young 'Smoother Golden Delicious' apple trees: I. Growth. J. Am. Soc. Hort. Sci. 111: 525-528.

Shribbs, J.M., and W.A., Skroch. 1986a. Influence of 12 ground cover systems on young 'Smoother Golden Delicious' apple trees: II. Nutrition. J. Am. Soc. Hort. Sci. 111: 529-533.

Skroch, W.A., and J.M. Shribbs. 1986. Orchard floor management: an overview. Hort. Sci. 21: 390-394.

Stanford, G., and E. Epstein. 1974. Nitrogen mineralization-water relations in soils. Soil Sci. Soc. Am. Proc. 38: 103-106.

Stott, K.G. 1976. The effects of competition from ground covers on apple vigour and yield. Ann. Appl. Biol. 3: 327-330.

- Swenson, A.A. 1973. The practical book of organic gardening. Newspaper Enterprise Associations Inc. New York, N.Y.
- Tamburro, C.H. 1992. Chronic liver injury in phenoxy herbicide exposed Vietnam veterans. *Environ. Res.* 59: 175-188.
- Tan, S., and G.D. Crabtree. 1990. Competition between perennial ryegrass sod and 'Chardonnay' wine grapes for mineral nutrients. *Hort. Sci.* 25: 533-535.
- Terblance, J.H., K.H. Gurgun, and I. Hesebeck. 1980. An integrated approach to orchard nutrition and bitter pit control. p. 71-82. *In: Mineral nutrition of fruit trees.* D. Atkinson, J.E. Jackson, R.O. Sharples, and W.M. Waller (Eds.) Butterworth, London.
- Tisdale, S.L., W.L. Nelson, and J.D. Beaton. 1985. Soil fertility and fertilizers. 4th ed. Macmillan Publishing Company, New York, N.Y.
- Thomas, R.L., R.W. Sheard, and J.R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion. *Agron. J.* 59: 240-243.

Tukey, J.W. 1953. The problem of multiple comparisons. Princeton University.
Princeton N.J.

Tukey, R.B., and E.L. Schoff. 1963. Influence of different mulching materials upon the
soil environment. Proc. Am. Soc. Hort. Sci. 82: 68-76.

Unger, P.W. 1976. Surface residue, water application and soil texture effects on water
accumulation. Soil Sci. Soc. Am. Proc. 40: 298-300.

Van Schreven, A.C. 1961. Bitter pit. Bull. Int. Inst. Refrig. Annexe 1961. 1: 167-171.

Wade, L.B., G. Goldstein, T.W. Dreschel, R.M. Wheeler, J.C. Sager, and W.M. Knott.
1992. Water relations, gas exchange and nutrient response to a long term
constant water deficit. Soil Sci. 153: 442-451.

Waller, W.M. 1980. Use of apple analysis. p. 383-394. *In*: Mineral nutrition of fruit
trees. D. Atkinson, J.E. Jackson, R.O. Sharples, and W.M. Waller (Eds.)
Butterworth, London.

Walsh, T., and T.F. O'Donohoe. 1945. Magnesium deficiency in some crop plants in
relation to the level of potassium nutrition. J. Agr. Sci. 35: 254-263.

- Watson, G.W. 1988. Organic mulch and grass competition influence tree root development. *J. Arboric.* 14: 200-203.
- Westermann, D.T. 1992. Lime effects on P availability in a calcareous soil. *Soil Sci. Soc. Am. J.* 56: 489-494.
- Welch, L.F., and A.D. Stott. 1960. Nitrification of fixed ammonium in clay minerals as affected by added potassium. *Soil Sci.* 90: 79-85.
- White, E.M. 1971. Grass cycling of calcium, magnesium, potassium, and sodium in solodization. *Soil Sci. Soc. Am. Proc.* 35: 309-319.
- White, G.C. and R.I. Holloway. 1967. The influence of simazine or a straw mulch on the establishment of apple trees in grassed down or cultivated soil. *J. Hort. Sci.* 42: 377-389.
- White, W.M. 1993. Dry aggregate distribution. *In: Soil sampling and methods of analysis.* M.R. Carter (Ed.) Lewis Publishers. p. 659-662.
- Wiersum, L.K. 1979. Effects of environment and cultural practices on calcium nutrition. *Communs. Soil Sci. Pl. Analysis.* 10: 259-278.

Wilhelm, W.W., H. Bouzerzour, and J.F. Powers. 1989. Soil disturbance-residue management effect on winter wheat growth and yield. *Agron. J.* 81: 581-588.

Yokoyama, K., K. Kaitt, T. Koga, and T. Aibe. 1991. Nitrogen mineralization and microbial populations in cow dung, dung balls, and underlying soil affected by paracoprid dung beetles. *Soil Biol. Biochem.* 23: 649-653.

York, E.T., R. Bradfield, and M. Peech. 1953. Calcium-potassium interactions in soils and plants: I. Lime-induced potassium fixation in Mardin silt loam. *Soil Sci.* 76: 379-386.

Chapter 9

Appendices

Appendix 1 Fertilizers and amendments used in Orchards 1 and 2 in 1991, 1992, and 1993.

Fertilizer	Year Applied	Producer	Rate Applied	Nutrient Content
Feathermeal*	1991	Floradale Ltd.	150 g tree ⁻¹	127 - 2.5 - 1.3 - 4.7 - 0.32
Bloodmeal*	1992	McGinnis or	100 g tree ⁻¹ in 1992	154 - 1.5 - 2.2 - 3.6 - 1.5
	1993	Nutrite	125 g tree ⁻¹ in 1993	
Fish Emulsion^	1991	Wilson	3 L tree ⁻¹	5 - 1 - 1
	1992			
Phosphate Rock^	1993	McGinnis	125 g tree ⁻¹	0 - 26 - 0
Sulphomag^	1993	Nutrite	125 g tree ⁻¹	0 - 0 - 20
Compost*	1991	Macdonald Campus, Dairy division	500 g tree ⁻¹	12 - 4.9 - 5.9 - 35 - 12

Modified from Salmins, S. 1993. Apple Tree Growth and Yield in Alternative Ground Management Systems. M.Sc. Thesis, Faculty of Graduate Studies and Research. p. 85.

* nutrient content is total N, P, K, Ca, and Mg respectively in mg g⁻¹.

^ nutrient content is total N, available P₂O₅, and water soluble K₂O respectively in percent.

Appendix 2 Fertilizers used in Orchard 3 in 1991, 1992, and 1993.

Fertilizer*	Year Applied	Producer	Rate Applied g tree ⁻¹
34-0-0-0	1991	CIL	100 in 1991
	1992		120 in 1992
0-20-20-03	1991	CIL	100 in 1991
	1992		150 in 1992
5-20-20-0	1993	CIL	200

* nutrient content is total N, available P₂O₅, water soluble K₂O, and total Mg respectively in percent.

Appendix 3 Organic pest controls used in Orchards 1 and 2 in 1991, 1992, and 1993.

Product	Producer	Rate Applied	Active Ingredients
Rotenone	Wilson	30 mL L water ⁻¹ Sprayed to wet leaf surface as required.	1% rotenone extracted from roots of tropical plants.
Safer's Soap	Safer's Ltd.	1:50 soap to water sprayed to wet leaf surface as required.	Potassium salts of fatty acids 50.5%
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.	<i>Bacillus thuringiensis</i> , 16 000 I.U. potency per mg.

Modified from Salmins, S. 1993. Apple Tree Growth and Yield in Alternative Ground Management Systems. M.Sc. Thesis, Faculty of Graduate Studies and Research. p. 86.

Appendix 4 Pesticides used in Orchard 3 in 1991, 1992, and 1993.

Product	Chemical Name	Year Applied	Supplier	Rate Applied*
Roundup ¹	Glyphosate	1991 1992 1993	Monsanto	1 kg ha ⁻¹
Gramoxone ¹	Paraquat	1991 1992 1993	Chipman	1 kg ha ⁻¹
Equal ²	Dodine	1991 1992	Chipman	1.75 kg ha ⁻¹
Guthion ³	Azinphosmethyl	1991 1992 1993	Chipman	2 kg ha ⁻¹
Imidan ³	Phosmet	1991 1992 1993	Chipman	5 kg ha ⁻¹
CarsolSP ⁴	Formetanate Hydrochloride	1991 1992 1993	Nor-PM	1 kg ha ⁻¹
Cyrex65W ²	Cyprex	1993	Zenaca	2.25 kg ha ⁻¹
Belmark300EC ³	Fenvalerate	1993	Ciba-Geigy	450 mL ha ⁻¹
Kelthane ⁴	Dicofol	1993	Rohm-Haas	4.5 kg ha ⁻¹
Captan80W ²	Captan	1991 1992 1993	Chipman	2.5 kg ha ⁻¹

* Rate as wettable powder in 1000 L water ha⁻¹.

1. Herbicide 2. Fungicide 3. Insecticide 4. Miticide

Modified from Salmins, S. 1993. *Apple Tree Growth and Yield in Alternative Ground Management Systems*. M.Sc. Thesis, Faculty of Graduate Studies and Research. p. 88.

Appendix 5 Soil organic matter and total N levels in Orchards 1 and 2, in the Ah horizon and below the Ah horizon to 0.3 m depth in September 1993.

Treatment	Orchard 1				Orchard 2			
	Organic Matter		Total N		Organic Matter		Total N	
	Ah	Ah-0.3	Ah	Ah-0.3	Ah	Ah-0.3	Ah	Ah-0.3
	-----%-----		---kg ha ⁻¹ ---		-----%-----		---kg ha ⁻¹ ---	
Cultivation	3.5 ^c (0.10)	1.7 ^a (0.24)	5200 ^a (430)	570 ^a (140)	2.6 ^a (0.23)	1.0 ^a (0.34)	4200 ^a (170)	520 ^a (190)
Grass	3.2 ^c (0.72)	1.2 ^a (0.32)	4500 ^a (740)	300 ^a (130)	2.7 ^a (0.10)	1.5 ^a (0.40)	4100 ^a (200)	450 ^a (110)
Mixed Flora	4.8 ^a (0.10)	1.5 ^a (0.51)	5100 ^a (360)	590 ^a (130)	2.9 ^a (0.25)	0.90 ^a (0.14)	4200 ^a (190)	310 ^a (130)
Manure	4.6 ^{ab} (0.15)	0.78 ^a (0.14)	4700 ^a (560)	810 ^a (290)	3.4 ^a (0.39)	0.51 ^a (0.10)	4900 ^a (860)	300 ^a (71)
Straw	4.2 ^b (0.12)	1.7 ^a (0.36)	4900 ^a (130)	610 ^a (250)	3.4 ^a (0.11)	2.2 ^a (0.14)	5700 ^a (290)	390 ^a (77)
Geotextile	3.6 ^c (0.21)	1.9 ^a (0.21)	5200 ^a (260)	620 ^a (110)	2.8 ^a (0.14)	0.53 ^a (0.24)	3800 ^a (370)	170 ^a (53)

Means within each orchard, variable, and sampling depth with same letter are not significantly different at 0.05 level of probability according to Tukey's multiple comparison test.

() standard error of means (n=8).

Ah denotes soil layer to bottom of Ah horizon.

Ah-0.30 m denotes soil layer from bottom of Ah horizon to 0.30 m depth.

Appendix 6 Mean monthly soil temperature (0.10 m depth), air temperature, and precipitation recorded at Macdonald College of McGill University (45° latitude, 74° longitude).

Year	May	June	July	August	September	October
Soil Temperature	°C					
1991	15.6	20.8	24.6	22.7	16.6	10.9
1992	15.1	19.1	20.7	20.1	-	6.9
1993	13.0	16.1	20.1	20.6	16.5	8.6
Air Temperature	°C					
1991	20.6	25.1	26.7	25.3	18.4	14.0
1992	19.9	22.8	23.2	23.1	-	-
1993	17.6	22.8	26.3	26.0	19.4	11.0
Precipitation	mm					
1991	90.4	59.4	91.8	133	67.3	65.6
1992	68.3	80.4	143	54.1	-	496
1993	69.2	74.8	94.6	59.0	131	4.4

Appendix 7

Weed Survey Within an Organic Apple Orchard

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August 1993.

Methodology

Percentage weed cover data for orchards 1 and 2 were collected between August 11 to 13, 1993. For each block/treatment combination, three (3) 0.25 m² (50 cm x 50 cm) quadrats were used to determine % cover. Coverage was visually estimated. Thus, % cover values for each species in any one block is the mean cover obtained in the three quadrats. Mean % cover for the four blocks for each weed species is also shown. Note that % cover data for each block may not necessarily equal 100% in all cases.

Composite Weed Species List For Orchards 1, 2, and 3.

Scientific Name	Family	Common Name	Growth Habit
<i>Avena sativa</i> L.	Graminae	Oats	Annual
<i>Digitaria sanguinalis</i> (L.) Scop.	Graminae	Large Crabgrass	Annual
<i>Echinochloa crusgalli</i> (L.) Beauv.	Graminae	Barnyardgrass	Annual
<i>Elytrigia repens</i> (L.) Nevski	Graminae	Quackgrass	Perennial
<i>Festuca rubra</i> L.	Graminae	Red Fescue	Perennial
<i>Panicum capillare</i> L.	Graminae	Witchgrass	Annual
<i>Phleum pratense</i> L.	Graminae	Timothy	Perennial
<i>Poa pratensis</i> L.	Graminae	Kentucky bluegrass	Perennial
<i>Setaria viridis</i> (L.) Beauv.	Graminae	Green foxtail	Annual
<i>Cyperus esculentus</i> L.	Cyperaceae	Yellow nutsedge	Perennial
<i>Polygonum convolvulus</i> L.	Polygonaceae	Wild buckwheat	Annual
<i>Polygonum pensylvanicum</i> L.	Polygonaceae	Pennsylvania smartweed	Annual
<i>Rumex crispus</i> L.	Polygonaceae	Curled dock	Perennial
<i>Chenopodium album</i> L.	Chenopodiaceae	Lamb's quarters	Annual
<i>Amaranthus retroflexus</i> L.	Amaranthaceae	Redroot pigweed	Annual
<i>Portulaca oleraceae</i> L.	Portulacaceae	Purslane	Annual
<i>Stellaria media</i> (L.) Vill.	Caryophyllaceae	Chickweed	Annual

<i>Capsella bursa-pastoris</i> (L.) Medic.	Brassicaceae	Shepherd's purse	Annual
<i>Erysimum cheiranthoides</i> L.	Brassicaceae	Wormseed mustard	Annual
<i>Lotus corniculatus</i> L.	Leguminosae	Bird's-foot trefoil	Perennial
<i>Medicago lupulina</i> L.	Leguminosae	Black medick	Annual
<i>Oxalis stricta</i> L.	Leguminosae	European wood sorrel	Perennial
<i>Trifolium campestre</i> Schreb.	Leguminosae	Low hop clover	Annual
<i>Trifolium pratense</i> L.	Leguminosae	Red clover	Perennial
<i>Vicia cracca</i> L.	Leguminosae	Tufted vetch	Perennial
<i>Malva neglecta</i> Wallr.	Malvaceae	Common mallow	Annual
<i>Daucus carota</i> L.	Umbelliferae	Wild carrot	Biennial
<i>Asclepias syriaca</i> L.	Asclepiadaceae	Common milkweed	Perennial
<i>Convolvulus arvensis</i> L.	Convolvulaceae	Field bindweed	Perennial
<i>Glechoma hederacea</i> L.	Labiatae	Ground-ivy	Perennial
<i>Linaria vulgaris</i> Mill.	Scrophulariaceae	Toadflax	Perennial
<i>Plantago major</i> L.	Plantaginaceae	Broad-leaved plantain	Perennial
<i>Lactuca scariola</i> L.	Compositae	Prickly lettuce	Annual
<i>Senecio vulgaris</i> L.	Compositae	Common groundsel	Annual
<i>Sonchus arvensis</i> L.	Compositae	Perennial sow-thistle	Perennial
<i>Sonchus oleraceus</i> L.	Compositae	Annual sow-thistle	Annual

<i>Taraxacum officinale</i> Weber	Compositae	Dandelion	Perennial
<i>Tragopogon pratensis</i> L.	Compositae	Meadow goat's-beard	Biennial

Orchard 1: Surface Cultivation

Species	Blk1	Blk2	Blk3	Blk4	Mean
Amaranthus	7	47	<<1	6	15%
Capsella	<<1	--	--	--	<<1%
Chenopodium	1	5	<1	2	2%
Convolvulus	--	--	59	--	15%
Echinochloa	<1	5	4	5	4%
Elytrigia	27	2	7	12	12%
Malva	--	6	--	--	2%
Oxalis	--	--	<<1	--	<<1%
Portulaca	17	8	<<1	62	22%
Stellaria	<<1	--	--	--	<<1%
Taraxacum	<<1	--	<1	--	<<1%
Bare ground	45	28	29	13	29%

Most abundant weed species (% Cover)

- | | | |
|----------------|-------|-----------|
| 1. Bare ground | = 29 | |
| 2. Portulaca | = 22 | annual |
| 3. Amaranthus | = 15 | annual |
| 4. Convolvulus | = 15 | perennial |
| 5. Elytrigia | = 12 | perennial |
| 6. Echinochloa | = 4 | annual |
| 7. Chenopodium | = 2 | annual |
| 8. Malva | = 2 | annual |
| 9. 4 species | = <<1 | |

Total number of species: 11.

Orchard 1: Straw					
Species	Blk1	Blk2	Blk3	Blk4	Mean
Asclepias	--	--	--	2	<1%
Avena	33	30	--	8	18%
Convolvulus	--	--	65	--	16%
Elytrigia	10	28	12	17	17%
Linaria	25	--	--	--	6%
Malva	--	--	--	23	6%
Straw (ground)	32	42	23	50	37%

Most abundant weed species (% Cover)

- | | | |
|-------------------|------|-----------|
| 1. Straw (ground) | = 37 | |
| 2. Avena | = 18 | annual |
| 3. Elytrigia | = 17 | perennial |
| 4. Convolvulus | = 16 | perennial |
| 5. Linaria | = 6 | perennial |
| 6. Malva | = 6 | annual |
| 7. Asclepias | = <1 | perennial |

Total number of species: 6.

Orchard 1: Manure Compost

Species	Blk1	Blk2	Blk3	Blk4	Mean
Amaranthus	<<1	--	2	--	<1%
Chenopodium	--	--	8	--	2%
Convolvulus	--	--	13	--	3%
Cyperus	--	--	--	3	<1%
Echinochloa	--	2	2	2	2%
Elytrigia	45	40	3	20	27%
Linaria	1	5	--	--	2%
Malva	--	--	7	42	12%
Oxalis	--	--	--	2	<1%
Poa	3	--	--	--	<1%
P. convolvulus	--	3	8	--	3%
S. oleraceus	2	--	13	1	4%
Taraxacum	49	25	27	18	30%
T. pratense	1	20	17	7	11%
Vicia	<<1	--	--	2	<1%
Manure compost	--	5	--	3	2%

Most abundant weed species (% Cover)

1. Taraxacum	= 30	perennial
2. Elytrigia	= 27	perennial
3. Malva	= 12	annual
4. T. pratense	= 11	perennial
5. S. oleraceus	= 4	annual
6. Convolvulus	= 3	perennial
7. P. convolvulus	= 3	annual
8. Chenopodium	= 2	annual
9. Echinochloa	= 2	annual
10. Linaria	= 2	perennial
11. Manure	= 2	
12. 5 species	= <1	

Total number of species: 15.

Orchard 1: Grass					
Species	Blk1	Blk2	Blk3	Blk4	Mean
Asclepias	<1	--	--	--	<<1%
Convolvulus	--	2	7	--	2%
Elytrigia	--	--	<1	--	<<1%
Festuca	74	48	72	65	65%
Malva	--	--	--	2	<1%
Oxalis	4	--	<1	2	2%
Poa	--	--	--	2	<1%
Taraxacum	1	17	5	3	7%
T. pratense	16	35	18	22	23%
Vicia	5	--	5	5	4%
Bare ground	--	--	2	--	<1%

Most abundant weed species (% Cover)

1. Festuca	= 65	perennial
2. T. pratense	= 23	perennial
3. Taraxacum	= 7	perennial
4. Vicia	= 4	perennial
5. Convolvulus	= 2	perennial
6. Oxalis	= 2	perennial
7. 4 species	= <1	

Total number of species: 10.

Orchard 1: Mixed Flora

Species	Blk1	Blk2	Blk3	Blk4	Mean
Asclepias	--	5	--	--	1%
Convolvulus	--	--	3	--	<1%
Daucus	9	3	2	25	10%
Elytrigia	8	20	8	7	11%
Linaria	16	32	45	--	23%
Oxalis	25	2	--	15	11%
Poa	17	2	13	20	13%
P. convolvulus	--	<1	--	3	<1%
P. pensylvanicum	--	<1	--	--	<<1%
Rumex	--	--	3	--	<1%
Setaria	--	--	<1	--	<<1%
S. oleraceus	2	--	--	--	<1%
Taraxacum	17	7	15	17	14%
T. pratense	<1	--	7	5	3%
Vicia	--	3	--	--	<1%
Bare ground	6	25	3	8	11%

Most abundant weed species (% Cover)

1. Linaria	= 23	perennial
2. Taraxacum	= 14	perennial
3. Poa	= 13	perennial
4. Elytrigia	= 11	perennial
5. Oxalis	= 11	perennial
6. Bare ground	= 11	
7. Daucus	= 10	biennial
8. T. pratense	= 3	perennial
9. Asclepias	= 1	perennial
10. 7 species	= <1	

Total number of species: 10.

Orchard 2: Surface Cultivation

Species	Blk1	Blk2	Blk3	Blk4	Mean
Amaranthus	23	23	12	19	19%
Capsella	<1	<1	3	--	<1%
Chenopodium	3	2	1	3	2%
Echinochloa	3	5	3	3	4%
Glechoma	--	--	<1	--	<<1%
Panicum	--	--	2	--	<1%
Portulaca	35	45	27	5	28%
Senecio	--	<1	--	--	<<1%
Taraxacum	7	2	3	3	4%
Bare ground	28	22	50	67	42%

Most abundant weed species (% Cover)

1. Bare ground = 42
2. Portulaca = 28 annual
3. Amaranthus = 19 annual
4. Echinochloa = 4 annual
5. Taraxacum = 4 perennial
6. Chenopodium = 2 annual
7. 4 species = <1

Total number of species: 9.

Orchard 2: Straw

Species	Blk1	Blk2	Blk3	Blk4	Mean
Amaranthus	--	--	<1	--	<<1%
Avena	12	16	7	3	10%
Elytrigia	10	--	7	5	6%
Linaria	23	--	--	--	6%
S. arvensis	--	2	--	--	<1%
S. oleraceus	2	--	--	2	1%
Taraxacum	--	--	2	--	<1
Straw (ground)	53	83	85	90	78%

Most abundant weed species (% Cover)

- | | | |
|-------------------|------|-----------|
| 1. Straw (ground) | = 78 | |
| 2. Avena | = 10 | annual |
| 3. Elytrigia | = 6 | perennial |
| 4. Linaria | = 6 | perennial |
| 5. S. oleraceus | = 1 | annual |
| 6. 3 species | = <1 | |

Total number of species: 7.

Orchard 2: Manure Compost					
Species	Blk1	Blk2	Blk3	Blk4	Mean
Amaranthus	3	4	3	12	6%
Capsella	--	<1	<1	--	<<1%
Chenopodium	25	27	18	14	21%
Cyperus	--	--	3	2	1%
Daucus	--	13	--	--	3%
Digitaria	--	--	<1	--	<<1%
Echinochloa	15	6	8	3	8%
Elytrigia	--	3	--	3	2%
Erysimum	--	--	--	1	<<1%
Lactuca	--	12	--	--	3%
Malva	2	--	--	<1	<1%
Phleum	--	--	3	7	3%
Plantago	3	--	--	--	<1%
Poa	1	--	2	--	<1%
P. convolvulus	8	--	3	--	3%
Senecio	--	<1	--	--	<<1%
Setaria	<1	<1	7	5	3%
S. oleraceus	5	--	10	13	7%
Taraxacum	13	18	22	7	15%
T. pratense	5	7	12	3	7%
Vicia	2	3	<1	--	1%
Manure compost	17	7	8	30	16%

Most abundant weed species (% Cover)

- | | | |
|----------------|------|-----------|
| 1. Chenopodium | = 21 | annual |
| 2. Manure | = 16 | |
| 3. Taraxacum | = 15 | perennial |
| 4. Echinochloa | = 8 | annual |

5. <i>S. oleraceus</i>	= 7	annual
6. <i>T. pratense</i>	= 7	perennial
7. <i>Amaranthus</i>	= 6	annual
8. <i>Daucus</i>	= 3	biennial
9. <i>Lactuca</i>	= 3	biennial
10. <i>Phleum</i>	= 3	perennial
11. <i>P. convolvulus</i>	= 3	annual
12. <i>Setaria</i>	= 3	annual
13. <i>Elytrigia</i>	= 2	perennial
14. <i>Cyperus</i>	= 1	perennial
15. <i>Vicia</i>	= 1	perennial
16. 7 species	= <1	

Total number of species: 21.

Orchard 2: Grass

Species	Blk1	Blk2	Blk3	Blk4	Mean
Elytrigia	--	<1	<1	--	<<1%
Festuca	67	57	68	52	61%
Lotus	2	<1	--	--	<1%
Medicago	20	<1	12	8	10%
S. oleraceus	--	--	8	--	2%
Taraxacum	2	17	3	7	7%
Tragopogon	2	2	--	<1	1%
T. pratense	8	24	8	32	18%
Bare ground	--	--	--	2	<1%

Most abundant weed species (% Cover)

1. Festuca	= 61	perennial
2. T. pratense	= 18	perennial
3. Medicago	= 10	annual
4. Taraxacum	= 7	perennial
5. S. oleraceus	= 2	annual
6. Tragopogon	= 1	biennial
7. 2 species	= <1	

Total number of species: 8.

Orchard 2: Mixed Flora

Species	Blk1	Blk2	Blk3	Blk4	Mean
Daucus	17	3	3	7	8%
Echinochloa	3	--	--	--	<1%
Elytrigia	--	12	--	--	3%
Festuca	--	7	58	--	16%
Linaria	--	--	--	3	<1%
Malva	--	--	--	<1	<<1%
Medicago	--	--	--	<1	<<1%
Panicum	--	--	<1	--	<<1%
Plantago	5	--	--	3	2%
Poa	18	38	--	10	17%
Setaria	--	--	<1	2	<1%
Taraxacum	35	22	22	38	29%
Tragopogon	--	--	--	12	3%
T. campestre	--	--	3	--	<1%
T. pratense	12	7	--	2	5%
Bare ground	10	12	13	20	14%

Most abundant weed species (% Cover)

1. Taraxacum	= 29	perennial
2. Poa	= 17	perennial
3. Festuca	= 16	perennial
4. Bare ground	= 14	
5. Daucus	= 8	biennial
6. T. pratense	= 5	perennial
7. Elytrigia	= 3	perennial
8. Tragopogon	= 3	biennial
9. Plantago	= 2	perennial
10. 7 species	= <1	

Total number of species: 15.

Appendix 8.1 Analysis of variance for soil nutrients in the Ah horizon in Orchard 1 in July 1992 and 1993.

Nutrient	Source	D.F.	July 1992		July 1993	
			F-Value	Pr>F	F-Value	Pr>F
NO ₃ ⁻ -N	Treatment	5	11.54	0.0001*	17.70	0.0001*
	Location	1	4.81	0.0425*	36.14	0.0001*
	Trt * Loc	5	0.59	0.7092	4.26	0.0099*
NH ₄ ⁺ -N	Treatment	5	2.07	0.1258	0.95	0.4796
	Location	1	1.26	0.2764	3.29	0.0865
	Trt * Loc	5	0.88	0.5125	0.39	0.8495
P	Treatment	5	2.43	0.0875	3.87	0.0189*
	Location	1	1.42	0.2505	0.11	0.7443
	Trt * Loc	5	0.71	0.6272	0.47	0.7949
K	Treatment	5	6.37	0.0023*	0.90	0.5062
	Location	1	5.22	0.0346*	7.02	0.0163*
	Trt * Loc	5	2.86	0.0453*	2.00	0.1272
Ca	Treatment	5	0.58	0.7150	0.49	0.7763
	Location	1	1.77	0.1998	0.01	0.9240
	Trt * Loc	5	1.06	0.4139	0.41	0.8384
Mg	Treatment	5	0.40	0.8390	0.99	0.4587
	Location	1	0.05	0.8287	3.31	0.0855
	Trt * Loc	5	0.49	0.7788	0.78	0.5786

* denotes significant at 0.05 level of probability.

Appendix 8.2 Analysis of variance for soil nutrients below Ah horizon to 0.20 m depth in Orchard 1 in July 1992 and 1993.

Nutrient	Source	D.F.	July 1992		July 1993	
			F-Value	Pr>F	F-Value	Pr>F
NO ₃ ⁻ -N	Treatment	5	9.18	0.0006*	9.81	0.0003*
	Location	1	2.32	0.1562	6.05	0.0243*
	Trt * Loc	5	1.25	0.3494	5.01	0.0047*
NH ₄ ⁺ -N	Treatment	5	1.32	0.3144	4.17	0.0142*
	Location	1	0.02	0.8891	5.00	0.0382*
	Trt * Loc	5	0.85	0.5406	16.27	0.0001*
P	Treatment	5	0.50	0.7691	5.38	0.0050*
	Location	1	0.68	0.4268	0.14	0.7103
	Trt * Loc	5	0.68	0.6494	2.66	0.0571
K	Treatment	5	0.72	0.6227	2.95	0.0475*
	Location	1	3.13	0.1021	0.03	0.8565
	Trt * Loc	5	4.15	0.0201*	2.40	0.0778
Ca	Treatment	5	0.72	0.6181	3.09	0.0408*
	Location	1	0.15	0.7073	1.80	0.1964
	Trt * Loc	5	0.48	0.7812	0.95	0.4745
Mg	Treatment	5	0.96	0.4785	4.83	0.0079*
	Location	1	0.15	0.7068	4.60	0.0458*
	Trt * Loc	5	0.63	0.6777	1.54	0.2262

* denotes significant at 0.05 level of probability.

Appendix 8.3 Analysis of variance for soil nutrients in Ah horizon in Orchard 2 in July 1992 and 1993.

Nutrient	Source	D.F.	July 1992		July 1993	
			F-Value	Pr>F	F-Value	Pr>F
NO ₃ ⁻ -N	Treatment	5	18.37	0.0001*	18.48	0.0001*
	Location	1	19.03	0.0004*	1.69	0.2097
	Trt * Loc	5	1.88	0.1502	0.42	0.8318
NH ₄ ⁺ -N	Treatment	5	0.64	0.6729	0.88	0.5199
	Location	1	1.24	0.2805	2.90	0.1056
	Trt * Loc	5	1.05	0.4207	0.44	0.8155
P	Treatment	5	4.47	0.0108*	9.33	0.0003*
	Location	1	8.98	0.0078*	7.61	0.0129*
	Trt * Loc	5	1.56	0.2216	0.79	0.5688
K	Treatment	5	4.68	0.0090*	8.28	0.0006*
	Location	1	2.36	0.1418	7.54	0.0133*
	Trt * Loc	5	1.38	0.2781	0.80	0.5664
Ca	Treatment	5	0.55	0.7346	1.61	0.2181
	Location	1	2.00	0.1744	4.63	0.0453*
	Trt * Loc	5	0.60	0.7029	1.12	0.3857
Mg	Treatment	5	0.99	0.4540	3.73	0.0215*
	Location	1	1.00	0.3308	8.21	0.0103*
	Trt * Loc	5	0.80	0.5645	1.00	0.4484

* denotes significant at 0.05 level of probability.

Appendix 8.4 Analysis of variance for soil nutrients below Ah horizon to 0.30 m depth in Orchard 2 in July 1992 and 1993.

Nutrient	Source	D.F.	July 1992		July 1993	
			F-Value	Pr>F	F-Value	Pr>F
NO ₃ -N	Treatment	5	19.12	0.0001*	21.22	0.0001*
	Location	1	2.48	0.1348	0.16	0.6915
	Trt * Loc	5	1.04	0.4272	0.88	0.5118
NH ₄ ⁺ -N	Treatment	5	2.93	0.0484*	9.41	0.0003*
	Location	1	0.47	0.5006	0.10	0.7578
	Trt * Loc	5	0.34	0.8836	2.90	0.0433*
P	Treatment	5	1.39	0.2828	10.29	0.0002*
	Location	1	1.77	0.2007	1.66	0.2136
	Trt * Loc	5	0.92	0.4904	2.33	0.0850
K	Treatment	5	1.79	0.1762	7.42	0.0011*
	Location	1	0.08	0.7849	7.20	0.0152*
	Trt * Loc	5	0.79	0.5739	3.47	0.0227*
Ca	Treatment	5	2.57	0.0696	9.07	0.0004*
	Location	1	1.05	0.3202	3.09	0.0958
	Trt * Loc	5	0.68	0.6439	3.33	0.0264*
Mg	Treatment	5	2.10	0.1214	9.62	0.0003*
	Location	1	1.02	0.3259	3.32	0.0851
	Trt * Loc	5	0.36	0.8702	4.35	0.0090*

* denotes significant at 0.05 level of probability.

Appendix 8.5 Analysis of variance for NO_3^- -N and NH_4^+ -N in Ah horizon in Orchards 1 and 2 in September 1992 and 1993.

Nutrient	Source	D.F.	September 1992		September 1993	
			F-Value	Pr>F	F-Value	Pr>F
Orchard 1						
NO ₃ ⁻ -N	Treatment	5	13.46	0.0001*	11.93	0.0001*
	Location	1	1.64	0.2170	6.77	0.0180*
	Tri * Loc	5	1.60	0.2137	0.75	0.5957
NH ₄ ⁺ -N	Treatment	5	0.40	0.8393	0.50	0.7734
	Location	1	0.17	0.6876	1.67	0.2128
	Trt * Loc	5	2.57	0.0682	1.08	0.4047
Orchard 2						
NO ₃ ⁻ -N	Treatment	5	13.49	0.0001*	31.35	0.0001*
	Location	1	4.68	0.0450*	0.80	0.3835
	Trt * Loc	5	3.21	0.0319*	1.46	0.2509
NH ₄ ⁺ -N	Treatment	5	2.32	0.0943	3.33	0.0322*
	Location	1	0.78	0.3908	2.00	0.1742
	Trt * Loc	5	0.65	0.6640	1.50	0.2382

* denotes significant at 0.05 level of probability.

Appendix 8.6 Analysis of variance for soil nutrients below Ah horizon to 0.30 m depth in Orchards 1 and 2 in September 1992 and 1993.

Nutrient	Source	D.F.	September 1992		September 1993	
			F-Value	Pr>F	F-Value	Pr>F
Orchard 1						
NO ₃ ⁻ -N	Treatment	5	8.52	0.0032*	9.95	0.0002*
	Location	1	0.26	0.6376	26.89	0.0001*
	Trt * Loc	5	1.54	0.3491	5.05	0.0046*
NH ₄ ⁺ -N	Treatment	5	0.77	0.5934	2.70	0.0621
	Location	1	0.21	0.6708	0.63	0.4372
	Trt * Loc	5	0.96	0.5319	2.96	0.0401
Orchard 2						
NO ₃ ⁻ -N	Treatment	5	3.83	0.0263*	14.45	0.0001*
	Location	1	2.75	0.1284	0.34	0.5698
	Trt * Loc	5	0.77	0.5918	1.00	0.4476
NH ₄ ⁺ -N	Treatment	5	0.44	0.8157	1.64	0.2096
	Location	1	8.95	0.0135*	0.34	0.5692
	Trt * Loc	5	0.88	0.5307	1.54	0.2258

* denotes significant at 0.05 level of probability.

Appendix 8.7 Analysis of variance for bulk density in the Ah horizon in Orchards 1 and 2 in July 1992 and 1993.

Orchard	Date	Source	D.F.	July		September	
				F-Value	Pr>F	F-Value	Pr>F
1	1992	Treatment	5	1.58	0.2247	0.35	0.8756
		Location	1	1.31	0.2675	2.53	0.1293
		Trt * Loc	5	1.22	0.3380	0.87	0.5177
1	1993	Treatment	5	2.87	0.0515	1.76	0.1235
		Location	1	0.07	0.7886	0.67	0.3496
		Trt * Loc	5	0.99	0.4518	1.24	0.2716
2	1992	Treatment	5	3.11	0.0399*	1.26	0.3294
		Location	1	7.72	0.0124*	2.41	0.1382
		Trt * Loc	5	0.77	0.5837	0.38	0.8534
2	1993	Treatment	5	2.70	0.0624	2.21	0.1113
		Location	1	4.59	0.0460*	3.99	0.0836
		Trt * Loc	5	0.14	0.9798	0.69	0.6823

* denotes significant at 0.05 level of probability.

Appendix 8.8 Analysis of variance for bulk density below the Ah horizon to 0.30 m depth in Orchards 1 and 2 in July 1992 and 1993.

Orchard	Date	Source	D.F.	July		September	
				F-Value	Pr>F	F-Value	Pr>F
1	1992	Treatment	5	0.34	0.8815	2.10	0.1572
		Location	1	0.73	0.4096	2.85	0.1667
		Trt * Loc	5	1.12	0.3991	2.98	0.1559
1	1993	Treatment	5	1.06	0.4200	1.54	0.2149
		Location	1	2.82	0.1103	2.96	0.0947
		Trt * Loc	5	2.67	0.0566	2.37	0.1057
2	1992	Treatment	5	0.53	0.7496	0.23	0.9446
		Location	1	0.52	0.4786	0.57	0.4661
		Trt * Loc	5	0.96	0.4711	1.37	0.3084
2	1993	Treatment	5	1.09	0.4045	0.96	0.5921
		Location	1	1.28	0.2729	1.54	0.1627
		Trt * Loc	5	0.43	0.8184	0.87	0.6668

Appendix 8.9 Analysis of variance for soil temperature in Orchards 1 and 2 in 1992 and 1993.

Orchard	Date	Source	D.F.	F-Value	Pr>F	Adj. Pr>F	
						G-G	H-F
1	1992	Trt.	5	85	0.0001	-	-
		Time	5	3700	0.0001	0.0001	0.0001
		Trt. * Time	25	39	0.0001	0.0001	0.0001
1	1993	Trt.	5	76	0.0001	-	-
		Time	5	870	0.0001	0.0001	0.0001
		Trt. * Time	25	4.8	0.0001	0.0001	0.0001
2	1992	Trt.	5	42	0.0001	-	-
		Time	5	3100	0.0001	0.0001	0.0001
		Trt. * Time	25	51	0.0001	0.0001	0.0001
2	1993	Trt.	5	58	0.0001	-	-
		Time	5	1800	0.0001	0.0001	0.0001
		Trt. * Time	25	12	0.0001	0.0001	0.0001

<u>Orchard</u>	<u>Date</u>	<u>G-G Epsilon</u>	<u>H-F Epsilon</u>
1	1992	0.75	1.6
1	1993	0.66	1.3
2	1992	0.69	1.4
2	1993	0.59	1.1

Appendix 8.10 Analysis of variance for soil volumetric water content in Orchards 1 and 2 in 1993.

Orchard	Date	Source	D.F.	F-Value	Pr>F	Adj. Pr>F	
						G-G	H-F
1	1993	Trt.	5	51	0.0001	-	-
		Time	5	82	0.0001	0.0001	0.0001
		Trt. * Time	25	5.4	0.0001	0.0001	0.0001
2	1993	Trt.	5	38	0.0001	-	-
		Time	5	165	0.0001	0.0001	0.0001
		Trt. * Time	25	3.6	0.0001	0.0004	0.0001

<u>Orchard</u>	<u>Date</u>	<u>G-G Epsilon</u>	<u>H-F Epsilon</u>
1	1993	0.70	1.4
2	1993	0.59	1.1

Appendix 8.11 Analysis of variance for aggregate stability in Orchards 1 and 2 in 1992 and 1993.

Orchard	Date	Source	D.F.	F-Value	Pr>F
1	1992	Trt.	5	4.1	0.0173*
1	1993	Trt.	5	0.98	0.4623
2	1992	Trt.	5	6.2	0.0027*
2	1993	Trt.	5	5.4	0.0047*

* denotes significant at 0.05 level of probability.

Appendix 8.12 Analysis of variance for leaf nutrient contents in Orchards 1 and 2 in 1992 and 1993.

Nutrient	Source	D.F.	1992		1993	
			F-Value	Pr>F	F-Value	Pr>F
Orchard 1						
N	Treatment	5	3.6	0.0240*	2.5	0.0765
P	Treatment	5	2.0	0.1296	2.3	0.0960
K	Treatment	5	9.2	0.0004*	6.9	0.0016*
Ca	Treatment	5	1.7	0.1994	2.6	0.0662
Mg	Treatment	5	4.5	0.0107*	8.5	0.0006*
Orchard 2						
N	Treatment	5	9.0	0.0001*	10	0.0002*
P	Treatment	5	15	0.0001*	3.9	0.0190*
K	Treatment	5	12	0.0001*	3.4	0.0307*
Ca	Treatment	5	0.92	0.4952	1.4	0.2791
Mg	Treatment	5	5.5	0.0044*	6.8	0.0017*

* denotes significant at 0.05 level of probability.

Appendix 8.13 Analysis of variance for apple nutrient contents in Orchard 3 in 1992 and 1993.

Nutrient	Source	D.F.	1992		1993	
			F-Value	Pr>F	F-Value	Pr>F
Orchard 3						
N	Treatment	3	9.1	0.0510	1.3	0.4057
P	Treatment	3	0.04	0.9884	1.5	0.3780
K	Treatment	3	1.7	0.3401	1.4	0.3933
Ca	Treatment	3	0.37	0.7803	0.38	0.7753
Mg	Treatment	3	2.7	0.2205	1.3	0.4135

Appendix 9

Comments on Repeated Measures Analysis of Data

In the past it has been common practice in agricultural research to analyze experiments with repeated measurements on the same experimental unit as split-plot designs. The problem with a "split-plot" approach is that the repeated measurements (time or locations) cannot be randomly assigned to the sub-plot factors. Since time and spatial variables are assigned systematically, repeated measures experiments do not accommodate the assumptions of true split-plot univariate designs. Thus any repeated measures experiment analyzed by split-plot analysis might increase type I errors through inflated F-values.

When repeated measures experiments are analyzed as split-plot designs it is assumed that all the repeated measurements have the same variance and that the correlation between any pair of measurements is the same. This condition is called compound symmetry. Typically, because of their covariance structure, repeated measures experiments violate this condition since measurements taken close together in time or space will be more highly correlated than measurements taken farther apart.

The condition of compound symmetry is often more strict than needed. A more pragmatic condition is the or H-F condition. For this prerequisite, any set of orthogonal contrasts among the repeated measures must have equal variances and

zero covariances. The H-F condition can be tested using a sphericity test and is available in SAS procedure GLM.

If repeated measures data satisfy the H-F condition (sphericity test not significant) then univariate F-tests are legitimate, and should be used given the elevated power of the tests. Note that experiments which have only two levels of the repeated measure automatically satisfy the H-F condition.

If data violate the H-F condition there are two options. Multivariate analysis is appropriate since this type of analysis requires no assumptions about the covariance arrangement of the repeated measures factors. This generality, however, results in multivariate tests having low power. A balance between univariate and multivariate F-tests is to decrease the degrees of freedom of the univariate test. Two such adjustments are the Greenhouse and Giser (G-G) and Huynh and Feldt (H-F) epsilon. Both methods formulate an epsilon and multiply the numerator and denominator by the epsilon before F-test calculations are made. The G-G and H-F epsilon are both provided in SAS Proc GLM procedure.