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Title: Effects of Tillage on Emergence of Mint Root Borer, *Fumibotys fumalis* Guenée, and on Other Agronomic Factors in Peppermint, *Mentha piperita* L.

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Studies were conducted in the Willamette Valley of western Oregon to evaluate the effects of plowing (7.5-15 cm deep) and disking (5-10 cm deep) in peppermint, *Mentha piperita* L., on the following factors: 1) emergence of adult "mint root borer", *Fumibotys fumalis* Guenée; 2) suppression of common groundsel, *Senecio vulgaris* L.; 3) spread of Verticillium wilt, *Verticillium dahliae* Kleb.; 4) soil chemical factors such as pH and nutrient elements; and 5) peppermint growth, yield, and oil quality and maturity.

Plowing and disking significantly reduced emergence of adult *F. fumalis*. In all treatments adult emergence peaked from early July to early August. Female emergence peaked about one week later than for males in two test plots. Populations of immature *F. fumalis* were aggregated, and were not significantly correlated with

populations of adults.

In one test plot, plowing significantly reduced the density, dry weight biomass, and plant vigor of *S. vulgaris*. Even though plowing reduced the density of *S. vulgaris* in other test plots, neither the dry weight biomass nor plant vigor were reduced. Disking reduced stands of *S. vulgaris* to a limited extent. Plowing significantly reduced false dandelion, *Hypochaeris radicata* L., by about 65 percent in one test plot.

Plowing or disking did not affect the number or percentage of plants showing typical symptoms of Verticillium wilt. However, Verticillium wilt was aggregated within test plots so the influence of tillage on the spread of Verticillium wilt is uncertain.

Plowing resulted in a more uniform distribution of pH and nutrients throughout the 0-15 cm soil layer. Plowed plots had higher levels of pH and Ca in the surface 0-5 cm of soil, and higher levels of P and K in 5-15 cm of soil. In disked plots, levels of pH, P, and K in 0-5 cm and 5-15 cm soil samples were intermediate between plowed and untilled plots. Tillage treatments did not significantly affect levels of Mg or B.

Density of peppermint plants was lower in plowed and disked plots than in untilled plots. Peppermint plant vigor was higher in tilled than untilled treatments at one test location, resulting in higher peppermint hay and oil yields. Peppermint hay and oil yields at other test locations were generally not affected by tillage treatments. Analysis of selected terpene compounds from oil samples indicated that plowing or disking did not affect peppermint oil quality, but may have delayed the process of oil maturation.

Plowed plots had a significantly greater percentage (ca. 14%) of total rhizome dry weight in 5-15 cm of soil than in disked or untilled plots.

Effects of Tillage on Emergence of Mint Root Borer, *Fumibotys fumalis* Guenée, and on Other Agronomic Factors in Peppermint, *Mentha piperita* L.

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INTRODUCTION

Peppermint, *Mentha piperita* L., is a major commercial crop in Oregon where it is grown principally in the Willamette Valley and central Oregon. During 1980 approximately 18,000 hectares of peppermint were grown in Oregon, producing 1,215,000 kilograms of oil valued at $24,300,000. This accounted for about 58 percent of the total United States production (Miles 1982).

The "mint root borer", *Fumibotys fumalis* (Guenée) (Lepidoptera: Pyralidae), is probably host-specific to *Mentha* spp. (Munroe 1976). *F. fumalis* occurs in peppermint fields in the Willamette Valley of Oregon, north central Oregon, and central Washington (Berry *et al.* 1977). Recently, *F. fumalis* has been found in eastern Oregon and western Idaho. Since its discovery in Umatilla County, Oregon in 1971 (Berry 1974), *F. fumalis* has become an economically important pest of peppermint. Approximately one-third of the peppermint acreage in the Willamette Valley during 1981 was treated with insecticides to control *F. fumalis* (Calkin *et al.* 1981).

Peppermint is a biennial which is grown as a perennial crop through an annual reproduction of rhizomes (C.E.

Horner, Courtesy Professor, Botany and Plant Pathology Department, Oregon State University, 1980 pers. comm.). Following harvest in August and September, larvae of *F. fumalis* primarily feed on rhizomes. Damage is most evident the following growing season when the peppermint stand becomes thinned and weakened because of a reduction in the number of rhizomes.

Current sampling techniques for *F. fumalis* are laborious and time consuming. Sampling consists of extracting larvae from soil samples with Berlese funnels following harvest. Fields are most effectively sampled when the majority of larvae reach the third instar. Before this, larvae are too small to be efficiently extracted, and later they consume more and cause more damage. The best time to sample for larvae is shortly after harvest. Large acreages are difficult to sample because the optimum time for sampling is short and the methods are slow. Control of larvae is currently accomplished with the insecticide chlorpyrifos applied post-harvest at 2.2 kg a.i./ha (Capizzi *et al.* 1983). However, chlorpyrifos should be watered in immediately after application, and growers using sprinkler irrigation may require a week or more to apply the insecticide. Since chemical control decisions need to be made quickly, and populations of *F. fumalis* may develop resistance to chlorpyrifos, research was necessary to investigate alternative control measures.

Tillage, i.e., plowing or disking, was chosen as an exploratory control measure because it has been used in peppermint to control weeds and diseases and to bury rhizomes to increase tolerance to winter injury. Tillage, usually performed when the mint is dormant, has a minimal effect on the plant. Thus, if effective, tillage could reduce the overwintering population of *F. fumalis* which would eliminate the need for extensive sampling and insecticide treatment. Since tillage affects other agronomic and production factors, I also investigated the effects of tillage on weeds, particularly common groundsel, Verticillium wilt, soil chemical components, peppermint growth, yield, and oil maturity and quality.

LITERATURE REVIEW

Effects of Tillage on Mint Root Borer and Other Insects

Larvae of mint root borer feed on rhizomes of peppermint, *Mentha piperita* L., (Berry 1974) and probably on other mints as well (Munroe 1976). The mint root borer was first identified by Guenée in 1854 as *Ebulea fumalis*, and has since undergone several taxonomic revisions. Forbes (1923) described the adult stage of *Pyrausta fumalis*. Most recently, Munroe (1976) placed it in a new genus, *Fumibotys*. Berry (1974) and Berry *et al.* (1977) described the life stages of the "mint root borer", its life history, and the damage it causes in peppermint. *F. fumalis* has one generation per year. The diapausing prepupae overwinter inside hibernacula in the soil. Adults begin emerging during early June and peak emergence occurs during mid-July. Adults live 8-10 days during which time females may each lay up to 400 eggs on the foliage (G.L. Parsons, Entomology Department, Oregon State University, 1982 pers. comm.). Newly hatched larvae feed on the foliage for ca. 4-5 days, then drop to the soil surface and enter the rhizomes. Larvae complete their development during late September and October, then construct hibernacula in which the prepupal stage overwinters in diapause.

Mechanical tillage may control a soil insect pest in several ways: 1) by changing the soil structure; 2) by burying, exposing, or mechanically damaging the pest; 3) by eliminating host plants of the insect pest; or 4) by increasing the crop's growth or vigor (Pfadt 1978). Tillage has been shown to reduce populations of several insect and other invertebrate pests in different crops (Barber and Dicke 1937, Fife and Graham 1966, Hunter 1967, Watsen and Larson 1968, Larson *et al.* 1970, Sloderbeck and Edwards 1979, Harrison *et al.* 1980, Folwell *et al.* 1981, Roach 1981, Grant *et al.* 1982). However, some insect pest populations or the damage they cause have significantly increased with conventional tillage practices compared to minimum tillage practices (Gaydon and Adkins 1969, All *et al.* 1979, Sloderbeck and Edwards 1979, Reed and Byers 1981).

Tillage has also been shown to affect some of the arthropod pests of peppermint. Hollingsworth and Berry (1982) reported that fall plowing delayed the need to treat twospotted spider mite, *Tetranychus urticae* Koch, by an average of one month. Data compiled by the Oregon State University Extension Service in Jefferson County, Oregon during 1980 indicated that fall plowing reduced spring larval densities of the redbacked cutworm, *Euxoa ochrogaster* Guenée. Cacka (1982) suggested that spring sampling of strawberry root weevil larvae, *Otiorhynchus ovatus* L., should be performed at a greater depth (15 cm) in fall plowed fields than in unplowed fields (10 cm).

Control of *F. fumalis* in commercial peppermint is currently accomplished by using the only registered insecticide for this purpose, chlorpyrifos. Studies indicate that chlorpyrifos controls about 90 percent of the larval population of *F. fumalis* (Berry 1978, Pike 1979). The insecticide carbofuran has been used to control infestations of *O. ovatus*, and if applied at the proper time, it also controls about 99 percent of the larval population of *F. fumalis* (Berry 1978).

For tillage to be a practical method of controlling *F. fumalis*, it must be comparable to insecticidal control in both effectiveness and cost. Pike and Glazer (1982) reported that "strip rotary tillage", a practice used by a small number of growers with furrow irrigated fields, resulted in ca. 81 percent reduction in emergence of adult *F. fumalis*. A preliminary study conducted by Extension Entomology personnel at Oregon State University (1979-1980) evaluated the effect of plowing and disking on control of *F. fumalis*. Results indicated that some control was possible with all tillage practices, but because of the low number of adults that emerged from the plots, no significant differences between tillage treatments were found. The cost of tillage in peppermint is less than the cost of insecticide treatment. An application of chlorpyrifos (2.2 kg a.i./ha) costs ca. $54/ha, whereas tillage costs about $47/ha to plow and double disk, and $25/ha to double disk (Weber and Holst 1978).

Effects of Tillage on Weeds

Mechanical tillage is one of the oldest methods of weed control (Swan 1978). Cultural methods were used more than thirty years ago to control weeds in peppermint (Freed and Renney 1953). Tillage commonly consisted of shallow plowing (15 cm deep or less) with a moldboard plow and disking the soil in the fall or early spring. While plowing controlled weeds present at that time, it also produced a favorable seedbed in which weed seeds brought to the soil surface could become established (Furtick 1955). Additional cultivations with fine-toothed harrows or rotary hoes were performed in the spring until mint plants reached a height of 12-15 cm (Green 1963). However, unless "row mint" was being grown, these additional cultivations could not be performed late enough in the season to obtain satisfactory weed control (Green 1963). Geese and sheep also have been used as a supplemental weed control measure. Disadvantages resulting in their limited use by growers included: the reluctance of geese to consume larger weeds;

their inability to control such weeds as common groundsel and purslane; the tendency of older sheep to feed on mint plants; and problems with predators, daily care, and sanitation (Furtick 1955, Green 1963).

Disadvantages of conventional weed control practices in peppermint coupled with the development of effective herbicides have led growers to rely primarily on herbicides for weed control. Six herbicides (terbacil, diuron, trifluralin, napropamide, bentazon, and oxyfluorfen) are currently registered for use on peppermint in Oregon (William 1983). In addition, paraquat has been made available over the past few years through an emergency registration. Even though these herbicides have provided good weed control, they all have disadvantages which limit their effectiveness and use (Ogg 1975).

More than twenty species of weeds have been reported to cause problems in peppermint (Guenther 1949, Liebel 1950, Furtick and Chilcote 1957, Green 1963). Weeds in peppermint compete for water, nutrients, and sunlight, and if distilled with the mint, impart unfavorable colors and flavors to the mint oil (Ellis *et al.* 1941). Weeds frequently found in peppermint fields in Oregon include: common groundsel, *Senecio vulgaris* L.; common dandelion, *Taraxacum officinale* Weber; false dandelion, *Hypochaeris radicata* L.; redroot pigweed, *Amaranthus retroflexus* L.; lambsquarter, *Chenopodium album* L.;

common purslane, *Portulaca oleracea* L.; nightshades, *Solanum* spp.; Canada thistle, *Cirsium arvense* (L.) Scop.; field bindweed, *Convolvulus arvensis* L.; and several species of grasses.

The effectiveness of weed control by mechanical cultivation depends on the life cycles of the weeds involved (Fryer and Evans 1968, Klingman and Ashton 1975). Annual weeds can be controlled if cultivation effectively buries their growing points, cuts the plant off below the soil surface, or disturbs the root system sufficiently to cause desiccation of the plant. However, cultivation may stimulate germination of many annual weed seeds, and unless subsequent cultivations follow, these newly emerged seedlings may cause problems. Even under frequent cultivation, some annual weeds, e.g., *S. vulgaris*, may still become a problem because they are able to mature and reproduce quickly (Fryer and Evans 1968). Biennials and simple perennials with tap roots also may be effectively controlled if they are buried or exposed to desiccation. However, some weeds with tap roots have the capacity to regenerate from portions of the roots if they are severed into sections by cultivation practices. *Taraxacum* spp. are capable of producing shoots from all cut portions (Fryer and Evans 1968, Mann and Cavers 1979). Cultivation may destroy creeping perennial seedlings in ways similiar to annual weeds. However, once they are established by vegetative and reproductive roots or stems, they become more difficult to control. Tillage may actually aid in the dissemination and establishment of creeping perennials by dispersing their vegetatively reproducing parts (Klingman and Ashton 1975). However, intensive cultivation may effectively control creeping perennials, e.g., *C. arvensis* and *C. arvense* (Fryer and Evans 1968), by eventually depleting carbohydrate reserves in their roots. While plowing and disking alone may not eradicate *C. arvensis*, Swan (1980) and Derscheid *et al.* (1970) reported that ca. 90 percent control of *C. arvensis* was accomplished using 2,4-D alone or in combination with cultivations.

Research conducted to evaluate herbicide-tillage interactions in peppermint have concentrated more on the effect of such combinations on injury to mint than on weed control. In one instance, both disking and plowing caused more peppermint injury than no-till when combined with most of the herbicides under study (Crop Science Department, Oregon State University 1980). Preliminary data reported by Ogg *et al.* (1982) suggested that mint growth, in combination with herbicides, was better in strip-rotovated plots than non-rotovated plots. Ogg (1975) reported that good weed control was achieved in the rows of strip-rotovated mint when combined with herbicide(s), but not in the irrigation rills.

Effects of Tillage on Diseases of Peppermint

Several diseases are known to cause economic losses in peppermint. The most common diseases and their causal organism(s) include: Verticillium wilt (*Verticillium dahliae* Kleb.); mint rust (*Puccinia menthae* Pers.); nematodes (3 spp.); and root rots (at least 5 spp.) (Horner 1955). Verticillium wilt is the major limiting factor of peppermint production in western Oregon, Indiana, Michigan, and parts of Wisconsin (Green 1963, Horner and Dooley 1965).

Green (1963) described the development of Verticillium wilt in peppermint. Verticillium wilt usually starts in isolated or small spots in the field and spreads during subsequent years of production. As early as April or May, affected plants begin to show symptoms of dwarfing and uneven growth. The leaves become bronze and then rapidly turn yellow followed by death of the plant. Plants infected later in the season show considerable twisting and curling, lack good color in the foliage, and may wilt. The plant then turns progressively yellow, brown, and then dies. Microsclerotia of *V. dahliae*, which form in maturing diseased stems and roots, are the means by which plants become infected with Verticillium wilt in subsequent years.

Koepsell and Horner (1975) recommended that growers wanting to continue peppermint production in Verticillium wilt infested fields should plant certified root stock, flame stubble immediately after harvest, and limit or not plow. They also recommended that growers should consider the use of resistant varieties, crop rotation, and soil fumigation to reduce the incidence of Verticillium wilt. Fall flaming has been shown to significantly reduce *V. dahliae* inoculum in stubble (Horner and Dooley 1965, McIntyre and Horner 1973). While plowing and cultivation are believed to spread the disease by moving infected debris and infested soil through the field (Horner 1955, Horner and Dooley 1965), no studies on the spread of Verticillium wilt by cultivation are available. "Deep plowing" of peppermint in the muck soils of the Midwest was reported to give good control of Verticillium wilt (Green 1958). This practice had several disadvantages and was later reported to give inadequate control (Thomas 1961).

Two cultivars of peppermint, Black Mitcham and Todd's Mitcham, comprise most of the acreage planted to peppermint in the United States. Black Mitcham peppermint is very susceptible to Verticillium wilt, whereas Todd's Mitcham is tolerant to the disease (Koepsell and Horner 1975). Since its release for commercial production in 1972 (Horner 1972), Todd's Mitcham peppermint has replaced much of the acreage previously planted with Black Mitcham. However, one disadvantage of Todd's Mitcham peppermint, is that it does not have as desireable plant growth characteristics as Black Mitcham (C.E. Horner, Courtesy Professor, Botany and Plant Pathology Department, Oregon State University, 1980 pers. comm.).

Horner (1955) reported that both peppermint rust and root rots could be effectively controlled if infected plant debris was buried in the soil 7.5-10 cm. Consequently, control of these diseases was accomplished by annual shallow plowing (10-15 cm) and a spring application of the herbicide Dinitro over areas of the field where infested plants remained uncovered. Incidence of peppermint rust is higher in fields plowed in the fall than in the spring, but root rot diseases of peppermint are more serious in fields plowed in the spring than in the fall (Horner 1952). Shallow plowing to control peppermint rust was abandoned after it was found that applications of Dinitro or spring flaming alone gave efficient control (Horner 1965).

Sumner *et al.* (1981) reviewed results reported by others on the effect of cultivation on plant diseases in several different crops. Some diseases were controlled by conventional tillage practices, but other diseases were either not affected or increased.

Effects of Tillage on Soil

Peppermint grows best on well-drained peat or muck or fertile sandy loam and silt loam soils in the Midwest and Pacific Northwest (Powers 1947, Green 1963). Applications of nitrogen fertilizer significantly increase peppermint hay weight and production of oil (Davis *et al.* 1957, Baird 1957, Skrubis 1964, Nelson *et al.* 1971). An increase in hay weight does not always result in an increase in oil yield. High rates of nitrogen may reduce the oil yield or delay the maturity of the plants (Davis *et al.* 1957, Nelson *et al.* 1971). Peppermint responds differently to applications of phosphorus and potassium. While peppermint may respond favorably to applications of potassium and phosphorus when applied to peat or muck soils (Powers 1947, Davis *et al.* 1957), practically no response occurs when applications are made on mineral soils (Baird 1957, Skrubis 1964, Huettig 1969) unless such soils have low levels of these nutrients (Jackson and Hee 1971).

Few studies have examined the effects of tillage on chemical properties in the soil. Jackson and Hee (1971) indicated that soil pH decreased in the top 2.5 cm of soil in peppermint fields that had not been plowed for several years. This is important because the roots of peppermint are very near the soil surface in fields that have not been plowed for several years. A drop in soil pH may lead to a reduction in crop yields resulting from decreased nutrient availability, decreased rate of microbial activities, and increased manganese and aluminum toxicities (Kauffman (1974).

The effects of cultivation on the physical condition of the soil were described by Brady (1974) and Soane and Pidgeon (1975). Short term favorable effects included breaking up clods, incorporating organic matter, and producing a favorable seedbed. Long term detrimental effects included hastening the oxidation of organic matter, breakdown of soil aggregates, and compaction of soil. Another disadvantage to cultivation is the problem of erosion. Water, wind, and "tillage" erosion may cause problems in cultivated areas of the Willamette Valley, Columbia Basin and the Columbia plateau (Papendick and Miller 1977). Where water erosion is a problem in the Willamette Valley, growers may prefer to plow peppermint fields in the spring rather than in the fall.

Effects of Tillage on Peppermint Plant Growth, Yield and Oil Quality

Commercial production of peppermint was described by Sievers and Stevenson (1948), Guenther (1949), Davis *et al.* (1957), and Green (1963). Peppermint is propagated vegetatively by rootstock which consists of aboveground stolons and belowground rhizomes (Horner 1955). Roots planted in furrowed rows (7.5-15 cm deep) during the fall or spring produce plants in rows during the first year (row mint). As the stolons and rhizomes spread and fill-in during subsequent years, a solid stand of plants (meadow mint) is produced. Fields are periodically fertilized and irrigated during the spring and summer. Long daylengths (16-18 hours) during the summer promote foliar growth and formation of oil (Langston and Leopold 1954). Peppermint is harvested during the early bloom stage in August and September. Some regrowth occurs following harvest; however most of the plant's energy is spent producing stolons and rhizomes as the days become shorter (Langston and Leopold 1954). Plants become dormant during the fall and remain dormant until early spring. Shallow plowing of peppermint places the roots deeper in the soil which makes them less susceptible to winter injury. Such cultivation, commonly practiced in central Oregon where winters are more severe and infestations of Verticillium wilt are less severe, should be performed when the mint is dormant or not actively growing (C.E. Horner, Courtesy Professor, Botany and Plant Pathology Department, Oregon State University, 1980 pers. comm.).

Growers generally prefer fall plowing to spring plowing because the mint seems to grow more rapidly in the spring resulting in a thicker, heavier stand (Horner 1952). Hollingsworth (1980) found no significant differences in selected plant growth characteristics between fall plowed and untilled fields. Cultivation methods other than plowing have been shown to affect growth and yield of peppermint. Nelson *et al.* (1971) reported that rototilled peppermint produced less hay weight and yielded less than untilled mint. Preliminary data reported by Ogg *et al.* (1982) indicated that peppermint grew better in strip-rotovated than non-rotovated plots when practiced alone or in combination with some herbicides.

The quantity and quality of peppermint oil produced varies geographically and seasonally (Bullis *et al.* 1948, Sievers and Stevenson 1948, Guenther 1961, Smith and Levi 1961, Green 1963). Such variation can be attributed to differences in environmental factors such as photoperiod and temperature (Burbott and Loomis 1967, Clark and Menary 1979a, 1980a) and management practices such as: 1) time of harvest (Bullis *et al.* 1948, Kahl *et al.* 1956, Nelson *et al.* 1971, Clark and Menary 1979b); 2) fertilizer applications (Powers 1947, Nelson *et al.* 1971, Jackson and Hee 1971); and 3) irrigation (Nelson 1971). Nelson *et al.* (1971) reported that cultivation, i.e., shallow rototilling and strip rotovating, delayed the optimum time for harvest compared to no-till based on the components of oil found on various harvest dates.

MATERIALS AND METHODS

Location and Description of Test Plots

Two test plots in 1981 and three test plots in 1982, located in the Willamette Valley of Oregon, were used to evaluate the effects of tillage on emergence of adult *Fumibotys fumalis* and on other agronomic factors in peppermint. Test plots in 1981 were located on the Ira Calef farm (location 1), 8 kilometers east of Springfield, and on the Charley Swengo farm (location 2), 1.6 kilometers north of Coburg. The test plot at location 1 was in an 8-year old, 22-hectare Black Mitcham peppermint field. The test plot at location 2 was in a 5-year old, 4-hectare Black Mitcham peppermint field. Soils at locations 1 and 2 were classified as Willamette loams.

Test plots in 1982 were located on the Bob and Lynn Shumaker farm (location 3), 2 kilometers west of Crabtree, Dave Harnisch farm (location 4), 12 kilometers south of Albany, and on the ASI farm (location 5), 2.5 kilometers northwest of Jefferson. Test plots at locations 3, 4, and 5 were in an 8-year old, 16-hectare Black Mitcham peppermint field, a 4-year old, 7.2-hectare Todd's Mitcham peppermint field, and a 4-year old, 8-hectare Todd's Mitcham peppermint field, respectively. Soils at locations 3, 4, and 5 were classified as a Newberg silt loam, Chehalis silt loam, and a Newberg fine sandy loam, respectively.

In this study, the tillage treatments investigated included plowing followed by disking, disking alone, and no-till. The tillage implements were provided by each grower and consisted of moldboard plows, tandem disks, and in two test plots either a spring-tooth harrow or a roller-harrow. The decision to use harrows following disking in two of the test plots was based on the type of tillage operations the growers would normally follow in that field.

Test Plots in 1981.--The experimental design of test plots at locations 1 and 2 in 1981 is shown in Figure 1. The test plot at location 1 was ca. 0.31 hectare, 45.72 m by 68.58 m. The east side of the test plot was divided into five equal sections (13.72 m). Each section was further divided into three equal subsections (4.57 m) which were randomly assigned tillage operations: plow, disk, or no-till (check). The north side was divided into five equal sections (9.14 m). These sections were then divided into two equal subsections (4.57 m) which were randomly assigned tillage operations: disk or no-till (check). Tillage operations randomly assigned to the east side were performed first, in a direction which was perpendicular to the east side and for the entire width of the plot (45.72 m). Tillage operations assigned to the north side were

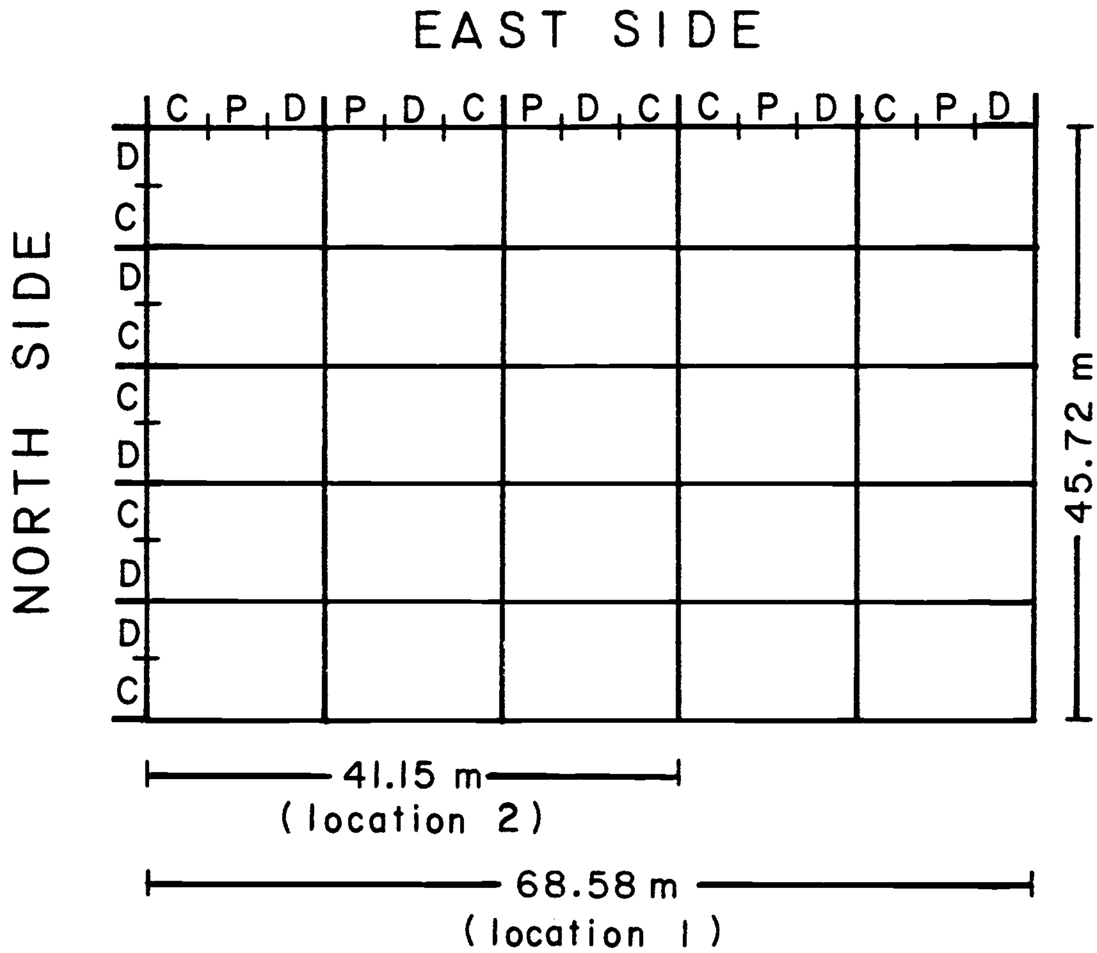


Figure 1. Experimental design used in test plots in 1981. Twenty-five replications were used in the test plot at location 1 (Springfield, Oregon) and 15 replications were used in the test plot at location 2 (Coburg, Oregon). Each replication consisted of six experimental plots (4.57 m X 4.57 m), one each of check (C), double disk, plow (P) and single disk, and plow and double disk, and two of single disk (D).

performed second, in a direction which was perpendicular to the north side of the field, and for the entire length of the plot (68.58 m). All plots were tilled on November 20, 1980. In addition to these tillage operations, another tillage operation (single disk and harrow) was performed during the first week in February 1981 over all previously plowed strips. Therefore, five tillage treatments were compared at location 1: single disk, double disk, plow and single disk, plow and double disk, and no-till (check), herein designated as D, DD, PD, PDD, and C, respectively. Each treatment was represented by 25 experimental plots (4.57 m by 4.57 m) except the D treatment which was represented by 50 experimental plots. Plowing was performed at a depth of 12.5 cm with a 4-bottom 45 cm moldboard plow. Disking was performed at a depth of 5 cm using a 4.25 m tandem disk. A spring-tooth harrow, set at a depth of 5 cm, was used following the tandem disk treatment in February.

The size of the test plot at location 2 was ca. 0.2 hectare (41.15 m by 45.72 m). The experimental design was very similiar to location 1 (Figure 1). The east side was divided into three equal sections. Each section was further divided into three equal subsections which were randomly assigned tillage treatments: plow, disk, or no-till (check). The north side was divided into five equal sections. Each section was further divided into two equal subsections which were randomly assigned tillage treatments: disk or no-till (check). Tillage was performed in the same sequence and direction as in the test plot at location 1, thereby resulting in the same five tillage treatments. Each treatment was represented by 15 experimental plots (4.57 m by 4.57 m) except the D treatment which was represented by 30 experimental plots.

In contrast to tillage operations at location 1, all tillage at location 2 was performed in the spring. Tillage was scheduled to be completed will before the mint broke winter dormancy, but rains delayed tillage until April 7, 1981. Plowing was performed using a 3-bottom 40 cm moldboard plow at a depth of 7.5 cm, and disking was performed using a tandem disk set at 5 cm.

Test Plots in 1982.--Similarities between D and DD treatments and between PD and PDD treatments in 1981 test plots resulted in a reduction from five treatments in 1981 to three treatments (DD, PDD, C) in 1982. This allowed more time to evaluate the effects of tillage on other agronomic factors. A randomized complete block design was used in all three test plots in 1982 (Figure 2).

The test plot at location 3 was ca. 0.2 hectare (41.15 m by 45.72 m). The experimental design was a randomized complete block design with three replications. All tillage was performed on November 13, 1981 with a 3-bottom 40 cm moldboard plow at a depth of 10-12.5 cm and a 4.27 m tandem disk at a depth of 7.5-10 cm. Experimental plots were 4.57

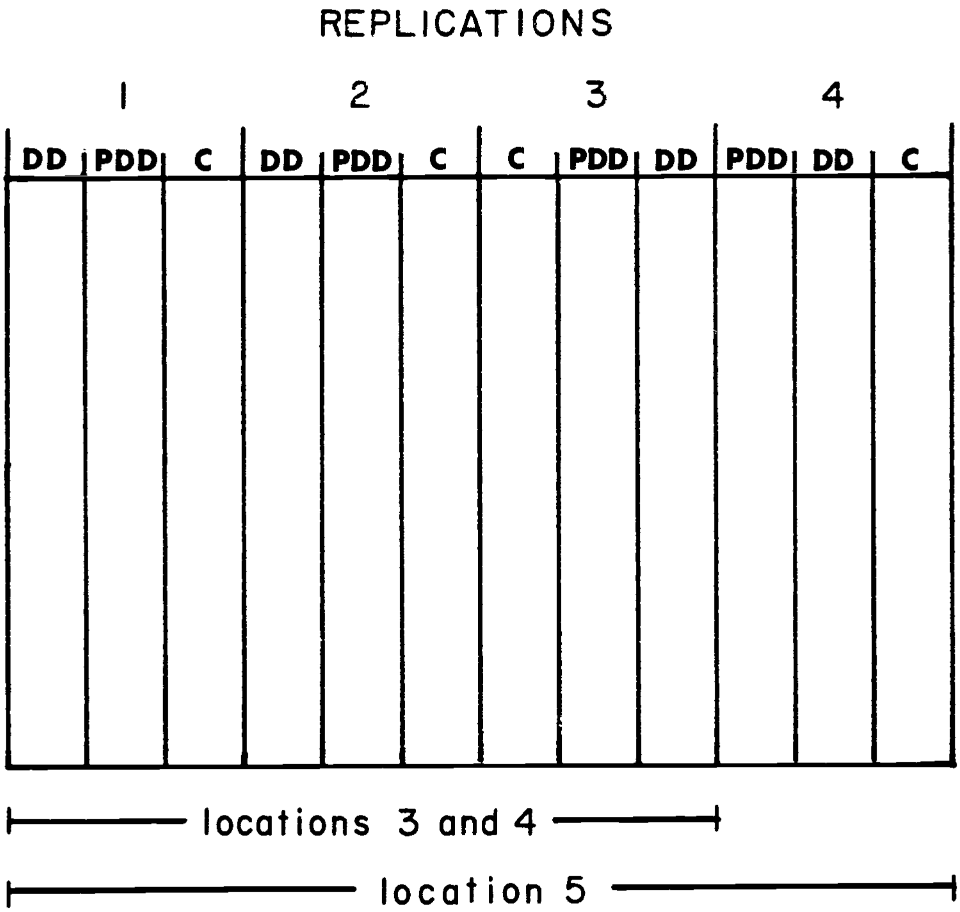


Figure 2. Randomized complete block design used in test plots in 1982. Three replications were used in each test plot at locations 3 and 4, and four replications were used in the test plot at location 5. Each replication consisted of three experimental plots. Treatments consisted of check (C), double disk (DD), and plow and double disk (PDD).

m by 45.72 m.

The test plot at location 4 was ca. 0.1 hectare (22.86 m by 41.15 m) and also was a randomized complete block design with three replications. All tillage was performed on February 4, 1982 with a 4-bottom 45 cm moldboard plow at a depth of 12.5-15 cm, a 2.44 m tandem disk at a depth of 7.5-10 cm, and a roller-harrow (harrow set at 5 cm). Two passes with the roller-harrow followed disking in all of the DD and PDD plots. Experimental plots were 4.57 m by 22.86 m.

The test plot at location 5 also was a randomized complete block design, but with four replications. All tillage was performed on March 6, 1982 with a 5-bottom 40 cm moldboard plow at a depth of 12.5-15 cm, and a 3.66 m tandem disk at a depth of 7.5-10 cm. The entire experimental area was ca. 0.25 hectare (73.15 m by 39.01 m) and each experimental plot was 6.10 m by 39.01 m.

Monitoring Mint Root Borer Emergence

Emergence of adult *F. fumalis* was monitored at locations 1, 3, and 4. These locations were chosen because they had relatively high numbers of *F. fumalis* larvae following harvest in the years preceding tillage. Average larval densities for each entire field were estimated at 6.2/1000 cm^2, 5.3/1000 cm^2, and 3.4/1000 cm^2, for locations 1, 3, and 4, respectively.

Prepupal or larval densities were estimated in each test plot prior to tillage. Densities were determined by taking 1000 cm^2 samples to a depth of the rhizomes (ca. 5-10 cm) using an open, three-sided metal sampling square and a shovel. All soil and plant material for each sample was placed in a plastic bag and taken back to the lab. Samples taken at location 1 were screened and sorted by hand to find hibernacula containing prepupae. Samples taken at locations 3 and 4 were first shaken to remove excess soil from the mint roots, then sorted by hand and the rhizomes placed in Berlese funnels to extract larvae. About 12 hours in Berlese funnels under 100 watt bulbs were required to completely dry rhizomes and extract larvae.

At location 1, fifteen out of all possible experimental plots from each treatment were randomly selected to monitor adult emergence. In each of these plots, three soil samples were taken on November 19, 1980 to determine densities of *F. fumalis* prior to tillage. At locations 3 and 4, experimental plots were divided into ten and five equal subplots (4.57 m by 4.57 m), respectively. Four soil samples were taken in each subplot on September 5, 1982 at location 3 and on September 10, 1982 at location 4. To monitor adult emergence, five subplots in each experimental plot were chosen at location 3 and three subplots in each experimental plot were chosen at location 4.

Adult *F. fumalis* emergence was monitored by placing emergence cages on the experimental plots during the summer following tillage treatments. Emergence cages were similiar in design to those used by others (Fife and Graham 1966, Watson and Larsen 1968, Watson *et al.* 1974). Two types of cages (types I and II) (Figure 3) were used in this study, but were not expected to affect emergence differently. Twenty-five type I cages and 50 type II cages were used. Type I cages, fitted with glass jars on the top, were used in 1981 to trap emerging adults. However, only a small percentage of adults were caught in the jars so the jars were removed in 1982 and the hole on the top of each cage was covered.

Fifteen cages per treatment were placed in the field at location 1 on June 7, 1981. The base of each cage was set 5-10 cm into the soil and soil was pushed up around the bases of all cages to prevent moths from escaping. Both types of emergence cages were used at this location. Fifteen type II cages were used per treatment at location 3 and nine type I cages per treatment were used at location 4. In 1982, all cages were placed in the fields on June 1.

Cages were checked weekly by lifting each cage slowly from one edge of the base and counting adults, recording their sex, and removing them from the cage. Plants inside the cages were periodically clipped with grass clippers to make finding the adults easier. After checking each cage, the cage was carefully replaced and checked for any

Figure 3. Two types of cages used to monitor emergence of adult *F. fumalis*. Type I (left): 90 cm X 90 cm (inside dimensions) square base made of 2.5 cm X 15 cm cedar boards, metal window screen tacked to all edges of the base and to the rigid pyramid-shaped wooden frame which was secured firmly to the base, 7.5 cm diameter hole at the top of the cage, fiberglass screen cones with 2-3 cm holes at the top were placed in the mouths of pint glass jars and both were placed on top of the pyramids to trap adults. Type II (right): 90 cm X 90 cm square base made of 2.5 cm X 10 cm cedar boards, fiberglass window screen (75 cm by 380 cm) stapled along one edge to the top edge of the base and the ends of the screen stapled together, top edge of the screen gathered together at the top and suspended ca. 50 cm off the ground by a wooden stake driven ca. 15 cm into the ground in the center of the cage.

possible exit holes. Adult emergence was monitored until August 18, 1981 at location 1 and until August 2, 1982 at locations 3 and 4.

Weed Evaluations

Evaluations on the effect of tillage on weeds were made in four of the five test plots. The test plot at location 5 was designed primarily to investigate the effects of herbicide-tillage treatments on several different weed species, but the entire plot was mistakedly oversprayed and no data were collected. Studies on the effects of tillage on weeds were designed to evaluate populations of common groundsel, *S. vulgaris*. *S. vulgaris* was present in all test plots and the effects of tillage were easily evaluated. Even though several other weeds were present in the test plots, evaluations were not always possible because the weeds were not uniformly distributed or they occurred in low densities within the test plots. The test plot at location 2 was selected primarily because it had a large population of *S. vulgaris*, and because it was tilled in the spring, it provided an opportunity to compare the effects of spring tillage versus fall tillage on *S. vulgaris*. The effects of tillage on *S. vulgaris* were evaluated by estimating plant vigor and measuring stand density and dry weight biomass.

Location 1.--The population of *S. vulgaris* at location 1 was estimated prior to tillage on November 19, 1980. At this time, only small seedlings of *S. vulgaris* were present. Plant vigor was estimated in each of the 150 experimental plots. Plant vigor was subjectively estimated as the percent of ground covered and space occupied by *S. vulgaris* within the canopy. Quantitative measurements of *S. vulgaris* also were made at this time in the same plots used to monitor *F. fumalis* emergence (15 experimental plots/treatment). Three 1000 cm^2 samples were taken in each experimental plot. The number of plants in each sample was recorded, and all plants were removed and bagged. Plants were air-dried in the lab, then oven-dried at 60 degrees C for 8 hours, and weighed.

The population of *S. vulgaris* was evaluated again April 10-12, 1981 prior to spring flaming. Plants at this time were beginning to flower and set seed. A herbicide application (diuron 2.25 kg a.i./ha and terbacil 1.13 kg a.i./ha) was made over the entire test plot about a week prior to this evaluation. Plant vigor was estimated in each of the 150 experimental plots, and five 1000 cm^2 samples per experimental plot were taken to evaluate density and dry weight biomass (samples were taken from the same plots evaluated in November 1980). Plant vigor was estimated again over the entire plot on July 7, 1981.

In addition to *S. vulgaris*, there was a moderately high population of false dandelion, *Hypochaeris radicata*, in this test plot. Density of this species was estimated over the entire area (20.9 m^2) of each experimental plot on November 19, 1980 and April 12, 1981.

Location 2.--The site of the test plot in the field at location 2 was selected because of the relatively high number of *S. vulgaris* in that part of the field. Estimations of plant vigor and measurements of *S. vulgaris* density and dry weight biomass were made in this test plot. Plant vigor was estimated in all 90 plots prior to tillage on March 27, 1981. Fifteen of the thirty D plots were randomly eliminated, and three 1000 cm^2 samples were taken from each of the remaining 75 plots to evaluate the density and dry weight of *S. vulgaris*. The entire plot was reevaluated on June 21, 1981 with the same methods used in March. Plants were mature and producing seed at this time. Terbacil (2.25 kg a.i./ha) was applied over the entire test plot in March about a week prior to my evaluations.

Locations 3 and 4.--Populations of *S. vulgaris* were evaluated only once on July 1, 1982 at location 4 and July 6, 1982 at location 3. Plants at this time were fully mature and setting seed. Plant vigor and density of *S. vulgaris* were estimated in each of five subplots within all experimental plots. The estimate of plant vigor was based on a subjective evaluation of the amount of ground covered and space occupied by the plants in the plot. Populations of *S. vulgaris* were much lower than in previous test plots so a larger sample was taken to determine densities of *S. vulgaris*. Three separate m^2 samples, using a 1 m X 1 m wooden frame, were taken in each subplot and *S. vulgaris* plants were counted. Dry weight biomass was not estimated.

An application of diuron (2.2 kg a.i./ha) was made at location 3 over the entire test plot after tillage treatments in late March.

Assessing the Spread of Verticillium Wilt

The effects of tillage on Verticillium wilt could not be assessed in 1981 at locations 1 and 2 because some of the disked treatments ran perpendicular to and across other tillage treatments. During the summer in 1981, two commercial peppermint fields with moderate infestations of Verticillium wilt were selected as sites to study the effects of tillage on the disease. Prior to harvest in 1981, areas were selected in each field and evaluated for wilt symptoms and percentage and severity of plant infection. These test plots were scheduled to be tilled fall 1981 or spring 1982 to evaluate the effect of tillage on the spread of the disease. However, these fields did not remain in production the following year. Therefore, the only test plots evaluated for spread of the disease were at locations 3 and 4. These test plots were not ideal for this study because levels of Verticillium wilt could not be determined prior to tillage, and it was assumed that all experimental plots were equally infested with the disease prior to tillage. Despite this problem, infestations of Verticillium wilt were evaluated in these plots during the summer of 1982 following tillage.

Evaluations of Verticillium wilt at locations 3 and 4 were made on August 3, 1982 as follows. The total number of "patches" of Verticillium wilt was counted in each subplot within each experimental plot. A patch of wilt was defined as any number of plants showing typical symptoms of the disease which were confined within an area of 1000 cm^2. Thus, if a number of infected plants were grouped together in the same proximity, but covered an area greater than 1000 cm^2, the plants were recorded as being 2, 3, or more patches. Different disease symptoms occurred within each patch, ranging from mild to severe. Disease symptoms were classified as being mild, moderate, or severe as follows:

1) Mild--a slight discoloration (yellow to purple) and twisting of upper leaf pairs.
2) Moderate--discoloration of all leaf pairs (not total chlorosis) and twisting of leaves more severe than above.
3) Severe--either total chlorosis of all leaf pairs or necrosis of some or all leaves and most leaves malformed.

Each patch was given two ratings: the most advanced disease symptom present, and the most prevalent or average symptom present. For example, a patch containing 10 wilted stems (2 mild, 6 moderate, and 2 severe) was given a rating of "severe" for the most advanced symptom and a rating of "moderate" for the most prevalent or average symptom.

Soil Chemical Composition

A preliminary investigation was made in 1981 at location 1 to determine the effects of tillage on the chemical composition of the soil. Five out of 25 replications, each represented by all five tillage treatments, were randomly selected for nutrient analysis. Soil samples were taken on April 14, 1981 using a 2.5 cm core soil sampler. Three soil cores were taken in each experimental plot to a depth of 15 cm. Soil cores were subdivided into 0-5 and 5-15 cm sections. All soil cores at both sampling depths (15 cores/soil sample) from each treatment were combined and thoroughly mixed. Soil samples were analyzed for soil acidity (pH), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), and boron (B) because soil acidity and these nutrients are the most likely to be affected by tillage in peppermint fields in the Willamette Valley (T.L. Jackson, Soil Science Department, Oregon State University, 1980 pers. comm.). Samples were analyzed by the soil diagnostics laboratory at

Oregon State University using standard procedures (Berg and Gardner 1978).

Even though these preliminary data could not be analyzed statistically, results indicated that tillage affected soil acidity and all nutrients except boron (Appendix IV, Table 1). In 1982, a more extensive investigation was made in test plots in which soil was analyzed for soil acidity and the same nutrients, except boron. Soil core samples were taken on April 19-21, 1982 in test plots at all three locations. Twenty-five soil cores were taken in each experimental plot. Each core was subdivided into 0-5 and 5-15 cm sections. Soil core samples from each experimental plot at each depth were combined, thoroughly mixed, and analyzed by the soil diagnostics laboratory at Oregon State University. Soil samples were taken prior to spring fertilizer applications in all three test plots.

Peppermint Stand, Yield and Oil Quality and Maturity

The peppermint stand was evaluated by estimating plant vigor and measuring selected plant characteristics such as plant density, height, and rhizome dry weight biomass. Evaluations of peppermint plant vigor were made on the same dates, in the same experimental plots, using the same criteria used to evaluate *S. vulgaris* vigor; subjective visual estimations of the percentage of ground covered and space occupied by peppermint plants. Combined percentages of *S. vulgaris* and peppermint vigor within each experimental plot never exceeded 100 percent, and were less than 100 percent in experimental plots with areas of bare soil. Peppermint plant density and height were determined by taking random 1000 cm^2 samples with an open, three-sided metal sampler. The number of stems at a constant height 15 cm above the soil surface in each sample were counted to estimate plant density. Plant height was estimated by selecting the longest stem in each sample and measuring its length from the soil surface to its tip.

Five samples were taken in each of ten randomly selected experimental plots for each tillage treatment at location 1 just prior to spring flaming on April 14, 1981. Only stems were counted on this date, and only stems measuring 5 cm or longer were included. Plant height was not measured directly because the plants were too short and soil surface was very irregular in tilled plots. However, plants in untilled plots (height ca. 10-15 cm) appeared slightly taller than plants in tilled plots. Plants in disked plots were slightly taller than plants in plowed plots. One sample was taken in each of ten experimental plots per tillage treatment at location 2 on June 23, 1981 to measure peppermint plant density and height. Plant density and height also were measured in each of five subplots per experimental plot on July 15, 1982 at locations 3 and 4.

Rhizome samples were collected at two soil depths, 0-5 cm and 5-15 cm, at locations 3 and 4 on October 17-18, 1982. Only the field at location 3 had been treated with chlorpyrifos for control of *F. fumalis* after harvest in 1982. Samples were taken with a 1000 cm^2 open, three sided metal sampler and a shovel. Five random samples were taken in each experimental plot at locations 3 and 4. A sample (1000 cm^2) consisted of all soil and rhizomes (including stolons) in the top 5 cm of soil. Rhizome samples also were taken 5-15 cm deep. Samples from each depth were placed in separate bags and taken to the lab. Rhizomes and stolons were removed from the soil using wire mesh screens. Rhizomes and stolons were then thoroughly washed to remove the soil, allowed to air-dry, and then oven-dried at 60 degrees C for 8 hours before weighing.

Peppermint was harvested in the test plot at location 1 on August 19, 1981. Samples were taken by removing all mint hay at ground level within an open, three-sided metal frame, 1 m X 1 m, using electric hedge trimmers run from a mobile gas powered generator. Three random m^2 samples were taken in each of six experimental plots per treatment. The six plots in each treatment were selected to represent the range of *S. vulgaris* vigor estimated on July 7, 1981. Vigor of *S. vulgaris* ranged from 10-100, 0-90, 15-60, 0-50, and 0-40 percent for treatments C, D, DD, PD, and PDD, respectively. The three m^2 hay samples from each plot were combined into one sample, weighed in the field, and placed in burlap bags. Samples were taken back to the lab, allowed to air-dry, and then distilled to recover the oil. Oil was extracted by steam distillation using four small stills each with a capacity of 15.2 liters. Steam pressure was maintained at 20 p.s.i. and liquid condensate coming from the condenser was kept between 37.8 and 43.3 degrees C.

Peppermint was harvested in test plots at locations 3 and 4 on August 7 and August 10, 1982, respectively. Three m^2 mint hay samples were taken in each of five subplots within each experimental plot. The three m^2 samples from each subplot were combined and weighed to determine fresh hay weight. Three 4.5 hay samples were taken from each experimental plot, and placed in burlap bags, allowed to air-dry, and then distilled.

Oil collected from the three 4.5 kg hay samples taken in 1982 was combined to determine the effects of tillage on the quality and maturity of the oil. Each oil sample was diluted 1:200 in pentane and analyzed by gas liquid chromatography (GLC) procedures. Samples were analyzed using a Hewlett-Packard gas chromatograph (HP5710A) equipped with a flame ionization detector and a HP18740B capillary inlet system. Chromatographic output was integrated on a Hewlett-Packard recording integrator (HP3390A) and results were stored on disks of an Apple II+ Computer interfaced with the integrator. Operating conditions of the GLC were as follows: inlet temperature

250 degrees C, detector temperature 300 degrees C, column temperature initially 90 degrees C for 4 minutes with a program rate of 4 cc/minute and final temperature 160 degrees C for 8 minutes. Gas flows were as follows: HE carrier gas through the column 0.7135 cc/minute; HE makeup gas, Hydrogen, and air to the detector at 30 cc/minute, 30 cc/minute, and 249 cc/minute, respectively.

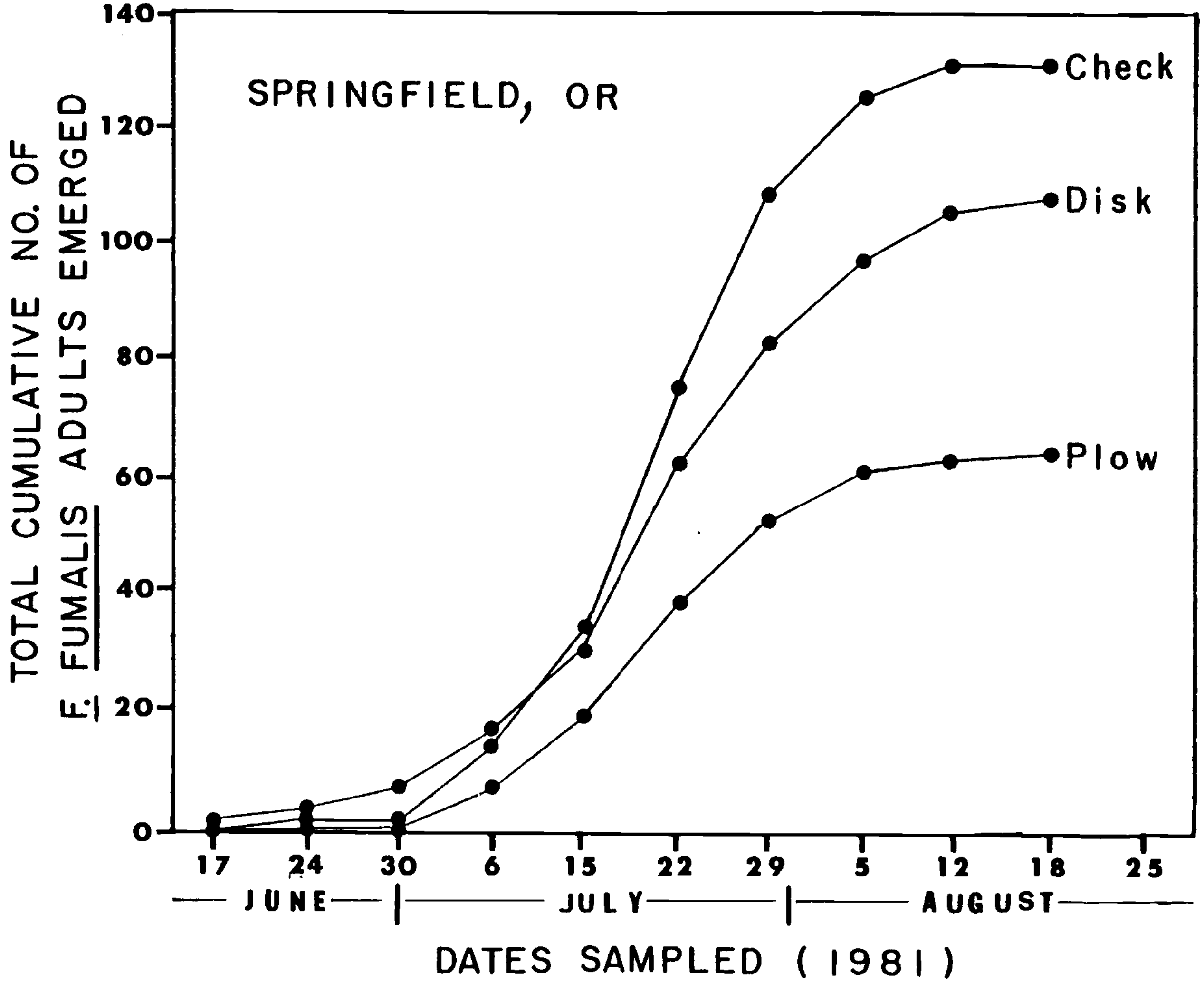
RESULTS AND DISCUSSION

Effects of Tillage on Emergence of Adult *F. fumalis*

The effects of tillage on *F. fumalis* populations were assessed by monitoring adult emergence during the summer following tillage operations. Results showed that there were significant differences ($p<0.05$) in the cumulative number of emerging adults between treatments at locations 1 and 3, and highly significant differences ($p<0.01$) between treatments at location 4 (Appendix I, Table 1). Significant differences were not found between combined D plus PD and DD plus PDD treatments at location 1, which indicated that one additional pass with a disk over plots already tilled would not significantly reduce the number of emerging adults. These results, coupled with the fact that most growers would probably disk at least twice when performing tillage operations, were the primary reasons for reducing the number of tillage treatments to three in 1982.

The total cumulative number of adults that emerged in test plots at locations 1, 3, and 4 are shown in Figures 4, 5, and 6, respectively. PDD treatments were not significantly different ($p<0.05$) from DD treatments at any of the locations, but were significantly different from C treatments at all locations (Table 1). DD treatments were

Figure 4. Effect of tillage on cumulative emergence of adult *F. fumalis* at location 1 during 1981. Each point represents the total cumulative number of adults in 15 emergence cages/treatment. Disk represents the average of single disk and double disk, and plow represents the average of plow--single disk and plow--double disk. Check represents untilled plots.



SPRINGFIELD, OR
Check
Disk
Plow
TOTAL CUMULATIVE NO. OF
F. FUMALIS ADULTS EMERGED
140
120
100
80
60
40
20
0
17
24
30
6
15
22
29
5
12
18
25
JUNE
JULY
AUGUST
DATES SAMPLED (1981)

Figure 4.

Figure 5. Effect of tillage on cumulative emergence of adult *F. fumalis* at location 3 during 1982. Each point represents the total cumulative number of adults in 15 emergence cages/treatment. Check, disk, and plow represent no-till, double disk, and plow--double disk treatments, respectively.

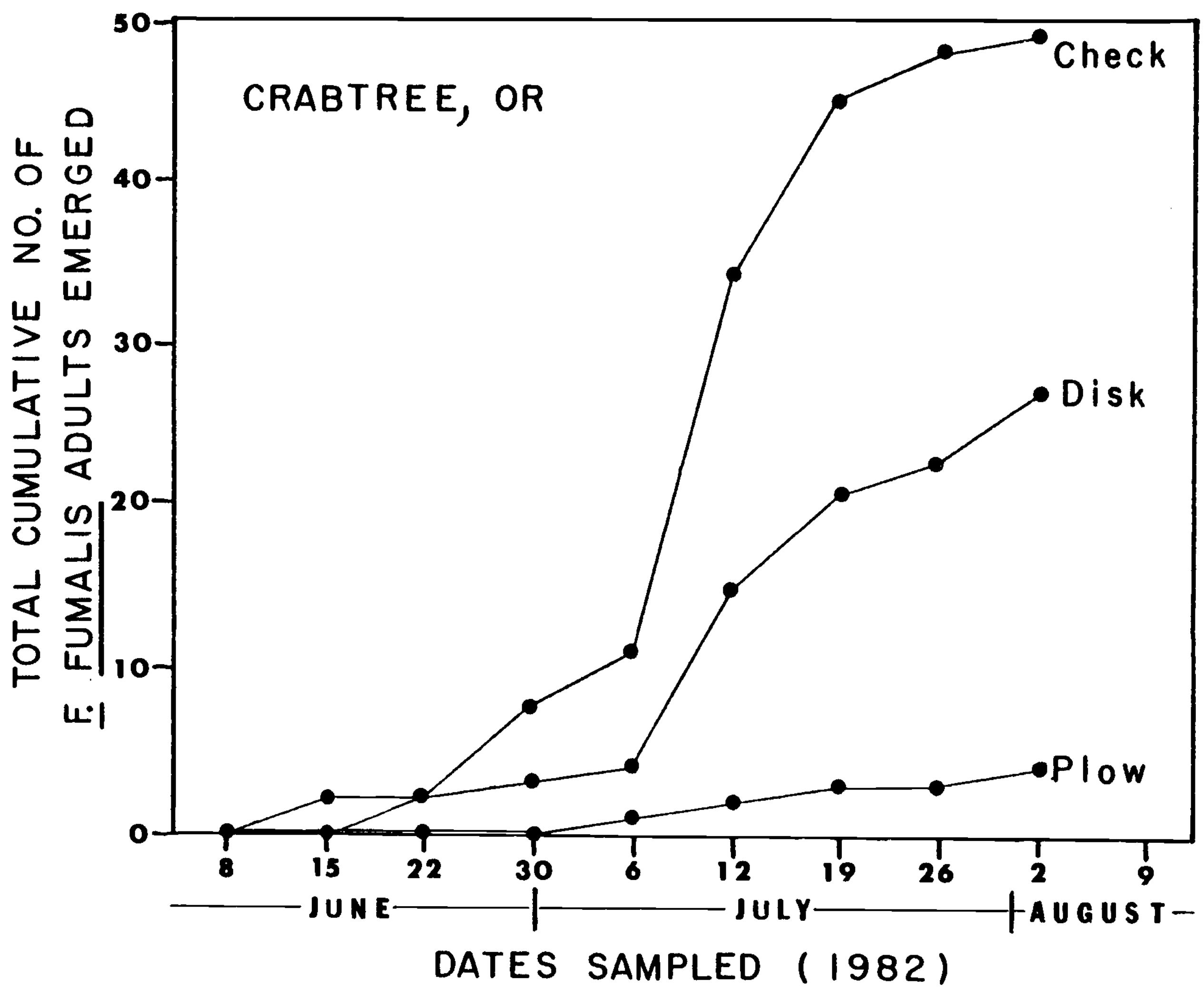
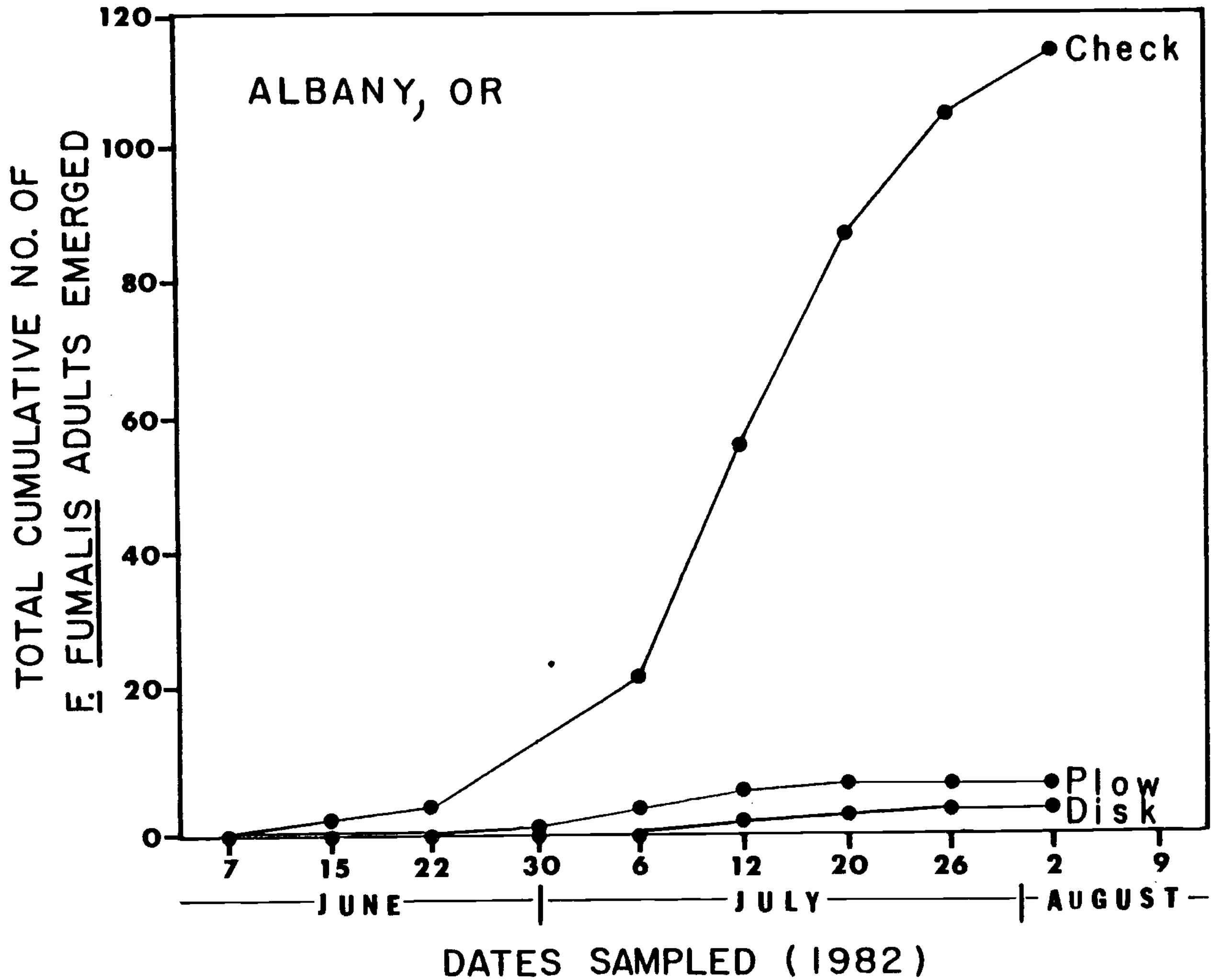

CRABTREE, OR
TOTAL CUMULATIVE NO. OF F. FUMALIS ADULTS EMERGED
50
40
30
20
10
0
Check
Disk
Plow
8
15
22
30
6
12
19
26
2
9
JUNE
JULY
AUGUST
DATES SAMPLED (1982)

Figure 5.

Figure 6. Effect of tillage on cumulative emergence of adult *F. fumalis* at location 4 during 1982. Each point represents the total cumulative number of adults caught in 9 emergence cages/treatment. Check, disk, and plow represent no-till, double disk, and plow-double disk treatments, respectively.



ALBANY, OR
Check
Plow
Disk
TOTAL CUMULATIVE NO. OF
F. FUMALIS ADULTS EMERGED
120
100
80
60
40
20
0
7
15
22
30
6
12
20
26
2
9
JUNE
JULY
AUGUST
DATES SAMPLED (1982)

Figure 6.

Table 1. Means of cumulative number of emerging *F. fumalis* adults for tillage treatments at three locations.

Tillage Treatment	Location 1 [1/] $\bar{x} \pm$ S.E.	Location 3 [2/] $\bar{x} \pm$ S.E.	Location 4 $\bar{x} \pm$ S.E.
PDD	4.0 ± 0.9 a [3/]	1.3 ± 0.3 a	2.0 ± 0.6 a
PD	4.5 ± 0.8 a	------	------
DD	6.5 ± 0.8 ab	9.0 ± 1.7 ab	1.0 ± 0.6 a
D	7.9 ± 1.1 b	------	------
C	8.7 ± 1.7 b	16.3 ± 4.4 b	38.3 ± 7.4 b

1/ Mean number of adults in 15 emergence cages/treatment.

2/ Mean number of adults in three replications/treatment (total of five cages at location 3 and total of three cages at location 4 in each replication).

3/ Means at each location followed by the same letter are not significantly different (ANOV. L.S.D. $p < 0.05$).

Table 2. Percentage reduction in total cumulative number of *F. fumalis* adults for tillage treatments compared with the check (no-till) treatment.

Tillage Treatment	Location 1	Location 3	Location 4	Average
PDD	54.2	91.9	94.8	80.3
PD	48.1	----	----	
DD	25.2	44.9	97.4	55.8
D	9.9	----	----	

significantly different from C treatments only at location 4. Comparisons between the two types of cages used in this study showed no significant differences ($p<0.10$) in numbers of emerging adults (Appendix I, Table 2). PDD treatments resulted in a greater overall average reduction in adult emergence (80.3 %) compared to DD treatments (55.8 %) even though DD treatments showed the greatest reduction (97.4 %) at location 4 (Table 2). The average reduction in emergence for PDD treatments at all locations and the reduction in emergence for DD treatments at location 4 were comparable to the results reported by Pike and Glazer (1982) for "strip rotary tillage". In addition, the reductions in adult emergence at locations 3 and 4 for PDD treatments and at location 4 for DD treatments were comparable to the reductions in larval populations of *F. fumalis* following treatment with chlorpyrifos (Berry 1978, Pike 1979). However, reductions in adult populations following treatment with chlorpyrifos could be greater than reductions in larval populations if chlorpyrifos adversely affects later larval instars, prepupae, pupae, or adults of *F. fumalis*.

The most apparent reasons for differences in adult emergence between test plots can be explained by examining how tillage treatments were performed. Reductions in populations of *F. fumalis* due to tillage practices was most likely caused by burying, exposing, or mechanically injuring the diapausing prepupae. Since prepupae overwinter within the top 5 cm of soil (Berry 1974), inversion of the top 12.5 cm of soil by plowing at location 1 would have buried prepupae 7.5 to 12.5 cm deep. Disking and harrowing 5 cm deep after plowing probably disturbed prepupae very little, so the reduction in adult emergence in plowed plots was mainly due to the inability of adults to emerge through the soil layer. Because of the design of the experiment at location 1, disking was performed at a slow speed, and thus, as a single treatment, disking did little more than disturb the upper 5 cm of soil. Therefore, the small reduction in the number of adults that emerged from disking treatments was probably due to mechanical injury and exposure of prepupae. Plowing at location 3 inverted the top 10 to 12.5 cm of soil and buried prepupae 5 to 12.5 cm deep. Disking at a faster speed than at location 1 and at a greater depth, immediately after plowing, disturbed the soil and rhizomes in which prepupae were located. Thus, reductions in adult emergence in PDD treatments was the result of burying, exposing, and mechanically injurying the prepupae. DD treatments at location 3 also reduced adult emergence more than at location 1, probably because disking was performed at a greater depth and speed which resulted in prepupal mortality by burial and mechanical injury. Plowing and disking at location 4 was performed in a similiar manner to that at location 3. However, the DD and PDD treatments were roller-harrowed twice after disking at location 4.

The extra disturbance of the soil by the harrow and packing the soil by the roller apparently caused additional mortality of prepupae because the greatest reductions in adult emergence for both DD and PDD treatments occurred at locaton 4. Fall tillage (locations 1 and 3) or spring tillage (location 4) could reduce adult populatons of *F. fumalis*. Any differences between fall or spring tillage would probably be due to the types of secondary tillage used.

Adults of *F. fumalis* were sexed after capture in emergence cages. However, some moths either escaped before their sex could be determined or were too damaged to sex. No significant differences were found between treatments ($p<0.10$) in the proportion of adult females to total adults (Appendix 1, Table 3). This would be expected since prepupae of both sexes overwinter inside hibernacula which are probably located within the same general soil layer (R.E. Berry, Entomology Department, Oregon State University 1983 pers. op.), and would be similiarly affected by tillage treatments.

Emergence of both sexes for all treatments combined is shown in Figures 7, 8, and 9 for locations 1, 3, and 4, respectively. Approximately an equal number of males and females was found in all test plots which agreed with the studies reported by Pike and Glazer (1982). Peak adult emergence occurred during late July in 1981 and during mid-July in 1982 which was within the period of peak

Figure 7. Weekly emergence of male and female adult *F. fumalis* at location 1 for all tillage treatments combined. Each point represents the total number of males or females caught in 75 cages. Total cumulative number of males and females were 171 and 229, respectively. Seventy-five adults were not sexed (not shown).

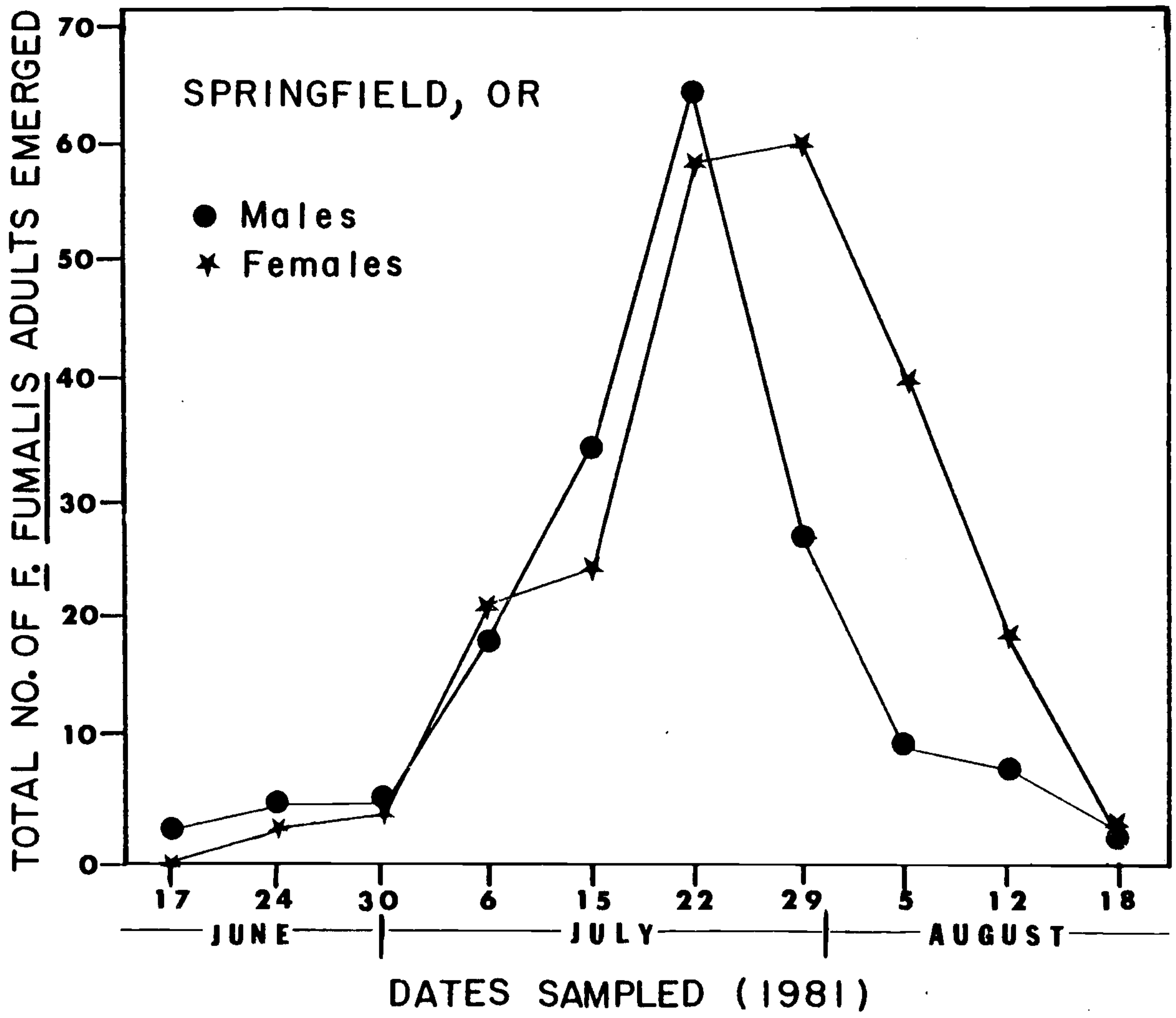

SPRINGFIELD, OR
Males
Females
TOTAL NO. OF F. FUMALIS ADULTS EMERGED
0
10
20
30
40
50
60
70
17
24
30
6
15
22
29
5
12
18
JUNE
JULY
AUGUST
DATES SAMPLED (1981)

Figure 7.

Figure 8. Weekly emergence of male and female adult *F. fumalis* at location 3 for all tillage treatments combined. Each point represents the total number of males or females caught in 45 cages. Total cumulative number of males and females was 31 and 35, respectively. Fourteen adults were not sexed (not shown).

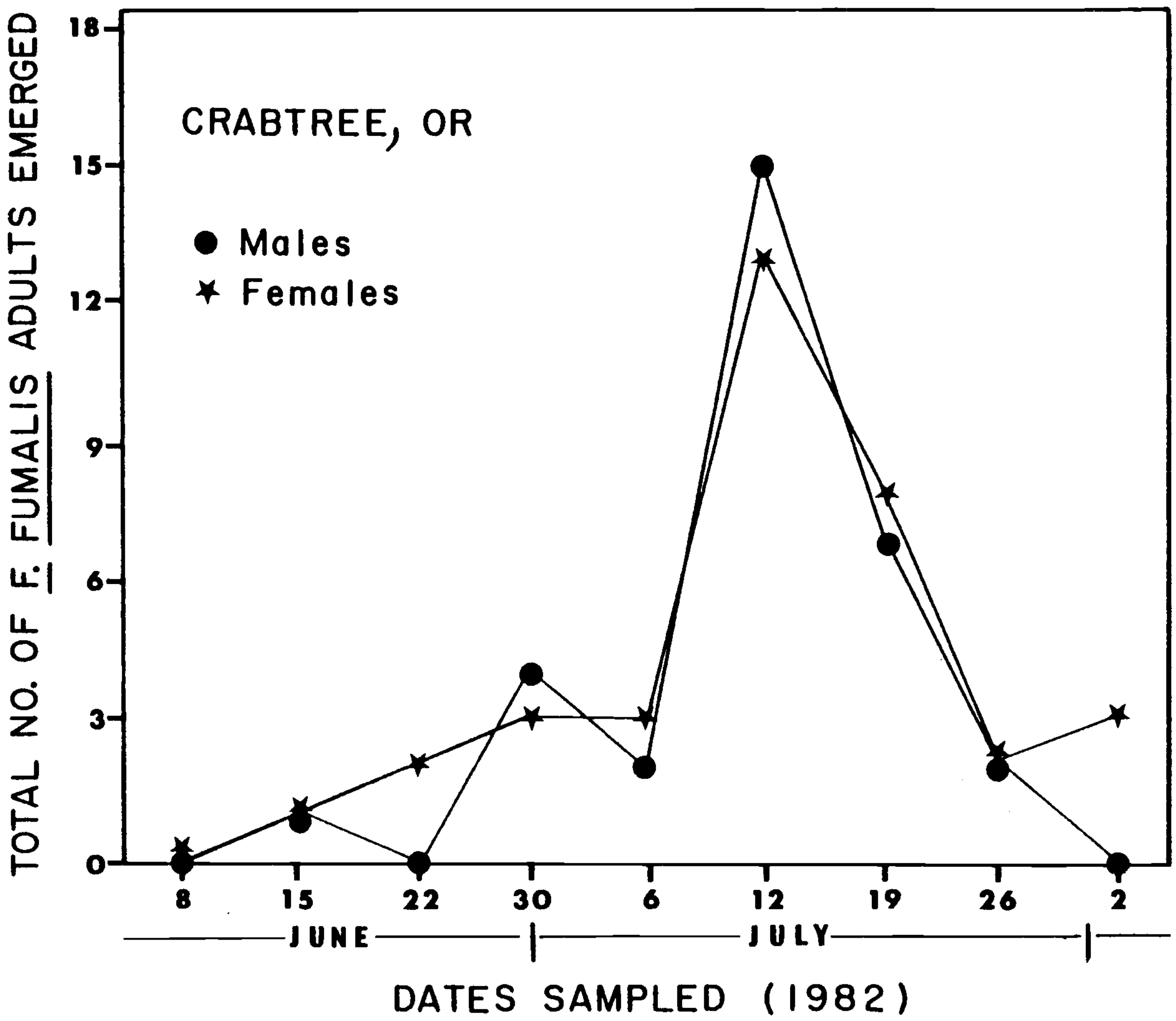

TOTAL NO. OF F. FUMALIS ADULTS EMERGED
18
15
12
9
6
3
0
CRABTREE, OR
Males
Females
8
15
22
30
6
12
19
26
2
JUNE
JULY
DATES SAMPLED (1982)

Figure 8.

Figure 9. Weekly emergence of male and female adult *F. fumalis* at location 4 for all tillage treatments combined. Each point represents the total number of males or females caught in 27 cages. Total cumulative number of males and females on August 2 was 59 and 52, respectively. Thirteen adults were not sexed (not shown).

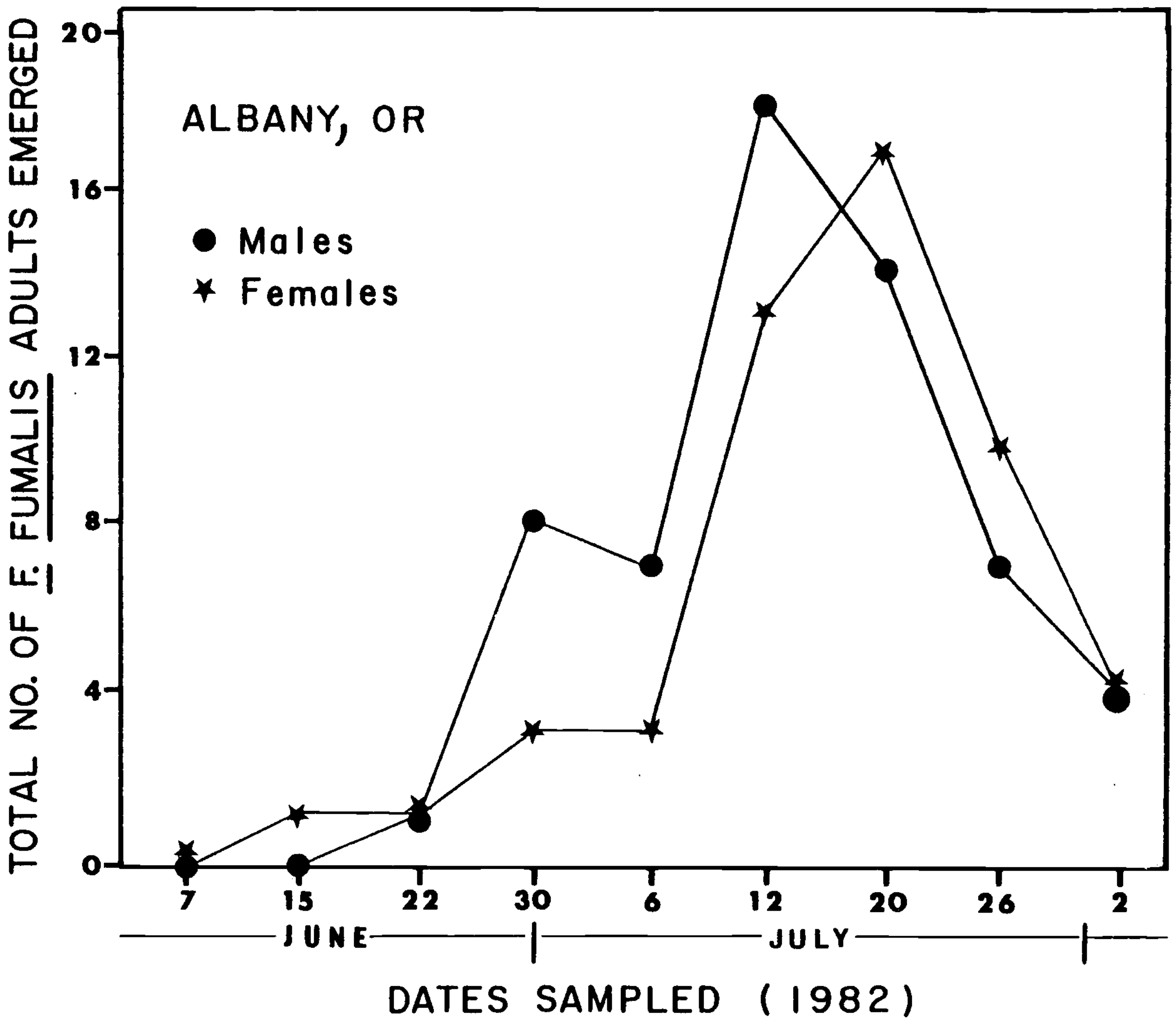

ALBANY, OR
Males
Females
TOTAL NO. OF F. FUMALIS ADULTS EMERGED
0
4
8
12
16
20
7
15
22
30
6
12
20
26
2
JUNE
JULY
DATES SAMPLED (1982)

Figure 9.

emergence reported by Berry (1974). Peak emergence of females occurred about one week later than males at locations 1 and 4, but there were no apparent differences at location 3.

Prepupal or larval densities were estimated prior to tillage treatments to determine if there was a relationship between pretreatment densities of immature *F. fumalis* and subsequent numbers of emerging adults. Proportional densities of emerged adults to immatures ranged from 0.09 to 0.19 in untilled plots and from 0.01 to 0.10 in tilled plots (Appendix I, Table 4). However, care should be taken in interpreting actual proportions of emerging adults based on pretreatment estimates of immature densities in this study, because no significant correlations were found between adult densities and either prepupal or larval densities in any of the treatments during 1981-82.

Densities of immature *F. fumalis* were determined by taking destructive soil samples. Emergence cages, used to monitor adult emergence, were placed in experimental plots without regard to soil samples taken previously in the plots. Thus, in order to obtain significant correlations between immature and subsequent adult densities of *F. fumalis*, it would have to be assumed that the population was either uniformly or randomly distributed. Dispersion characteristics of natural insect populations have been estimated by determining ratios such as $s^2/\bar{x}$ (Southwood 1966) and $x^*/\bar{x}$ (Lloyd 1967), where s^2,

$\bar{x}$, and x^* are the least squares estimators for variance, mean density, and mean crowding, respectively, for the population being assessed. If these ratios exceed 1.0, then the organism is described as having a clumped or aggregated distribution. In my study, these ratios were greater than 1.0 in all three test plots indicating that populations of immature *F. fumalis* were aggregated (Table 3). This probably accounted for the lack of significant correlations between immature and adult densities, because populations with aggregated distributions are extremely variable when sampled.

Table 3. Means, variances, and dispersion parameters for *F. fumalis* prepupal (location 1—1981) and larval (locations 3 and 4—1982) populations.

Location	No. of Samples n	Means/ 1000 cm^2 $\bar{x}$	Variance s^2	Dispersion Parameters 1/ s^2/x	$x^*/\bar{x}$
1	225	9.20	44.89	4.88	1.42
3	332	4.30	19.49	4.53	1.82
4	180	7.56	27.33	3.61	1.35

1/ Dispersion parameter calculated using the formula: $x^* = \bar{x} + ((s^2/\bar{x}) - 1)$ (Lloyd 1967).

Effects of Tillage on *Senecio vulgaris* and *Hypochaeris radicata*

Senecio vulgaris L. has been classified as both an annual and winter annual (Montgomery 1964). Peak periods of germination may occur during the spring (Brenchley and Warington 1930, 1933), or during the fall (Chancellor 1964), or during the spring and the fall (Roberts 1964, Fryer and Evans 1968, Popay and Roberts 1970b). *Senecio vulgaris* is able to germinate and grow any time of the year when suitable conditions occur (Brenchley and Warington 1930, 1933, Roberts 1964, Popay and Roberts 1970b), and thus may be classified as an annual with an indeterminate life cycle (Anderson 1977). Generation time may be as little as six weeks or as long as six months and 2 or 3 generations may be produced per year (Fryer and Evans 1968).

S. vulgaris reproduces by seeds which have been reported to have a relatively short period of innate dormancy (Brenchley and Warington 1930, 1933, Roberts 1964, Popay and Roberts 1970a, 1970b). The seeds also may have an indefinite period of enforced dormancy when buried in the soil. Seed dormancy is due to decreased levels of light, O_2 concentration, and temperature, and increased concentrations of CO_2 (Popay and Roberts 1970a). Studies have shown that, with regular mixing of the soil, viable seeds of *S. vulgaris* can be reduced by as much as 99.3 percent after three years (Brenchley and Warington 1930) and 99.7 percent after five years (Roberts 1964). Cultivation may stimulate germination of weed seeds by bringing enforced dormant seeds to the soil surface and exposing them to favorable conditions such as increased light and improved soil aeration (Fryer and Evans 1968). Brenchley and Warington (1933) suggested that frequent cultivation, coupled with induced rapid germination and aided by a favorable seedbed, will destroy most of the viable seeds of *S. vulgaris* which are capable of recolonization.

Evaluations of *S. vulgaris*.--The objective of my study was to determine the effects of fall or spring tillage, i.e., plowing and/or disking, on the spring and summer stands of *S. vulgaris* in peppermint. Evaluations of *S. vulgaris* were made on plants in various stages of growth. *S. vulgaris* plants typically emerge as seedlings, followed by a rosette phase of vegetative growth, a period of seed production, and death (Harper and Ogden 1970). The stages of plant growth evaluated in this study included: 1) seedlings with three to eight primary leaves (November- location 1), 2) recently emerged seedlings and larger plants which had emerged the previous fall or winter and were just beginning to form seed heads (March and April- locations 1 and 2), and 3) mature plants which were producing seed and had emerged after spring flaming (June and July--locations 1, 2, 3, and 4).

Evaluations of *S. vulgaris* stands were made just prior to tillage at locations 1 and 2 to determine the distribution and abundance of plants within experimental plots. Evaluations were made by taking direct quantitative measurements of plant density and dry weight biomass, and subjective visual estimates of plant vigor. Averages of plant density, dry weight and vigor were different between treatments. However, there was also considerable variation in the population of *S. vulgaris* at locations 1 and 2 (Appendix II, Table 1). For statistical purposes, experimental plots were assumed to be equally infested with *S. vulgaris* prior to tillage treatments. Pretreatment evaluations of *S. vulgaris* were not made at locations 3 and 4 because there were very few plants in test plots prior to tillage. Therefore, in 1982, experimental plots within replications were considered equally infested with *S. vulgaris* for statistical purposes.

Results of evaluations of *S. vulgaris* at location 1 showed that there were highly significant differences ($p<0.01$) between treatments in density, dry weight biomass, and plant vigor on April 12, 1981, and in plant vigor on July 7, 1981 (Appendix II, Table 2). Most of the plants were beginning to flower in April and were nearly mature in July. No significant differences ($p<0.10$) were found between D plus PD and DD plus PDD treatments in density, dry weight biomass, or plant vigor. This indicated that no further reduction would occur with an additional disking treatment over previous D or PD treatments. However, DD treatments were significantly different ($p<0.05$) from C treatments in all evaluations of *S. vulgaris* in April and July at location 1 (Table 4).

Plowed treatments significantly reduced ($p<0.05$) the density, dry weight biomass, and plant vigor of *S. vulgaris* by over 95 percent compared to untilled treatments in April (Table 5). Reductions in *S. vulgaris* vigor for plowed treatments in July averaged 80 percent. Reductions in density, dry weight biomass, and plant vigor for disked treatments compared to untilled treatments ranged from 25.8 to 59.7 percent in April and from 15.7 to 29.9 percent in July (Table 5).

Evaluations of *S. vulgaris* were made again at location 2 on June 21, 1981 when plants were flowering and setting seed. There were highly significant differences ($p<0.01$) in *S. vulgaris* density and plant vigor between treatments (Appendix II, Table 3). There also tended to be differences ($p<0.10$) in dry weight biomass between treatments. Even though C treatments had a significantly higher density of *S. vulgaris* ($p<0.05$), except in D treatments, the vigor of the *S. vulgaris* stand was significantly lower in C treatments than all other treatments (Table 6). In addition, C treatments had the

Table 4. Mean density, dry weight biomass, and plant vigor of *S. vulgaris* for tillage treatments at location 1 on April 12 and July 7, 1981.

Tillage Treatment	4/12/81 Density #/1000 cm^2	4/12/81 Biomass g/1000 cm^2	4/12/81 Stand Vigor (%)	7/7/81 Stand Vigor (%)
PD	0.1 ± 0.0 a [1/]	0.02 ± 0.02 a	1.5 ± 0.6 a	8.0 ± 1.5 a
PDD	0.1 ± 0.1 a	0.05 ± 0.05 a	2.1 ± 0.4 a	9.7 ± 2.5 a
DD	6.0 ± 2.0 ab	1.57 ± 0.37 b	30.6 ± 6.5 b	31.3 ± 3.8 b
D	10.2 ± 3.8 bc	1.82 ± 0.51 bc	34.1 ± 7.9 b	37.7 ± 3.5 bc
C	14.8 ± 5.0 c	3.07 ± 0.78 c	46.0 ± 8.9 b	44.7 ± 7.3 c

1/ Means in the same column followed by the same letter are not significantly different (ANOV. L.S.D. $p<0.05$).

Table 5. Percentage reductions in density, dry weight biomass and plant vigor of *S. vulgaris* for tillage treatments compared to the check (no-till) at location 1 on April 12 and July 7, 1981.

Tillage Treatment	4/12/81 Density	4/12/81 Biomass Dry Wt.	4/12/81 Plant Vigor	7/7/81 Plant Vigor
PD	99.6	99.2	96.7	82.1
PDD	99.5	98.4	95.4	78.3
DD	59.7	48.7	33.5	29.9
D	31.4	40.5	25.8	15.7

Table 6. Mean density, dry weight biomass and plant vigor of *S. vulgaris* for tillage treatments at location 2 on June 23, 1981.

Tillage Treatment	Density #/1000 cm^2	Biomass 2/ g/1000 cm^2	Plant Vigor %
PD	3.3 ± 1.0 a 1/	4.62 ± 1.00	20.7 ± 2.1 b
PDD	4.8 ± 1.1 ab	4.82 ± 0.83	30.3 ± 2.2 c
DD	9.6 ± 1.8 b	5.94 ± 1.02	26.0 ± 2.5 bc
D	15.8 ± 2.4 c	7.86 ± 1.49	29.7 ± 3.4 c
C	19.5 ± 3.6 c	3.88 ± 1.19	6.3 ± 1.4 a

1/ Means in same column followed by same letter are not significantly different (ANOV. L.S.D. $p<0.05$).

2/ Treatments in this evaluation tended to be different based on analysis of variance ($p<0.10$).

lowest average dry weight biomass of *S. vulgaris*. Figure 10 shows the relationship between stands of *S. vulgaris* and peppermint at location 2. C treatments had the highest density of *S. vulgaris* and the most vigorous stand of peppermint compared to other tillage treatments. Intraspecific and interspecific competition of *S. vulgaris* plants were probably much greater in untilled plots. *S. vulgaris* plants in untilled plots were more spindly and had fewer lateral branches than in tilled plots which resulted in the lowest dry weight biomass measurements and estimates of *S. vulgaris* plant vigor.

Disked treatments had densities of *S. vulgaris* plants which were intermediate between plowed and untilled treatments. Peppermint plant vigor and percentage of bare soil also were intermediate in disked treatments. Less intraspecific and interspecific competition of *S. vulgaris* plants in disked treatments, compared to untilled treatments, resulted in *S. vulgaris* plants which were more vigorous and had more lateral branches. Thus, *S. vulgaris* plants in disked treatments were larger than in untilled treatments and had greater dry weight biomass and plant vigor. Even though *S. vulgaris* dry weight biomass was greater in disked treatments than in plowed treatments, the more vigorous and dense stand of peppermint in disked treatments concealed more *S. vulgaris* than in plowed treatments. This

Figure 10. Relationships between percentages of common groundsel, peppermint, and bare soil (top) and between densities of common groundsel and peppermint (bottom) at location 2 in June 1981.

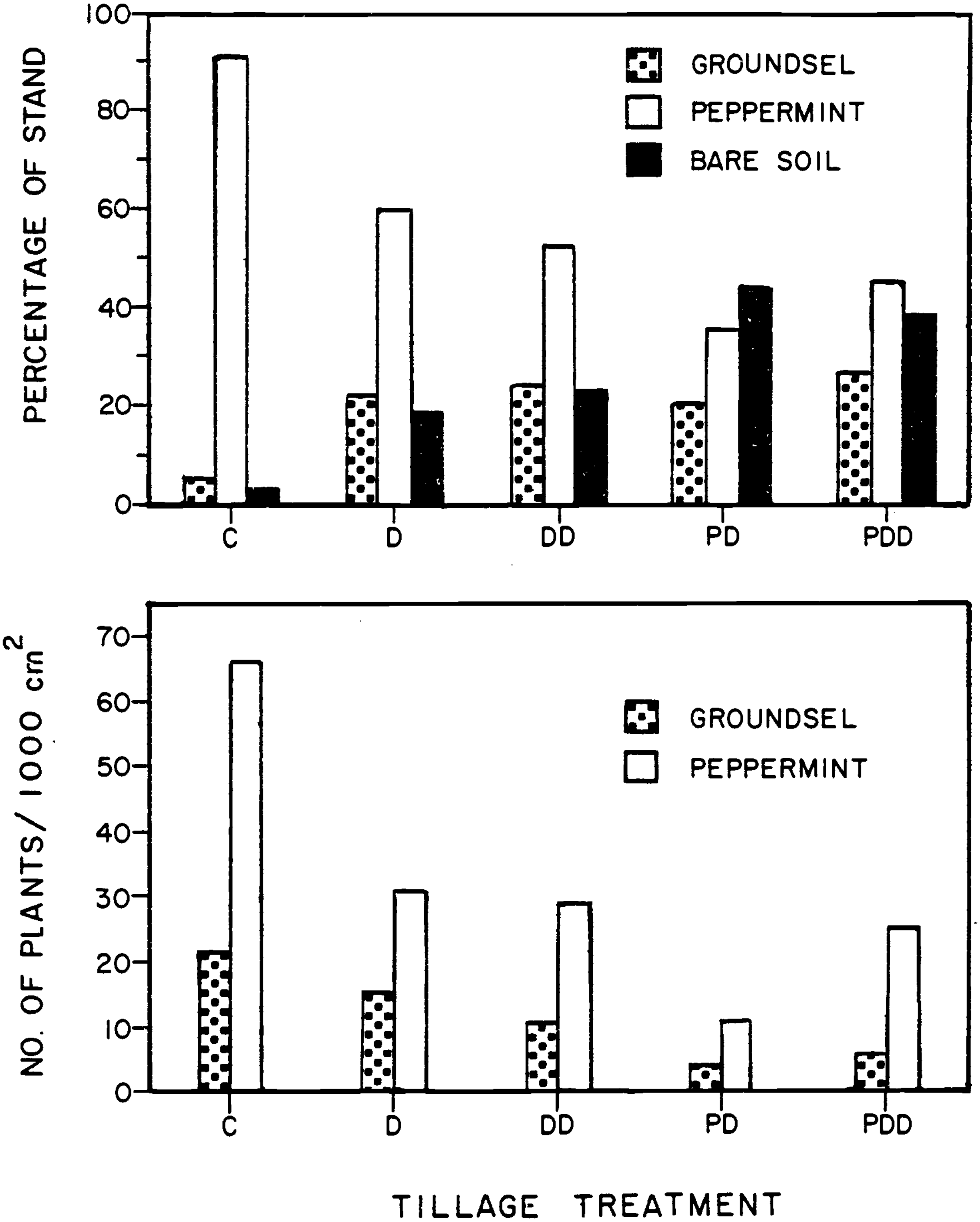

PERCENTAGE OF STAND
100
80
60
40
20
0
GROUNDSEL
PEPPERMINT
BARE SOIL
C
D
DD
PD
PDD
NO. OF PLANTS/1000 cm²
70
60
50
40
30
20
10
0
GROUNDSEL
PEPPERMINT
C
D
DD
PD
PDD
TILLAGE TREATMENT

Figure 10.

explains how disked and plowed treatments received similiar estimates of *S. vulgaris* plant vigor.

Density of *S. vulgaris* at locations 3 and 4 was estimated in July when the plants were fully mature and setting seed. Significant differences ($p<0.05$) were found between treatments only at location 3 (Appendix II, Table 4). Densities of *S. vulgaris* for PDD treatments at location 3 were significantly lower ($p<0.05$) than in C treatments, but were not significantly lower than D treatments (Table 7). PDD and DD treatments at location 3 reduced densities of *S. vulgaris* by ca. 71 and 26 percent, respectively.

Neither density nor plant vigor of *S. vulgaris* was significantly different between treatments ($p<0.10$) at location 4. Even though reductions in *S. vulgaris* densities for PDD and DD treatments averaged about 82 and 47 percent, respectively (Table 7), the reductions were not consistent enough between replications to find differences between treatments. Tilled plots had a lower density of peppermint plants than nontilled plots at locations 3 and 4 which resulted in larger and more vigorous *S. vulgaris* plants. Thus, no differences were found between treatments in plant vigor evaluations.

Plowed treatments had significantly lower densities of *S. vulgaris* than untilled treatments at all locations probably because most of the *S. vulgaris* seeds and plants located on the soil surface were buried 0-15 cm deep

Table 7. Mean density of *S. vulgaris* for tillage treatments at location 3 on July 6, 1982 and at location 4 on July 1, 1982.

Tillage Treatment	Location 3 Density 1/ $\bar{x} \pm$ S.E.	Location 4 Density $\bar{x} \pm$ S.E.
PDD	66.7 ± 22.8 a 2/	26.7 ± 17.2 3/
DD	169.0 ± 44.4 b	86.5 ± 27.2
C	230.0 ± 60.1 b	250.0 ± 120.9

1/ Average number of plants in three replications (total number of plants/15m^2).

2/ Means followed by the same letter are not significantly different (ANOV. L.S.D. $p<0.05$).

3/ Means were not significantly different based on analysis of variance ($p<0.10$).

with plowing. The greatest reduction in *S. vulgaris* density in plowed treatments occurred at location 1 where disking 5 cm deep after plowing may not have brought seeds up to the soil surface. More seeds may have been brought up to the soil surface when plowing was shallower (location 2) or when disking after plowing was deeper (locations 3 and 4).

Disked treatments also had lower densities of *S. vulgaris* than untilled treatments. Reductions in densities in disked treatments probably resulted from mechanical injury and seeds being buried as the soil was mixed. Cultivation often stimulates germination of weed seeds by improving the condition of the soil. However, a rough soil surface, as was the case in disked treatments, may result in lower emergence than with a fine, firm soil surface (Fryer and Evans 1968). This could explain why a higher density of *S. vulgaris* plants was found in untilled plots.

Roberts and Dawkins (1967) and Roberts and Potter (1980) reported that the influx of seeds affected evaluation of cultivation on *S. vulgaris* emergence. The influx of seeds into experimental plots from adjacent plots or from outside of the test plot may have occurred in my study, but it is not known what influence it may have had on evaluations.

Even though plowed and disked treatments had lower densities of *S. vulgaris* in experimental plots, dry weight and plant vigor estimates were not always correspondingly lower than in untilled plots. Lower densities of peppermint and *S. vulgaris* in tilled plots than in untilled plots apparently allowed *S. vulgaris* plants to become larger, resulting in higher estimates of dry weight biomass and plant vigor. The vigor of the peppermint stand in untilled plots also may have influenced the stand of *S. vulgaris*. Growth of *S. vulgaris* appeared to be better in untilled treatments at location 1 where the peppermint was less vigorous than at location 2 where the peppermint was more vigorous. It is not known whether the less vigorous stand of peppermint at location 1 was primarily due to the presence of *S. vulgaris* or to other undefined factors.

Relationships Between Evaluations of *S. vulgaris* Stands.--Linear correlation coefficients for the relationships between evaluations of *S. vulgaris* stands made on the same dates are in Appendix II, Table 6. The significance of these relationships is given in Table 8. Density, dry weight biomass, and plant vigor of *S. vulgaris* were usually highly correlated ($p<0.01$) with each other when *S. vulgaris* stands were primarily seedlings (November 1980--location 1). However, when *S. vulgaris* stands included both young seedlings and larger plants, correlations between dry weight with density and dry weight with plant vigor were usually not significant

Table 8. Significance of Pearson product-moment correlation coefficients for evaluations of *S. vulgaris* density, dry weight biomass and vigor for tillage treatments in test plots in 1980-82.

		Tillage Treatments									
Location 1		Density (#/1000 cm^2)					Dry weight (g/1000 cm^2)				
	Date	C	D	DD	PD	PDD	C	D	DD	PD	PDD
Dry Weight (g/1000 cm^2)	11/18/80	**	**	*	**	**					
	4/12/81	**	**	**	**	NS					
Plant Vigor (%)	11/18/80	*	**	**	**	**	**	**	**	*	**
	4/12/81	**	**	**	NS	NS	**	**	**	NS	NS
Location 2		Density (#/1000 cm^2)					Dry Weight (g/1000 cm^2)				
	Date	C	D	DD	PD	PDD	C	D	DD	PD	PDD
Dry Weight (g/1000 cm^2)	3/23/81	NS	NS	**	NS	NS					
	6/21/81	**	**	**	**	**					
Plant Vigor (%)	3/23/81	**	**	**	**	**	NS	NS	**	NS	NS
	6/21/81	**	**	NS	NS	NS	**	**	*	NS	NS
Locations 3 and 4		Location 3 Density (#/3 m^2)					Location 4 Density (#/3 m^2)				
		C		DD		PDD	C		DD		PDD
Plant Vigor (%)		**		NS		NS	**		*		**

* Significant at $p<0.05$.
** Significant at $p<0.01$.
NS Not significant.

(March 1981--location 2). The dry weight of one large plant could equal the dry weight of several seedlings. Therefore, dry weight biomass of *S. vulgaris* probably varied greatly depending on the relative abundance of seedlings and larger plants in samples. Density and plant vigor were highly correlated ($p<0.01$) at location 2 in March probably because greater densities of seedlings and larger plants covered a greater percentage of the soil surface. Stands of *S. vulgaris* which included both seedlings and larger plants, also were evaluated at location 1 in April, only three weeks after pretreatment evaluations at location 2. There were more significant correlations between evaluations at location 1 than at location 2. The greater number of samples taken at location 1 (5-1000 cm^2) compared to location 2 (3-1000 cm^2) may have resulted in less variation of samples at location 1 which in turn resulted in higher correlations. When densities of *S. vulgaris* were low, as in plowed treatments at location 1 in April and location 2 in June, evaluations of plant characteristics were generally not significantly correlated. There was a lack of correlation because *S. vulgaris* had a density and dry weight of zero in 13 out of the 15 experimental plots in PD and PDD treatments at location 1.

Test plots at all locations were flamed in the spring (mid-April to mid-May) with a field propane burner to control mint rust. Spring flaming killed all *S.*

vulgaris plants in test plots; therefore most plants evaluated in June or July were produced from seeds which had germinated after flaming and were about the same age. Density, dry weight and plant vigor evaluations in untilled and disked treatments were usually significantly correlated at location 2 in June. In contrast to March evaluations, plants in June were nearly equal in size within treatments resulting in less variation in dry weight measurements.

Stands of *S. vulgaris* in 1982 test plots were not as dense as in 1981 test plots. Density and plant vigor were significantly correlated for all treatments at location 4 and for the C treatment at location 3. Since the size of the sampling unit was greater in 1982 (one m^2) than in 1981 (1000 cm^2), the greater surface area sampled in 1982 may have given better estimates of the actual density of *S. vulgaris*.

In my study, measurements of density, dry weight, and plant vigor of *S. vulgaris* varied with respect to the interpretations of reductions in *S. vulgaris* among tillage treatments, especially at location 2. All three measurements should be used whenever possible, but using plant vigor estimates rather than measuring density and biomass could save considerable time. The relationships between these measurements may depend on 1) the abundance of plants in the plots, 2) the number of samples taken and size of the sample unit, and 3) the relative abundance of different sizes of plants.

Other Weed Species.--False dandelion, *Hypochaeris radicata* L., was fairly abundant in experimental plots at location 1. This species was relatively clumped, so treatments were compared by analyzing the proportion of plants remaining in plots after tillage (April 12, 1981) to the totals in the plots prior to tillage (November 18, 1980). Only plants one or more years old were counted. Plants were usually tightly clumped in a small area, so the actual number of plants could not always be determined unless they were destructively sampled. When this was the case, a small clump of plants was recorded as one plant even though several plants may have been present. Results showed that there were highly significant differences between treatments in the proportion of *H. radicata* plants remaining in April ($p<0.01$) (Appendix II, Table 7). Plowed treatments resulted in significantly smaller proportion of plants remaining than disked and untilled treatments (Table 9). The proportion of plants in plowed treatment plots was about 65 percent less than in untilled plots, indicating that plowing could give about 65 percent control of *H. radicata*. Disked treatment plots had a slightly higher proportion of *H. radicata* than untilled plots which may be due to separation of some of the small clumps, resulting in a higher count than the original clump received. The reason why only 75 percent of the *H. radicata* plants were recovered in untilled plots in April

Table 9. Mean proportion of *H. radicata* remaining in plots on April 12, 1981 compared to pretreatment samples on November 18, 1980 for tillage treatments at location 1.

Tillage Treatment	Proportion $\bar{x} \pm$ S.E.
PD	0.22 ± 0.06 a
PDD	0.31 ± 0.16 a
C	0.75 ± 0.08 b
DD	0.83 ± 0.11 b
D	0.83 ± 0.10 b

Means followed by the same letter are not significantly different (ANOV. L.S.D. $p<0.05$).

is not known. It is possible that plants counted as individuals in November grew into clumps by April and were counted as a single plant. If this was true, plowed treatments may have actually reduced the number of *H. radicata* plants by more than 65 percent. Although *H. radicata* plants were not counted after April, it was observed that the lower numbers of plants in the plowed treatments were maintained through the remainder of the growing season.

Several other weed species were present in test plots, but they were not evaluated because they occurred in low densities or were clumped within experimental plots. The predominant species were: common dandelion, *T. officinale* (locations 2 and 3); Canada thistle, *C. arvense* (location 3); field bindweed, *C. arvensis* (location 3); and several species of grasses (locations 1, 2, and 3).

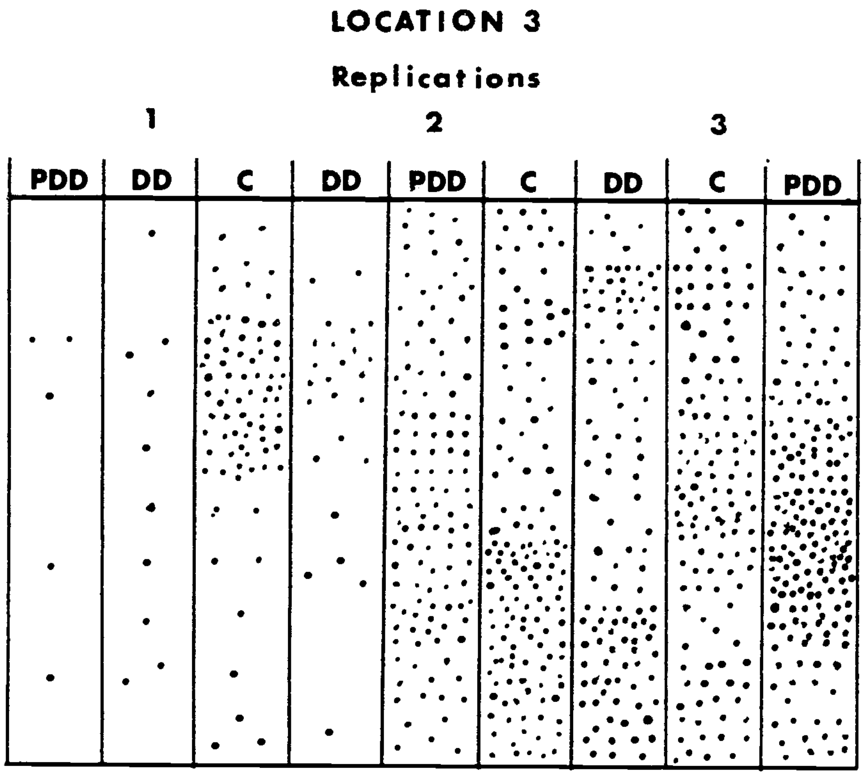
Effects of Tillage on Verticillium wilt

Verticillium wilt was first discovered on peppermint in Oregon in 1944 (Boyle 1944), and by 1965 it had spread to about 4,400 hectares in Oregon (Horner and Dooley 1965). Annual tillage used during this period to control weeds and some diseases may have contributed to the spread of Verticillium wilt within fields (Horner and Nadakavukaren 1958-1959). According to Horner (1955) and Horner and Dooley (1965) tillage probably increased the incidence of Verticillium wilt by spreading infected plant debris and infested soil. Flaming with a propane field burner after harvest greatly reduces the *V. dahliae* inoculum in infected stems (Horner and Dooley 1965, McIntyre and Horner 1973), and is presently used in fields infested with Verticillium wilt. Horner (1970) reported that the incidence of Verticillium wilt remained static over a five year period on about 7,600 hectares of peppermint when fall flaming and limited tillage was used. Sewell and Wilson (1974) reported that for Verticillium wilt in hops (*Verticillium albo-atrum*), non-cultivation resulted in about 28% control of Verticillium wilt compared to cultivation when wilt incidence was high, but non-cultivation tended to have more wilt when the incidence of wilt was low.

In this study, test plots at locations 3 and 4 were evaluated to determine the influence of tillage on the spread of Verticillium wilt. These test plots were selected primarily to monitor emergence of adult *F. fumalis*. These test plots were not selected until after harvest in 1981 so the incidence and distribution of Verticillium wilt within each test plot during the previous growing season could not be determined. Therefore, it was assumed that all experimental plots within each replication were equally infested with the disease. Evaluations of Verticillium wilt in each test plot were made just prior to harvest in 1982. Results showed that there were no significant differences ($p<0.10$) between treatments in the total number of "patches" of wilt at either location 3 or 4 (Appendix III, Table 1). The distribution of wilt patches in test plots are shown in Figure 11. The distribution of these patches appears to be aggregated which suggests that the previous assumption of a uniform infestation of wilt prior to tillage was inaccurate.

Even though tillage did not affect the incidence of wilt because of the apparent clumped distribution of the disease, it is likely that tillage could affect the expression of disease symptoms. Each patch was given two ratings; most prevalent or average symptom present and most advanced symptom present. Within each rating, symptoms were classified as mild, moderate, or severe. To determine if tillage affected the degree of symptom expression, ratios of the number of patches having each symptom type to

Figure 11. Test plots at locations 3 (top) and 4 (bottom) showing the distribution of *Verticillium* wilt as assessed on August 3, 1982. Each point represents a "patch" of *Verticillium* wilt.


LOCATION 3
Replications
1
2
3
PDD
DD
C
DD
PDD
C
DD
C
PDD

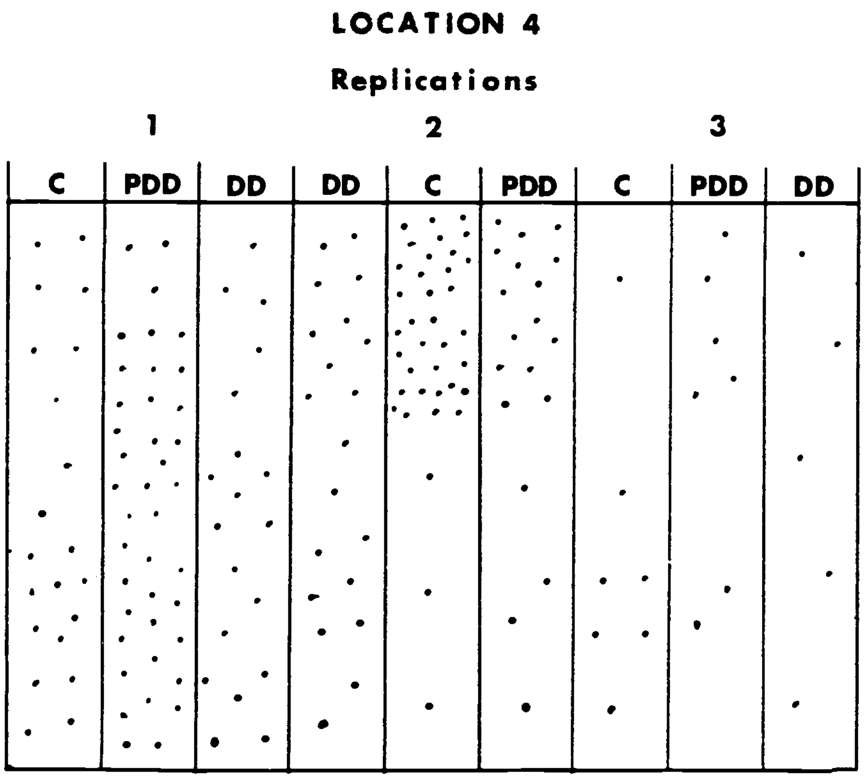

LOCATION 4
Replications
1
2
3
C
PDD
DD
DD
C
PDD
C
PDD
DD

Figure 11.

the total number of patches within each experimental plot were determined and compared for each rating. No significant differences ($p<0.10$) were found between treatments at either location 3 or 4 in the ratio of numbers of patches classified as mild, moderate, or severe to the total number of patches within either the average or the most advanced rating (Appendix III, Table 2). This may suggest that tillage does not influence the degree of symptom expression of Verticillium wilt.

An evaluation of the percentage of plants showing symptoms also was used to assess spread of the disease. An attempt was made to evaluate the percentage of plants with symptoms of Verticillium wilt at location 5 on August 1, 1982. Two hundred stems were randomly chosen in each experimental plot. Stems with typical symptoms of the disease were classified as mild, moderate, or severe based on previously described criteria. No significant differences ($p<0.10$) were found between treatments, either in the total number of stems which had disease symptoms, or in the percentage of stems classified as mild, moderate, or severe (Appendix III, Table 3). A relatively low percentage of plants (0-11 %) exhibited symptoms in all experimental plots. As the percentage of plants with symptoms of Verticillium wilt decreases, a larger number of stems would have to be sampled to accurately estimate the actual incidence of wilt in a field.

Tillage did not appear to increase the incidence of

Verticillium wilt or affect the expression of disease symptoms. However, an apparent unequal distribution of wilt within plots prior to tillage made it difficult to draw any definite conclusions. If tillage does spread Verticillium wilt, a reliable estimate of the degree of spread can be determined only by evaluating parameters such as symptom expression, and percentage and severity of plant infection in designated areas during the summer preceding disease evaluations.

Effects of Tillage on the Chemical Composition of the Soil

Results of selected chemical analyses of soil samples taken at location 1 in 1981 are given in Appendix IV, Table 1. The most apparent differences were in soil test values for soil samples taken at 0-5 cm. Plowed treatments at this sampling depth had soil test values for pH, Ca, and Mg which were greater than other treatments, and values for P and K which were less than other treatments. Plowed treatments also had greater P and K levels in 5-15 cm soil samples compared to other treatments. Disked treatments showed no apparent differences compared to the untilled treatment, probably because disking did little more than disturb the upper 5 cm of soil. Also, there were no noticeable differences in B between treatments so it was excluded from soil chemical analyses in 1982. Soil samples were taken in all test plots in 1982 to determine the significance of the apparent differences found in 1981.

Analyses of variance for soil chemical tests of soil samples taken at locations 3, 4, and 5 in 1982 are given in Appendix IV, Tables 2, 3, and 4, respectively. Tillage treatments had significantly different ($p<0.05$) pH levels in 0-5 cm soil samples at all locations, and highly significantly different ($p<0.01$) pH levels in 5-15 cm samples at location 3 (See Appendix IV). Phosphorus levels in both 0-5 and 5-15 cm soil samples also were significantly different ($p<0.05$) between tillage treatments at location 3. Highly significant differences ($p<0.01$) were found between tillage treatments in K levels of 0-5 cm soil samples at locations 4 and 5, and significant differences ($p<0.05$) were found in K levels of 5-15 cm soil samples at location 5. Calcium levels of 0-5 cm soil samples were significantly different ($p<0.05$) between treatments at all locations. No significant differences ($p<0.10$) were found in Mg levels of either 0-5 or 5-15 cm soil samples at any location. While certain other soil test values tended to be different ($p<0.10$) between treatments, i.e., K (0-5 cm) at location 3 and pH (5-15 cm) and P (0-5 cm) at location 5, all other soil test values not mentioned above were not significantly different between treatments. Summaries of all selected chemical analyses of soil samples taken in 1982 at locations 3, 4, and 5 are given in Tables 10, 11, and 12, respectively.

Peppermint fields which have not been plowed or limed for several years generally have high levels of acidity in the top 5 cm of soil (Jackson and Hee 1971, Kauffman 1974). Reductions in soil pH in the top 5 cm of soil has been attributed to applications of ammonium forms of nitrogen fertilizers which result in the release of H+ ions during nitrification (Kauffman 1974, Dow *et al.* 1981). Soil test values of pH in untilled treatments at all locations in 1982 indicated that soil pH was higher in the top 5 cm of soil than in the 5-15 cm soil depth (Tables 10, 11, and

Table 10. Means of soil chemical components for tillage treatments from two sampling depths at location 3 on April 20, 1982.

Treatments/ Sampling Depth (cm)	pH $\bar{x} \pm$ S.E.	P ppm $\bar{x} \pm$ S.E.	K ppm $\bar{x} \pm$ S.E.	Ca meq./100g $\bar{x} \pm$ S.E.	Mg meq./100g $\bar{x} \pm$ S.E.
	Soil Chemical Components				
C/0-5	5.2 ± 0.0 a [1/]	123 ± 8 b	365 ± 53 [2/]	17.6 ± 0.2 a	6.2 ± 0.1
DD/0-5	5.3 ± 0.0 a	120 ± 4 b	351 ± 55	19.2 ± 0.5 b	6.4 ± 0.2
PDD/0-5	5.5 ± 0.0 b	57 ± 11 a	186 ± 23	19.1 ± 0.1 b	6.4 ± 0.1
C/5-15	5.8 ± 0.0 c	16 ± 1 a	109 ± 18	22.3 ± 0.5	6.7 ± 0.1
DD/5-15	5.7 ± 0.1 b	29 ± 2 a	128 ± 27	21.6 ± 0.5	6.7 ± 0.1
PDD/5-15	5.6 ± 0.1 a	43 ± 6 b	161 ± 16	20.9 ± 0.2	6.7 ± 0.1

1/ Means in the same column within the same sampling depth, followed by the same letter, are not significantly different (ANOV. L.S.D. $p<0.05$).

2/ Means which are not followed by letter(s) are not significantly different based on analysis of variance ($p<0.05$).

Table 11. Means of soil chemical components for tillage treatments from two sampling depths at location 4 on April 19, 1982.

Treatments/ Sampling Depth (cm)	pH $\bar{x} \pm$ S.E.	P ppm $\bar{x} \pm$ S.E.	K ppm $\bar{x} \pm$ S.E.	Ca meq./100g $\bar{x} \pm$ S.E.	Mg meq./100g $\bar{x} \pm$ S.E.
	Soil Chemical Components				
C/0-5	5.4 ± 0.1 a [1/]	106 ± 3 [2/]	919 ± 75 b	13.1 ± 0.2 a	4.0 ± 0.1
DD/0-5	5.6 ± 0.0 b	99 ± 2	750 ± 65 a	13.6 ± 0.3 b	4.0 ± 0.1
PDD/0-5	5.6 ± 0.0 b	97 ± 1	646 ± 25 a	13.7 ± 0.3 b	4.0 ± 0.1
C/5-15	5.7 ± 0.0	107 ± 6	644 ± 80	14.9 ± 0.4	4.3 ± 0.2
DD/5-15	5.8 ± 0.1	98 ± 3	534 ± 71	15.4 ± 0.8	4.2 ± 0.2
PDD/5-15	5.7 ± 0.0	104 ± 2	610 ± 60	14.5 ± 0.3	4.1 ± 0.1

1/ Means in the same column within each sampling depth, followed by the same letter, are not significantly different (ANOV. L.S.D. $p<0.05$).

2/ Means which are not followed by letter(s) are not significantly different based on analysis of variance ($p<0.05$).

Table 12. Means of soil chemical components for tillage treatments from two sampling depths at location 5 on April 21, 1982.

Treatments/ Sampling Depth (cm)	pH $\bar{x} \pm$ S.E.	P ppm $\bar{x} \pm$ S.E.	K ppm $\bar{x} \pm$ S.E.	Ca meq./100g $\bar{x} \pm$ S.E.	Mg meq./100g $\bar{x} \pm$ S.E.
			Soil Chemical Components		
C/0-5	4.9 ± 0.1 a [1/]	132 ± 2 [2/]	521 ± 7 c	7.4 ± 0.2 a	2.2 ± 0.0
DD/0-5	5.1 ± 0.1 ab	128 ± 3	355 ± 10 b	9.4 ± 0.7 b	2.5 ± 0.2
PDD/0-5	5.4 ± 0.2 b	119 ± 5	241 ± 10 a	9.7 ± 0.4 b	2.2 ± 0.2
C/5-15	5.5 ± 0.0	108 ± 5	220 ± 2 a	10.3 ± 0.1	2.3 ± 0.1
DD/5-15	5.6 ± 0.1	110 ± 5	230 ± 14 a	10.8 ± 0.7	2.5 ± 0.2
PDD/5-15	5.3 ± 0.0	118 ± 4	282 ± 7 b	10.0 ± 0.5	2.3 ± 0.1

1/ Means in the same column within the same sampling depth, followed by the same letter, are not significantly different (ANOV. L.S.D. $p<0.05$).

2/ Means which are not followed by letter(s) are not significantly different based on analysis of variance ($p<0.05$).

12). Plowed treatments at all locations resulted in significantly higher pH values ($p<0.05$) than in untilled treatments due to the inversion of more basic layers of soil. Double disking resulted in significantly higher pH values ($p<0.05$) at location 4, and slightly higher pH values at locations 3 and 5, than in untilled treatments because of some mixing of the soil at a depth greater than 5 cm.

According to Jackson and Hee (1971), P and K nutrients accumulate in the 2.5 cm of surface soil where P and K fertilizers have been applied for several years on established peppermint fields. Results of soil chemical analyses in 1981 and 1982 supported their observations. Untilled treatments had P levels which were 3.7 to 7.6 times higher (locations 1 and 3), and K levels which were 2.5 to 3.3 times higher (locations 1, 3, and 4) in 0-5 cm samples than in the 5-15 cm soil samples (Tables 10, 11, and 12; Appendix IV, Table 1).

The greatest difference in P levels between the 0-5 and 5-15 cm soil samples from untilled treatments occurred at location 3, and this was the only location where significant differences in P levels between tillage treatments were found. PDD treatments inverted and mixed the soil resulting in a relatively even distribution of P throughout the 0-15 cm sampling zone at locations 1, 3, and 5. The PDD treatment at location 3 had P levels which were significantly lower ($p<0.05$) in 0-5 cm samples and significantly higher ($p<0.05$) in 5-15 cm samples than in both DD and C treatments (Table 10). DD treatments were less effective than PDD treatments in incorporating high levels of P (0-5 cm) deeper in the soil (5-15 cm) resulting in P levels which were intermediate to PDD and C treatments at locations 3 and 5.

Results of soil chemical analyses of K were similiar to those of P. For example, K was much more evenly distributed throughout the 0-15 cm sampling zone in PDD treatments, and in DD treatments, K levels were usually intermediate between levels found in PDD and C treatments. PDD treatments at location 5 had significantly higher K levels in 5-15 cm samples than in DD and C treatments (Table 12). DD and PDD treatments had significantly lower ($p<0.05$) K levels in 0-5 cm samples compared to C treatments at locations 4 and 5 (Tables 11 and 12). PDD treatments, and to a lesser extent DD treatments, incorporated soil with higher levels of P and K deeper in the soil. Most of the differences between tillage treatments occurred where there were relatively large differences in P and K levels between 0-5 and 5-15 cm soil samples from untilled plots.

Soil test values of Ca were significantly higher ($p<0.05$) in PDD and DD treatments in 0-5 cm soil samples at all locations in 1982 (Tables 10, 11, and 12). Calcium levels were higher in 5-15 cm soil samples than in 0-5 cm soil samples from untilled plots. Again, as was the case with P and K nutrients, inversion and/or mixing of the soil within the 0-15 cm sampling zone in PDD and DD treatments resulted in soil with higher levels of Ca being brought to the soil surface.

No significant differences were found in soil test values of Mg, probably because there was little difference in the amounts of Mg between 0-5 and 5-15 cm soil samples from untilled plots. Therefore, inversion and mixing of the soil in PDD and DD treatments would not have changed the distribution of Mg in the soil strata sampled.

Effects of Tillage on Peppermint Plant Growth, Yield, and Oil Quality and Maturity

Peppermint Plant Growth.--Evaluations of peppermint plant growth were made by taking subjective visual estimates of plant vigor and direct quantitative measurements of stem density, stem height, and rhizome dry weight biomass. Estimates of peppermint plant vigor were made at locations 1 and 2, and in conjunction with plant vigor estimates of *S. vulgaris*. Stem density was estimated at locations 1, 2, 3, and 4 and stem height was estimated at locations 2, 3, and 4. Rhizome dry weight biomass was determined at locations 3 and 4 during October 1982.

Stem density was estimated at location 1 during mid-April just prior to spring flaming. Most mint plants at this time were just beginning to emerge and/or grow and had stems less than 15 cm tall. Stem density was estimated at locations 2, 3, and 4 from late June to mid-July when mint plants were much taller and actively growing. Stem density was significantly different ($p<0.05$) between treatments at location 4 and highly significantly different ($p<0.01$) between treatments at locations 1, 2, and 3 (Appendix V, Table 1). Plowed treatments usually had significantly lower stem densities of peppermint ($p<0.05$) than disked and untilled treatments (Table 13). Most mint

Table 13. Mean number of peppermint stems for tillage treatments at location 1 on April 17 and location 2 on June 21, 1981, and locations 3 and 4 on July 15, 1982.

Tillage Treatment	Location 1 [1/] $\bar{x} \pm$ S.E.	Location 2 $\bar{x} \pm$ S.E.	Location 3 [2/] $\bar{x} \pm$ S.E.	Location 4 $\bar{x} \pm$ S.E.
PD	24.3 ± 2.9 a [3/]	10.7 ± 4.7 a	-----	-----
PDD	32.0 ± 4.1 a	26.7 ± 6.1 ab	114.2 ± 7.4 a	162.3 ± 14.6 a
DD	48.5 ± 5.9 b	28.2 ± 6.8 b	158.8 ± 1.9 b	226.8 ± 22.9 b
D	55.1 ± 6.7 b	31.8 ± 14.2 b	-----	-----
C	52.5 ± 6.9 b	66.1 ± 4.4 c	187.3 ± 8.0 c	245.8 ± 5.8 b

1/ Mean number of stems per 1000 cm^2 at locations 1 and 2.
2/ Mean number of stems per 5000 cm^2 at locations 3 and 4.
3/ Means followed by the same letter are not significantly different (ANOV. L.S.D. $p<0.05$).

plants in plowed treatments were present in discernible rows, much like row mint, and bare soil between these rows accounted for the lower stem densities. Stem densities in disked treatments were usually intermediate between plowed and untilled treatments, and were significantly lower ($p<0.05$) in untilled treatments at locations 2 and 3.

Stem height was estimated by measuring the tallest stem, from ground level to its tip, in the same 1000 cm^2 samples used to estimate stem density. Stem height was significantly different ($p<0.05$) between treatments at location 3 and highly significantly different ($p<0.01$) between treatments at location 2 (Appendix V, Table 2). Stem height at location 4 was not significantly different ($p<0.10$) between treatments. PDD treatments had significantly shorter stems ($p<0.05$) compared to C treatments at location 2, and compared to DD and C treatments at location 3 (Table 14). DD treatments at location 2 also had significantly shorter stems ($p<0.05$) than in C treatments, but stem height was not significantly different between disked and untilled treatments at location 3. Stem height may give an indication of plant development if measurements are made early in the spring when the mint is just beginning to grow. However, stem height measured later in the growing season during June of July, may not give an accurate estimation of plant maturity because at lower densities, plants in plowed or disked mint may expend more energy to produce lateral shoots than

Table 14. Mean height (cm) of tallest peppermint stems for tillage treatments at location 2 on June 21, 1981 and locations 3 and 4 on July 15, 1982.

Tillage Treatment	Location 2 [1/] $\bar{x} \pm$ S.E.	Location 3 [2/] $\bar{x} \pm$ S.E.	Location 4 $\bar{x} \pm$ S.E.
PD	19.7 ± 4.0 a [3/]	------	------ [4/]
PDD	26.7 ± 3.8 ab	296.8 ± 8.2 a	280.7 ± 11.6
DD	25.5 ± 1.7 ab	324.3 ± 23.6 b	305.3 ± 12.3
D	30.5 ± 3.2 b	------	------
C	50.8 ± 1.4 c	369.2 ± 9.5 b	300.7 ± 13.7

1/ Mean height of tallest stems in 10 samples.
2/ Mean height of tallest stems in three replications, each replication consisting of total combined height of five stems at locations 3 and 4.
3/ Means in the same column followed by the same letter are not significantly different (ANOV. L.S.D. $p<0.05$)
4/ Means not followed by letters are not significantly different based on analysis of variance ($p<0.10$).

terminal growth of mainstems.

Peppermint plant vigor was estimated in conjunction with *S. vulgaris* plant vigor during June at location 2 and during July at location 1. There were highly significant differences ($p<0.01$) in peppermint plant vigor between tillage treatments at locations 1 and 2 (Appendix V, Table 3). Comparisons between tillage treatments showed that tillage affected peppermint plant vigor at locations 1 and 2 differently (Table 15). Plant vigor in plowed treatments was significantly greater ($p<0.05$) than in disked and untilled treatments at location 1, but was significantly lower than in disked and untilled treatments at location 2. Plant vigor in disked treatments was intermediate between plowed and untilled treatments at locations 1 and 2. Peppermint plant vigor was significantly lower ($p<0.05$) in disked treatments than in untilled treatments at location 2. Peppermint plant vigor was not estimated at locations 3 and 4, but plant vigor was observed to increase in the order of PDD, DD, and C treatments during early to mid-summer at both locations.

Peppermint density, height, and plant vigor in disked treatments during June and July were generally intermediate between plowed and untilled treatments at all locations. Most mint plants in plowed treatments grew in discernible rows, with areas of bare soil between rows. This generally resulted in lower estimates of density and plant vigor than in disked and untilled treatments.

Table 15. Mean peppermint plant vigor (%) for tillage treatments estimated on July 7 at location 1 and June 21 at location 2 in 1981.

Tillage Treatment	Location 1 $\bar{x} \pm$ S.E.	Location 2 $\bar{x} \pm$ S.E.
PD	66.0 ± 2.8 b [1/]	36.3 ± 2.3 a
PDD	68.7 ± 2.3 b	45.3 ± 3.7 b
DD	48.7 ± 4.5 a	53.7 ± 3.7 c
D	51.0 ± 3.9 a	59.0 ± 3.6 c
C	43.3 ± 6.2 a	91.7 ± 1.6 d

1/ Means in the same column followed by the same letter are not significantly different (ANOV. L.S.D. $p<0.05$).

Even though plowed treatments at location 1 had the lowest densities of peppermint plants during April, plant vigor was greatest in plowed treatments compared to other treatments by early July. This may be attributed to stands of *S. vulgaris* and *H. radicata* which were lower in plowed plots compared to other treatments. Higher densities of *S. vulgaris* and *H. radicata* in disked and untilled plots apparently reduced peppermint plant vigor through competition.

Untilled treatments at location 2 had significantly higher densities and plant vigor of peppermint than in tilled treatments in late June. Peppermint plant vigor in plowed treatments at location 1 was better than at location 2 probably because tillage at location 2 was performed on April 7, after the mint began to grow in the spring. This may have resulted in a greater delay in plant growth in tilled treatments at location 2 than at location 1 since spring tilled mint has been observed to grow slower than fall tilled mint (Horner 1952).

The apparent differences in peppermint plant vigor in untilled treatments between locations 1 and 2 probably cannot be explained on the basis of differences in potential stands of *S. vulgaris* because untilled treatments at both locations had approximately equal density, dry weight biomass, and plant vigor of *S. vulgaris* in March and April. Untilled treatments at location 1 had heavy infestations of *F. fumalis* which probably weakened the mint, and made it less competitive which allowed *S. vulgaris* more opportunity to become established. Differences in other biological factors and management practices between locations 1 and 2 also may have influenced peppermint plant growth at both locations.

Rhizome dry weight measurements were taken at two soil depths, 0-5 cm and 5-15 cm. Results showed that rhizome dry weight in 0-5 cm samples was significantly different ($p<0.05$) between treatments at location 3, but was not significantly different ($p<0.10$) between treatments at location 4 (Appendix V, Table 4). Rhizome dry weight in 5-15 cm samples was highly significantly different ($p<0.01$) between treatments at locations 3 and 4. The percentage of rhizome dry weight in 5-15 cm samples compared to the total rhizome weight from 0-15 cm samples also was highly significantly different between treatments ($p<0.01$).

Rhizome dry weight in 5-15 cm samples was significantly greater ($p<0.05$) in PDD treatments than in DD and C treatments (Table 16). PDD treatments (14.1-14.8 %) had significantly higher ($p<0.05$) percentages of rhizome dry weight in 5-15 cm samples compared to the total rhizome dry weight in 0-15 cm samples than DD (3.8-6.0 %) and C (1.9-3.8 %) treatments. All treatments were significantly different from each other ($p<0.05$) in rhizome dry weights in 0-5 cm samples at location 3; PDD and C treatments had the lowest and highest rhizome dry weights, respectively.

Since peppermint is typically shallow rooted, one of

Table 16. Mean rhizome dry weight (grams)[1] at two sampling depths and the proportional percentages of rhizome dry weight in 5-15 cm samples to the total rhizome dry weight from 0-15 cm samples for tillage treatments in 1982.

Location/ Treatment	Sampling Depth 0-5 cm $\bar{x} \pm$ S.E.	Sampling Depth 5-15 cm $\bar{x} \pm$ S.E.	Proportional Percentage 5-15 cm/0-15 cm $\bar{x} \pm$ S.E.
3 / PDD	13.77 ± 1.08 a[2]	2.67 ± 0.12 b	14.80 ± 0.89 b
3 / DD	18.04 ± 1.79 b	0.60 ± 0.13 a	3.79 ± 1.24 a
3 / C	22.76 ± 1.17 c	0.48 ± 0.05 a	3.82 ± 1.77 a
4 / PDD	20.49 ± 3.36[3]	3.58 ± 0.44 b	14.14 ± 1.77 b
4 / DD	19.23 ± 2.41	1.13 ± 0.28 a	6.01 ± 1.46 a
4 / C	17.40 ± 1.89	0.32 ± 0.05 a	1.89 ± 0.53 a

1/ Means of rhizome dry weight represent the average of three replications, each replication consisting of the total rhizome biomass of 5-1000 cm^2 samples.

2/ Means in the same column within the same location, followed by the same letter, are not significantly different (ANOV. L.S.D. $p<0.05$)

3/ Means which are not followed by letters are not significantly different (ANOV. $p<0.10$).

the objectives of tillage is to bury rhizomes deeper in the soil. In my study, plowing resulted in the production of rhizomes deeper in the soil strata, probably because these rhizomes were produced by plants originating deeper in the soil. Even though rhizome dry weight in 5-15 cm samples in disked treatments was greater than in untilled treatments, disking was less effective in burying rhizomes than was plowing. Differences in the effects of tillage on rhizome dry weight in 0-5 cm samples between locations 3 and 4 could be the result of several undefined factors.

Peppermint Yield.--Peppermint plant growth at location 1 was generally poorer in experimental plots with more vigorous stands of *S. vulgaris*, suggesting that vigorous stands of *S. vulgaris* also could affect the peppermint yield at harvest. Thus, yields of fresh hay weight and oil at location 1 were measured in each of six experimental plots per treatment. Plots selected for harvest were representative of the range of *S. vulgaris* plant vigor evaluations made in July.

Yield measurements at location 1 and linear correlations between *S. vulgaris* plant vigor and peppermint yields are given in Table 17. Peppermint fresh hay and oil yields increased, and *S. vulgaris* plant vigor decreased in the order of untilled, disked, and plowed treatments. Peppermint fresh hay weight showed significant negative correlations ($p<0.05$) with *S.*

Table 17. Mean peppermint yield and Pearson correlation coefficients (r) for the relationship between *S. vulgaris* plant vigor and peppermint yield for tillage treatments at location 1 in 1981.

Tillage Treatment	Peppermint Yield: Wet Weight (kg/3 m^2)	Peppermint Yield: Oil (ml/3 m^2)	*S. vulgaris* Plant Vigor (%): Range	*S. vulgaris* Plant Vigor (%): Average	Wet weight (r) 1/	Oil (r)
C	2.99	10.37	10-100	48.3	-.03 NS	-.07 NS
D	4.10	12.65	0-90	36.7	-.81 *	-.72 NS
DD	4.20	14.85	15-60	33.3	-.94 **	-.65 NS
PD	5.27	15.42	0-50	15.0	-.78 NS	-.37 NS
PDD	5.12	16.9	0-40	12.5	-.83 *	-.62 NS

NS Not significant.
* Significant at $p<0.05$.
** Significant at $p<0.01$.
1/ Peppermint harvested in six experimental plots per treatment on August 19, 1981 was correlated with *S. vulgaris* plant vigor evaluated on July 7, 1981.

vulgaris for D, DD, and PDD treatments. All other correlations between peppermint yields and *S. vulgaris* also were negative which indicated that *S. vulgaris* did reduce peppermint yields. There was no way to determine whether the apparent increases in peppermint hay and oil yields in tilled treatments was mainly due to reductions in *S. vulgaris* or the effects of tillage on the peppermint itself. The lack of significant correlations between *S. vulgaris* plant vigor and peppermint yield was probably due to the influence of other factors, e.g., *F. fumalis* or *H. radicata*, and the inherent sampling variation of peppermint and *S. vulgaris*.

In 1982, fifteen fresh hay samples (kg/3 m^2) and nine oil samples (ml/4.5 kg fresh hay) from each treatment within each replication were compared at locations 3 and 4. In addition, oil yield (ml/3 m^2) also was compared by extrapolating from fresh hay (kg/3 m^2) and oil (ml/4.5 kg fresh hay) samples. Oil (ml) collected from 4.5 kg fresh hay samples at location 4 was the only yield index in 1982 that showed significant differences between treatments ($p<0.05$) (Appendix V, Table 5). DD treatments at location 4 had significantly lower amounts of oil (ml) collected per unit of fresh hay weight than in C treatments (Table 18). This result cannot be explained on the basis of peppermint density or height because these measurements were comparable in disked and untilled treatments in July (Tables 13 and 14).

Table 18. Mean peppermint oil yield (ml/4.5 kg fresh hay) for tillage treatments at location 4 in 1982.

Tillage Treatment	Oil (ml/4.5 kg fresh hay) $\overline{x} \pm$ S.E.
DD	24.60 ± 0.91 a
PDD	29.63 ± 2.28 ab
C	33.47 ± 3.10 b

Means followed by the same letter are not significantly different (ANOV. L.S.D. $p<0.05$).

A summary of peppermint fresh hay and oil yields at locations 3 and 4 is given in Appendix V, Table 6. Fresh hay yields for all tillage treatments in 1982 (See Appendix V), especially for untilled and disked treatments, were greater than at location 1 in 1981 (Table 17). Since all three locations were heavily infested with *F. fumalis*, these apparent differences in peppermint yields may reflect the additional impact of *S. vulgaris* on reducing peppermint yields at location 1. *S. vulgaris* was much less abundant at locations 3 and 4 than at location 1. Fresh hay yields at locations 3 and 4 were comparable among tillage treatments even though peppermint in plowed and disked treatments generally had lower density and height measurements in July. This seems to reflect the ability of peppermint to branch and fill in the tilled treatments. Nelson *et al.* (1971) reported that production of dry hay matter in untilled treatments (solid stand) began much earlier than in tilled treatments (strip row or rototilled) and attributed this to a delay in plant growth because plants in tilled treatments filled in from stolon growth.

Linear correlations between peppermint yields and factors potentially affecting yields for each tillage treatment at locations 3 and 4 are given in Tables 19 and 20, respectively. Generally, these factors were not significantly correlated with peppermint yields. Peppermint yields showed some significant negative correlations ($p<0.05$) with Verticillium wilt and some

Table 19. Pearson product-moment correlation coefficients for peppermint yields and potential factors affecting yields within tillage treatments at location 3 in 1982.

	Yield								
Potential Factors	Fresh Hay Weight 1,2/ (kg/ 3 m^2)			Oil 3,4/ (ml/4.5 kg hay)			Oil (ml/3 m^2)		
	C	DD	PDD	C	DD	PDD	C	DD	PDD
F. fumalis	NS	NS	NS	NS	NS	NS	NS	NS	NS
Verticillium	-.63*	-.60*	NS	NS	.66*	NS	NS	NS	NS
S. vulgaris	NS	NS	NS	NS	.89*	NS	NS	.82*	NS
Peppermint Height	NS	NS	.71*	NS	NS	NS	NS	.91*	NS
Peppermint Stem Density	NS	NS	NS	NS	NS	NS	NS	NS	NS
Peppermint Hay Weight	----	----	----	NS	NS	NS	NS	.83*	NS

* Significant at $p<0.05$.
NS Not significant.
1/ Fifteen samples for correlations between fresh hay and 1) *F. fumalis* and 2) Verticillium.
2/ Ten samples for correlations between fresh hay and 1) *S. vulgaris*, 2) peppermint height, and 3) peppermint stem density.
3/ Nine samples for correlations between oil yields and 1) *F. fumalis*, 2) Verticillium, and 3) fresh hay.
4/ Six samples for correlations between oil yields and 1) *S. vulgaris*, 2) peppermint height, and 3) peppermint stem density.

Table 20. Pearson product-moment correlation coefficients for peppermint yields and potential factors affecting yields within tillage treatments at location 4 in 1982.

	Yield								
	Fresh Hay Weight (n=15) (kg/3 m^2)			Oil (n=9) (ml/4.5 kg hay)			Oil (n=9) (ml/3 m^2)		
Potential Factors	C	DD	PDD	C	DD	PDD	C	DD	PDD
F. fumalis	NS	NS	NS	NS	NS	NS	NS	NS	NS
Verticillium	NS	NS	.52*	NS	NS	-.76*	NS	NS	NS
S. vulgaris	NS	NS	NS	NS	NS	NS	NS	NS	NS
Peppermint Height	.54*	NS	NS	NS	NS	NS	NS	NS	NS
Peppermint Stem Density	NS	NS	NS	NS	NS	NS	NS	NS	NS
Peppermint Hay Weight	----	----	----	NS	NS	NS	NS	NS	NS

* Significant at $p<0.05$.
NS Not significant.

significant positive correlations with the height of peppermint plants. However, yields also showed some positive significant correlations with Verticillium wilt and *S. vulgaris* which cannot be explained since these pests are usually associated with yield reductions.

Quality and Maturity of Peppermint Oil.--Eight monoterpenes selected to assess quality and maturity of peppermint oil were: limonene, 1,8-cineole, menthone, menthofuran, menthyl acetate, neomenthol, menthol, and pulegone. These monoterpenes comprised between 70-80 percent of the total oil.

Results showed that levels of pulegone were significantly different ($p<0.05$) between treatments at location 4, and levels of menthofuran tended to be different ($p<0.10$) between treatments at locations 3 and 4 (Appendix V, Tables 7 and 8). Treatments did not significantly affect levels of limonene, 1,8-cineole, menthone, menthyl acetate, neomenthol, or menthol. Mean monoterpene content for tillage treatments at locations 3 and 4 are given in Tables 21 and 22, respectively.

The quality of peppermint oil depends on a large number of organic compounds (Cash *et al.* 1971), which mainly consist of monoterpenes and a few sesquiterpenes (Croteau and Loomis 1972). Generally, a higher quality of peppermint oil is composed principally of menthone, menthol and menthyl esters with low levels of pulegone and

Table 21. Summary of the effects of tillage on selected terpene components (% of total terpenes) of peppermint oil at location 3 in 1982.

	Tillage Treatments		
	C	DD	PDD
Terpenes	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.
limonene	1.25 ± 0.06	1.22 ± 0.09	1.17 ± 0.16
1,8-cineole	3.82 ± 0.10	3.73 ± 0.30	4.30 ± 0.27
menthone	17.91 ± 1.27	20.37 ± 1.83	20.60 ± 0.59
menthofuran 1/	2.28 ± 0.19	1.92 ± 0.14	2.04 ± 0.01
menthyl acetate	4.40 ± 0.81	4.35 ± 0.42	4.34 ± 0.18
neomenthol	3.21 ± 0.25	3.25 ± 0.20	3.48 ± 0.02
menthol	40.32 ± 2.85	38.53 ± 2.44	42.24 ± 0.72
pulegone	0.57 ± 0.20	0.57 ± 0.13	0.60 ± 0.02

1/ Menthofuran tended to be different between treatments (ANOV. $p<0.10$).

Table 22. Summary of the effects of tillage on selected terpenes (% of total terpenes) in peppermint oil at location 4 in 1982.

	Tillage Treatments		
	C	DD	PDD
Terpenes	$\overline{x} \pm$ S.E.	$\overline{x} \pm$ S.E.	$\overline{x} \pm$ S.E.
limonene	1.52 ± 0.18	1.38 ± 0.03	1.42 ± 0.14
1,8-cineole	5.14 ± 1.10	4.28 ± 0.24	4.40 ± 0.34
menthone	22.74 ± 0.34	23.24 ± 0.08	23.04 ± 0.63
menthofuran 1/	2.47 ± 0.16	2.70 ± 0.32	3.06 ± 0.19
menthyl acetate	4.99 ± 0.70	5.38 ± 0.25	4.97 ± 0.41
neomenthol	3.45 ± 0.08	3.43 ± 0.09	3.38 ± 0.06
menthol	39.07 ± 0.89	40.29 ± 0.95	38.91 ± 0.99
pulegone 2/	0.12 ± 0.01 a	0.23 ± 0.05 a	0.48 ± 0.02b

1/ Menthofuran tended to be different between treatments (ANOV. $p<0.10$).

2/ Means followed by the same letter are not significantly different (ANOV. L.S.D. $p<0.05$).

menthofuran (Burbott and Loomis 1967, Clark and Menary 1980b). Plowed treatments had significantly higher levels of pulegone than untilled treatments at location 4 (Table 22), but since the levels of pulegone here comprised less than 0.5 percent of the total oil content in all tillage treatments, it is doubtful that plowing reduced oil quality on the basis of this compound. Levels of menthofuran were higher in untilled treatments at location 3, but also were higher in tilled treatments at location 4. Cash *et al.* (1971) reported that reductions in oil quality due to increased levels of menthofuran, based on organoleptic tests, would not occur until levels of menthofuran reached about 8.5 percent of the total oil content. Since the level of menthofuran for all tillage treatments was well below 8.5 percent, plowing or disking probably did not affect oil quality based on this compound.

The chemical compositon of peppermint oil changes through the growing season. Generally, levels of menthol, menthyl acetate, and menthofuran increase, and levels of pulegone and menthone decrease as the peppermint oil matures (Watson and St. John 1955, Burbott and Loomis 1969, Lammerink and Manning 1973). Guenther (1949) reported that "row mint" is generally harvested a few weeks later than "meadow mint" because new mint matures later than older mint. Plants from plowed treatments in this study were produced in rows much like new or "row mint". Peppermint plants in untilled plots were observed to be more mature on July 21, 1982 at locations 3 and 4 with a greater proportion of plants in the bud stage, than in plowed or disked treatments indicating that tillage also could delay oil maturation.

Reitsema (1958) proposed a scheme of monoterpene interconversions, later revised by Burbott and Loomis (1967), which assigned pulegone as the precursor of menthofuran and menthone, and menthone as the precursor of the menthols. Pulegone in higher levels is normally found early in the growing season (Burbott and Loomis 1969). Burbott and Loomis (1967) reported that warm nights and short days favored the formation of pulegone and menthofuran, and cool nights and long days favored the formation of menthone.

Spring tillage (location 4) in peppermint has been observed to delay plant growth compared to fall tillage (location 3) (Horner 1952). Levels of menthofuran at location 3 tended to be different between treatments ($p<0.10$) (Table 21), and were highest in nontilled treatments which could indicate that peppermint oil was slightly more mature in nontilled plots than in tilled plots. In contrast, levels of menthofuran at location 4 were highest in plowed treatments, but levels of pulegone also were significantly higher ($p<0.05$) in plowed treatments than in disked and untilled treatments (Table 22). Spring flaming of peppermint at location 4 was performed about one month later than at location 3 resulting in more rapid plant growth at location 3 during the early growing season. A delay in plant growth at location 4 could also delay the process of oil maturation. If levels of pulegone were higher than normal at location 4 when environmental conditions, i.e., shorter days and warmer nights, favored the formation of pulegone and menthofuran, then this may account for the higher levels of these compounds in oil from plowed treatments. Differences in monoterpene content between varieties at locations 3 (Black Mitcham) and 4 (Todd's Mitcham) are not known. Differences in other biological factors or management practices between locations 3 and 4 also may have influenced the composition of oil, but the effects are not known. Nelson *et al.* (1971) reported that tillage methods in peppermint, including "strip row" and "rototilled", delayed blooming by one week and by three weeks, respectively. Rototilled treatments had slightly lower levels of menthofuran, menthol, and menthyl acetate, and higher levels of pulegone and menthone.

Clark and Menary (1979b) reported that lower densities of peppermint (10-20 plants/m^2) generally had higher levels of menthofuran and menthone and lower levels of menthol and menthyl acetate than in higher densities of peppermint (30-60 plants/m^2). They attributed this to the production of more lateral shoots in less dense stands of peppermint which resulted in the presence of more immature oil. In my study, peppermint plants in plowed plots were not as dense as in disked and untilled plots, produced many lateral branches and retained a large proportion of their older leaves. Plants in disked and untilled treatments were predominantly mainstems with fewer lateral branches, and had lost their older leaves by harvest.

Studies have shown that lower levels of pulegone and menthone, and higher levels of menthofuran, menthyl acetate and menthol are found in older leaves located on the mainstem (Anna Marin, Department of Entomology, Oregon State University, 1983 unpublished data). These studies also indicated that fully expanded leaves located at the top of lateral branches have higher levels of menthone and menthyl acetate, and lower levels of menthofuran than in mainstem leaves. Levels of menthol in these lateral leaves were about the same as in mid-mainstem leaves, and levels of pulegone in these lateral leaves were comparable to levels found in top mainstem leaves. The production of lateral branches and retention of older leaves in plowed mint, and to a lesser extent in disked mint, may affect the composition of peppermint oil, but the extent of such an affect could not be determined from this study.

CONCLUSION

Plowed treatments significantly reduced emergence of adult *F. fumalis* by an average of ca. 80%. The greatest reductions in adult emergence (ca. 93%) occurred in plowed plots which were disked to a depth of 10 cm. Double disked treatments reduced emergence of adult *F. fumalis* by an average of ca. 56%, and the greatest reduction (ca. 97%) occurred when a roller-harrow was used after disking. Pike and Glazer (1982) suggested that 81% reduction in emergence of adult *F. fumalis* for "strip rotary tillage" may not be sufficient to replace insecticidal control measures. They also suggested that strip rotary tillage combined with insecticide treatments could maximize control. However, using insecticides in conjunction with tillage treatments could eliminate the benefit of delaying the development of resistance to insecticides in *F. fumalis*. The use of plowing or disking, when performed properly, to control *F. fumalis* will probably be sufficient at least for lower infestations of *F. fumalis*. However, the possibility of replacing insecticide treatments with tillage at higher infestations of *F. fumalis* will depend on having better estimates of economic thresholds of *F. fumalis* because tillage is usually performed after feeding damage occurs.

Tillage treatments did not affect emergence of males and females differently. The period of peak adult emergence for all treatments ranged from early July to early August and was extended about a week at location 1 compared to locations 3 and 4. Peak emergence of females occurred about a week later than for males at locations 1 and 4. There was about 80 to 90% natural mortality of *F. fumalis* from the immature stage, i.e., larvae or prepupae, to the adult stage. However, immature densities were not significantly correlated with densities of emerging adults. Populations of immature *F. fumalis* appeared to have an aggregated distribution.

The effects of tillage treatments on *S. vulgaris* varied between test plots. Reductions in *S. vulgaris* by plowing or disking was determined by comparing density, dry weight biomass, and plant vigor in tilled plots with untilled plots. The greatest reductions in *S. vulgaris* occurred in plowed treatments at location 1. Plowing at location 1 significantly reduced the density, dry weight, and plant vigor of *S. vulgaris* by ca. 95% in April and by ca. 80% in July. This reduction occurred where heavy infestations of *F. fumalis* apparently weakened and thinned the stand of peppermint which allowed higher densities of *S. vulgaris* in untilled plots to become better established. The density of *S. vulgaris* at locations 2 and 3 also was significantly lower in plowed treatments than in untilled treatments. However, *S. vulgaris* dry weight and plant vigor at these locations were not significantly lower in plowed treatments than in untilled treatments. This can probably be attributed to more vigorous stands of peppermint in untilled plots at locations 2 and 3 due to lower infestations of *F. fumalis* or *S. vulgaris*.

Disking did not reduce stands of *S. vulgaris* as much as plowing. DD treatments significantly reduced the density, dry weight biomass, and plant vigor of *S. vulgaris* at location 1. DD treatments at location 2 also had significantly lower densities of *S. vulgaris* than in untilled treatments, but plant vigor of *S. vulgaris* was significantly higher than in untilled treatments. More vigorous stands of peppermint at location 2 than at location 1 probably explains why reductions of *S. vulgaris* in disked treatments differed between locations.

Disking did not give sufficient control of *S. vulgaris* to replace current herbicide treatments, although it could be used in conjunction with some herbicides to obtain better control. The possibility of using plowing alone to control *S. vulgaris* is uncertain. While reductions of *S. vulgaris* in plowed treatments may have given sufficient control for one season, it is not known if long term control would be acheived because *S. vulgaris* is capable of rapid reproduction and recolonization. Plowing one year to control *S. vulgaris* may give an added benefit since *S. vulgaris* is known to show resistance to some herbicides (Radosevich and Appleby 1973, Ryan 1970). Plowing significantly reduced populations of *H. radicata* ca. 65%, but disking did not reduce the populations.

Plowing or disking did not affect the number or percentage of peppermint plants showing typical symptoms of Verticillium wilt, or the expression of wilt symptoms. It was necessary to assume that treatments were equally infested with Verticillium wilt prior to tillage because pretreatment evaluations of Verticillium wilt could not be made. This assumption proved to be incorrect because Verticillium wilt appeared to be clumped within experimental plots. Therefore, it is uncertain whether tillage had any effect on the spread of Verticillium wilt. However, the incidence of Verticillium wilt is generally assumed to increase in tilled peppermint. Therefore, peppermint should be flamed in the fall, prior to tillage, to reduce *V. dahliae* inoculum in infected plant debris.

Soil in the surface 0-5 cm from untilled treatments usually had higher levels of P and K, and lower levels of pH and Ca, than soil in 5-15 cm. Plowed treatments inverted and mixed the surface 0-15 cm of soil which resulted in more even distributions of nutrients throughout the 0-15 cm of soil. Plowed treatments generally had higher levels of P and K in the 5-15 cm of soil, and higher levels of pH and Ca in the surface 0-5 cm of soil. Disking 7.5-10 cm deep mixed the surface 7.5-10 cm of soil resulting in levels of pH, P, and K in 0-5 cm and 5-15 cm which were intermediate between plowed and untilled treatments. Differences between tillage treatments were not apparent when nutrients were already evenly distributed throughout the surface 0-15 cm of soil. The effects of changes in pH and distribution of nutrients on the nutrient uptake by peppermint plants was not determined in this study.

Density and height of peppermint plants was generally significantly lower in plowed treatments than in disked or untilled treatments. Peppermint plants in plowed treatments grew in discernible rows, and peppermint plant vigor and yield depended on the ability of these plants to produce lateral branches and fill-in over bare soil between rows. Peppermint plant density, height, and vigor in disked treatments were significantly lower in some test plots than in untilled treatments. Tilled treatments at location 1 had higher estimates of peppermint plant vigor than in untilled treatments, however, at location 2, tilled plots had lower estimates of peppermint plant vigor than in untilled treatments. These differences could be attributed to the influence of undefined biological factors and management practices on peppermint in untilled plots. Differences also might have occurred because spring tillage (location 2) was conducted after the peppermint began to grow in the spring which delayed plant growth. Fall tillage (location 1) generally results in earlier plant growth in the spring.

Plowed treatments had a significantly greater percentage (ca. 14%) of total rhizome dry weight at a 5-15 cm soil depth than disked or untilled treatments.

Peppermint hay and oil yields at location 1 appeared to be greater in plowed and disked plots than in untilled plots. This could be attributed to injury caused by *F. fumalis*, and competition from *S. vulgaris*, and *H. radicata* in untilled plots. Oil yield (ml/4.5 kg fresh hay) at location 4 was the only yield index in 1982 that was significantly different between tillage treatments. In this instance, the disked treatment had a significantly lower oil yield (ml) per unit fresh hay than in untilled treatments.

Oil samples from tillage treatments in 1982 were analyzed for their terpene contents to determine if tillage affected peppermint oil quality and maturity. Plowing or disking did not seem to affect oil quality compared to untilled treatments. Significantly higher levels of pulegone and slightly higher levels of menthofuran in plowed treatments indicated that plowing could delay the process of oil maturation. This result was most apparent at location 4 where the peppermint was plowed in the spring and flamed during mid-May.

Results of my study indicate that tillage, particularly plowing followed by disking, can significantly reduce the adult population of *F. fumalis*. Tillage has additional benefits in the production of peppermint. For example; 1) tillage can reduce the populations of some weed species, particularly *S. vulgaris* and *H. radicata*; 2) tillage can improve pH levels and the distribution of nutrients in soils that have been planted in peppermint for several years which could improve nutrient uptake by peppermint plants; 3) pest suppression and improved nutrient uptake could reduce the costs of production through the use of fewer pesticide applications and reduced rates of fertilizers; and 4) the use of tillage rather than pesticides can help delay the development of resistance in insects and weeds and reduce the unnecessary impact of pesticides on the environment and natural enemies. The influence of tillage on the spread of Verticillium wilt remains uncertain and growers should carefully consider the advantages and disadvantages of tillage prior to its use.

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APPENDICES

APPENDIX I

Table 1. Analyses of variance on the influence of tillage on total cumulative number of emerging *F. fumalis* adults at each location.

Location 1: Springfield

Source	df	SS	MS	F
Treatments	4	252.53	63.13	3.33*
No-till vs. Avg. Till	1	108.00	108.00	5.70*
Difference among Till	3	144.53	48.18	2.54
D vs. PD 1/	1	83.33	83.33	4.40*
DD vs. PDD 1/	1	48.13	48.13	2.54
D + PD vs. DD + PDD	1	13.07	13.07	0.69
Error	70	1326.14	18.94	
Total	74	1578.67		

Location 3: Crabtree

Source	df	SS	MS	F
Replication	2	69.56	34.78	
Treatment	2	337.56	168.78	10.26*
Rep X Trmt	4	65.78	16.44	
Total	8	472.89		

Location 4: Albany

Source	df	SS	MS	F
Replication	2	130.89	65.45	
Treatment	2	2714.89	1357.45	26.64**
Rep X Trmt	4	203.78	50.95	
Total	8	3049.56		

1/ Tillage treatments: single disk (D), double disk (DD), plow and single disk (PD), and plow and double disk (PDD).

* Significant difference at $p < 0.05$.
** Significant difference at $p < 0.01$.

Appendix I (cont.)

Table 2. Comparison of types of emergence cages used at location 1, during the summer of 1981. Springfield, OR.

	Cage Types				
	I		II		
Treatments	n	$\bar{x}$	n	$\bar{x}$	unpaired-t
C	5	8.30	10	9.00	0.18 N.S.
D	5	6.00	10	8.80	1.27 N.S.
DD	6	7.67	9	5.77	1.14 N.S.
PD	3	3.67	12	4.75	0.53 N.S.
PDD	6	4.00	9	4.00	0.00 N.S.
Treatments Combined	25	6.44	50	6.28	0.14 N.S.

Table 3. Analysis of variance for the effects of tillage on the proportion of total adult females to total adult males and females at each location.

Location 1: Springfield

Source	df	SS	MS	F
Treatments	4	0.163	0.041	0.519 N.S.
Error	70	5.502	0.079	
Total	74	5.665		

Location 3: Crabtree

Source	df	SS	MS	F
Replications	2	0.390	0.195	
Treatments	2	0.142	0.071	0.517 N.S.
Rep X Trmt	4	0.549	0.138	
Total	8	1.082		

Location: Albany

Source	df	SS	MS	F
Replications	2	0.159	0.080	
Treatments	2	0.014	0.007	0.077 N.S.
Rep X Trmt	4	0.363	0.091	
Total	8	0.536		

Appendix I (cont.)

Table 4. Relationships between *F. fumalis* prepupal or larval densities and the number of adults emerging from cages at locations 1, 3, and 4 during 1981 and 1982.

Location 1: Springfield

Treatment	n	Densities 1/ Prepupae $\bar{x} \pm$ S.E.	Adults $\bar{x} \pm$ S.E.	Proportion adults/ prepupae	r
C	15	89.1 ± 11.0	8.7 ± 1.7	0.09	0.49 NS
D	15	79.6 ± 10.2	7.9 ± 1.1	0.10	0.06 NS
DD	15	69.7 ± 7.6	6.5 ± 0.8	0.09	0.42 NS
PD	15	77.0 ± 8.9	4.5 ± 0.8	0.06	0.32 NS
PDD	15	68.9 ± 9.2	4.0 ± 0.9	0.06	-0.05 NS

Location 3: Crabtree

Treatment	n	Densities 1/ Larvae $\bar{x} \pm$ S.E.	Adults $\bar{x} \pm$ S.E.	Proportion adults/ larvae	r
C	15	36.1 ± 3.5	3.2 ± 0.7	0.09	-0.10 NS
DD	15	39.3 ± 4.2	1.8 ± 0.4	0.04	-0.01 NS
PDD	15	35.7 ± 4.6	0.2 ± 0.2	0.01	0.01 NS

Location 4: Albany

Treatment	n	Densities 1/ Larvae $\bar{x} \pm$ S.E.	Adults $\bar{x} \pm$ S.E.	Proportion adults/ larvae	r
C	9	67.8 ± 6.8	12.7 ± 2.1	0.19	0.48 NS
DD	9	50.7 ± 6.0	0.3 ± 0.2	0.01	0.35 NS
PDD	9	56.8 ± 8.2	0.7 ± 0.3	0.01	-0.21 NS

1/ Prepupal and larval densities were determined from soil samples taken prior to tillage operations and were adjusted to the same area (0.836 m^2) present on the inside of emergence cages.

Appendix II

Table 1. Means and standard deviations for density, biomass, and plant vigor of *Senecio vulgaris* made in experimental plots prior to tillage treatments on November 19, 1980 at location 1 and on March 27, 1981 at location 2.

Location 1: Treatment	Density[1/] #/1000 cm^2 $\bar{x} \pm$ S.D.	Biomass Dry Weight (g) $\bar{x} \pm$ S.D.	Plant Vigor[2/] % $\bar{x} \pm$ S.D.
C	22.6 ± 49.2	0.13 ± 0.18	18.9 ± 20.3
D	20.0 ± 30.6	0.18 ± 0.35	21.2 ± 30.3
DD	18.2 ± 24.4	0.19 ± 0.31	19.9 ± 29.8
PD	18.4 ± 30.4	0.18 ± 0.32	13.9 ± 17.9
PDD	11.9 ± 18.0	0.11 ± 0.16	13.7 ± 20.8
Location 2: Treatment	**Density #/1000 cm^2 $\bar{x} \pm$ S.D.**	**Biomass Dry weight (g) $\bar{x} \pm$ S.D.**	**Plant Vigor % $\bar{x} \pm$ S.D.**
C	17.9 ± 12.7	5.51 ± 1.93	59.0 ± 20.1
D	12.7 ± 8.4	4.36 ± 1.88	53.0 ± 23.2
DD	11.0 ± 10.8	2.44 ± 1.81	43.7 ± 29.7
PD	12.9 ± 11.8	4.14 ± 2.67	48.0 ± 27.0
PDD	13.9 ± 15.0	3.45 ± 1.56	42.0 ± 25.1

1/ Three 1000 cm^2 samples in each experimental plot were averaged and then an average of 15 experimental plots per "treatment" was taken.
2/ Average of 15 experimental plots per "treatment".

Appendix II (cont.)

Table 2. Analysis of variance of density, biomass, and plant vigor of *S. vulgaris* after tillage treatments at location 1 on April 12 and June 7, 1981.

Evaluation: Density 4/12/81

Source	df	SS	MS	F
Treatments	4	2469.0	617.2	4.78 **
C vs. Avg. Till	1	1380.7	1380.7	10.69 **
Diff. Among Till	3	1088.3	362.8	2.81 *
D vs. PD	1	764.1	764.1	5.92 *
DD vs. PDD	1	259.3	259.3	2.01 N.S.
D+PD vs. DD+PDD	1	64.9	64.9	0.51 N.S.
Error	70	9040.8	129.2	
Total	74	11509.8		

Evaluation: Dry Weight Biomass 4/12/81

Source	df	SS	MS	F
Treatments	4	99.81	24.95	8.29 **
C vs. Avg. Till	1	57.94	57.94	19.26 **
Diff. Among Till	3	41.87	13.96	4.64 **
D vs. PD	1	24.26	24.26	8.07 **
DD vs. PDD	1	17.42	17.42	5.79 *
D+PD vs. DD+PDD	1	0.19	0.19	0.06 N.S.
Error	70	210.61	3.01	
Total	74	310.42		

Evaluation: Plant Vigor 4/12/81

Source	df	SS	MS	F
Treatments	4	24103.1	6025.8	11.76 **
C vs. Avg. Till	1	10022.5	10022.5	19.56 **
Diff. Among Till	3	14080.6	4693.5	9.16 **
D vs. PD	1	7970.7	7970.7	15.55 **
DD vs. PDD	1	6077.6	6077.6	11.86 **
D+PD vs. DD+PDD	1	32.3	32.3	0.06 N.S.
Error	70	35878.8	512.6	
Total	74	59981.9		

Appendix II, Table 2 (cont.)

Evaluation: Plant Vigor 7/7/81

Source	df	SS	MS	F
Treatments	4	16551.3	4137.8	15.65 **
C vs. Avg. Till	1	6348.0	6348.0	24.02 **
Diff. Among Till	3	10203.3	3401.1	12.87 **
D vs. PD	1	6600.8	6600.8	24.98 **
DD vs. PDD	1	3520.8	3520.8	13.32 **
D+PD vs. DD+PDD	1	81.7	81.7	0.31 N.S.
Error	70	18503.3	264.3	
Total	74	35054.6		

* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.

Appendix II (cont.)

Table 3. Analysis of variance for density, biomass, and plant vigor of *S. vulgaris* after treatments at location 2 on June 21, 1981.

Evaluation: Density

Source	df	SS	MS	F
Replications	14	1323.3	94.5	
Treatments	4	2895.3	723.8	10.72 **
C vs. Avg. Till	1	1478.5	1478.5	21.89 **
Diff. Among Till	3	1416.8	472.3	6.99 **
D vs. PD	1	1165.5	1165.5	17.26 **
DD vs. PDD	1	168.1	168.1	2.49 N.S.
D+PD vs. DD+PDD	1	83.2	83.2	1.23 N.S.
Rep. x Trmt.	56	3782.1	67.5	
Total	74	8000.8		

Evaluation: Dry Weight Biomass

Source	df	SS	MS	F
Replications	14	459.34	32.81	
Treatments	4	144.25	36.06	2.31 N.S.
C vs. Avg. Till	1	44.88	44.88	2.88 N.S.
Diff. Among Till	3	99.34	33.16	2.12 N.S.
D vs. PD	1	78.70	78.70	5.05 *
DD vs. PDD	1	9.46	9.46	0.61 N.S.
D+PD vs. DD+PDD	1	11.18	11.18	0.72 N.S.
Rep. x Trmt.	56	873.47	15.60	
Total	74	1477.05		

Evaluation: Plant Vigor

Source	df	SS	MS	F
Replications	14	2628.00	187.71	
Treatments	4	5844.65	1461.16	23.08 **
C vs. Avg. Till	1	4961.33	4961.33	78.37 **
Diff. Among Till	3	883.33	294.44	4.65 **
D vs. PD	1	607.50	607.50	9.60 **
DD vs. PDD	1	140.83	140.83	2.22 N.S.
D+PD vs. DD+PDD	1	135.00	135.00	2.13 N.S.
Rep. x Trmt.	56	3545.35	63.31	
Total	74	12018.00		

* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.01$.

Appendix II (cont.)

Table 4. Analysis of variance for density and plant vigor of *S. vulgaris* at location 3 on July 6, 1982.

Evaluation: Density

Source	df	SS	MS	F
Replications	2	28382.9	14191.4	
Treatments	2	40870.9	20435.5	9.95 *
Rep. x Trmt.	4	8211.2	2052.8	
Total	8	77465.6		

Evaluation: Plant Vigor

Source	df	SS	MS	F
Replications	2	1442.9	721.5	
Treatments	2	286.9	143.5	1.09 N.S.
Rep. x Trmt.	4	525.8	131.4	
Total	8	2255.6		

Table 5. Analysis of variance for density and plant vigor of *S. vulgaris* at location 4 on July 1, 1982.

Evaluation: Density

Source	df	SS	MS	F
Replications	2	26422.9	13211.5	
Treatments	2	79590.9	39795.5	2.38 N.S.
Rep. x Trmt.	4	67506.4	16876.6	
Total	8	173520.2		

Evaluation: Plant Vigor

Source	df	SS	MS	F
Replications	2	738.89	369.45	
Treatments	2	1355.55	677.77	2.64 N.S.
Rep. x Trmt.	4	1027.78	256.95	
Total	8	3122.22		

* Significant at $p \leq 0.05$.

Appendix II (cont.)

Table 6. Pearson product-moment correlation coefficients of density, biomass, and plant vigor of *S. vulgaris* stands for tillage treatments at four locations in 1980-82.

Location 1		Density (#/1000 cm^2)					Dry Weight (g/1000 cm^2)				
	Date	C	D	DD	PD	PDD	C	D	DD	PD	PDD
Dry Weight (g/1000 cm^2)	11/18/80	.84	.75	.53	.90	.79					
	4/12/81	.61	.81	.75	.99	.14					
Plant Vigor (%)	11/18/80	.58	.80	.72	.66	.79	.64	.81	.84	.56	.80
	4/12/81	.61	.92	.85	.07	.49	.70	.87	.92	.06	-.02

Location 2		Density (#/1000 cm^2)					Dry Weight (g/1000 cm^2)				
	Date	C	D	DD	PD	PDD	C	D	DD	PD	PDD
Dry Weight (g/1000 cm^2)	3/23/81	.25	.20	.83	-.01	.40					
	6/21/81	.81	.87	.65	.82	.72					
Plant Vigor (%)	3/23/81	.77	.91	.85	.87	.82	.43	.37	.71	.32	.17
	6/21/81	.65	.62	.33	.27	-.29	.81	.59	.52	.36	.12

Location 3: 7/6/82	Location 3 Density (#/3 m^2)			Location 4 Density (#/3 m^2)		
Location 4: 7/1/82	C	DD	PDD	C	DD	PDD
Plant Vigor (%)	.61	.39	.47	.73	.55	.59

Appendix II (cont.)

Table 7. Analysis of variance for proportion *H. radicata* plants in plots on April 12, 1981 to pretreatment evaluations on November 18, 1980 at location 1.

Source	df	SS	MS	F
Replication	24	9.139	0.381	
Treatment	4	8.750	2.188	8.30 **
Rep. X Trmt.	96	25.307	0.264	
Total	124	43.197		

** Significant at $p<0.01$.

APPENDIX III

Table 1. Analysis of variance for the effects of tillage on the total number of patches of Verticillium wilt at locations 3 and 4 on August 3, 1982.

Location 3: Crabtree

Source	df	SS	MS	F
Replication	2	18490.89	9245.44	
Treatment	2	6828.22	3414.11	2.44 N.S.
Rep X Trmt	4	5608.44	1402.11	
Total	8	30927.56		

Location 4: Albany

Source	df	SS	MS	F
Replication	2	776.22	388.11	
Treatment	2	102.89	51.45	0.55 N.S.
Rep X Trmt	4	373.11	93.28	
Total	8	1252.22		

Table 2. Analysis of variance for the effects of tillage on the ratio of numbers of patches within each symptom class to the total number of patches within two types of ratings at locations 3 and 4.

LOCATION 3: Crabtree
Rating: Most prevalent or average symptom
Symptom Class: Mild

Source	df	SS	MS	F
Replication	2	0.1077	0.0539	
Treatment	2	0.1834	0.0917	2.76 N.S.
Rep X Trmt	4	0.1331	0.0331	
Total	8	0.4242		

Symptom Class: Moderate

Source	df	SS	MS	F
Replication	2	0.0169	0.0085	
Treatment	2	0.0550	0.0275	1.87 N.S.
Rep X Trmt	4	0.0588	0.0147	
Total	8	0.1307		

Appendix III, Table 2 (cont.)

Symptom Class: Severe

Source	df	SS	MS	F
Replication	2	0.0424	0.0212	
Treatment	2	0.0376	0.0188	2.68 N.S.
Rep X Trmt	4	0.0280	0.0070	
Total	8	0.1080		

Rating: Most severe symptoms
Symptom Class: Mild

Source	df	SS	MS	F
Replication	2	0.0742	0.0371	
Treatment	2	0.0719	0.0360	0.71 N.S.
Rep X Trmt	4	0.2042	0.0510	
Total	8	0.3503		

Symptom Class: Moderate

Source	df	SS	MS	F
Replication	2	0.0292	0.0146	
Treatment	2	0.0113	0.0056	1.12 N.S.
Rep X Trmt	4	0.2020	0.0050	
Total	8	0.0606		

Symptom Class: Severe

Source	df	SS	MS	F
Replication	2	0.1280	0.0640	
Treatment	2	0.1305	0.0653	2.56 N.S.
Rep X Trmt	4	0.1021	0.0255	
Total	8	0.3606		

LOCATION 4: Albany
Rating: Most prevalent or average symptom
Symptom Class: Mild

Source	df	SS	MS	F
Replication	2	0.0483	0.0242	
Treatment	2	0.0148	0.0074	0.12 N.S.
Rep X Trmt	4	0.2522	0.0631	
Total	8	0.3153		

Appendix III, Table 2 (cont.)

Symptom Class: Moderate

Source	df	SS	MS	F
Replication	2	0.0047	0.0024	
Treatment	2	0.0270	0.0135	0.31 N.S.
Rep X Trmt	4	0.1754	0.0438	
Total	8	0.2072		

Symptom Class: Severe

Source	df	SS	MS	F
Replication	2	0.0285	0.0142	
Treatment	2	0.0041	0.0020	0.83 N.S.
Rep X Trmt	4	0.0098	0.0025	
Total	8	0.0424		

Rating: Most severe symptoms
Symptom Class: Mild

Source	df	SS	MS	F
Replication	2	0.0378	0.0189	
Treatment	2	0.0067	0.0033	0.05 N.S.
Rep X Trmt	4	0.2518	0.0629	
Total	8	0.2962		

Symptom Class: Moderate

Source	df	SS	MS	F
Replication	2	0.0267	0.0133	
Treatment	2	0.0345	0.0172	1.49 N.S.
Rep X Trmt	4	0.0464	0.0116	
Total	8	0.1075		

Symptom Class: Severe

Source	df	SS	MS	F
Replication	2	0.0923	0.0461	
Treatment	2	0.0695	0.0348	1.60 N.S.
Rep X Trmt	4	0.0869	0.0217	
Total	8	0.2487		

Appendix III (cont.)

Table 3. Analysis of variance for the effects of tillage on the total number of stems/200 showing symptoms of Verticillium wilt, and on the ratio of each symptom class to the total number of stems expressing symptoms at location 5 on August 1, 1982.

Total number of infected stems / 200

Source	df	SS	MS	F
Replication	3	70.67	23.56	
Treatment	2	46.50	23.25	0.36 N.S.
Rep X Trmt	6	382.83	63.81	
Total	8	500.00		

Ratios:
Symptom Class: Mild

Source	df	SS	MS	F
Replication	3	0.2877	0.0960	
Treatment	2	0.1158	0.0579	1.68 N.S.
Rep X Trmt	6	0.2064	0.0344	
Total	8	0.6099		

Symptom Class: Moderate

Source	df	SS	MS	F
Replication	3	0.2260	0.0753	
Treatment	2	0.1044	0.0522	1.25 N.S.
Rep X Trmt	6	0.2508	0.0418	
Total	8	0.5812		

Symptom Class: Severe

Source	df	SS	MS	F
Replication	3	0.0008	0.0003	
Treatment	2	0.0007	0.0004	0.11 N.S.
Rep X Trmt	6	0.0191	0.0032	
Total	8	0.0206		

APPENDIX IV

Table 1. Results of preliminary soil chemical analyses of soil samples taken at location 1 on April 14, 1981.

Sampling Depth (0-5 cm)

Treatment	pH	P ppm	K ppm	Ca (meq./100 g)	Mg	B ppm
C	4.9	86	351	6.5	2.3	0.91
D	4.9	98	382	6.7	2.4	0.96
DD	5.0	87	312	7.1	2.5	0.94
PD	5.3	41	215	9.3	2.7	0.91
PDD	5.2	51	226	9.1	2.7	0.91

Sampling Depth (5-15 cm)

Treatment	pH	P ppm	K ppm	Ca (meq./100 g)	Mg	B ppm
C	5.3	23	137	10.6	2.7	1.14
D	5.3	22	172	10.6	2.7	0.96
DD	5.3	28	148	10.5	2.7	0.99
PD	5.2	51	211	9.4	2.7	1.04
PDD	5.3	34	156	10.3	2.7	0.99

Appendix IV (cont.)

Table 2. Analyses of variance for selected chemical tests of soil samples taken from location 3 at two depths on April 20, 1982.

Sampling Depth: 0-5 cm

Soil Test: Soil Acidity (pH)

Source	df	SS	MS	F
Replication	2	0.0022	0.0011	
Treatment	2	0.0956	0.0478	10.75 *
Rep. X Trmt.	4	0.0178	0.0044	
Total	8	0.1156		

Soil Test: Phosphorus (ppm)

Source	df	SS	MS	F
Replication	2	90.9	45.4	
Treatment	2	8294.2	4147.1	14.92 *
Rep. X Trmt.	4	1111.8	277.9	
Total	8	9496.9		

Soil Test: Potassium (ppm)

Source	df	SS	MS	F
Replication	2	16920.9	8460.4	
Treatment	2	59590.9	29795.4	5.61 NS
Rep. X Trmt.	4	21261.8	5315.4	
Total	8	97773.6		

Soil Test: Calcium (meq./100 g)

Source	df	SS	MS	F
Replication	2	0.74	0.37	
Treatment	2	4.82	2.41	8.46 *
Rep. X Trmt.	4	1.14	0.29	
Total	8	6.70		

Soil Test: Magnesium (meq./100 g)

Source	df	SS	MS	F
Replication	2	0.127	0.063	
Treatment	2	0.047	0.023	1.40 NS
Rep. X Trmt.	4	0.067	0.017	
Total	8	0.240		

Appendix IV, Table 2 (cont.)

Sampling Depth: 5-15 cm
Soil Test: Soil Acidity (pH)

Source	df	SS	MS	F
Replication	2	0.0467	0.0233	
Treatment	2	0.1067	0.0533	32.00 **
Rep. X Trmt.	4	0.0067	0.0017	
Total	8	0.1600		

Soil Test: Phosphorus (ppm)

Source	df	SS	MS	F
Replication	2	84.2	42.1	
Treatment	2	1093.6	546.8	15.00 *
Rep. X Trmt.	4	145.8	36.4	
Total	8	1323.6		

Soil Test: Potassium (ppm)

Source	df	SS	MS	F
Replication	2	1358.0	679.0	
Treatment	2	4220.7	2110.3	1.29 NS
Rep. X Trmt.	4	6557.3	1639.3	
Total	8	12136.0		

Soil Test: Calcium (meq./100 g)

Source	df	SS	MS	F
Replication	2	0.429	0.214	
Treatment	2	3.229	1.614	2.47 NS
Rep. X Trmt.	4	2.611	0.653	
Total	8	6.269		

Soil Test: Magnesium (meq./100 g)

Source	df	SS	MS	F
Replication	2	0.029	0.014	
Treatment	2	0.009	0.004	0.10 NS
Rep. X Trmt.	4	0.171	0.043	
Total	8	0.209		

* Significantly different at $p<0.05$.
** Significantly different at $p<0.01$.

Appendix IV (cont.)

Table 3. Analyses of variance for selected chemical tests of soil samples taken from location 4 at two depths on April 19, 1982.

Sampling Depth: 0-5 cm

Soil Test: Soil Acidity (pH)

Source	df	SS	MS	F
Replication	2	0.0156	0.0078	
Treatment	2	0.0688	0.0344	7.73 *
Rep. X Trmt.	4	0.0178	0.0045	
Total	8	0.1021		

Soil Test: Phosphorus (ppm)

Source	df	SS	MS	F
Replication	2	1.5	0.8	
Treatment	2	149.5	74.8	3.54 NS
Rep. X Trmt.	4	84.5	21.1	
Total	8	235.6		

Soil Test: Potassium (ppm)

Source	df	SS	MS	F
Replication	2	51895.0	25947.5	
Treatment	2	113909.0	56954.5	21.16 **
Rep. X Trmt.	4	10767.0	2691.8	
Total	8	176571.0		

Soil Test: Calcium (meq./100 g)

Source	df	SS	MS	F
Replication	2	1.140	0.570	
Treatment	2	0.745	0.373	13.20 *
Rep. X Trmt.	4	0.113	0.028	
Total	8	1.998		

Soil Test: Magnesium (meq./100 g)

Source	df	SS	MS	F
Replication	2	0.109	0.054	
Treatment	2	0.002	0.001	0.06 NS
Rep. X Trmt.	4	0.078	0.019	
Total	8	0.189		

Appendix IV, Table 3 (cont.)

Sampling Depth: 5-15 cm
Soil Test: Soil Acidity (pH)

Source	df	SS	MS	F
Replication	2	0.0089	0.0044	
Treatment	2	0.0156	0.0078	1.00 NS
Rep. X Trmt.	4	0.0311	0.0078	
Total	8	0.0556		

Soil Test: Phosphorus (ppm)

Source	df	SS	MS	F
Replication	2	113.6	56.8	
Treatment	2	110.9	55.5	1.04 NS
Rep. X Trmt.	4	212.4	53.1	
Total	8	436.9		

Soil Test: Potassium (ppm)

Source	df	SS	MS	F
Replication	2	63615.8	31807.9	
Treatment	2	18908.8	9454.4	3.05 NS
Rep. X Trmt.	4	12402.2	3100.6	
Total	8	94926.8		

Soil Test: Calcium (meq./100 g)

Source	df	SS	MS	F
Replication	2	0.436	0.218	
Treatment	2	1.216	0.608	0.46 NS
Rep. X Trmt.	4	5.257	1.314	
Total	8	6.909		

Soil Test: Magnesium (meq./100 g)

Source	df	SS	MS	F
Replication	2	0.096	0.048	
Treatment	2	0.042	0.021	0.39 NS
Rep. X Trmt.	4	0.218	0.054	
Total	8	0.356		

* Significantly different at $p<0.05$.
** Significantly different at $p<0.01$.

Appendix IV (cont.)

Table 4. Analyses of variance for soil chemical tests of soil samples taken from location 5 at two depths on April 21, 1982.

Sampling Depth: 0-5 cm

Soil Test: Soil Acidity (pH)

Source	df	SS	MS	F
Replication	2	0.1267	0.0633	
Treatment	2	0.2867	0.1433	8.60 *
Rep. X Trmt.	4	0.0667	0.0167	
Total	8	0.480		

Soil Test: Phosphorus (ppm)

Source	df	SS	MS	F
Replication	2	104.2	52.1	
Treatment	2	269.6	134.8	4.53 NS
Rep. X Trmt.	4	119.1	29.8	
Total	8	492.9		

Soil Test: Potassium (ppm)

Source	df	SS	MS	F
Replication	2	1044.7	522.3	
Treatment	2	119512.7	59756.3	611.84 **
Rep. X Trmt.	4	390.7	97.7	
Total	8	120948.0		

Soil Test: Calcium (meq./100 g)

Source	df	SS	MS	F
Replication	2	2.382	1.191	
Treatment	2	9.269	4.634	9.63 *
Rep. X Trmt.	4	1.924	0.481	
Total	8	13.576		

Soil Test: Magnesium (meq./100 g)

Source	df	SS	MS	F
Replication	2	0.287	0.143	
Treatment	2	0.127	0.063	2.38 NS
Rep. X Trmt.	4	0.107	0.027	
Total	8	0.520		

Appendix IV, Table 4 (cont.)

Sampling Depth: 5-15 cm

Soil Test: Soil Acidity (pH)

Source	df	SS	MS	F
Replication	2	0.0267	0.0133	
Treatment	2	0.0867	0.0433	6.50 NS
Rep. X Trmt.	4	0.0267	0.0067	
Total	8	0.1400		

Soil Test: Phosphorus (ppm)

Source	df	SS	MS	F
Replication	2	52.7	26.3	
Treatment	2	148.7	74.3	0.87 NS
Rep. X Trmt.	4	340.7	85.2	
Total	8	542.0		

Soil Test: Potassium (ppm)

Source	df	SS	MS	F
Replication	2	677.5	338.8	
Treatment	2	6744.9	3372.4	17.79 *
Rep. X Trmt.	4	758.4	189.6	
Total	8	8180.9		

Soil Test: Calcium (meq./100 g)

Source	df	SS	MS	F
Replication	2	2.696	1.348	
Treatment	2	0.996	0.498	1.19 NS
Rep. X Trmt.	4	1.678	0.419	
Total	8	5.369		

Soil Test: Magnesium (meq./100 g)

Source	df	SS	MS	F
Replication	2	0.260	0.130	
Treatment	2	0.047	0.023	1.75 NS
Rep. X Trmt.	4	0.053	0.013	
Total	8	0.360		

* Significantly different at $p<0.05$.

** Significantly different at $p<0.01$.

APPENDIX V

Table 1. Analyses of variance for the effects of tillage on peppermint stem density at locations 1, 2, 3, and 4.

Location 1: April 17, 1981

Source	df	SS	MS	F
Treatment	4	7343.7	1835.9	6.03 **
Error	45	13704.1	304.5	
Total	49	21047.8		

Location 2: June 21, 1981

Source	df	SS	MS	F
Treatment	4	16566.2	4141.56	11.75 **
Error	45	15864.3	352.5	
Totol	49	32430.5		

Location 3: July 15. 1982

Source	df	SS	MS	F
Replication	2	401.7	200.9	
Treatment	2	8160.7	4080.4	48.60 **
Rep. X Trmt.	4	335.8	83.9	
Total	8	8898.2		

Location 4: July 15, 1982

Source	df	SS	MS	F
Replication	2	1413.4	706.7	
Treatment	2	11395.1	5697.5	7.07 *
Rep. X Trmt.	4	3223.6	805.9	
Total	8	16032.1		

* Significant at $p<0.05$.
** Significant at $p<0.01$.

Appendix V (cont.)

Table 2. Analyses of variance for the effects of tillage on peppermint stem height at locations 2, 3, and 4.

Location 2: June 21, 1981

Source	df	SS	MS	F
Treatment	4	5689.9	1422.5	13.29 **
Error	45	4816.5	107.0	
Total	49	10506.3		

Location 3: July 15, 1982

Source	df	SS	MS	F
Replication	2	2600.7	1300.4	
Treatment	2	7998.4	3999.2	9.50 *
Rep. X Trmt.	4	1684.3	421.7	
Total	8	12283.4		

Location 4: July 15, 1982

Source	df	SS	MS	F
Replication	2	111.7	55.9	
Treatment	2	1030.2	515.1	0.75 NS
Rep. X Trmt.	4	2737.3	684.3	
Total	8	3879.2		

* Significant at $p<0.05$.
** Significant at $p<0.01$.
NS Not significant.

Appendix V (cont.)

Table 3. Analyses of variance for the effects of tillage on percentages of peppermint plant vigor at locations 1 and 2.

Location 1: July 7, 1981

Source	df	SS	MS	F
Treatment	4	7478.5	1869.6	7.13 **
Error	70	18350.0	262.1	
Total	74	25828.5		

Location 2: June 21, 1981

Source	df	SS	MS	F
Replication	14	3672.0	262.3	
Treatment	4	26698.6	6674.7	57.58 **
Rep. X Trmt.	56	6491.4	115.9	
Total	74	36862.0		

** Significant at p<0.01.

Table 4. Analyses of variance for the effects of tillage on rhizome dry weight biomass (g/1000 cm^2) at 0-5 cm and 5-15 cm, and on the ratio (x100) of 5-15 cm to 0-15 cm rhizome dry weight at locations 3 and 4 in October 1982.

Location 3: 0-5 cm

Source	df	SS	MS	F
Replication	2	21.13	10.56	
Treatment	2	121.24	60.62	17.35 *
Rep. X Trmt.	4	13.97	3.49	
Total	8	156.34		

Location 3: 5-15 cm

Source	df	SS	MS	F
Replication	2	0.01	0.00	
Treatment	2	9.10	4.55	90.83 **
Rep. X Trmt.	4	0.20	0.05	
Total	8	9.31		

Appendix V, Table 4 (cont.)

Location 3: 5-15 cm/0-15 cm

Source	df	SS	MS	F
Replication	2	19.67	9.84	
Treatment	2	241.86	120.93	36.87 **
Rep. X Trmt.	4	13.12	3.28	
Total	8	274.65		

Location 4: 0-5 cm

Source	df	SS	MS	F
Replication	2	95.05	47.53	
Treatment	2	14.52	7.26	1.01 NS
Rep. X Trmt.	4	28.81	7.20	
Total	8	138.38		

Location 4: 5-15 cm

Source	df	SS	MS	F
Replication	2	0.96	0.48	
Treatment	2	17.21	8.61	47.76 **
Rep. X Trmt.	4	0.72	0.18	
Total	8	18.89		

Location 4: 5-15 cm/0-15 cm

Source	df	SS	MS	F
Replication	2	14.98	7.49	
Treatment	2	233.35	116.68	25.74 **
Rep. X Trmt.	4	18.13	4.53	
Total	8	266.47		

* Significant at $p<0.05$.
** Significant at $p<0.01$.
NS Not significant.

Appendix V (cont.)

Table 5. Analyses of variance for the effects of tillage on peppermint yields at locations 3 (August 7) and 4 (August 10) in 1982.

Location 3: Yield of fresh hay (kg/15 m^2)

Source	df	SS	MS	F
Replication	2	48.18	24.09	
Treatment	2	46.81	23.41	3.87 NS
Rep. X Trmt.	4	24.19	6.05	
Total	8	119.18		

Location 3: Yield of oil (ml/4.5 kg fresh hay)

Source	df	SS	MS	F
Replication	2	34.05	17.25	
Treatment	2	6.00	3.00	0.39 NS
Rep. X Trmt.	4	31.09	7.77	
Total	8	71.14		

Location 3: Yield of oil (ml/15 m^2)

Source	df	SS	MS	F
Replication	2	75.14	37.57	
Treatment	2	93.41	46.71	1.63 NS
Rep. X Trmt.	4	114.80	28.70	
Total	8	283.35		

Location 4: Yield of fresh hay (kg/ 15 m^2)

Source	df	SS	MS	F
Replication	2	17.09	8.55	
Treatment	2	28.90	14.45	2.56 NS
Rep. X Trmt.	4	22.61	5.65	
Total	8	68.61		

Location 4: Yield of oil (ml/4.5 kg fresh hay)

Source	df	SS	MS	F
Replication	2	62.66	31.33	
Treatment	2	118.65	59.34	7.59 *
Rep. X Trmt.	4	31.29	7.82	
Total	8	212.60		

Appendix V, Table 5 (cont.)

Location 4: Yield of oil (ml/15 m^2 fresh hay)

Source	df	SS	MS	F
Replication	2	66.30	33.15	
Treatment	2	243.33	121.62	2.77 NS
Rep. X Trmt.	4	175.92	43.98	
Total	8	485.55		

* Significant at $p<0.05$.
NS Not significant.

Table 6. Summary of peppermint yields within tillage treatments at locations 3 and 4 in 1982.

Location 3: Black Mitcham Peppermint (harvested August 7)
Fall tillage: tilled on November 13, 1981

	Yield		
Treatment	Fresh Hay (kg/3 m^2)	Oil (ml/4.5 kg hay)	Oil (ml/15 m^2)
C	6.98	11.80	18.27
DD	6.11	11.46	15.85
PDD	5.94	12.12	16.17

Location 4: Todd's Mitcham Peppermint (harvested August 10)
Spring tillage: tilled on February 8, 1982

	Yield		
Treatment	Fresh Hay (kg/3 m^2)	Oil (ml/4.5 kg hay)	Oil (ml/3 m^2)
C	7.30	11.16	18.09
DD	7.92	8.20	14.22
PDD	7.07	9.88	14.67

Appendix V (cont.)

Table 7. Analyses of variance for the effects of tillage on selected terpene components (% of total terpenes) from peppermint oil samples at location 3.

Limonene

Source	df	SS	MS	F
Replication	2	0.067	0.033	
Treatment	2	0.010	0.005	0.13 NS
Rep. X Trmt.	4	0.156	0.039	
Total	8	0.233		

1-8 Cineole

Source	df	SS	MS	F
Replication	2	0.133	0.067	
Treatment	2	0.558	0.279	1.24 NS
Rep. X Trmt.	4	0.898	0.224	
Total	8	1.589		

Menthone

Source	df	SS	MS	F
Replication	2	11.680	5.840	
Treatment	2	13.311	6.656	1.33 NS
Rep. X Trmt.	4	20.077	5.019	
Total	8	45.069		

Menthofuran

Source	df	SS	MS	F
Replication	2	0.317	0.158	
Treatment	2	0.204	0.102	6.17 NS
Rep. X Trmt.	4	0.067	0.017	
Total	8	0.586		

Appendix V, Table 7 (cont.)

Menthyl Acetate

Source	df	SS	MS	F
Replication	2	3.131	1.566	
Treatment	2	0.006	0.003	0.01 NS
Rep. X Trmt.	4	2.038	0.509	
Total	8	5.175		

Neomenthol

Source	df	SS	MS	F
Replication	2	0.361	0.181	
Treatment	2	0.125	0.062	0.99 NS
Rep. X Trmt.	4	0.252	0.063	
Total	8	0.737		

Menthol

Source	df	SS	MS	F
Replication	2	46.448	23.224	
Treatment	2	20.561	10.281	1.00 NS
Rep. X Trmt.	4	41.187	10.297	
Total	8	108.197		

Pulegone

Source	df	SS	MS	F
Replication	2	0.203	0.102	
Treatment	2	0.001	0.001	0.02 NS
Rep. X Trmt.	4	0.123	0.031	
Total	8	0.328		

NS Not significant at $p<0.05$.

Appendix V (cont.)

Table 8. Analyses of variance for the effects of tillage on selected terpene components (% of total terpenes) from oil samples at location 4.

Limonene

Source	df	SS	MS	F
Replication	2	0.160	0.080	
Treatment	2	0.032	0.016	0.39 NS
Rep. X Trmt.	4	0.163	0.041	
Total	8	0.354		

1-8 Cineole

Source	df	SS	MS	F
Replication	2	2.142	1.071	
Treatment	2	1.285	0.643	0.42 NS
Rep. X Trmt.	4	6.091	1.523	
Total	8	9.518		

Menthone

Source	df	SS	MS	F
Replication	2	2.142	1.071	
Treatment	2	0.388	0.194	0.83 NS
Rep. X Trmt.	4	0.943	0.234	
Total	8	3.464		

Menthofuran

Source	df	SS	MS	F
Replication	2	0.754	0.377	
Treatment	2	0.528	0.264	4.59 NS
Rep. X Trmt.	4	0.230	0.058	
Total	8	1.512		

Appendix V, Table 8 (cont.)

Menthyl Acetate

Source	df	SS	MS	F
Replication	2	1.587	0.794	
Treatment	2	0.331	0.165	0.24 NS
Rep. X Trmt.	4	2.749	0.687	
Total	8	4.667		

Neomenthol

Source	df	SS	MS	F
Replication	2	0.036	0.018	
Treatment	2	0.008	0.004	0.09 NS
Rep. X Trmt.	4	0.180	0.045	
Total	8	0.224		

Menthol

Source	df	SS	MS	F
Replication	2	7.801	3.901	
Treatment	2	3.392	1.696	0.83 NS
Rep. X Trmt.	4	8.202	2.051	
Total	8	19.395		

Pulegone

Source	df	SS	MS	F
Replication	2	0.006	0.003	
Treatment	2	0.199	0.010	35.82 **
Rep. X Trmt.	4	0.011	0.003	
Total	8	0.216		

** Significant at p<0.01.
NS Not significant at p<0.05.