AN ABSTRACT OF THE THESIS OF

Braja Bandhu Datta for the degree of Master of Science in Horticulture presented on March 12, 1996, Title: Multiple Pest Suppression with Cover Crops in Strawberry.

Abstract approved: ______________________
Ray D William

The experiment was conducted to compare multiple pest (weed, soil arthropod and diseases) suppression by cereal cover crops in 'Selva' and 'Totem' strawberry. In addition, perlite was used to compare improvement of soil and root aeration which might modify strawberry black root rot complex.

Small-seeded summer annual weeds were suppressed in cover crop treatments compared to control treatment. 'Micah' barley in growth phase suppressed more than 81% of the total weeds compared to control plots with no cover crop in early spring. Small seeded weeds and perennial thistles were suppressed with 'Wheeler' rye residues. In early summer, cover crop residues failed to suppress different types of weeds 60 days after killing of cereal with herbicide. In summer, total weed biomass was variable due to the biomass of pigweed. Pigweed density was not significantly different compared to control treatment both within and between rows of strawberry.

Cover crops suppressed symphylan 62 to 87%, except 'Micah' barley (25%). No pattern was found on total soil arthropods including beneficial insects due to treatments. Fewer gray mold (*Botrytis cinerea* Fr.) infected fruits were evident in all cover crop treatments compared to control treatment. Strawberry in 'Wheeler' rye was least (21% only) infected in both cultivars which might suggest suppression of gray mold. Perlite treatments enhanced new root growth while all cereal cover crops suppressed strawberry black root rot complex slightly. No evidence was found in suppression of black root rot in the greenhouse study.

Distinct differences in strawberry plant growth were evident between the cover crop treatments and non-cover crop treatments including 'Micah' applied on surface. Strawberry growth was doubled during July 10 to August 15 in both cultivars. 'Micah' barley applied on surface produced better growth in both 'Selva' and 'Totem' strawberry than the growth in other treatments. No significant difference was found on leaflet length, leaf and runner number among treatments. Crown numbers per plant in 'Selva' on November 27 indicated significant differences in 'Micah' on surface that produced 36% more crowns per plant than that of any other treatment. 'Micah' barley applied on surface produced 50% more shoot biomass and about 45% greater yield compared to 'Micah' barley planted in the plot. Cover crop treatments alone reduced total strawberry yield (kg/ha) slightly in 'Selva' in the establishment year compared to the control treatment. Total strawberry yield was variable among treatments where 'Micah' barley on surface produced greatest yield. Average fruit weight per berry (g/fruit) was greater in the perlite alone next to control treatment. Small fruit size was produced in main cover crop treatments, whereas 'Micah' on surface increased yield. Total 'Selva' yield was 61% greater in perlite treatment than the yield in perlite with 'Wheeler' rye treatment and 31% greater than the control treatment. Early season marketable fruits, total number of fruits and total yield were lower in control and 'Wheeler' rye treatments.

Multiple Pest Suppression with Cover Crops in Strawberry

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Braja Bandhu Datta, Author

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Dedicated to
my parents for
wonderful diversified world

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Chapter I

INTRODUCTION

The commercial strawberry, *Fragaria x ananassa* Duch., originated as an accidental hybrid of the wild new world species *F. chiloensis* and *F. virginiana* in a European botanical garden approximately 250 years ago. Most notably, the movement of day-neutrality from *F. virginiana* into the cultivated strawberry created the opportunity for year-round production. Recent collections of native material have uncovered a wide range of potentially useful traits in both *F. virginiana* and *F. chiloensis*, including architecture, disease and pest resistance, frost tolerance, fruit quality, photoperiod, photosynthetic rate, and yield (Hancock et. al., 1993; Westwood, 1993).

Diversity is the dominant feature of Oregon's largest agricultural industry, where high-value horticultural specialty crops are the largest component (47%). Oregon ranks among the top four states in U. S. production of berry crops. In 1993, strawberry produced largest amount (33%; $50.8 million) of the total wholesale value among the berry crops in Oregon (Crabtree et. al., 1994). California is the most dominant producer of fresh market strawberry but Oregon strawberries are processed because of their superior quality of color, texture and flavor.

Many aspects of strawberry production have been improved through breeding and alternative cultural practices. Mulching is one of the most important practices, especially for fruit quality maintenance. Growers on sloping land in Oregon plant winter soil covers to minimize soil erosion. Mulching strawberry plants for winter protection is a recommended cultural practice in the cold climates to prevent cold injury. Cover crop residues used as a mulch have potential as management tools in vegetable cropping systems (Leather, 1983; Putnam, 1986). Fall-planted cover crops killed in spring is practiced in strawberry cultivation in different regions of the United States. These systems have shown significant weed suppression and conservation of soil moisture without significant yield reduction in strawberry.

Strawberry plant growth is a biological phenomenon involving multiple level of organization. These can be divided as molecules, organelles, cells, tissue, component organs (individual leaf etc.), main organs (root, stem, foliage etc.) and the whole plant. The study was done on main organ system and whole plant level of strawberry. The superior quality of Oregon's strawberry is largely attributed to the cultivars grown and the mild climate of the Willamette valley.

The studies were initiated in order to gain a better understanding of multiple pest (weeds, soil arthropods, diseases and others) suppression with cover crops in strawberry in the establishment season. Also, strawberry plant growth as influenced by spring planted cover crops was evaluated. Cover crop growth and development were evaluated in the first experiment along with perlite, an artificial soil medium that provides better soil aeration. The effect of soil cover on weed suppression also was evaluated. Consecutive studies were done in the same field by planting strawberry. 'Totem' strawberry, a Junebearer, the major cultivar grown in Oregon and the Pacific Northwest of the United States and 'Selva', a day-neutral variety, for the fresh market from California were used in this experiment.

Chapter II

REVIEW OF LITERATURE

A. Cereal cover crops, weed and allelopathy

A.1. Cereal cover crop growth and development:

Cover cropping is an old practice that involves the growing of a crop such as cereals, legumes and/or other crops, primarily for soil cover or to improve and conserve soil quality by adding organic matter (Akobundu and Okigbo, 1984; Putnam, 1990; Power and Biederbeck, 1991). Cover crops also contribute to the management of weeds, insect pests and plant pathogens (William, 1981; Lal et. al., 1991; Luna, 1993). Cover crops can be grown as perennials or annuals depending on the cropping system. Grass sods are commonly used in perennial cropping system such as tree fruits, caneberries and grapes, whereas annual cover crops are used in annual cropping system, especially in vegetables. In Oregon, cover cropping in strawberry production is practiced only on sloping land where barley is planted between rows in fall to reduce soil erosion.

A survey of green manure/cover crop growers in Latin America, Asia, Africa and Oceania revealed less popularity in that region (Yost and Evans, 1988). However, annual cover crops along with proper management practices might have the potential to enhance horticultural cropping systems (William, 1989). The effective use of cover crop requires careful examination of crop production objectives in relation to soil and climate (Bruce et. al., 1991).

Annual cover crops may be classified as winter annual cover and warm season cover. Winter covers are generally planted in fall and killed in the spring before planting main crop such as cereal rye (*Secale cereale* L.), barley (*Hordium vulgare* L.), oat *(Avena sativa* L.), ryegrass (*Lollium* spp.), hairy vetch (*Vicia vilosa* Roth.), Austrian peas (*Pisum sativum* Poir.), crimson clover (*Trifolium incarnatum* L.) and others. Warm season covers are used to plant during the summer fallow period. These include buckwheat *(Fagopyrum esculentum* Moench), sudangrass (*Sorghum bicolor* cv. sudanese) and others. (Angustia, 1995).

Rye (*Secale cereale* L.) is a winter hardy, erect, herbaceous plant that grows well on marginal soils. It is a long day plant capable of developing an extensive root system that reduces soil erosion and nutrient loss (Nuttonson, 1958). In the Mid-western and Pacific Northwest of the United States, rye is widely grown as a cereal, interplanted with legume in winter pastures, or tilled as a green manure crop (Amador and Gliessman, 1990).

In Kentucky, establishment and management of cover crops were evaluated where 'Wheeler' rye, 'Barsoy' barley, and 'Tyler' wheat cereal grains produced greater biomass (180 to 260 g/m2) than the pasture species tall fescue, creeping red fescue and white clover. Glyphosate applied at 1.1 and 2.2

kg ai/ha was also effective, while 0.6 kg ai/ha controlled only cereal grain growth adequately (Weston, 1990).

A.2. Weed and cereal cover crops:

Weeds, a category of vegetation, are described as plants that are competitive, persistent and interfere with human activities. Dr. Crafts (1975) meant that weeds did not exist before the human ability to judge and select among the various species of the plant kingdom. For this reason, weeds are now considered as one of the important pests that have impact on worldwide crop production (Ross and Lembi, 1985; Radosevich and Holt, 1984).

Considering true weeds, only 3 percent of the total plant species (about 250,000 species) behave as weeds; about 250 species or 0.1 percent of the total plants species are recognized as major problem weeds in the world of agriculture. In fact, only 0.01 percent or 25 species cause major problems in any one crop production system (Holm et. al., 1977; Radosevich and Holt, 1984).

Since the late 1970s, numerous reports indicate that residues of fall-seeded small grains provide a measurable level of weed control in successive vegetables (Phatak, 1992; Putnam, 1990). Cover crops are generally sown in the late summer or fall and killed by frost, mowing or with herbicides the following spring prior to planting a designated vegetable. Residues from cover crops would suppress weeds by their physical presence on the soil surface and possibly through the transient release of allelochemicals. About 90% weed suppression was noted 60 days after the termination of winter rye cover crop growth in vegetable production system (Putnam et. al., 1983; Smeda and Weston, 1995). Many researchers have found that production of large-seeded vegetables (pumpkin, snap beans, peas, cucumbers, etc.) in cover crop residues was successful (Peachey, et al., 1993; Putnam and DeFrank, 1983;), whereas lack of establishment or injury occurred in lettuce, radish and tomato (Overland, 1966; Masiunas et. al., 1995).

The effect of rye, wheat and triticale cover crop mulches on weed emergence patterns, weed biomass, and soybean development were studied where red root pigweed (*Amaranthus retroflexus*) and common lambsquarters (*Chenopodium album*) emergence patterns were not altered by mulches. Early in the season, mulches reduced weed biomass. Under weed-free conditions, cover crop mulches had no detrimental effects on soybean development and yields were not different from bare soil control (Moore et. al., 1994).

Field experiments were conducted to determine the effect of a short-term spring-seeded smother plant (yellow mustard) on corn development and weed control. These results suggest that it may be possible to develop spring-seeded smother plants that reduce weed biomass up to 80% but have only a small impact on corn yield (De-Haan et. al., 1994).

Flemingia macrophylla is a multipurpose tree which is especially useful for mulching, weed control and soil protection due to the slow decomposition rate of its leaves, its dense growth, drought tolerance, ability to withstand flooding and coppicing. Notes are given on its botany, ecology, weed control properties, biomass production, fodder value, alley cropping systems and as a cover crop, other uses (as fuelwood, host to the lac insect, source of an orange dye, medicinal applications), establishment, and pests and problems (Budelman, 1989).

Weed management systems were studied in *Phaseolus vulgaris* cv. 'Montcalm red' with cover crop and other practices. Barley was sown as a cover crop at 125 kg/ha and killed with glyphosate at 0.4 kg before sowing *P. vulgaris*. Hairy nightshade (*Solanum sarrachoides*) increased rapidly when weed management methods (hand hoeing) were reduced. It was concluded that *P. vulgaris* is an economical crop for North Central growers, but adequate weed management technologies along with cover crops are necessary for profitable production (Burnside et. al., 1993).

In Minnesota, winter rye was either autumn-sown into small grain stubble in a no-till system or was spring-sown into prepared seed beds. Soybean was tolerant of the cover crop, provided soil water was adequate, and weed control of 50-90% was achieved, with the autumn-sown rye generally giving best control. Autumn- and spring-sown rye had less available soil water in June of both 1989 and 1990 than a hand-weeded control. It was concluded that about 38 cm of available water was needed to produce soybean yields in the rye system equivalent to those from a hand-weeded control; however, with more than 50 cm, the autumn-sown rye system may be beneficial (Warnes et. al., 1991; Helsel et. al., 1991).

In Kentucky, Wheeler rye, Barsoy barley and Tyler wheat produced greater biomass (180-260 g/m2) for establishment and management in vegetable systems. Cereal grain covers provided the best situations for seedling establishment, with rye and wheat providing greatest weed suppression. Cucumber was the most easily established while peas were the most difficult (Weston, 1990).

Comparing reduced input using rye with conventional management systems, *Phaseolus vulgaris* yields were 58-76% lower in the reduced input system than in the conventional system. Lower yields were attributed to greater weed competition, inadequate N nutrition, reduced seed quality, and reduced crop population density. Soil compaction, allelopathy, and other factors also may have decreased yields. Use of the reduced input system in place of the conventional system substantially decreased production costs, but also greatly lowered revenues because of lower yields (Liebman et. al., 1993).

An experiment was conducted to determine the light, soil temperature, and soil moisture conditions under cover crop residues of hairy vetch (*Vicia villosa*) and rye (*Secale cereale*). Soil maximum temperature and daily soil temperature amplitude were reduced by cover crop residue. Residue prevented the decline of soil water content during drought periods. Results indicated that reductions in light transmitance and daily soil temperature amplitude by cover crop residue were sufficient to reduce emergence of weeds but that maintenance of soil moisture could increase weed emergence (Teasdale and Mohler, 1993).

In broccoli, aphid infestation on harvested broccoli heads was consistently less in leguminous cover crops than under clean cultivation. With compost, leaf water content was lower in the clean cultivated treatment than with living mulch, probably because low soil N levels limited root growth and therefore restricted water uptake. Broccoli head size and yields were similar with living mulches and clean cultivation in synthetic fertilizer plots (Costello, 1994).

Spring dry pea *(Pisum sativum* L.) is considered to be a biologically important pulse crop grown in the Pacific Northwest and Canada. An integrated pest management field study was done over 6 years to assist growers in adopting conservation cropping practices for spring dry peas. The influence of three weed management levels and two tillage regimes on the productivity of spring pea were observed in a winter wheat (*Triticum aestivum* L.)-spring barley (*Hordeum vulgare* L.)-spring pea rotation. Yields of pea grown under conservation tillage were equal to or greater than yields in conventional tillage when averaged over weed management levels. The reduced tillage system on the integrated pest management project met conservation compliance for both planting pea into spring barley residue and planting winter wheat into pea residue. In addition to reducing erosion, the conservation pea production system did not increase herbicide use and cost substantially, thus maintaining environmental quality (Young et. al., 1994a & b).

A.3. Interaction or allelopathy and cover crop:

Plant interaction is usually associated with the negative effect of materials from one plant and subsequent absorption by the roots of another. However, movement of these plant materials involving one or two way of organic or inorganic metabolism, may be beneficial (Putnam and Duke, 1978, Rice, 1974). Leaching of metabolites from the above ground plant parts by rain, dew, and mist also was shown to be a source of movement of beneficial materials between plants (Tukey, 1966).

The effect of amensalism, a negative form of interference known as allelopathy in agriculture, on crop production occurs from the decomposition of plant parts in the soil or the production of toxins, allelochemicals by living mulch and their release into the environment of adjacent plants (Radosevich and Holt, 1984; Rice, 1974). Cover cropping with allelopathic plants like *Vicia faba*, barley, rye, or barley or rye intercropped with *V. faba* were sown after vegetable harvest in autumn and disced-in before sowing cabbages in May. All cover crops reduced weed biomass: rye with *V. faba* was the most effective and fresh cabbage yields were significantly greater with a *V. faba* crop than without a cover crop (Gliessman, 1989).

Many cover crops release allelochemicals at a significant level that reduce weed emergence (Andres and Clemont, 1984; Barnes and Putnam, 1983; Putnam et. al., 1983; Tukey, 1969). The maximum allelochemical concentration occurs within 20 days after rye decomposition begins (Chou and Patrick, 1976).

Surface residues of immature cereal grains were more inhibitory to the emergence of numerous summer annual weeds compared to mature cover crops. The author concluded that probable reason was release of inhibitors through quick decomposition (Putnam, 1988). Weed suppression from rye residues can last 30 to 75 days after the cover crop is killed, depending on initial rye biomass and environmental conditions (Putnam, 1986; Putnam and DeFrank, 1983). In Kentucky, cover crops were effective in suppressing weed growth at 45 days after chemical control. However, significant weed growth existed in all cover crop plots 60 days after killing (Weston, 1990).

Buckwheat (*Fagopyrum esculentum* Moench), grown as an economic crop or a cover crop, generally suppresses the growth of Canada thistle. An experiment with buckwheat indicates that the suppression of Canada thistle may be due to competition for resources and not allelopathy. Indirect evidence suggests that VAM fungus (*Glomusintra radices*) might also be involved in this process (Eskelsen and Crabtree, 1991).

Environmental factors influence allelochemical production in higher plants and also related biological activity (Rice, 1984; Tukey, 1969). Increased air temperatures enhanced allelochemical concentration and consequent inhibition of plant growth (Putnam and Tang, 1986; Rizvi and Rizvi, 1992). Fast growing plants in fertile environments contained lower allelochemical concentration than slow growing species in areas of limited fertility. Besides affecting allelochemical concentration, allelopathy was enhanced in soils of low fertility (Stowe and Osborne, 1980; Mwaja et. al., 1995).

B. Strawberry, cover crops and weeds

B.1. Strawberry and cover crop:

Mulching strawberry plants for winter protection is a recommended cultural practice in the cold climates to prevent cold injury (Angelo, 1939; Boyce and Smith 1967). Study on straw mulch with 'Midway' strawberry in Vermont, USA, produced the highest yields when mulch was removed as early in the spring as possible. Delaying the removal of mulch beyond the accumulation of approximately 120 degree day unit (base 40) resulted in significant yield reductions (Boyce et. al., 1988).

Sparkle and Honeoye strawberries planted with perennial ryegrass (*Lolium perenne*) produced higher yields with bigger fruit than in control plots in first year, but yields in subsequent years were similar in all treatments (Newenhouse and Dana, 1989).

Effects of row cover, mulching and nitrogen fertilizer on vegetative and fruit development of two day-neutral cultivars, Tribute and Tristar, were studied in Eastern Canada. Yield, fruit size, crown number and crown weight were not affected by fertilizer treatment. Similarly, row cover did not show any benefit, even with regard to lengthening of the harvesting season. Black polyethylene mulch increased yield but decreased fruit size compared with straw mulch (Lareau, et. al., 1991).

Using fall planted cover crops, weed growth was reduced by 80% to 95% in the early spring but decreased to 55% to 85% of control by mid summer. Strawberry yields were not significantly different between treatments; however, berry yields appeared somewhat reduced where cover crops were present (Smeda and Putnam, 1988). Research showed strawberry plant dry matter and leaf area development stopped in October, suggesting cover crops planted at this time might not interfere with strawberry vegetative growth in Oregon (Olsen et. al., 1985).

B.2. Weed management in strawberry:

All strawberry plants including those interplanted with perennial ryegrass (*Lolium perenne*) grew at similar rates during the establishment year, although plants grown in living mulch plots had smaller leaves than plants in control plots. Living mulch prevented annual weed establishment. A tillering type of ryegrass was the best living mulch that quickly covered the ground but did not spread into the crop rows, and grew tall enough to afford wind protection (Newenhouse and Dana, 1989).

Grass straw mulches (orchard grass and red fescue including viable seeds) were applied to established strawberry plants to reduce weed growth in combination with herbicides. These treatments showed promising results providing no viable grass seed in the mulch (Stahler and Crabtree, 1993). In red raspberries, cereal cover crops planted in fall also showed promising results of weed suppression without reducing yield (Kaufman et. al., 1993).

In a newly-planted strawberry field, sheep sorrel (*Rumex acetosella*) competed with the crop, especially inhibiting the rooting of stolons from June to October, and it also slowed the development of parent rosettes. After the first harvest, weed infestations decreased strawberry yields by as much as 50%, and delayed maturation of fruits. The detrimental effects of sheep sorrel on the strawberry crop were increased under irrigation (Vezina and Bouchard, 1989).

C. Morphology and physiology of strawberry plant parts

The cultivated strawberry (*Fragaria x ananassa* Duch.) belongs to family Rosaceae. It is an octaploid (2n=56) perennial herb characterized as leaves and flowers in a basal tuft, giving off prostrate stems or runners. Berry-like fruits are formed with an enlarged receptacle which bears the minute seed-like achenes (Jepson, 1951).

C.1. Roots:

Strawberry has an adventitious root system where roots emerge from the base of new leaves along the crown of strawberry rootstock. This maintains the perennial nature of this crop (Dana, 1980). Roots will not emerge unless they are in contact with or at least partially covered by moist soil. A mature strawberry plant usually has 20 to 35 primary roots, sometimes that exceed as many as 100. The secondary rootlets branch from the primary roots and absorb most of the nutrients and water (Strik, 1996).

Primary roots survive approximately one year. They may survive for a longer period under favorable circumstances. In stress or disease-infected conditions, they may only survive a few weeks. Primary roots are called the soil-penetrating roots. They may penetrate soils to a depth of 100-105 cm (Hanson, 1931; Huges, 1965). About 50 to 90% of the total root system is found within the upper 15 cm of soil and 25 to 50% of the roots are in the upper 7.5 cm (Rom and Dana, 1960; Galletta and Bringhurst, 1990).

Environmental factors within 15 cm of surface soil is the most critical for strawberry plant growth. Size of the root system depends on natural vigor of rootstock and the conditions set up for plant growth and development. In matted row system, mother and daughter plants may have relatively short, small root systems due to reduced individual plant size (Galletta and Bringhurst, 1990). The color and consistency of the central vascular cylinder (the stele) of strawberry roots are often used as the indicators of root and plant health (Marini and Boyce, 1977). Types and condition of soil have great influence on root growth and penetration. Usually lighter or well cultivated porous soil increases root penetration compared to less porous soil (Galletta and Bringhurst, 1990).

C.2. Stems or crowns:

The strawberry appears to be an acaulescent (stemless, with leaves and flowers arising from a basal turf) perennial herb. Strawberry stem is compressed into a rosetted crown about 2.5 cm long. The outside is covered by overlapping leaf bases called stipules. The stem or crown produces leaves at close intervals along the determinate axis, flowers at the terminal position on the axis and roots from the base of the crown (Dana, 1980; Darrow, 1966).

Several axillary buds in the lateral and a terminal bud in the top position belong to the strawberry crown. Axillary buds may remain dormant or may extend to become runners. Sometimes these buds form branch crowns that relates to the subsequent development of the strawberry plant (Dana, 1980). Axillary buds also may form inflorescenes at the top of the shoot area after having two or more leaf primordia. The crown terminal bud bears five to seven developing leaves usually enclosed within the stipules of the last emerged leaf. After the terminal bud forms into an inflorescence, vegetative crown growth continues by the top most axillary bud (Galletta and Bringhurst, 1990; Arney, 1953 a & b).

Strawberry plants are sometimes considered as woody perennials and are less cold hardy than most fruit crops. Low temperature often reduces plant vigor and yield due to crown injury. Research has shown that crowns of many cultivars will be injured at temperatures of -6.6 to -3.9^{o}C and killed at -12.2 to -9.4^{o}C (Boyce and Reed, 1983; Boyce and Linde, 1986; Galletta and Bringhurst, 1990). Crowns may be injured showing brown tissues at low temperature from -16 to -8^{o}C and plants may be killed at -20^{o}C. As crown temperatures decrease below about -3.9^{o}C the extent of injury increases and yield decreases (Boyce and Smith, 1967; Marini and Boyce, 1977 & 1979). Tissue discoloration or degree of browning revealed by longitudinally cutting crowns also indicates low temperature injury (Angelo et. al., 1939).

C.3. Leaves:

Leaves of strawberry are compound pinnate and trifoliate, consisting of three leaflets attached to the main leaf stem or petiole. Each leaflet has its own stem or petiolule. Petioles are enlarged at the base to form a winged stipule that wraps around the crown. Upper leaf surfaces have characteristic colors varying from light green to very dark green. Lower leaf surfaces often contain a waxy layer with permanent veins. All leaf and petiole surfaces have amounts and types of hairiness that are characteristic of clone and plant age (Galletta and Bringhurst, 1990).

The number of leaves and the leaf area on plants in the fall has been positively correlated with fruit production in the following year (Morrow and Darrow, 1940; Sproat et. al., 1935; Strik and Proctor, 1988a). The terminal vegetative axis carries 5 to 10 unexpended leaves, or primordia. Number of primordia increase during the winter dormancy period (Arney, 1955a & 1955b).

Strawberry leaves may live from 1 to 3 months varying widely in thickness, area and cuticle thickness. Leaves are capable of high water use and wilt easily due to large number of stomata and inter-cellular areas. Leaf and secondary roots may die in warm and dry periods (Galletta and Bringhurst, 1990).

In an experiment, polyethylene film cover advanced flowering and fruiting in strawberry on different dates between October and December. Petiole extension in Josaenghongsim and Chodong strawberry was little affected by covering. Authors concluded that the later the covering, the larger the petioles, especially under artificial long days (Schmitz and Lenz, 1989).

C.4. Runners:

New strawberry plants called 'daughter' plants, develop along runners or the stolons that grow from axillary buds of the crown. One or two leaf stipules develop at the first node on the runner, which is often called the 'blind node' because it usually does not form a plant. Leaves and roots develop at the second node of the runner and succeeding nodes are closely spaced together, forming the crown of a daughter plant. In fruit production plantings, runners are removed to encourage development of branch crowns and flower buds. The number of runners is greater with plant vigor, which is promoted by large amounts of chilling. Day-neutral cultivars usually produce fewer runners than short day cultivars (Pritts and Worden, 1988; Anonymous, 1994).

Production of runners, dry weight of plant and leaf number and yield all decreased as planting date was delayed from 16 May to 7 September using freshly harvested runners and frigo plants, that is cold-stored runners (Schmitz and Lenz, 1989).

In a trial comparing the effects of lifting runners late in mid-September, mid-October or mid-November, the balance between vegetative and generative growth was disturbed and yield/m^2 were depressed by lifting at all dates, compared with non-lifted controls remaining in the beds. In plant propagation trials, within-row row distances of 10-25 and 15-30 cm yield/plant declined with closer planting, but yield/ m^2 was highest with the closest spacing (Wijsmuller and Dijkstra, 1991).

C.5. Flower bud initiation:

Strawberry flower bud initiation is a complex physiological process. As a perennial plant, it has to be balanced in its vegetative growth and reproduction (Strik, 1985). The transition from vegetative to floral growth is regulated by photoperiod and temperature. When flower initiation begins, the first indication is broadening and flattening of the apex, with the terminal flower appearing first (Guttridge, 1952; Ruef and Richey, 1926; Durner and Polling, 1988).

According to flower bud initiation and development, the strawberry falls into three categories; those produce flower and fruit once, twice or more than twice per year. These are Junebearers, a short-day plant; everbearers or long-day plants and day-neutrals that essentially are not affected by photoperiod (Darrow and Waldo, 1934).

Junebearers initiate flowers in the late fall, usually prior to harvest; primarily a through true photoperiodic stimulus. There is evidence that no new flower buds initiate for the Junebearer in spring (Darrow and Waldo, 1934; Robertson and Wood, 1954; Durner and Polling, 1988). Flower buds in Junebearers occur in late September or early October in North America at the same time regardless of plant age (Hill and Davis, 1929; Jahn and Dana, 1969; Schilletter and Richey, 1930 & 1931).

Everbearing cultivars, are long-day plants and generally initiate flower buds throughout the growing season except during the early spring when initial fruiting takes place (Darrow and Waldo, 1934). Initiation usually takes place in the primary terminal meristem. Axillary flower buds seldom develop to maturity (Guttridge, 1952).

Day-neutral cultivars initiate flower buds throughout the growing season, unless temperatures exceed approximately 86 ^{o}F (Darrow and Waldo, 1934). At high temperatures floral initiation is greatly inhibited (Durner et. al, 1984). Day neutral plants produce flowers and runners simultaneously (Strik, 1985).

C.6. Flower and inflorescence:

Strawberry flowers consist of both male and female sexual parts that grow on a young stem and expanding from the crown known as inflorescence. Guttridge (1985) stated that inflorescences are as 'a dichasial cyme, which is very variable in detailed structure'. A dichasium is a determinate cluster of flowers that arises from a common peduncle by dichotomous branching immediately beneath the terminal flower.

The floral axis of the strawberry is swollen at the tip of the pedicel to form a receptacle. Into the swollen tip, hundreds of pistils are inserted spirally around the receptacle. The successively initiated flowers are progressively smaller and have fewer pistils. A primary flower may have 400 or more pistils, the secondary 200-300 and tertiary 50-150 (Janick and Eggert, 1968). Cultivar and growing conditions may influence the number of pistils in any given flower but no relationship exists among flowers at different position on the inflorescence.

Breen and Martin (1981) observed that 'Benton' produced less than one truss/crown in its first fruiting year. In the autumn, lower temperatures were better for inflorescence initiation in the third 10-day period of September and in October (Hortynski et. al., 1994). The number of flowers/plant also increased with longer exposure to low temperatures. The earlier the covering of polyethylene film, the higher the early yield regardless of cultivar (Ahn et. al., 1988).

C.7. Fruits:

Strawberry fruit forms through fertilization initiating the growth of the embryo into a hard seed within a hard indehiscent, single-seeded fruit called an achene. The edible portion of the fruit is an enlarged, fleshy ripened receptacle upon which many individual achenes are present. After pollination, strawberry ripening takes 20 to 50 days, depending on cultivar, prevalent temperature, pollen availability, berry size and regularity of fertilization.

Large-fruited primary berries ripening in the spring in lower temperatures are often irregular in shape and ripen in about 30 days. Everbearing fruit ripening during the high summer temperatures often resulted in small size and ripen quickly in 20 to 30 days. In the fall when temperatures are cooler and pollen is abundant, ripening is slower (35 to 50 days), but the fruit is larger, regular in shape and of better quality (Galletta and Bringhurst, 1990).

Day-neutral and short-day strawberry cultivars were evaluated in a comparison study. The variability in marketable yield originated in fruit count (26%), total yields (18%), average leaf size (22%), and runner count (19%) per plant was observed. Selva was one of the most productive day-neutral cultivars, had the heaviest fruits (25 and 17 g in 1990 and 1991, respectively), and the fewest culled fruits (36 and 19% in 1990 and 1991, respectively) (Baumann et. al., 1993).

In general, the yield and percentage (number) of green fruits decreased during fruit development while the yield and percentage of red fruits increased. The yield of red fruits frequently decreased in the last part of the harvesting period due to *Botrytis cinerea* infection. The highest yield of red fruits in cultivars Sima and Primek was obtained at a level of 25-30% green fruits. This is, therefore, considered to be the optimum time for once-over mechanical harvesting (Kaack, 1991).

C.8. Yield components of strawberry:

Genetic and environmental factors determine the yield of specific varieties by affecting the development of inflorescences (Guttridge, 1955). The yield of strawberry is determined by the multiplicative effect of at least four components. These are the number of crowns/plant, the number of inflorescences/crown, number of flowers(berries)/inflorescence and the mean berry weight (Hondelmann, 1965; Webb et. al., 1973; Strik and Proctor, 1988b).

Cultivar, cultural procedures and year-to-year environmental factors may have significant effects on dry weight accumulation and distribution pattern in strawberry (Baumann et. al., 1993; Popenoe and Swartz, 1985). Vegetative biomass increased from November to June independent of plant density. The distribution pattern of day-neutral 'Tribute' paralleled that of Junebearing 'Redchief' where each fruit contributed more than 40% of the total biomass per plant (Archbold and MacKown, 1995).

Root tissues of container-grown plants comprised an equal or greater proportion of the total biomass compared to foliar tissue in November, but contributed proportionally less after harvest in June (Long and Murneek, 1937). A 3-fold to 4-fold greater leaf than root biomass was found in late fall and postharvest sampling dates for strawberry cultured in a hill system (Olsen et. al., 1985).

The greatest yields of marketable fruits were obtained at the closest plant spacing (7 cm x 107 cm) under commercial production in ribbon rows at Langley, British Columbia. Marketable yield depended upon the numbers of crowns/plant and trusses/crown. Components of yield which increased greatly from first year to second year came mainly from an increase in crowns/plant. The number of crowns/plant was adversely affected by crowding, but closer spacing still resulted in increases in marketable yield/ha (Hesketh et. al., 1990; Wijsmuller and Dijkstra, 1991).

A spaced row system incorporating recent research findings was compared with a matted row system for fruit production in strawberries. On 5 May 1988, Earliglow plants were set into black plastic mulch in single rows 1 m apart with 15 cm between plants in the spaced row system; runners were controlled by spraying with paraquat. Matted rows were established from plants set at 1 m x 0.45 m and the following cultural practices were completed: pinning down of runners, blossom removal and chemical spraying for weed control. Both plots were protected over winter by straw mulch or polypropylene row covers. Yields in 1989 were similar for both systems (761 and 725 gm/2m^2 plot for matted row and single spacing, respectively) but mean berry weight and mean berry weight of marketable fruits (2.5 cm in diameter) were significantly higher in the single row system. The number of branch crowns, crown dry weight, leaf area and leaf dry weight were also significantly higher in the single row system (Stang et. al., 1991).

Yields of greenhouse-grown plants were about half those of field-grown plants, but fruit size and quality were similar for both. Brighton was the most productive cultivar under greenhouse conditions (total yield 322 g/plant). The day-neutral cultivars Brighton, Fern and Toro produced 47, 38 and 53% respectively, of their total marketable yield during the first 5 weeks of harvesting under greenhouse conditions, whereas for the short-day cultivars Douglas and Toro, early yields were 22 and 24% of the total respectively (Paraskevopoulou-Paroussi et. al., 1991).

D. Other factors and strawberry

D.1. Fertilizer and strawberry:

A considerable amount of research effort has been directed towards assessing the response of strawberry to nitrogen (N) fertilizers. The results have varied depending on soil type, fertility, water availability and cultivar differences from no effect to significant yield increases (Blatt, 1987; Keefer et. al., 1978; Long and Murneek, 1937; VanMeter, 1935). Nitrogen is the major nutrient utilized by strawberry and also the major element applied after planting (40 kg/ha) during bed establishment for matted row culture (Stang et. al.1991). Nitrogen supports daughter plant production to fill the matted rows. An early fall application is intended to maintain adequate plant nutrient status and vegetative vigor during the critical flower bud initiation period (Long, 1939).

D.2. Temperature and strawberry:

All mulches including cut grass increased the minimum soil temperature at a depth of 5 cm during low temperature, and were effective in maintaining a wetter soil moisture regime in raised beds of 'Tioga' strawberry (Gupta and Acharya, 1993). Photoperiod and temperature have an effect on the starch accumulation in strawberry roots. Generally, shorter photoperiods resulted in greater accumulation of starch regardless of temperature (Mass, 1986; Bringhurst et. al., 1960).

Temperature was most highly and positively correlated with yield and fruit weight in the first 10-day period of May. In the second and third periods of this month and in June, lower temperatures and humidity were needed for high productivity. In late August, early September and November, high temperatures, water deficit and sunshine were beneficial. Individual fruit weight showed less correlation with atmospheric factors, but trends were similar to those for the total yield (Hortynski et. al., 1994).

High air temperatures during the growing season are a common occurrence in many strawberry production regions. High temperature reduces the photosynthetic rate and increases transpiration water loss that may exceed the plant's ability to replace it. Results of high temperature stress can be reduced growth (Abdelrahman, 1984; Renquist et. al., 1982), lower yields (Abdelrahman, 1984; Chesness and Braud, 1970; Valentine, 1980) and poor fruit quality (Chesness and Braud, 1970; Darrow, 1966; Valentine, 1980). A study with June-bearing strawberry showed significant negative relationship between fresh weight and soluble solids content of fruit with temperature ranging between 25 ^{0}C to 40 ^{0}C. Runner growth was inhibited following 3 days of exposure to high temperature and persisted 4 days until return to moderate temperature. The critical temperature range for strawberry growth inhibition was determined to be between 35 °C to 40 °C (Hellman and Travis, 1988).

D.3. Strawberry and soil aeration:

In a greenhouse hydroponics culture, five substrates were used in combination with perlite, peat and pumice-stone in a vertical system using polyethylene tubes and polystyrene pots in August. Fruit of 'Brighton' cultivar was collected from December until June. The study indicated that strawberry grown on a substrate of perlite 80% + peat 20% produced higher yields (250 gm/plant) than other treatments. But there is no difference between polystyrene pots and polyethylene tubes with respect to yield (Lindardakis and Manios, 1991).

With a view to developing successful year-round strawberry production, 7 growing media including perlite were tested for hydroponics culture of strawberry cultivars Chodong and Yeobong. The porous scoria proved to be a good material in terms of oxygen supply, water absorption, drainage and moisture retention. Yield increased 3-5% using combination of scoria and rockwool (Han et. al., 1993).

Root temperature control by soil aeration affect the growth and yield of strawberry. A hydroponics culture of 'Reiko' strawberry with constant temperature showed high root temperature decreased root dry weight during a seven-month growing period while crown dry weight was not affected by temperature. Highest yields in summer crops were obtained by planting in April or May at root temperatures of 18 °C or 23.5 °C, while yield by planting in June was independent of decreasing root temperatures (Udagawa et. al., 1990a & b).

E. Multiple pests, cover crops and strawberry

E.1. Cover crop and soil arthropods:

In cucumber production in Oregon, specific cereal cover crop residues suppressed small-seeded weeds, symphylans and maybe white mold disease. Multiple pest suppression with cover crop residues begins to make sense to farmers and may be a marketable concept for consumers (William and Crabtree, 1994).

Symphylans are a centipede-like, soil arthropods that cause considerable damage to vegetable crops in the Pacific Northwest by feeding on roots. In spring-planted cereal cover crop system, symphylan density in the soil was reduced 75% in Micah barley plots compared to the density in Dyfonate™ treated or untreated soil. Allelochemicals present in Micah barley may be affecting the symphylans (Peachey et. al., 1993).

Floating row covers in newly transplanted strawberries cv. Douglas, which transmit 75-80% of sunlight, caused an increased number of eggs, nymphs and adults of mite with the progress of the season. No other arthropods occurred at any serious level. Row covers did not affect mite populations over non-covered plots; however, acaricide sprays over the last 8 weeks of harvest significantly reduced counts of eggs, larvae and adults over non-sprayed plots (Rubeiz et. al., 1993).

E.2. Cover crop and strawberry gray mold (*Botrytis cinerea* Pers.:Fr.):

Gray mold of strawberry caused by *Botrytis cinerea* Pers.:Fr. is an important disease in strawberry production throughout most of the world (Mass, 1978). The cottony growth of the causal organism is often found on the ripening and harvested berries, sometimes causing economic losses of over 50% by reducing yields, fruit grade and shelf life (Jarvis, 1962; Mass, 1978). The causal organism occurs and survives on the plants and decaying vegetation (Mass, 1984). The fungus is usually quiescent in the receptacle during the flower and green fruit stages. The fungus becomes aggressive as berries ripen and gray mold appears at the proximal end of the fruit (Powelson, 1960).

Optimum temperature for sporulation of gray mold (*Botrytis cinerea)* on strawberry leaves, autoclaved or air-dried, was between 17 and 18 °C at all wetness duration. As temperature increased or decreased from the optimum, sporulation decreased for the same wetness duration. Very little sporulation was observed at 25 °C and no sporulation was observed at 30 °C. The latent period of *B. cinerea* on dead leaf tissue was longest at the lowest temperature (6 to 7 days at 5 °C) and decreased to less than 3 days as temperature increased to the optimum between 15 to 22 °C (Sosa-Alvarez et. al., 1995).

Incidence of gray mold of small fruit and snap beans is controlled principally with protectant fungicide sprays applied to blossoms and ripening fruit. Cultural practices, including sanitation, irrigation management and modification of canopy architecture, are used to improve control (Johnson et. al., 1994). Cover crop practices can modify both the physical environment within the field and the resulting population of associated organisms (William, 1981).

Incidence of gray mold on harvested strawberry fruit was evaluated with respect to environmental influences and fungicide regimes over four consecutive years. Disease incidence at harvest was correlated with the average daily values of 13 environmental variables during four discrete periods (or combinations thereof). These periods occurred from bloom until harvest and were defined by the timing of fungicide applications in designated treatments. Disease incidence was correlated strongly with environmental variables measured during the bloom period, particularly the duration of relative humidity >80% and >90% and surface wetness at 15-25 °C. Environmental factors after bloom were poorly correlated with disease incidence, with the exception of vapor pressure deficit (negative correlation) and rainfall during periods defined by the first postbloom spray (Wilcox and Seem, 1994).

Everbearing 'Tristar' strawberry with ground cover between and within rows consisted of plastic, straw or bare soil were studied for anthracnose fruit rot (*Colletrotrichum acutatun*). Disease incidence was related to amount of rain (cm), days from introduction of innoculum, duration of wetness, average temperature during the wetness period and distance from the spore source. Results indicate that surface topography or ground cover greatly affects spore dispersal by rain splash and that the use of straw mulch reduces disease incidence (Madden et. al., 1993).

E.3. Cover crop and strawberry black root rot:

Blackening and decay of roots in association with plant stunting are common in perennial strawberry (*Fragaria x ananassa*) plantings worldwide. This syndrome is commonly referred to as black root rot (BRR), although its causal agent(s) are not well characterized. A field survey was conducted in New York, USA, to identify physical and cultural factors associated with BRR. Soil compaction, fine soil texture, absence of raised beds, high application rates of the herbicide terbacil, advanced age of planting, nonuse of metalaxyl and cumulative years of strawberry monoculture appeared to be associated with the disease. Populations of *Pratylenchus spp*. were not associated with poor root health. Studies suggested that most factors that compromise root growth may predispose strawberry plants to infection by site-specific BRR pathogens (Wing et. al., 1995).

In 'Heritage' and 'Taylor' red raspberry, *Phytophthora fragariae* and *P. citricola* were extremely virulent, causing complete root rot and plant death; the same isolates of *P. fragariae* also failed to produce typical red stele symptoms on inoculated 'Catskill' and 'Blakemore' strawberry plants (Wilcox, 1989).

In the first year of production when yield potential was being limited by the strawberry root rot complex, yield, stand counts, leaf mineral nutrient levels, and nematode population levels were evaluated for each of three treatments consisting of 67% methyl bromide plus 33% chloropicrin (MC33), 98% methyl bromide plus 2% chloropicrin (MC2) and a nonfumigated control. Yield was significantly greater in the fumigated plots than the control plots (Wolfe et. al., 1990).

Chapter III

MATERIALS AND METHODS

Field experiments involving strawberry and various cereal cover crops along with perlite were conducted at the Oregon State University (OSU) vegetable research farm, east of Corvallis, Oregon and in the west greenhouse, OSU during 1995 as follows:

A. Strawberry pre-plant practices: Cereal cover crops growth and weed suppression

Three types of cereal commonly grown in Oregon for winter cover crops, 'Micah' barley, 'Steptoe' barley, and 'Wheeler' rye were compared in this experiment. A vertical wedge of perlite, an artificial plant medium, was included to improve soil oxygen. Cereals were planted to assess plant growth and development, dry matter production, and weed suppression in spring, 1995. A Chehalis silt clay loam soil was cultivated in mid February, 1995. Seven treatments including Micah barley, Micah barley plant residue applied to soil surface (Micah S), Steptoe barley, Wheeler rye, Wheeler rye with perlite wedge, perlite wedge, and a control treatment without any cereal were compared. These treatments were assigned to 6m (20 ft) by 4 m (13 ft) plots in a randomized complete block design with four replications. Two replications (1st and 2nd) were separated from the 3rd and 4th replications by a distance of 1.5 m as shown in the experimental layout (fig. 1).

Perlite was placed in a wedge after plowing the soil in February, 1995. A furrow 7.6 cm (3 in) wide and 10.2 cm (4 in) deep was made by hand hoeing in perlite plot. Each furrow was filled with perlite using approximately 0.05 cubic meter (1.8 cft). A thin crust (1.5 cm) of soil was applied over the perlite to prevent loss by wind or water.

Cereal was planted in 18 (6x3) rows spaced 22.5-cm on March 3, 1995, using a cone planter. An additional strip of Micah barley was planted nearby to harvest and place on the soil surface to compare the effect of surface residues only with residues grown *in situ*.

A seeding rate of 300 seeds/m2 (30 seeds/sq.ft.) was used for optimum coverage of each plot. The Micah barley strip was seeded at a rate four times that of other plots to ensure the same number of plants for the four replications. A standard germination test was performed with paper towel before planting cereal to ensure the proper number of seedlings establishment in each plot. Seedlings emerged within two weeks from the date of planting. Rainfall provided moisture to grow the cereal covers, with 2.5-cm irrigation per week supplied by overhead sprinklers as needed.

Pre-plant fertilizer was not applied. A top-dressing of nitrogen 30 kg/ha applied as urea was broadcast using a hand spreader in all plots three weeks after seeding the cereal.

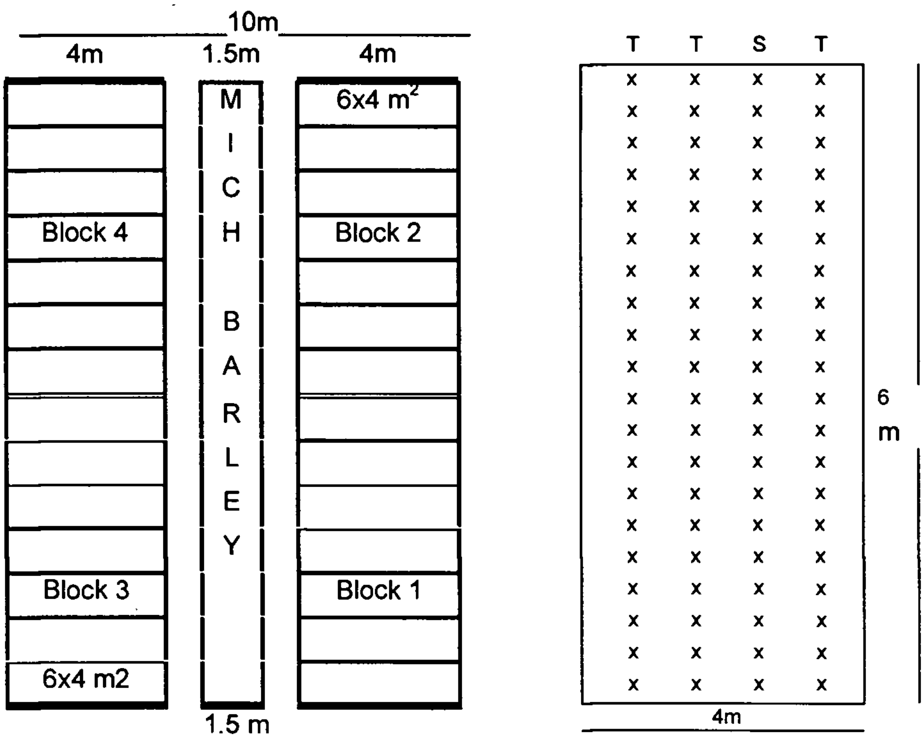

Fig. 1.a Fig. 1.b

Figure 1: Layout of experimental design for cereal cover crops and strawberry, 1995 (Fig. 1.a: whole field, each block contain 7 treatments; Fig. 1.b: single plot (6X4 m^2) where, T = Totem row, S = Selva row).

Ground coverage by cereals was assessed 6 weeks after cereal planting. Above ground cereals and weeds were sampled by cutting the plants near the soil surface within a quadrant of 0.37 m2 (2 x 2 sq. ft.) placed randomly in each plot. Fresh and dry matter weight of samples were measured to assess the moisture content of the plant and biomass production. Weed populations were identified and grouped as follows: annual bluegrass, thistles, common groundsel, pineapple weed and total including miscellaneous weeds. Average cereal plant height was measured by randomly selecting 10 plants. Weed and cereal dry matter weight was recorded after drying the samples through a tunnel dryer at 110 °C .

In order to maintain the residues in the plot, cereals were killed by herbicide spraying 2% glyphosate (Roundup™) six weeks after planting. Three weeks after spraying, dried cereal plants were flailed and the residue was left on the soil surface.

B. Strawberry planting and post-plant practices

B.1. Strawberry planting:

Certified strawberry plants (nursery rootstock) of June-bearing 'Totem' and everbearing 'Selva' varieties were planted in the same cereal field by hand with the least disturbance of the cereal residue on June 2, 1995. Totem was planted in 3 rows while Selva variety was planted in one center row within each plot. The two outside rows of Totem were considered as guard rows. Strawberry plants were established in a matted row system at a 30 cm (12 inches) spacing within the row and 91.4 cm (36 inches) between rows. Each plot consisted of 20 plants; during sampling, two plants from the ends of each row were excluded as border.

Nitrogen fertilizer at the rate of 30 kg/ha was applied as urea using a hand spreader in June after plant establishment and in July before a second cereal seeding on July 11, 1995. Irrigation was provided by overhead sprinklers when necessary, or about 2.5-cm per week.

B.2. Multiple pest suppression:

B.2.1. Cereal planting and biomass collection:

After planting strawberry, cereals were replanted in order to suppress weeds and gray mold (*Botrytis cinerea* Fr.) disease incidence. The area between strawberry rows was cultivated with a rototiller before seeding cereal. Cereal was replanted on July 11, 1995, in a band 0.5 m (20 in) wide with a lawn seed spreader. After six weeks, green cereal plants were mown and blown towards the rows of strawberry by a lawn mower, leaving the cereals about 8 cm (3 in) above the ground. Cereal cover crop fresh and dry matter weight, and average plant height were measured on August 15, 1995 following the procedures described in section A.1 in this chapter III. Cereal was replanted on October 6, 1995 for winter ground coverage within a 0.45 m (18 in) band between strawberry rows using a lawn seed spreader.

B.2.2. *Weed management and weeding:*

To assess weed suppression from cereals, weeds were sampled by cutting the above ground parts at the soil surface between the rows of Totem and Selva on June 27, 1995. On August 15, weeds were sampled both between and within the strawberry row. The earlier procedures were followed for this purpose, except for sampling within the row area, in which one random sample was taken from a rectangular area of 0.185 m^2 (2 x1 sq. ft.) in each row of Totem and Selva for a total of 0.37 m^2. Weeds were identified and grouped as pigweed, nightshade and total including miscellaneous weeds. Fresh and dry weights were weighed and weed population was recorded. No herbicide was applied to control weeds. Weed control was achieved by hand-hoeing on July 10, and September 23, 1995, unless soil was cultivated by rototiller for cereal planting.

B.2.3. *Soil arthropods :*

Symphylans (*Scutigerella immaculata* (Newport); Scutigerellidae), a soil arthropod, were collected on five different dates from April 4, through November 27, 1995 while standing cover crop and cover crop residues were in the plot. Soil samples were collected using a shovel (standard 30 cm) or a soil core 18 cm long (diameter 11 cm) randomly selected at 3 different sites in Totem and Selva rows and between the rows. Symphylans were counted while soil samples were loosened by hand and observed for 2 minutes. Total symphylan population from the 3 samples were recorded. On November 27, soil samples were collected from one randomly selected Selva row in an rectangular area of 20 cm x 20 cm x 6 cm using a hand-made soil sampling tool. Soil insects and arthropods were collected using Berlese Funnel extraction for six days as soil moisture was saturated. Symphylans and other arthropods were counted under a magnifying glass and the numbers were recorded.

B.2.4. *Strawberry fruit rot* (*Botrytis cinerea* Fr.):

To assess the fruit rot (gray mold) incidence in strawberry, 20 nearly ripe fruits were collected from each variety in each plot and treated as follows: 1) washed with 2% bleach (Clorox^{TM}) for 5 minutes, 2) rinsed with distilled water, 3) placed in plastic cell-pack with upright calyx, 4) covered in a polyethylene bag with a moist paper towel to maintain 100% humidity and placed in cool place with less light than the laboratory, 5) counted the number of rotten fruit at 6 days and 6) visually rated the total percent rotten area on a scale of 0 - 9, where 0 = not rotten and 9 = 100% rotten. These procedures are followed for strawberry gray mold assessment in the plant pathological laboratory, Oregon State University, Corvallis, OR (Johnson, 1995).

B.2.5. *Strawberry black root rot:*

Root health was observed visually to determine the strawberry black root rot condition on November 27 after destructive harvest of five Selva strawberry plants from each plot. Fresh and dry weights of both roots and shoots were measured. Newly developed primary roots were observed visually. Percent ratio of white primary roots and old black roots were evaluated visually and recorded.

B.3. Strawberry production:

B.3.1. *Plant growth and development:*

During the growing seasons, strawberry plant growth and development were measured on June 7 and August 15, 1995 as follows: five Totem and Selva plants were selected randomly to measure shoot length (highest leaf length), petiole length and length of the middle leaflet in each plot. Number of leaves, crowns and runners per plant were counted. Crown diameter was measured at the base of the stem using slide-calipers.

During flower bud initiation, especially for the June-bearing Totem strawberry, the rate of photosynthesis (CO_2 assimilation rate, mmol.m^{-2} s^{-1}) and stomatal conductance (µmol.m^{-2} s^{-1}) of leaves of Totem and Selva were measured on October 4, 1995 using CIRAS-1 portable photosynthesis system (PP system, Inc., Switzerland). Two leaves were selected for each variety and marked before starting the measurement in each plot. Averages were calculated on the basis of 2.5 cm^2 leaf area.

At the end of Selva fruit harvest, a destructive method was used to determine the root and shoot dry matter. Random selection of five plants were harvested from each plot and roots and shoots were separated. The fresh weight of the shoot including leaves, petioles, crowns and inflorescence with remaining small fruits (no daughter plant or runner) were weighed. Roots were collected from the soil, washed and fresh weights were measured. Roots and shoots were weighed after drying through a tunnel dryer at 110 °C. The number of crowns also were counted.

Runners were cut with the rototiller and disked when they exceeded the 25 cm row width on July 1, August 26 and October 5, 1995.

B.3.2. *Strawberry yield:*

The first inflorescence of the Selva variety was removed on July 20, 1995, to improve plant growth. No inflorescence was removed from the Totem strawberry. Average numbers of inflorescence per plant were determined by the end of the harvest period for each variety by random selection of 10 plants in each plot. From September 14 through October 30, 1995, everbearing Selva strawberry were harvested six times at approximately one week intervals. Totem yield, harvested about six weeks after planting, was not considered in analysis because the flower bud was already initiated in the nursery plants.

Yield was collected from 3 m of row consisting of 10 plants per plot. At each harvest, total number of fruits were separated as marketable fresh (more than 2.5 cm in diameter, Stang et. al., 1991) and deformed fruits. Rotten fruits were not counted. Average fruit weight and number of fruits per plant were calculated from the total fruit weight and total number of fruit divided by the number of plants per plot. Average berry size was calculated from the total fruit weight divided by the total number of fruits.

C . Greenhouse experiment

C.1. Experiment on gray mold disease (*Botrytis cinerea* Fr.):

Evaluation of cereal residue suppression on gray mold disease in Selva strawberry was conducted in the greenhouse on October 8,1995. Similar size of strawberry plants were collected with intact root system and soil from a farmer's field and placed in plastic pots (standard 1 gallon size). Plants were moved to greenhouse at standard growing conditions. Three cereal cover crops, Wheeler rye, Micah and Steptoe barley and control treatment without cereals were compared with four replications. Two weeks after transplanting, 1 gm dry weight of 21 day-old pre-stored cereal residues was applied to the surface of each pot. Treatments were separated by using a block of polyethylene sheet barrier to prevent spore movement. Irrigation was provided to maintain high humidity for enhancing gray mold disease. Field grown fruit was removed from the plant to assess the effect of cereal residues on disease incidence. Unfortunately, due to lack of pollinators or pollination and fruit set within the greenhouse, the experiment unable to evaluate gray mold disease incidence in strawberry.

C.2. Experiment on strawberry black root rot:

Evaluation of cereal residues on strawberry black root rot in Selva strawberry was conducted in the greenhouse on October 8, 1995. Soil infected with black root rot from a farmer's strawberry field (Mr. Matt Unger, Hillsboro, Oregon) was placed in plastic pots (standard 1 gallon size). Three treatments, Wheeler rye, Micah barley and control without cereal were compared with four replications. One gm of cereal seeds were planted in the pot and grown outside the greenhouse. Five weeks after planting, cereal was killed using 2% glyphosate (Roundup™).. Two weeks after killing, cereal shoot dry matter was weighed and mixed with pot-soil. Selva strawberry plants stored at $0^{o}C$ for 6 weeks were planted one in each pot and kept in the greenhouse. Strawberry plants often died even after replanting. Prolonged storage and microorganism activity may have contributed to poor survival.

Strawberry daughter plants with four leaves were collected from the control plots at the vegetable farm. One plant was planted in each pot on October 3, 1995. Within 5 weeks after planting, standard management was practiced and visual observations were made on plant growth. After 5 weeks, fresh and dry matter of shoots (above ground plant parts) and roots were measured separately.

D. Statistical analysis

Analysis of variance (ANOVA) was conducted for the soil cover treatments in randomized complete block design using the computer software package 'StatGraphic 7.0'. A P-value of 0.10 was considered acceptable for this experiment because biological response from cover crops on pest suppression and other interactions often are more variable than a chemical pest control treatment designed to kill. Mean separation was calculated using LSD, Duncan's multiple range test with an F-distribution at 0.05 probability level. In some cases, non-orthogonal contrast was performed to compare treatment effects.

Chapter IV

RESULTS AND DISCUSSION

The experiment was conducted to compare multiple pest suppression by cereal cover crops in strawberry. All comparisons with perlite to improve soil and root aeration and Micah barley treatments to look at root effect will be discussed in a separate section.

A. Effect of cereal cover crops

Cereal cover crops planted 8 weeks before planting strawberry produced dry matter residues from 200 to 400 kg/ha (Fig. 2). In spring, Micah barley produced the most biomass followed by Wheeler rye. Biomass production of cereal cover crops was reduced within strawberry row in August, possibly due to higher temperature (Fig. A-1 & A-2) or competition for resources with strawberry plants. Plant height of cover crops was similar in both seasons but Steptoe barley achieved the tallest height (Fig 3).

Cover crop suppression of weeds is well known in vegetables and strawberry production systems. The major weed species found in the study field during the cover crop growing season were annual bluegrass (*Poa annua*; family: Poaceae), Canada thistle *(Cirsium arvense* Scop.; Asteraceae), common groundsel (*Senecio vulgaris* L.; Asteraceae), pineapple weed (*Matricaria*

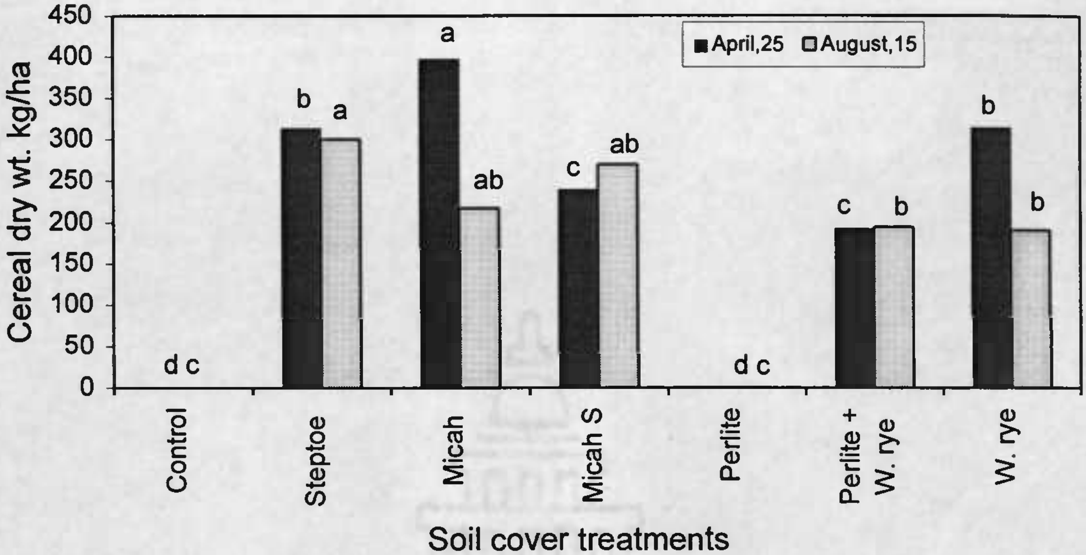

Figure 2: Cereal dry weight (kg/ha) before and after planting strawberry, 1995.
(Micah S = Micah barley residues applied on soil surface)

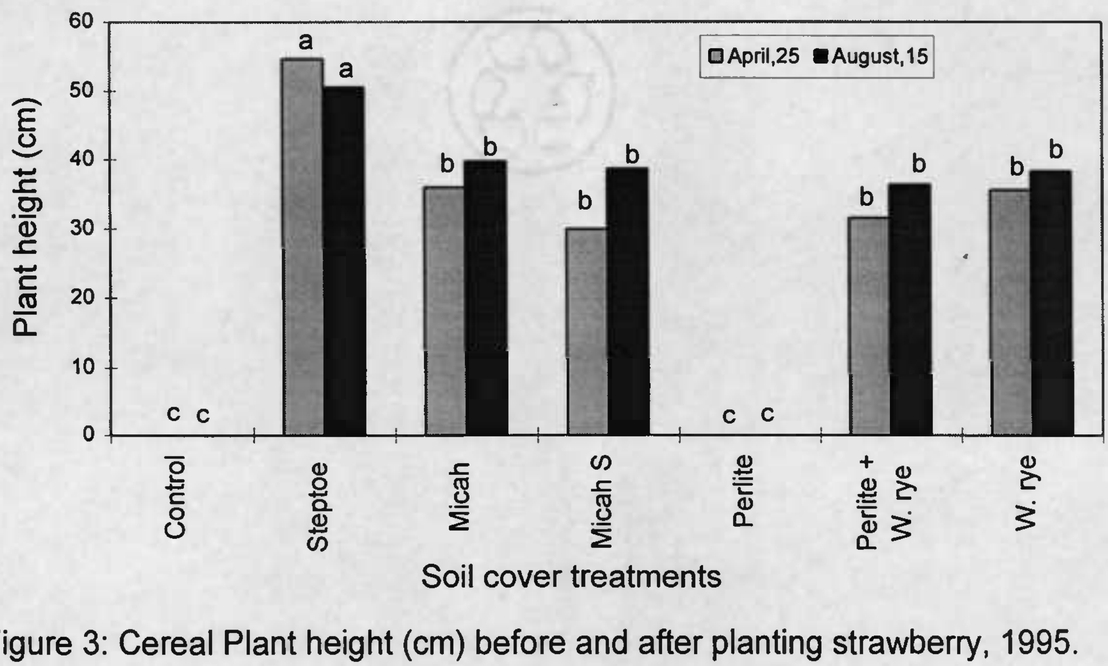

Figure 3: Cereal Plant height (cm) before and after planting strawberry, 1995.

matricarioides (Less) Porter; Asteraceae), nightshade (*Solanum sarrachoides* Sendtner; Solanaceae) and pigweed (*Amaranthus sp*; Amaranthaceae).

In the early spring, total weed biomass was affected by all soil cover treatments. Micah barley produced the least total weed biomass (196.2 kg/ha) before planting strawberry (Table 1). Micah barley in growth phase suppressed more than 81% of the weeds compared to control plots with no soil coverage on April 25, 1995. On the other hand, no significant difference among Micah barley, Steptoe barley and Wheeler rye treatments was found (Table 1). Small seeded weeds were suppressed by soil coverage with cereal or living mulches through different types of interactions or allelopathy. Annual bluegrass, a small seeded weed was suppressed by the main plot treatments of Wheeler rye, Micah and Steptoe barley, which did not significantly differ from each other on April 25, 1995. In case of pineapple weed, Wheeler rye and Micah barley planted in the plot provided good suppression, whereas Steptoe barley provide moderately good but other treatments did not control pineapple weed (Table 1). Best weed suppression for Canada thistle was achieved in rye plot next to Micah barley plot; however, we can not conclude that result is perfect for this perennial weed suppression (Table 1) as Eskelsen and Crabtree (1991) suggested that there might be interspecific competition or Vasicular-arbuscular micorrhizal (VAM) fungus (*Glomusintra radices*) interaction involved in this process. In the early stage of strawberry establishment, about 8 weeks after killing cereal, soil cover

Table 1: Effect of cereal cover crop residues on different weeds and total weed dry matter production (kg/ha) before planting strawberry on April 25, 1995.

Cereal soil cover treatments	Weed dry matter production (kg/ha)				
	Annual bluegrass	Thistle	Common groundsel	Pineapple weed	Total
Control	324.3a *	115.4bc	198.1	106.2bc	1045.9a
Steptoe barley	39.7 c	91.9bc	26.5	51.6bc	370.0bc
Micah barley	27.3 c	37.6c	50.8	31.9c	196.2c
Micah on surface	291.6ab	262.7ab	212.4	139.2a	1091.6a
Perlite	134.6bc	404.1a	192.4	63.2bc	1209.7a
Perlite + W. rye	132.7bc	92.2bc	67.1	54.3bc	653.2b
Wheeler rye	24.9 c	6.5c	15.4	34.3c	438.9bc
P-value	0.01	0.01	0.08	0.01	0.01

* Means followed by the same letter within a column are not significantly different based on Duncan's multiple range test, $\alpha = 0.05$.

treatments were ineffective in suppressing different types of weeds. It may reflect the earlier result obtained by Putnam (1986) and Weston (1990) that the effective time of cover crops to suppress weeds ranged between 45 to 60 days after killing. Micah barley residues suppressed weeds in the early season establishment of strawberry, though there is no significant difference among other soil cover treatments (Table 2).

In Summer, Weed density was lower with a slight variation in all cover crop treatment compared to control treatment in both within row and between rows of strawberries on August 15 (Table 3). Micah and Steptoe barley provided good weed suppression compared to control treatment in both between and within rows of strawberries (Table 4).

In non-orthogonal contrast analysis between cover crops (Micah, Steptoe barley and Wheeler rye) vs non-cover crop (control treatment) showed highly significant difference in weed suppression with cover crops regardless of sampling date (Table 5).

Temperature and relative humidity have great influence on gray mold incidence on strawberry fruits. Percent rotten fruit were evaluated in the lab within 100% relative humidity for gray mold incidence. In Selva strawberry, fruits from all cover crop treatments produced fewer gray mold infected fruits compared to control treatment but not significantly different (p-value 0.3). Strawberry in Wheeler rye plot was infected the least (21%) (Fig. 4). Percent rotten area within the fruit was observed on a visual scale. Results of percent rotten area showed similar trends as number of percent rotten fruit (p-value 0.1) (Fig. 5). In visual field observation, more gray mold infected Selva fruits were noticed in Micah barley applied on soil surface in the later part of the harvest season probably due to rain and low temperature (Fig. A-1, A-2, & A-3).

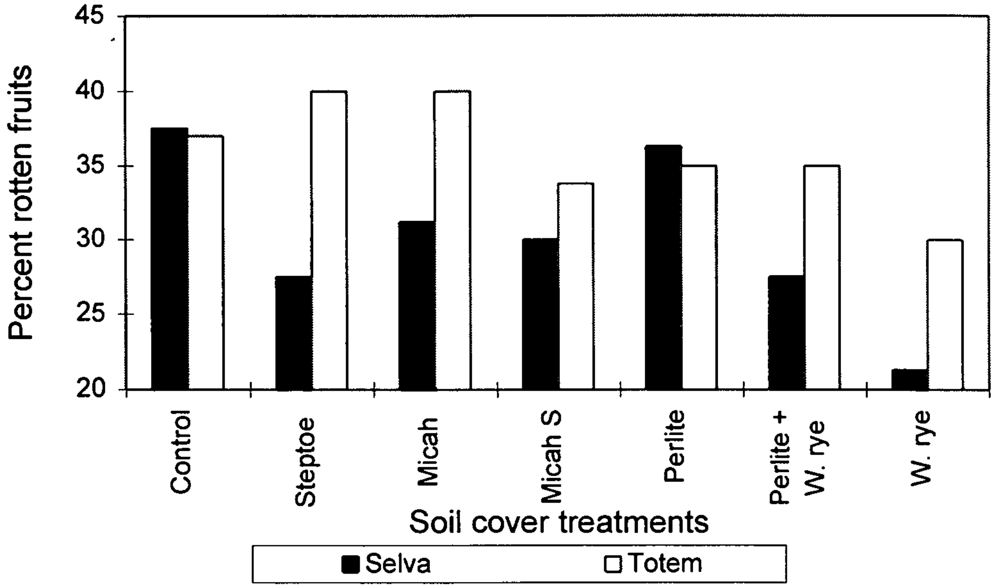

Figure 4: Effect of soil cover treatments on percent of rotten strawberry fruits caused by gray mold in Totem (on July 21) and Selva (on September 14), 1995.

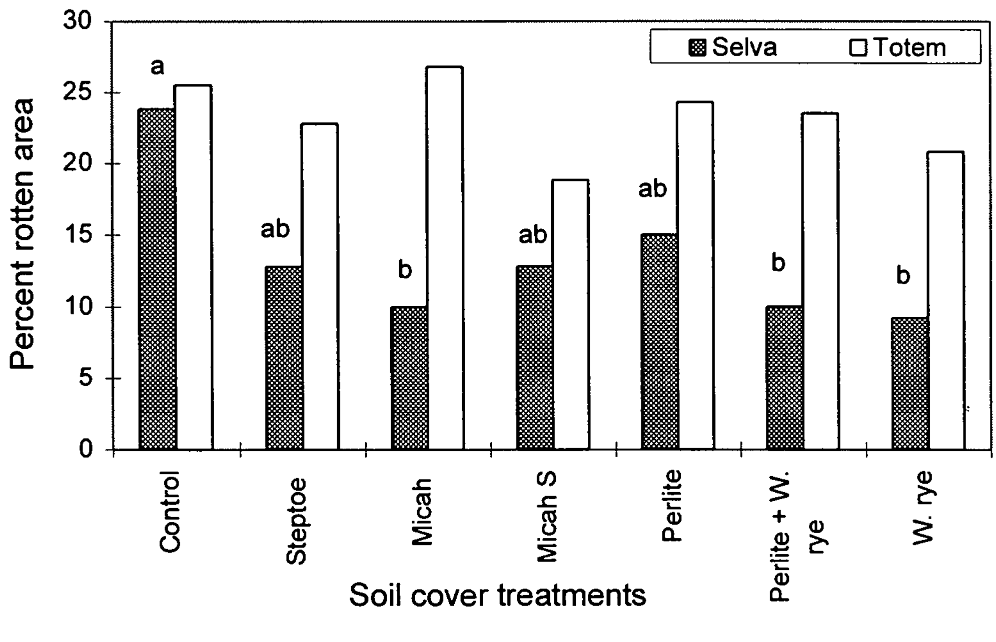

Figure 5: Effect of soil cover treatments on percent area of rotten strawberry fruits caused by gray mold in Totem (on July 21) and Selva (on September 14), 1995.

Table 2: Effect of cereal cover crop residues on different type of weeds and total weed dry matter production (kg/ha) on June 27, 1995.

Cereal soil cover treatments	Weed dry matter production (kg/ha)			
	Pigweed	Thistles	Common groundsel	Total*
Control	182.5	0.0	0.95	183.5
Steptoe barley	218.9	2.0	8.99	235.9
Micah barley	220.6	7.4	10.62	238.6
Micah on surface	60.1	4.1	4.12	76.2
Perlite	234.7	3.4	2.16	247.8
Perlite + W. rye	114.1	1.4	3.45	122.5
Wheeler rye	206.8	3.4	8.72	224.1
P-value	0.40	0.25	0.40	0.12

* Total including miscellaneous weeds; ANOVA conducted after log(base 10) transformation.

Table 3: Effect of cereal cover crop residues on different weeds and total weed density (No./m^2) within row and between rows of strawberry on August 15, 1995.

Cereal soil cover treatments	Weed density/m^2					
	Between rows			Within row		
	Pigweed	Nightshade	Total*	Pigweed	Nightshade	Total
Control	78.4 a**	16.2	72.3	37.8 a	21.6	95.6 a
Steptoe barley	13.5 b	18.9	33.1	8.8 b	18.2	33.1 b
Micah barley	25.0 b	11.5	38.5	22.3 ab	5.4	35.1 b
Micah on surface	28.4 b	24.3	42.7	12.2 b	23.0	54.7 ab
Perlite	47.3 ab	16.9	40.5	25.7 ab	11.5	64.2ab
Perlite + W. rye	12.8 b	13.5	32.4	19.6 ab	7.4	27.7 b
Wheeler rye	43.2 ab	14.2	37.8	21.6 ab	8.1	57.4 ab
P-value	0.05	0.95	0.24	0.01	0.42	0.05

* Total including miscellaneous weeds.
** Means followed by the same letter within a column are not significantly different based on Duncan's multiple range test, $\alpha = 0.05$.

Table 4: Effect of cereal cover crop residues on different weeds and total weed dry matter production (kg/ha) within row and between rows of strawberry on August 15, 1995.

Cereal soil cover treatments	Weed dry matter production (kg/ha)					
	Between rows			Within row		
	Pigweed	Nightshade	Total*	Pigweed	Nightshade	Total
Control	1458.3a**	34.6	1493.5 a	828.4 a	221.4	1052.9 a
Steptoe barley	26.9 c	33.3	78.9 c	74.4 b	88.6	197.1 b
Micah barley	69.8 c	26.0	96.3 c	264.3 b	53.6	384.8 b
Micah on surface	752.2b	163.5	917.8 ab	201.5 b	267.9	535.3 b
Perlite	734.5b	102.3	842.1 b	204.8 b	150.7	377.6 b
Perlite + W. rye	59.3 c	48.1	159.3 c	229.6 b	63.2	344.3 b
Wheeler rye	305.4bc	40.8	356.7 bc	285.2 b	65.3	379.1 b
P-value	0.01	0.25	0.01	0.01	0.29	0.01

* Total including miscellaneous weeds.

** Means followed by the same letter within a column are not significantly different based on Duncan's multiple range test, $\alpha = 0.05$.

Table 5: Non-orthogonal contrast analysis of several treatment effect on weed suppression, Selva strawberry plant growth and yield during 1995 season.

Contrasting treatments	Effect to look at	Parameter	Sampling	P-value
'Micah', 'Steptoe' barley, 'Wheeler' rye vs control	Cover crops vs non-cover crop	Weed suppression (biomass production)	I. April 25	<0.01
			II. August 15	
			a. Between rows	<0.01
			b. Within row	0.01
'Micah', 'Micah' on surface vs control	Root and placement		I. April 25	0.12
			II. August 15	
			a. Between rows	0.02
			b. Within row	0.03
'Micah', 'Steptoe' barley, 'Wheeler' rye vs control	Cover crops vs non-cover crop	'Selva' strawberry growth	I. Shoot fresh wt. (Nov. 27)	0.19
			II. Crown # (Nov. 27)	0.57
			III. Root dry wt. (Nov. 27)	0.42
'Micah', 'Micah' on surface vs control	Root and placement		I. Shoot fresh wt. (Nov. 27)	0.88
			II. Crown # (Nov. 27)	0.35
			III. Root dry wt. (Nov. 27)	0.92
Perlite, perlite with 'Wheeler' rye vs control	Soil aeration		I. Shoot fresh wt. (Nov. 27)	0.81
			II. Crown # (Nov. 27)	0.70
			III. Root dry wt. (Nov. 27)	0.10
'Micah', 'Steptoe' barley, 'Wheeler' rye vs control	Cover crops vs non-cover crop	'Selva' strawberry yield	I. Total yield	0.27
			II. Avg. fruit wt.	0.14
'Micah', 'Micah' on surface vs control	Root and placement		I. Total yield	0.91
			II. Avg. fruit wt.	0.25
Perlite, perlite with 'Wheeler' rye vs control	Soil aeration		I. Total yield	0.28
			II. Avg. fruit wt.	0.27

In Totem strawberry, no significant difference was found among all the treatments on number of rotten fruits and area of rotten fruit by gray mold. Wheeler rye produced slightly better results compared to control plot (Fig. 5).

Related research involving cover crops and no-tillage cultivation in vegetable cropping systems is suggesting dramatic effects on symphylan pests and various arthropod guilds (Peachey et. al., 1993). In winter, symphylan activity in strawberry was suppressed with Wheeler rye, Steptoe barley and Micah barley applied on the soil surface, but not in Micah barley grown in the plot. Symphylan populations in control plot was 70% higher than those three treatments (Table 6). Distribution of symphylan population in the field was not uniform. Early season sampling of symphylan produced negligible populations per plot in all treatments (data not shown in table). At the end of harvesting Selva on November 27, 1995, soil arthropods were extracted using a Berlese funnel. Although total soil arthropods varied slightly, no pattern was established including beneficial insects (Table 6).

Rate of photosynthesis is one of the important factors involving plant growth especially during flower bud initiation period. Results showed good relationship between stomata conductance and photosynthesis rate in Totem leaves, although no significant difference was found among treatments (Fig. 6 & 7). In Selva, all cover crop treatments showed higher stomata conductance compared to control (Fig. 6). Steptoe barley demonstrated slightly lower

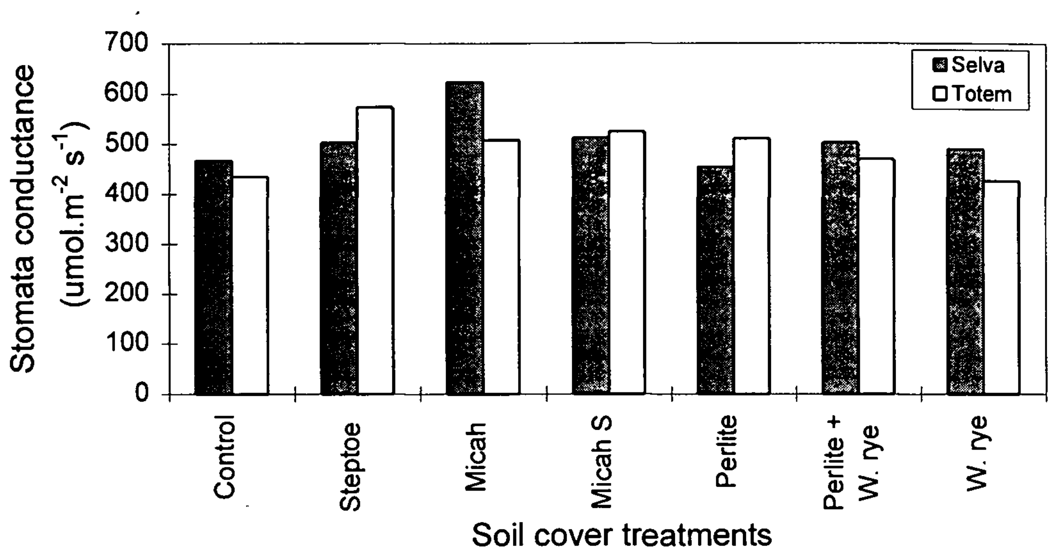

Figure 6: Effect of soil cover treatments on stomata conductance (μmol m^{-2} s^{-1}) of strawberry leaves on October 14, 1995 (P-value: Selva = 0.2, Totem = 0.4).

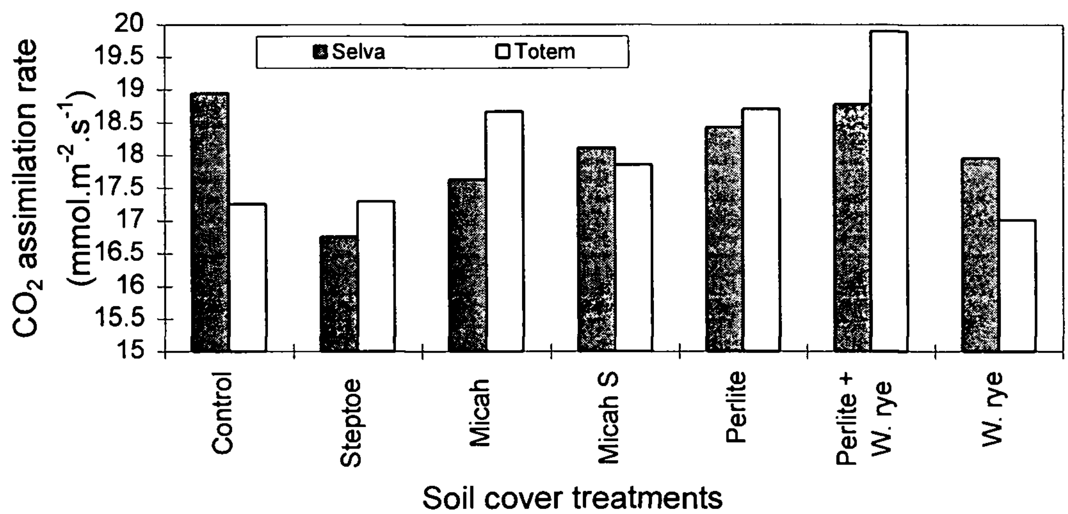

Figure 7: Effect of soil cover treatments on CO_2 assimilation rate (mmol m^{-2} s^{-1}) of strawberry leaves on October 14, 1995 (P-value: Selva = 0.7, Totem = 0.4).

Table 6: Effect of cereal cover crop residues on symphylans and other soil arthropods extracted from Berlese funnel after Selva strawberry harvest on November 27, 1995 .

Cereal soil cover treatments	Symphylan* population/m^3	Other soil arthropods /m^3
Control	833 c**	8959
Steptoe barley	312 ab	7625
Micah barley	624 bc	10834
Micah on Surface	104 a	8125
Perlite	208 ab	5417
Perlite + Wheeler rye	104 a	7208
Wheeler rye	104 a	10709
P-value	0.01	0.22

* On 4/23/95 less population p-value = 0.85 and no symphylan was found on 6/30, 9/12 and 10/30/ 95 respectively.

** Means followed by the same letter within a column are not significantly different based on Duncan's multiple range test, $\alpha = 0.05$.

photosynthesis rate but no difference was found among the treatments in Selva (Fig. 7).

Individual plant parameters: shoot, petiole and leaflet length; leaf, crown, inflorescence and runner number and crown diameter are important for plant growth which leads to better fruit yield production. Results were not consistent among cultivars. In Selva, no significant difference in plant growth parameters was found among treatments on July 10, 1995. At this time, plants were only 6 weeks old and in the establishment stage (Table 7). Only Micah on surface (Micah S) treatment showed slightly better results than the other treatments (Table 7). Results showed distinct differences between the cover crop treatments and non-cover crop treatments including Micah applied on surface by August 15, 1995 (Table 8). Shoot length of strawberry was higher in all cover crop treatments than non-cover crop plots. Perhaps competition for light caused slight elongation of strawberry shoot length while cereal plants were standing between strawberry rows. No significant difference was found on leaflet length, leaf and runner numbers among treatments (Table 7 & 8). Strawberry crown numbers per plant were not different on both July 10 and August 15. However, diameter of the crown was significantly different from each other on August 15. Destructive harvest of Selva plants on November 27 indicated significant differences in numbers of crown per plant where Micah on surface produced greatest crown numbers than any other treatment (Table 9).

Table 7: Effect of cereal soil cover treatments on shoot length, petiole length, leaflet length, number of leaves, number of crowns, crown diameter and number of runners per plant in Selva strawberry on July 10, 1995.

Cereal soil cover treatments	Shoot length (cm)	Petiole length (cm)	Leaflet length (cm)	Leaf number	Crown diameter (mm)	Runner number
Control	14.1	9.1	4.9	4.1	10.1	0.5
Steptoe barley	14.7	9.1	5.5	4.3	10.3	0.4
Micah barley	13.1	7.9	5.1	4.2	11.2	0.6
Micah on surface	16.1	9.4	6.7	4.5	11.7	1.4
Perlite	14.3	8.2	6.1	4.1	10.9	0.5
Perlite + W. rye	15.1	9.0	6.2	4.4	12.2	0.9
Wheeler rye	14.2	8.8	5.5	4.4	10.4	1.1
P-value	0.33	0.56	0.26	0.86	0.42	0.26

Table 8: Effect of cereal soil cover treatments on shoot length, petiole length, leaflet length, number of leaves, number of crowns, crown diameter, number of runners and number of inflorescences per plant in Selva strawberry on August 15, 1995.

Cereal soil cover treatments	Shoot length (cm)	Petiole length (cm)	Leaflet length (cm)	Leaf numbers	Crown diameter (mm)	Runner numbers	Inflorescence numbers
Control	26.2 a*	16.0a	10.3	9.9	23.9a	5.1	2.0 bc
Steptoe barley	29.1 b	19.4bc	9.7	9.5	28.8ab	6.9	1.6 ab
Micah barley	28.2 ab	17.7ab	10.5	10.4	24.1a	6.0	1.5 a
Micah on surface	25.7 a	16.0a	9.7	9.2	28.4ab	5.6	2.9 d
Perlite	25.9 a	16.1a	9.8	10.6	29.5ab	6.1	2.4 cd
Perlite + W. rye	29.8 b	20.6 c	9.1	10.1	33.7 b	7.5	1.9 abc
Wheeler rye	28.2 ab	18.4 b	9.6	9.9	25.6a	5.4	1.7 ab
P-value	0.01	0.01	0.84	0.92	0.01	0.11	0.01

* Means followed by the same letter within a column are not significantly different based on Duncan's multiple range test, $\alpha = 0.05$.

Table 9: Effect of cereal soil cover treatments on the number of crowns per plant on the three different dates in Selva strawberry, 1995.

Cereal soil cover treatments	Selva crown numbers/plants, 1995		
	July 10	August 15	November 27
Control	1.3	1.8	17.5a*
Steptoe barley	1.3	2.0	15.5a
Micah barley	1.4	1.8	16.0a
Micah on surface	1.3	1.8	27.5b
Perlite	1.4	2.0	25.0b
Perlite + W. rye	1.3	2.3	16.0a
Wheeler rye	1.3	1.7	13.3a
P-value	0.43	0.2	0.01

* Means followed by the same letter within a column are not significantly different based on Duncan's multiple range test, $\alpha = 0.05$.

In Totem, Individual plant parameters showed no significant difference among treatments 6 weeks after strawberry planting. Micah applied on surface demonstrated slightly better growth in shoot length and crown diameter (Table 10). After 12 weeks of strawberry planting, vigorous plant growth was noticed with slight variation among treatments (Table 11). Strawberry plants in Micah and Steptoe barley produced long shoots whereas Micah on surface was the shortest. Petiole length was increased in all cover crop treatments compared to no soil coverage (Table 11). No difference was noticed on leaflet length, crown number and runner number, though in the latter part of the season more runner growth was observed. Plants with wider crown diameter were evident in Wheeler rye plots compared to control treatment (Table 11). Strawberry plant growth doubled from July 10 to August 15, 1995, both in Selva and Totem strawberry (Table 7, 8,10 & 11). Comparison of Selva strawberry shoot (above ground plant parts) fresh weight, crown number and root dry weight between cover crops vs control treatment using non-orthogonal contrast indicated no significant difference in plant growth (Table 5).

Yield performance in the establishment year of Selva produced 1.5 to 5 ton/ha (Table 12). Total yield was variable among treatments where Micah barley on surface produced greatest yield. All other treatments showed no difference except Wheeler rye with least amount of fruit production (Table 12). Average fruit weight per berry was higher in control. Small fruit size was produced in main cover crop treatments, whereas Micah on surface plot produced a slightly bigger

Table 10: Effect of cover soil cover treatments on shoot length, petiole length, leaflet length, number of leaves, number of crowns, crown diameter and number of runners per plant in Totem strawberry on July 10, 1995.

Cereal soil cover treatments	Shoot length (cm)	Petiole length (cm)	Leaflet length (cm)	Leaf numbers	Crown numbers	Crown diameter (mm)	Runner numbers
Control	17.8	11.3*	6.5	5.6	2.0	13.7	0.3
Steptoe barley	17.5	11.1	6.5	5.5	1.8	11.9	0.2
Micah barley	17.3	11.0	6.3	5.0	1.5	12.8	0.2
Micah on surface	18.1	12.3	5.8	5.8	2.0	13.2	0.1
Perlite	18.1	11.5	6.6	5.6	2.0	13.1	0.0
Perlite + W. rye	17.7	11.5	6.2	5.6	1.8	13.0	0.2
Wheeler rye	16.2	10.0	6.2	5.1	1.8	11.4	0.1
P-value	0.54	0.22	0.87	0.83	0.45	0.33	0.33

Table 11: Effect of cereal soil cover treatments on shoot length, petiole length, leaflet length, number of leaves, number of crowns, crown diameter and number of runners per plant in Totem strawberry on August 15, 1995.

Cereal soil cover treatments	Shoot length (cm)	Petiole length (cm)	Leaflet length (cm)	Leaf numbers	Crown numbers	Crown diameter (mm)	Runner numbers
Control	30.4ab*	19.5abc	10.9	10.8ab	2.0	28.8a	6.7ab
Steptoe barley	31.9 b	21.1 c	10.9	12.2b	2.1	30.9ab	6.8ab
Micah barley	31.9b	19.8bc	12.1	12.4b	2.1	32.6ab	7.7b
Micah on surface	28.2a	17.5 a	10.7	8.7a	2.0	32.1ab	5.9a
Perlite	28.5a	18.0ab	10.5	11.4ab	2.3	33.4b	6.9ab
Perlite + W. rye	30.6ab	20.9 c	9.8	10.3ab	2.4	35.2b	6.9ab
Wheeler rye	29.9ab	19.9bc	9.9	11.4ab	2.4	35.5b	7.7b
P-value*	0.05	0.01	0.16	0.1	0.13	0.05	0.09

* Means followed by the same within a column letter are not significantly different based on Duncan's multiple range test, $\alpha = 0.05$.

Table 12: Effect of cereal soil cover treatments on total fruit production (kg/ha), total number of fruits, average berry weight (g/fruit) and total number of fresh marketable fruits in Selva strawberry, 1995.

Cereal soil cover treatments	Total fruit production kg/ha	Number of fruits/plant	Average fruit wt. g/fruit	Number of marketable fresh fruits
Control	3391.7bcd*	5.4abc	19.2b	4.3ab
Steptoe barley	2602.5abc	4.7abc	16.4ab	3.7ab
Micah barley	2352.8ab	4.3ab	15.5a	3.3 a
Micah on surface	4201.1cd	7.3bc	17.7ab	4.8ab
Perlite	4945.7d	7.9c	19.3b	6.0b
Perlite + W. rye	1915.0ab	3.9ab	14.1a	2.8a
Wheeler rye	1498.7a	3.4a	15.5a	2.4a
P-value*	0.01	0.05	0.05	0.05

* Means followed by the same letter within a column are not significantly different based on Duncan's multiple range test, $\alpha = 0.05$.

fruit. Total number of fruits per plant was higher in Micah barley applied on soil surface. All cover crop treatments showed less marketable fresh fruits than control, though no significant difference was found. Micah applied on surface produced slightly better marketable fruits (Table 12).

During harvest season, greater yield was obtained from September 25 to October 3, 1995. Early season yield (Fig. 8) and marketable fruits per plant (Fig. 9) was lower in control and Wheeler rye treatments. Total number of fruits per plant also showed similar as marketable fruit on September 7 (Fig. 10).

Comparison of Selva strawberry total yield and average fruit production between cover crops vs control treatment using non-orthogonal contrast indicated no significant difference (Table 5). This might suggests no detrimental interaction between cover crops and strawberry.

Totem strawberry yield for the first year was ignored, although fruits were harvested 7 weeks after planting strawberry on July 20, 1995 (Fig. A-5 & A-6).

B. Comparison in Micah barley treatments

Micah barley planted in the plot and Micah barley applied on the soil surface were considered in the experiment to separate the root effect from shoot/root growth of barley on strawberry. No significant difference was found in total weed suppression between the two treatments but Micah on surface showed slightly better result on both June 27 and August 15 in within row areas of strawberry (Table 2 & 4). On August 15, Micah on surface did not suppress the growth of pigweed biomass between strawberry rows area (Table 4), though no difference was observed in pigweed density (Table 3). Comparison between Micah barley treatments vs control treatment using non-orthogonal contrast indicated significant difference in suppressing weeds on August 15. But no difference was found in suppressing weeds on April 25 where Micah barley applied on surface treated as control (Table 5).

No difference was found between two treatments on gray mold incidence in Selva in September. Micah on surface showed slightly better effect on gray mold suppression in Totem in July (Fig 5) which may suggest involvement of other factors.

Yield component of strawberry was greater in Micah on surface compared to Micah barley. In contrast analysis for Selva plant growth and yield, no difference was found between Micah barley treatments vs control treatment (Table 5). However, Micah on surface produced 50% more shoot biomass (Fig. 11) and about 45% greater yield compared to Micah barley (Table 12).

C. Comparison in perlite treatments

Perlite, an artificial soil media, was used to improve soil aeration which might reduce the black root rot complex often associated with root health and

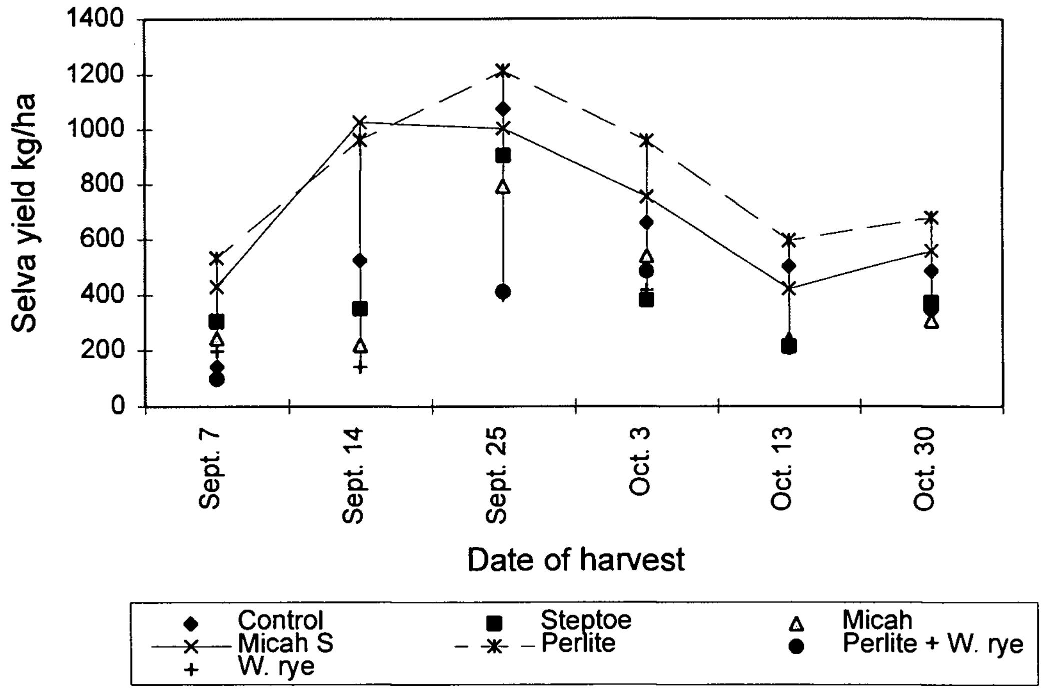

Figure 8: Effect of soil cover treatments on Selva strawberry yield (kg/ha) harvested on different dates, 1995.

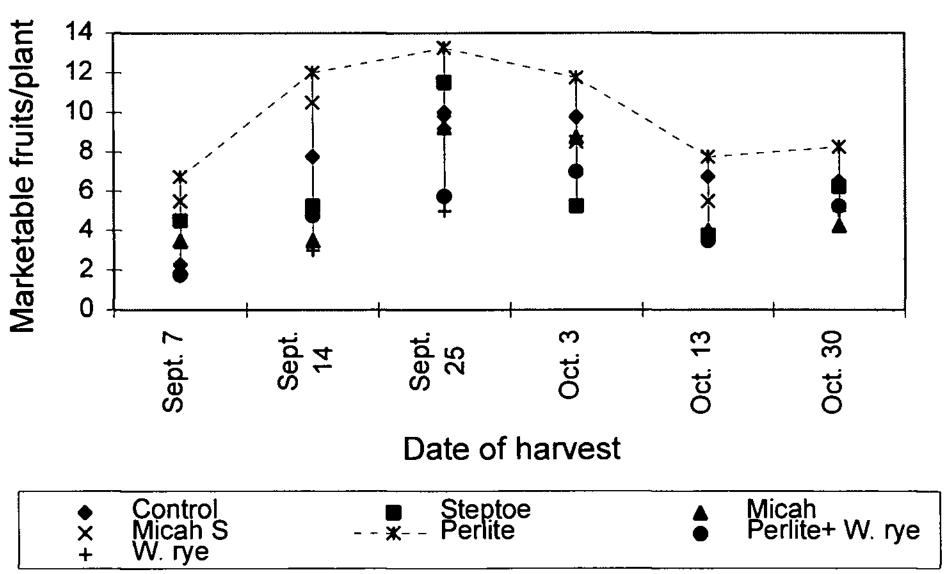

Figure 9: Effect of harvest date with soil cover treatments on marketable fruits per plant of Selva strawberry, 1995.

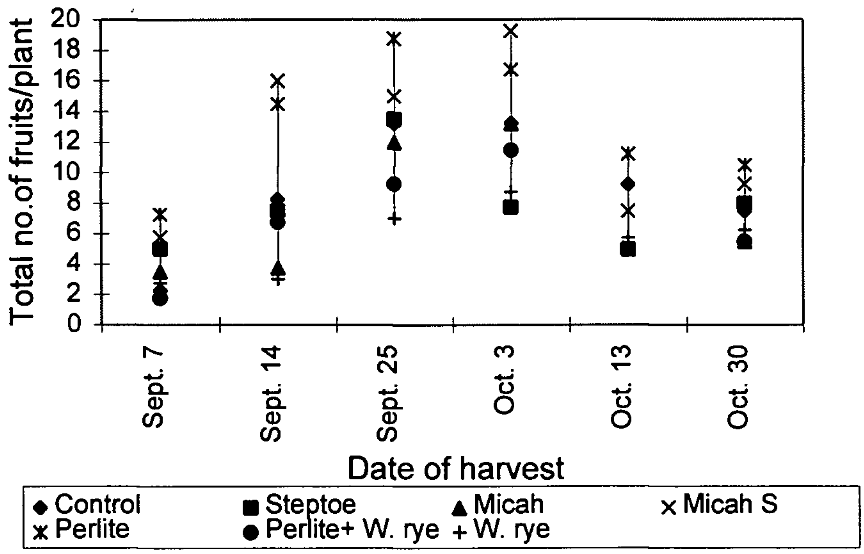

Figure 10: Effect of harvest date with soil cover treatments on total number of fruits per plant of Selva strawberry, 1995.

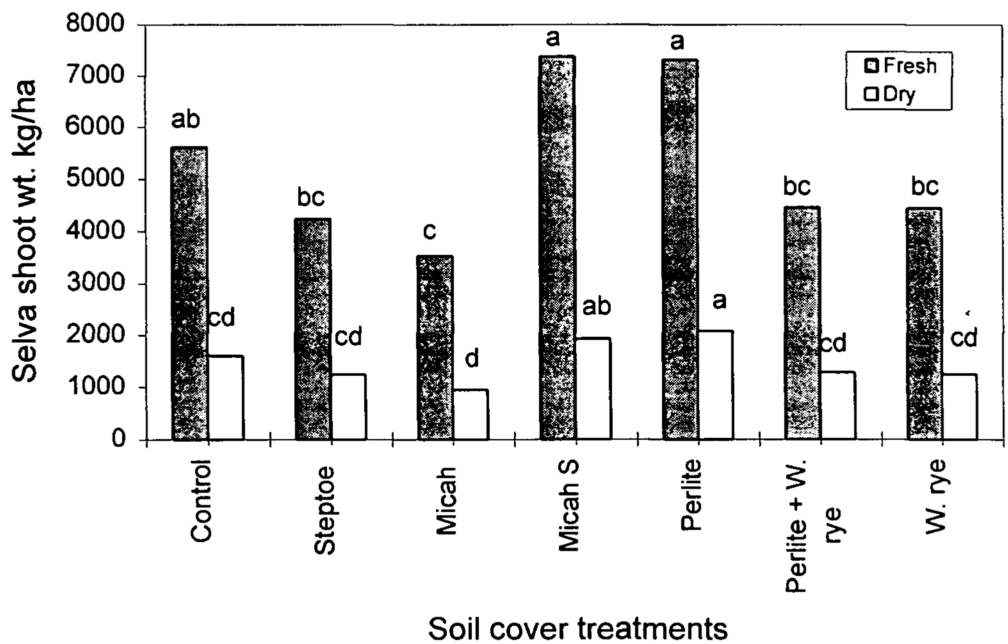

Figure 11 : Effect of soil cover treatments on shoot weight (kg/ha) of Selva strawberry on November 27, 1995.

poor root growth. Root dry weight of strawberry in perlite treatments was similar to control and slightly better than all cereal cover crops except Micah barley on the soil surface (Table 13). Perlite with Wheeler rye produced 33% higher root dry weight than Wheeler rye alone. No significant difference was found in primary roots (Table 13).

Visual observation of new primary root growth compared to old nursery roots and dead roots might suggest better root growth or suppressive effect on black root rot complex. Although not significantly better than control, perlite treatments enhanced new root growth. All cereal cover crops suppressed new root growth slightly (Table 13) whereas in contrast analysis for Selva root dry weight, significant difference was found between perlite treatments vs control treatment (Table 5).

No significant different was found on strawberry plant growth parameters in both Selva and Totem except slightly elongated petiole in perlite with Wheeler rye treatment compared to perlite (Table 7, 8, 10 & 11). Number of inflorescences (Table 7) and crowns (Table 9) in Selva strawberry was greater in perlite treatment compared to perlite with Wheeler rye and control. No significant difference was found in contrast analysis between perlite treatments vs control treatment in case of Selva yield (Table 5). In Selva, total yield in perlite treatment was produced 61% greater than perlite with Wheeler rye treatment and 31% greater than control treatment (Table 12).

Table 13: Effect of cereal soil cover treatments on root dry matter production (kg/ha), primary root length and percent ratio of new primary root over old and dead root in Selva strawberry on November 27, 1995.

Cereal soil cover treatments	Selva root		Ratio primary root % (Visual rating)
	Dry weight kg/ha	length (cm)	
Control	204.7abc*	15.3	32
Steptoe barley	184.7 ab	13.7	21
Micah barley	177.3 ab	17.0	46
Micah on surface	225.3 bcd	19.9	26
Perlite	274.7 d	19.9	40
Perlite + W. rye	252.0 cd	17.8	55
Wheeler rye	168.7 a	15.7	38
P-value	0.01	0.30	0.13

* Means followed by the same letter within a column are not significantly different based on Duncan's multiple range test, $\alpha = 0.05$.

D. Greenhouse experiment

The greenhouse experiment failed to assess gray mold incidence on strawberry due to lack of pollination and deformed fruit production. Black root rot was evaluated on the basis of root health. No difference in shoot and root dry weight and the number of leaves was found among the treatments for the 6-week period of the greenhouse experiment. Strawberry in Micah barley produced slightly better growth than the other treatments (Table 14).

Table 14: Effect of cereal treatments on fresh and dry weight (g/plant) of both shoot and root, and number of leaves per plant of Selva strawberry in greenhouse, 1995.

Treatments*	Shoot weight g/plant		Root weight g/plant		Number of leaves per plant
	Fresh	Dry	Fresh	Dry	
Control	6.1	1.8	3.1	0.70	1.5
Wheeler rye	6.8	1.8	3.3	0.74	1.5
Micah barley	10.9	3.4	3.8	0.78	1.7
P-value	0.4	0.36	0.9	0.97	0.25

* Means are not significantly different among the treatments based on Duncan's multiple range test, $\alpha = 0.05$.

Chapter V

CONCLUSION

Comparison of cereal cover crops to suppress multiple pests (weed, arthropod and disease) in Selva and Totem strawberry were studied. Weeds were suppressed from 58 to 94% in all cover crop treatments during the growth phase of cover crops compared to the control group. Early spring Micah barley suppressed more than 81% of the total weeds compared to control plots with residues. In early-summer, no difference was found in cover crops treatments 60 days after killing with glyphosate. Mid-summer weed biomass were variable due to vigorous growth of pigweed where density was not significantly different compared to control treatment in both within and between rows of strawberries. Although weeds were suppressed with cover crops in spring, replanting in early summer failed to suppress pigweed. Therefore, further studies are needed to incorporate other management practices with cover crops for weed suppression.

All cover crops suppressed symphylan 62 to 87% except Micah barley (25%) in fall using Berlese funnel extraction. But no pattern was established on total soil arthropods including beneficial insects. Suppression of symphylan and management of soil arthropods requires additional study in terms of cropping systems. Wheeler rye suppressed strawberry gray mold (*Botrytis cinerea*) slightly (21% of fruits were still infected in Selva). Perlite increased root dry weight 25 to 36% of strawberry and enhanced new primary root growth which may indicate suppressive effect on black root rot complex. No evidence was found in suppression of black root rot in greenhouse study, but Micah barley produced slightly better shoot biomass than the other treatments. More research is needed with cover crops to assess the suppressive effect in disease incidence.

Strawberry plant growth was radically increased in mid-summer in both cultivars, whereas no difference was shown within 6-week after strawberry planting. Distinct differences between the cover crop treatments and non-cover crop treatments, including Micah applied on surface, was noticed on strawberry plant growth. Micah on surface produced better results in terms of crown numbers and shoot biomass (at least 36% and 23-52% higher respectively) than any other treatment. All cover crops reduced strawberry yields slightly during the establishment year. Perlite and Micah barley on surface produced higher total number of fruits, marketable fresh fruits and total yield. In early season, lower total yield, marketable and total number of fruits were produced in control and Wheeler rye treatments. In order to minimize the yield reduction, more efforts on the timing of cereal planting might achieve the goal.

Multiple pest suppression using cover crops in strawberry will require additional research. Since no detrimental effect of cover crops on strawberry yield and beneficial arthropods was found. Therefore, research possibilities with integration of other cultural practices are open for more exploration.

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APPENDIX

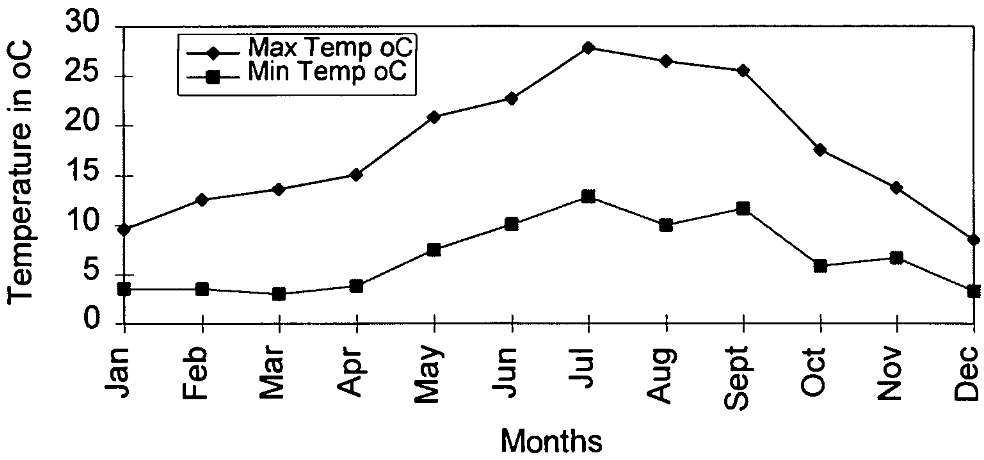

Figure A-1: Maximum and minimum air temperature (°C) during the study year, 1995 (Source: OCS).

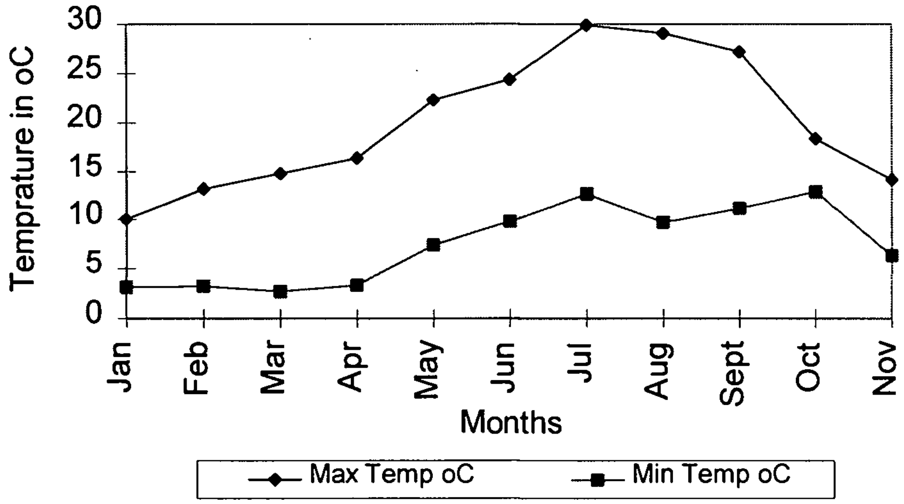

Figure A-2: Maximum and minimum surface temperature (°C) during the study year, 1995 (Source: OCS).

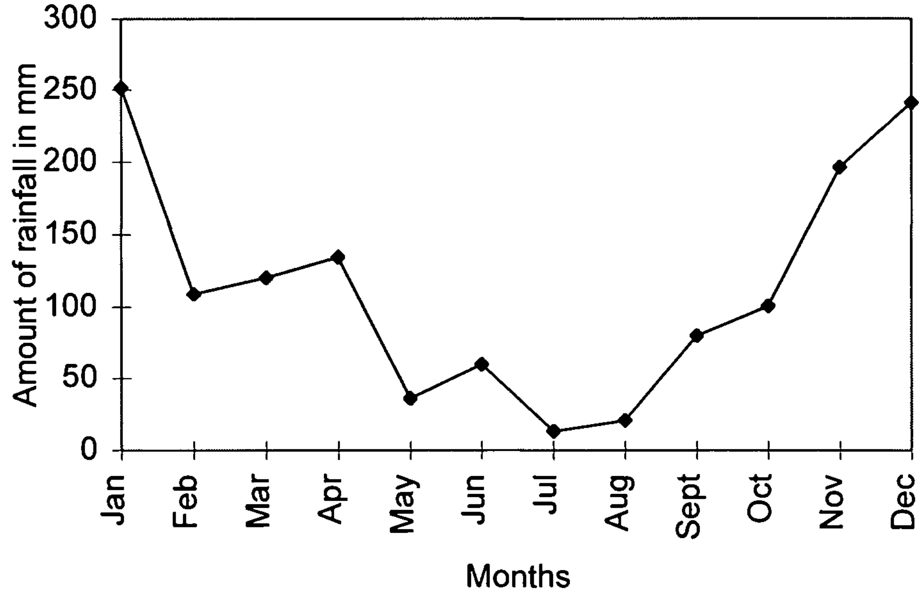

Figure A-3 : Amount of total rainfall (mm) during the study year, 1995 [Source: Oregon Climate Service (OCS)].

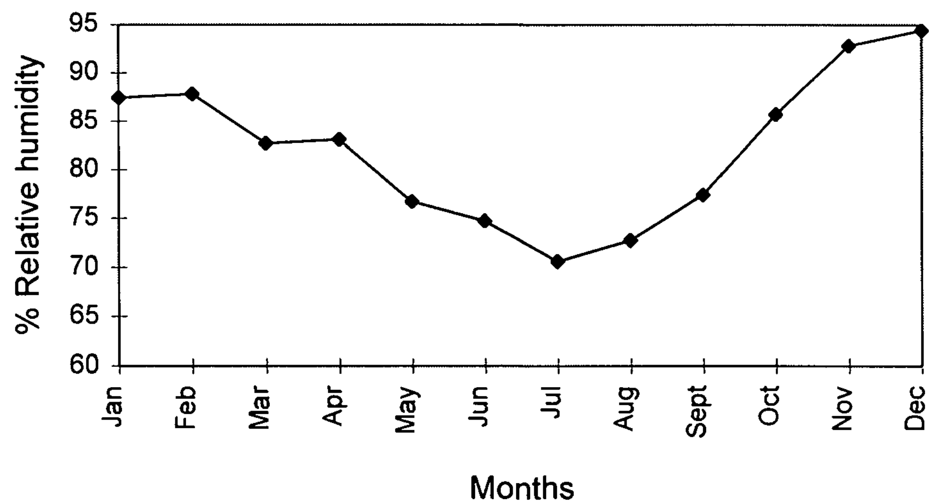

Figure A-4 : Percent Relative humidity during the study year, 1995 (Source: OCS).

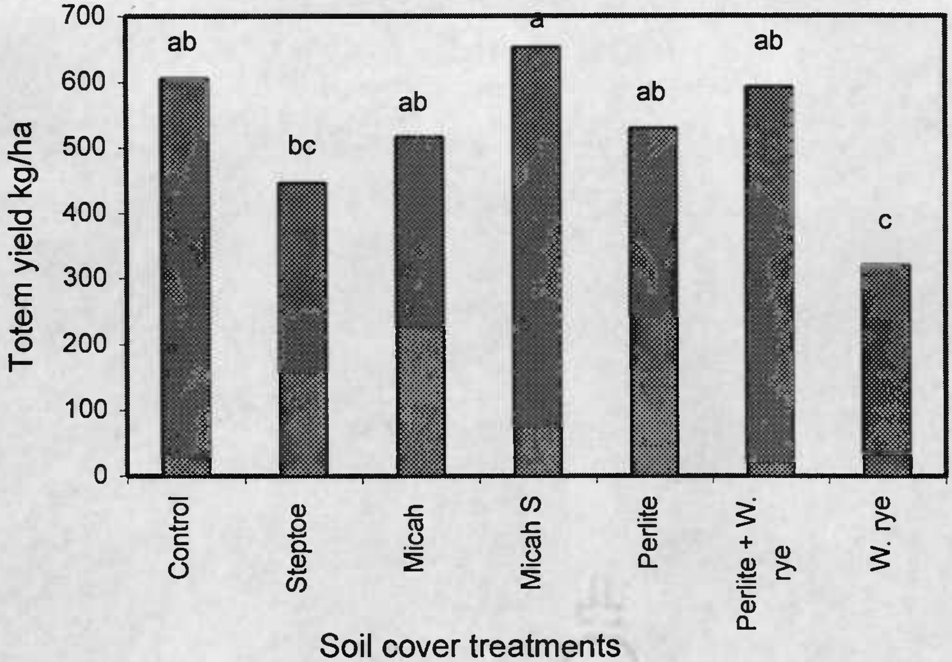

Figure A-5: First year fuirt production (kg/ha) of Totem strawberry in July, 1995.

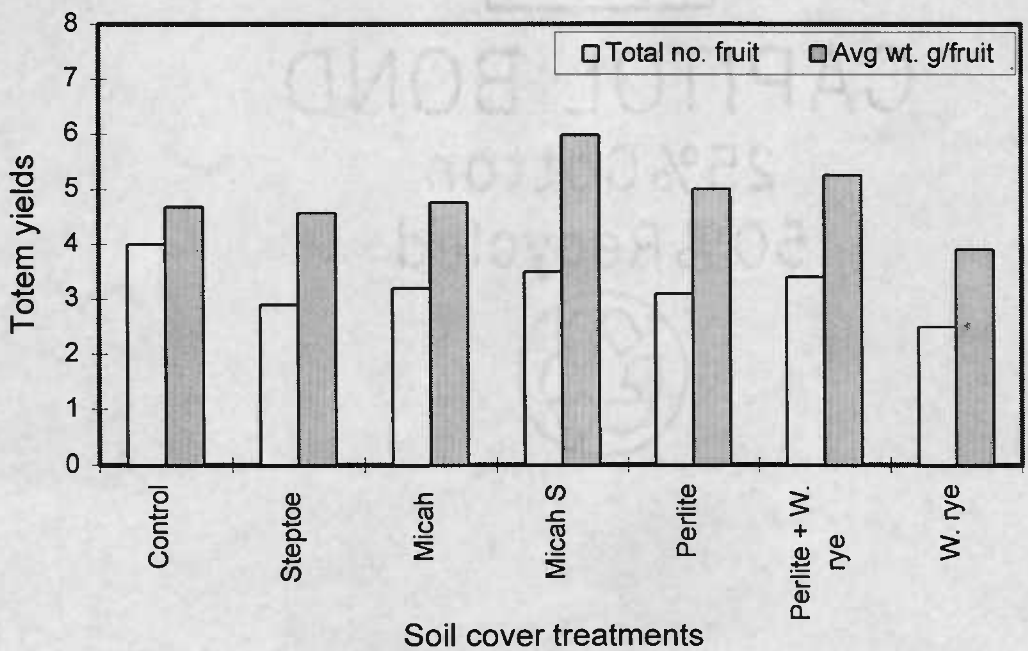

Figure A-6: Total number of fruits per plant and average berry weight (g/fruit) of Totem strawberry in the first year of production, 1995 (p-value >0.10).