AN EXPLORATION OF COVER CROPS FOR VEGETABLE PRODUCTION SYSTEMS IN TROPICAL SITUATIONS

DISSERTATION

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By

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ABSTRACT

Little research has been done on spring-sown cover crops for vegetable production in the northern temperate and tropical regions. Results obtained from studying spring-sown cover crops can be extrapolated to tropical situations as in both cases the cover crops have a limited period (1½ to 2 months) to accumulate above-ground biomass prior to being killed for mulch. Cover crops suppress weeds through competition, physical suppression, and production of allelochemicals, and primary crops may be equally affected. There is a need to research cover crops for specific regions and crops.

Pure and biculture stands of rye (*Secale cereale* L.) and field pea (*Pisum sativum* L.) were established and killed for mulch by mowing in spring 1996, and undercutting in 1997 and 1998. Their effect on weed and tomato (*Lycopersicon esculentum* Mill.) growth were compared to a weedy check, a tilled and un-weeded check, and a tilled, conventionally weeded check. Activated charcoal was buried 1 cm deep in rye, pea, and weeded control plots to test its potential in trapping allelochemicals, and to determine if the cover crops produced any growth inhibiting compounds. Four tropical species, siratro (*Macroptilium atropurpureum*), lablab bean (*Lablab purpureus*), velvet bean (*Mucuna pruriens*), and soybean (*Glycine max*) were tested in greenhouse studies for their weed

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control potential and effect on tomato growth and yield. Weeds were suppressed in treatments with higher rye ratios and high cover crop biomass. Yields of tomato in the bicultures with 1:1 and 1:3 rye to pea ratios when undercut in 1997 were as high as 50 MT. ha^{-1}. These bicultures also suppressed weeds before mowing or undercutting by as much as 90% compared to the weedy check and yielded more than 4 MT. ha^{-1} of above-ground biomass. Extracts from the activated charcoal buried in rye and pea plots suppressed lettuce seed germination at the highest concentration compared to those from the weeded check and fresh activated charcoal. Siratro and soybean accumulated above-ground biomass faster than lablab and velvet bean, significantly suppressing weeds both before and after kill. Tomato fruit yields in siratro and soybean mulches were higher than those from tomato plants grown in lablab and velvet bean mulches.

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To my family.

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PUBLICATIONS

Research Publication

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FIELD OF STUDY

Major Field: Horticulture

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CHAPTER 1

INTRODUCTION

OVERVIEW

Agriculture in developed countries has for decades been heavily mechanized with large applications of agricultural chemicals. Despite the large amounts of crops harvested, there has been rising concern over the effect of this form of agriculture on the quality and sustainability of soil, water, and air environments. Out of these concerns also arise questions about detrimental effects of some of these practices on the well-being of the flora and fauna of the earth. In developing countries including Uganda, most crops are still produced with very few agricultural chemicals. Farm mechanization is also limited with most farmers in the villages using animal traction and hand hoes for cultivation, both of which are usually labor intensive. In addition, continuous tillage in many cases has led to deterioration of soil quality and sustainability of farm operations, and soil erosion is prevalent in hilly areas. These and others problems led scientists, environmentalists, and progressive farmers to rethink the concept of sustainable agriculture.

Sustainable agriculture has been defined by many authors in essentially the same manner. Humphreys (1994) defines it as " the use of farming practices and systems which maintain or enhance the economic viability of agricultural production, the natural resource base, and other ecosystems which are influenced by agricultural activities". This means resources have to be managed in such a way as to satisfy current human needs while at the same time maintaining or improving environmental quality and conserving natural resources. Agriculture should maintain as much as possible the natural state of the environment while producing at economically feasible levels to satisfy the needs of the human race. This means that in some cases increasing off-farm input may be the only way to maintain sustainability, while in others it may be possible to do so with low-input, organic or alternative forms of agriculture (Lal et al., 1991). Farmers in developed countries use considerable off-farm, fossil-fuel based inputs to maintain high levels of production, but the trend now is turning to production methods with reduced or no application of these inputs. In developing countries with limited use of fossil-fuel based inputs, the goal should be to maximize the use of organic and farm based inputs and practices to improve levels of production and maintain environmental quality and productivity.

The short-term objective of sustainable agriculture is to increase or maintain profitable agricultural production levels. The long-term objectives are more encompassing and include better land use, reduction of soil erosion, maintenance or improvement of soil fertility and soil organic matter, reduction of water pollution, and reduced use of nonrenewable natural resources (Lal et al., 1991). Reduced

tillage, no-till, and organic farming methods are being promoted as some of the ways to achieve these goals, and one of the tools for this purpose is the use of cover crops in agriculture. On large-scale farms cover crops can be effective in reducing soil erosion besides contributing to developing sustainable systems for soil fertility management. On intensely cultivated tropical farms, cover crops can play an important role in improving and re-cycling soil fertility. In an 8-year study comparing conventional to organic and low-input farming practices, Clark et al. (1998) reported small but significant increases in soil organic carbon, soluble P, and exchangeable K. The low-input system also seemed to store excess N better than the conventional system.

Cover crops are legumes, mustards, cereals or grasses, or mixtures of these species grown to control soil erosion, improve soil structure and fertility, serve as sinks for plant nutrients, suppress weeds, and control some insect pests and pathogens (Abdul-Baki and Teasdale, 1993; Barnes and Putnam, 1983; Creamer et al., 1996a; Hartwig, 1988; Ristaino et al., 1997). Thus they contribute to the sustainability of agriculture, preservation of soil resources, and maintenance of environmental quality. Cover crop species used in the northern temperate countries include rye (*Secale cereale* L.), clover (*Trifolium* sp.), vetch (*Vicia* sp.), wheat (*Triticum* sp.), and alfalfa (*Medicago sativa* L.) (Abdul-Baki and Teasdale, 1993; Barnes and Putnam, 1983; Creamer et al., 1996a; Hartwig, 1988; Ristaino et al., 1997). In the tropics cover crops include legumes such as calopo (*Calopogonium mucunoides* L.), centro (*Centrosema pubescens* L.), tick clovers (*Desmodium* sp.), soybean (*Glycine max* L.), dolichos (*Lablab purpureus* L.), siratro

(*Macroptilium atropurpureum* L.), and velvet bean (*Mucuna sp.*) (Skerman et al., 1988). Many of these are used as forages for livestock as well. Grasses include signal grass (*Brachiaria* sp.), sorghum (*Sorghum* sp.), and panicum (*Panicum* sp.). Cover crops can be used as living or killed mulches. Living mulches should be low growing with a dense, smothering ground cover to suppress weeds while minimizing competition with other crops. Killed cover crops can have a tall growing habit because they are killed before other crops are established, but they should accumulate as much biomass as possible prior to being killed. Before cover crops can be recommended to farmers, their attributes have to be studied in the environments of proposed applications and use so that both the positive and negative characteristics are documented and the best choices made. Cover crops consume soil water and nutrients before they are killed or before other crops are established, so how this affects the subsequent crops must be assessed before any recommendations are given to farmers.

COVER CROPS AND WEED CONTROL

Vegetable production in developing countries including Uganda is primarily by small-scale farmers with low crop yields. This is because of limited access to land, labor, agricultural chemicals, information on how to deal with changing production conditions and market demands, and due to pests, diseases and declining soil fertility. Average yield of tomatoes (*Lycopersicon esculentum* Mill.) in Uganda, for example, is 5 t/ha in farmers' fields, but 25 t/ha in research trials. On

reach up to 8C (Wilkins and Bellinder, 1996). Maximum soil temperatures are generally more affected than the minimums, and this would be an advantage in tropical climates.

ALLELOPATHY

Allelopathy is the direct or indirect harmful effect of one plant's chemicals on another plant (Putnam, 1988). In nature it is a mechanism used by some plants to keep others out of their space and protect their resources, and this is achieved in various ways (Putnam, 1988). Plant growth-inhibiting compounds can be released into the soil thus preventing the establishment of other plants in the vicinity. Some allelochemicals act by slowing down or curtailing photosynthesis, while others can change the amount of chlorophyll in neighboring plants (Alsaadawi, 1992). The affected plants cannot make enough food and subsequently die. Allelochemicals can be released from plants by volatilization as gases through pores in the leaves, leaching from leaves that fall off the plants and decompose, or exudation into the soil from roots. Allelochemicals produced by plants are very diverse, ranging from simple hydrocarbons to complex polycyclic aromatics (Putnam, 1988). Practically all classes of secondary compounds have one or more members with allelochemical activity identified, and some waste products from metabolic activity have also been implicated. Some primary metabolites and major intermediates have been reported to have allelochemical activity (Rice, 1984). It is believed that all plants produce some kind of allelochemical, though their effect on other plants

may be weak and undetectable. There are two forms of allelopathy, autotoxicity and heterotoxicity (Miller, 1996). The former means plants can prevent germination and growth of the same plant species, while the latter means plants of other species are affected. Plants belonging to the latter group can affect both crop and weed species. Some work has been done to determine the allelopathic potential of several cover crops, and to identify the allelochemicals, especially in rye.

White et al. (1989) studied the allelopathic potential of crimson clover (*Triticum incarnatum* L.) and hairy vetch (*Vicia villosa* Roth.) under no-till conditions. Hairy vetch had a greater phytotoxic effect on the bioassay test species than crimson clover in both the debris and extract studies. Germination and seedling growth of corn (*Zea mays* L.), Italian ryegrass (*Lolium multiflorum* Lam.), cotton (*Gossypium hirsutum* L.), pitted morning glory (*Ipomea lacunosa* L.), and wild mustard (*Sinapsis arvensis* L.) decreased progressively, varying with species, when treated with increasing concentrations of aqueous extracts of the cover crops. Lehle et al. (1993) tested the allelopathic potential of Hope white lupine (*Lupinus albus* L.) herbage and herbage extracts on several crop and weed species. At lower rates the lupine herbage incorporated into moist loam soil stimulated cotton, soybean (*Glycine max* L.), large crabgrass (*Digitalia sanguinalis* (L.) Scop.), and johnsongrass (*Sorghum halepense* (L.) Pers.) growth. At higher rates it inhibited cotton seedling emergence, and cotton and soybean fresh weights increase. In this case the amount of lupine herbage determined the outcome.

Early studies showed that extracts of 'Wheeler' rye shoot herbage had phytotoxic compounds. Barnes et al. (1987) isolated and characterized

allelochemicals in the rye extract. They identified the compounds as 2,4-dihydroxy-1,4(2H)-benzoxazin-3-one (DIBOA) and 2(3H)-benzoxazilinone (BOA). In a more recent study Yenish et al. (1995) examined the disappearance of rye cover crop residue and its allelochemicals in a field study. The aerial biomass declined linearly over time, with 50% left 105 days after mowing. In the two years of the study, 50% of the 0-day chemicals in the residue disappeared by 10 to 12 days. The duration of weed suppression by the rye cover crop more closely followed the disappearance of the allelochemicals than the disappearance of the residue itself, showing that for this rye variety, weed control was most likely more by chemical means than by physical suppression. Creamer et al. (1996b) investigated the mechanism of weed suppression by several cover crop species. Aqueous extracts of greenhouse-grown rye straw inhibited the germination of lettuce (*Lactuca sativum* L.) seed, with the percent suppression decreasing with successive extractions. In addition, leached rye straw plus leachate suppressed lettuce seed germination, while leached rye straw alone did not. These studies showed that cover crop species may produce allelochemicals which may not be selective in suppressing only weed species. It is desirable to determine if potential cover crops have allelopathic effects on the crops that they are targeted to control weeds in. Some legumes in the pea, lentil, and vetch families release beta-(3-isoxazolinonyl) alanine from their roots into the soil. This compound is thought to be allelopathic as it reduces growth in seedlings of various grasses and lettuce (Schenk and Werner, 1991).

Many of the studies to date on using cover crops in sustainable agriculture focused on the physical aspect of the living or dead mulch in suppressing weeds. There is potential for utilizing allelopathy in addition to physical suppression to control weeds in reduced and no-till farming systems. However, research has to be done to determine the most appropriate cover crops and management techniques for best results. Allelochemical effects also vary among locations and growing seasons due to differences in soils and climates, so activity at each location must be determined *in situ*. Duration and efficacy of allelochemicals in the soil also varies because they can be lost through leaching, microbial breakdown, chemical processes, and plant uptake (Weidenhamer, 1996). They can also be bound and demobilized by soil organic matter. Nonetheless a cover crop that can control weeds both physically and allelochemically should consistently provide the best results.

COVER CROPS AND VEGETABLE PRODUCTION

A cover crop that suppresses weeds physically or chemically might have the same effect on vegetable crops, which would undermine its positive attributes. If cover crops suppress weeds effectively, their effect on the target vegetable crops must also be determined before they are recommended to farmers. Conditions in tropical conditions are different from those in the temperate regions, and research has to be done to determine the effect of cover crops on the establishment, growth and eventual yield of the vegetable crops. With a revived and increasing interest in

the use of cover crops in conservation agriculture, several studies have shown that vegetable crops produced under reduced and zero tillage can perform the same as or even better than those grown under conventional tillage.

NeSmith et al. (1994) compared conventional tillage and no-till soil management with rye as a cover crop sown in the fall in the production of summer squash (*Cucurbita pepo* L.) for two years. The two tillage systems produced similar yields though in 1991 early yield was 27% less under no-till. This study showed a potential for the use of conservation tillage in the warmer southeastern United States. Abdul-Baki and Teasdale (1993) compared tomato productivity in a no-tillage system with hairy vetch and subterranean clover mulches sown in the fall and mown the following spring to mulching with black polyethylene, paper, or no mulch in conventional systems. Plant mulches delayed fruit maturity by approximately 10 days, but tomato yield in the hairy vetch mulch was more than 2 times that of the no mulched control, and higher than that from the black polyethylene mulched plants.

A study by Bordelon and Weller (1997) showed grapevines in cover cropped plots growing less than those in weed-free conventionally weeded controls. They compared leaf area, leaves per vine, shoot length, and grapevine biomass. Treatments included spring-planted cover crops. Total vine dry weight in spring-planted rye, together with fall-planted wheat and rye were the highest. Little additional work has been done on the effect of cover crops sown and killed in the warm season on the primary crop, as would be the case in the tropics

As already mentioned, allelochemicals can affect both crop and weed species. Before a promising cover crop species is established to control weeds in a primary crop, it must be determined not to have any detrimental effect on the primary crop's growth and development. Germination of corn and cotton decreased progressively, varying with species, when treated with increasing concentrations of aqueous extracts of crimson clover and hairy vetch (White et al., 1989). At lower rates, Hope white lupine herbage incorporated into moist loam soil stimulated cotton and soybean growth (Lehle et al., 1993). At higher rates it inhibited cotton seedling emergence, while cotton and soybean fresh weights decreased. Weed species included in these studies were also affected, showing that allelochemicals were not selective in their effects.

COVER CROP SPECIES MIXTURES

In a survey carried out among cover cropping farmers in California, the more desirable cover crop characteristics were nitrogen fixation, production of high biomass, and high weed competitive ability (Ridgely and Van Horn, 1995). To achieve these characteristics it has been found that a legume/monocot mixture would be more desirable for weed control because the two species would complement each other in various ways (Walker, 1993). Legume mulches tend to decompose faster than monocot mulches. Thus it is hypothesized that non-legume mulches will contribute more to suppressing weeds while legume mulches will add nitrogen to the soil. This should result in overall better crop growth as opposed to

using one type of cover crop mulch, if the right monocot/legume mixtures can be identified. Hairy vetch residue decomposed faster resulting in greater weed emergence later in the season than rye residue, thus a much higher initial rate of hairy vetch was required to achieve the same degree of weed control as a moderate rate of rye (Mohler and Teasdale, 1993). Nitrogen released by the decomposing hairy vetch residue may also contribute to the higher weed populations compared to the rye residue. Vetch residue also persisted less than wheat residue (Shelby et al., 1988).

Most legumes fix nitrogen through their nodules while monocots contribute very little nitrogen to the soil when they decompose. The legumes may even fix more nitrogen when planted in a mixture than as a pure stand (Agboola and Fayemi, 1972), and nitrate leaching losses are greater in a pure legume stand than in a legume/monocot mixture. Sainju and Singh (1997) reported that non-leguminous crops reduced nitrate leaching by 29% to 94% and legumes by only 6% to 48%. Non-leguminous cover crops in the mixture reduce soil nitrate N and water from the top soil, thus reducing nitrate N leaching below the root zone (Meisinger et al., 1991; Wyland et al. 1996). Clark et al. (1994) also reported that a rye-hairy vetch biculture scavenged nitrogen which would have been leached, and maintained corn yields by adding fixed N to the soil. When compared to hairy vetch and crimson clover, Sainju et al. (1998) reported rye to have the greatest weed density and above-ground biomass, and to scavenge soil nitrate early in the growing season. Summer annual legumes, for example cowpeas, add 100 to 130 lbs of nitrogen to the soil in 3 months of growth (Ingels et al., 1997). Killed cover

crop mulch is usually left on the soil surface, thus nitrogen may not be readily available to the primary crops before the mulch decomposes. Some nitrogen will also be lost to the atmosphere through volatilization from the decomposing mulches.

In another study Shelby et al. (1988) analyzed leaf tissue of tomatoes grown in pure hairy vetch and wheat residues for nutrient content. Tomatoes grown in vetch residue contained higher concentrations of N and Mg, but lower concentrations of K and Ca than those grown in wheat residue. Monocot species have a C/N ratio much higher than that of legume species. A high C/N ratio (over 25) under an intensive cropping system results in microbial immobilization of available soil N in the topsoil (Shelby et al., 1988). Plant residues with a low C/N ratio will be mineralized faster, thus availing N for more immediate crop use (Wyland et al., 1996). With residues left on the surface, N mineralization may not take place that same season, but N should be available for the succeeding crop. Vegetable crops in legume/monocot mulches would most likely have less weed competition than those in a pure legume mulch and have access to more soil nitrogen than those in a pure monocot mulch. Ranells and Wagger (1996) reported small reductions (4 to 15 %) in N release from monocot/legume bi-cultures compared to legume monocultures. Thus the advantages of legume/monocot bicultures as cover crop mulch for weed control should also result in reasonable crop yields because the bicultures decompose slowly with not much loss of N releasing potential. However this would also depend on the cover crop species, the

ratio of legume to non-legume in the mixtures, and subsequently their effect on soil properties and soil fertility.

A cover crop treatment that contributed in other ways in addition to controlling weeds would be more desirable. The foregoing studies showed that combinations of over-wintered legume/monocot cover crop treatments are more desirable for weed control as compared to pure legume or monocot stands.

CRITICAL PERIOD FOR WEED CONTROL

Cover crop mulch usually decomposes to some extent allowing weeds to emerge through and maybe even grow robustly if conditions are suitable. However most crops have a critical period of weed control, which is defined as the specific minimum period or window during which competition from weeds must be minimized to ensure maximum growth and yield (Weaver and Chin, 1983). The critical period is made up of periods which may overlap. The first one is a time span in which weeds can be left in a crop before starting to interfere with the crop. The second one is a time during which there must be no weeds growing to affect primary crop growth, thus yield will not be affected by any subsequent crop growth. Weaver and Chin (1983) recorded tomato yields significantly reduced by weeds emerging before or up to 35 days after transplanting and remaining in the crop up to harvest time. Weeds emerging thereafter had no effect on yield. Weeds which remained in the crop for more than 35 days after planting resulted in reduced yields. Earlier weed growth did not reduce tomato yields. The conclusion was that

the critical period for weed control in this tomato crop was 28 to 35 days after transplanting. Yields were similar to those of weed-free controls. By regressing crop dry weight on weed dry weight the authors showed weed biomass per unit area to be a better predictor of crop yield than weed density. Other authors have found weed density to be strongly negatively correlated to crop yield, so results vary from study to study.

OBJECTIVES OF THIS RESEARCH

Interest in cover crop use in crop production is growing and much research has been done for the temperate regions. However results obtained cannot be directly applied to the tropical regions due to differences in climates, growing seasons and potential cover crop species. Cover crops will have an effect on weed and primary crop growth, and may have specific weed control mechanisms, all of which should be determined specifically for tropical conditions. The main goal of this research was to examine the use of spring-sown annual cover crops in fresh market tomato production systems, which could then be extrapolated to tropical situations. There is a strong need to examine the use of annual cover crops in tropical vegetable production systems. Fresh market tomatoes and other vegetables have a high demand on the markets in tropical countries as processed vegetables are not affordable to the majority of the consumers. As these results will be extrapolated to tropical situations, experiments were designed to cover as many aspects of cover crop research as possible.

Specific Objectives

1. To determine the potential of varying combinations and seed rates of spring-sown legume/monocot mixtures on weed suppression.

So far there is nothing reported on the ratios of legume/monocot mixtures that would control weeds effectively when sown in the spring or in the tropics. It is desirable to establish the rates of legume/monocot mixtures that would control weeds effectively in warmer climates or weather conditions. Cover crop treatments were evaluated for rate of establishment, ease of killing by undercutting, and weed control potential before and after undercutting.

2. To determine the effect of varying combinations and seed rates of legume/monocot mixtures on tomato plant establishment, growth and yield.

Different legume/monocot combinations and seed rates have different degrees of weed suppression and different effects on levels of nitrogen and other soil nutrients. The resulting weed pressure and level of soil fertility affects the performance of the tomato plants. This study was designed to see how tomato plants grow and yield in the various legume/monocot mixtures.

3. To determine if activated charcoal can be used to trap allelochemicals released by various cover crops.

Cover crops control weeds through competition, physical suppression, and production of allelochemicals. In nature most plants produce allelochemicals but few have been identified. This study was to test the potential of using activated

charcoal to capture allelochemicals which can then be subjected to further tests in the lab.

4. To evaluate the effect of 4 tropical legume species on above-ground biomass accumulation, weed suppression, and tomato growth.

Annual cover crops suited to tropical conditions have to be identified and assessed for their weed suppression potential and effect on vegetable crop growth. There are many potential tropical legume species which have to be investigated before recommendations are made. This study was a preliminary investigation of 4 tropical legume species with a potential for use as cover crops in Uganda and other countries with similar climates and soils.

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CHAPTER 2

WEED CONTROL USING SPRING SOWN COVER CROPS

INTRODUCTION

The use of cover crops in minimum or no-till crop production systems is not a new concept and the associated benefits are well documented. Some of the benefits are reduction of soil erosion and compaction, addition of nitrogen to the soil where legumes are used as cover crops, and higher levels of soil moisture under the cover crop mulch (Clark et al., 1994; Galloway and Weston, 1996; Rowland et al., 1994). Cover crops can also suppress weeds in the short-term through physical suppression, competition for resources, or allelopathy (Creamer and Bennett, 1997; Teasdale and Mohler, 1992; Putnam and DeFrank, 1983).

The potential for spring-planted cover crops in weed control in the northern temperate regions has not been as extensively researched as for fall-planted cover crops. Research on cover crops for annual crop production in the tropics is also limited. Most countries in the tropics have two rainy seasons a year, each lasting approximately four months. A system involving spring-planted cover crops would have application to tropical climates because in both cases, in order to fit in the growing season, cover crops have to grow for 1½ to 2 months prior to establishing

the primary crop. In many developing countries farmers use considerable labor to keep crops weed-free mainly by hand hoeing. Using cover crops could help to alleviate this problem by providing weed control.

In sustainable agriculture the goal is to suppress weeds in order to obtain reasonable crop yields while reducing the detrimental effects on the environment resulting from the use of herbicides or intensive cultivation. In an earlier study, weed suppression increased with increasing cover crop biomass of rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth.) cover crops (Mohler and Teasdale, 1993). Small-seeded weed species were more easily suppressed than those with large seeds. Sometimes weeds may re-surge after the cover crop residue decomposes, but by then the primary crops should be established and be able to compete with the weeds.

A legume/monocot mixture might be more desirable as a plant cover for weed control because the two types of plants would complement each other in several ways (Creamer and Bennett, 1997; Walker, 1993). Legume mulches with a low C:N ratio decompose rapidly, while monocot mulches with a high C:N decompose at a slower rate. Legumes fix nitrogen through their nodules while monocots contribute very little nitrogen to the soil when they decompose. Careful selection of mixtures and C:N ratios should optimize cover crop weed suppression while reducing the chance of excess N leaching leading to heavy weed cover.

When compared to over-wintering cover crops, spring-planted cereals controlled weeds best, suggesting this as a feasible option (Bordelon and Weller, 1997). It has also been reported that spring-planted winter rye has leafy shoots

with tender stems and remains vegetative (Ateh and Doll, 1996), making it a more manageable cover crop than fall planted rye which rapidly elongates and flowers the following spring. To prevent competition between the cover crops and the primary crop it is now common practice to kill the cover crops before the primary crops are established. Methods used to kill cover crops include mowing, herbicide applications, and undercutting using an implement developed by Creamer et al. (1995) at the Ohio State University.

Light quality and intensity, soil temperature, and moisture affect seed germination and are in turn affected by cover crop mulch on the soil surface (Creamer et al., 1996; Teasdale and Mohler, 1992). Increasing mulch residue rates lowered the amount of light reaching the soil surface, resulting in a corresponding reduction in weed seedling emergence. Leafy residue is more effective in reducing soil temperature amplitudes and maintaining soil moisture than residue of mainly stems (Creamer et al., 1996).

Many plants are known to produce allelochemicals that can directly or indirectly affect the growth of nearby plants (Putnam, 1988). The winter rye variety "Wheeler" used in this study produces 2,4-dihydroxy-1,4(2H)-benzoxazin-3-one (DIBOA) and 2(3H)- benzoxazilinone (BOA) (Barnes et al., 1987), which have been shown to strongly suppress the germination and growth of a number of weed and crop species. Peas (*Pisum sativum*) and other legumes are known to produce the allelochemical beta-(3-isoxazolinonyl) alanine from their roots, and it reduced the growth of seedlings of various grasses and lettuce (*Lactuca sativum* L.) (Schneck and Werner, 1991).

The overall goal in this field study was to determine the potential of a spring-planted cover crop to control weeds and provide soil cover in a tomato crop with the hope that this cropping system would have application to crop production practices in the tropics. Legume/monocot mixtures were explored because they would suppress weeds as well as providing N to the soil. Varying proportions and seeding rates of legume/monocot mixtures will have different weed suppression levels and affect soil N levels differently.

Winter rye and field peas were used as cover crops in field studies. Winter rye has already been used in studies as an over-wintering cover crop and has exhibited good weed control potential. Field peas fix large amounts of N from the atmosphere and under the right conditions accumulate above-ground biomass rapidly (Bremer et al., 1988; Evans and Herridge, 1987).

I was also interested in determining the role of allelopathy in cover crop suppression of weeds under field conditions. Allelochemical extracts from cover crops have been used in bioassay studies, most of the extracts being obtained by leaching the cover crop tissue with distilled water (Creamer et al., 1996; Hoffman et al., 1996; White et al., 1989). Activated charcoal has been used as an adsorption agent in a number of studies to trap a wide range of compounds including plant pigments, pesticides and herbicides (Gan et al., 1995; Hoagland, 1989; Mohan and Karthikeyan, 1997). Literature on the use of activated charcoal for adsorption of allelochemicals is very limited. In a field study Dabney et al. (1996) used activated charcoal to adsorb compounds produced by crimson clover (*Trifolium incarnatum* L.) a day after killing the cover crop. Stand density of sorghum (*Sorghum bicolor*

(L.) Moench) subsequently improved by 15% compared to treatments where activated charcoal was not used, although seedling size remained the same. This study showed that activated charcoal has a potential for use in the extraction of allelochemicals in the field.

The specific objectives of this study were to (a) determine if spring-sown cover crops can establish a plant stand that can be cut prior to planting vegetable crops and provide near or complete suppression of weed growth, (b) compare the efficiency of different populations of legume/monocot bi-cultures and pure stands in weed suppression, and (c) determine if activated charcoal can be used to extract allelopathic compounds produced by the cover crops.

MATERIALS AND METHODS

Field trials were conducted at the Ohio State University Waterman Agricultural and Natural Resources Farm in Columbus, Ohio, on a Miami silt loam (Mesic Typic Hapludalf) soil in 1996, 1997, and 1998. The land was plowed and then rototilled to obtain a fine seedbed. Flat seedbeds measuring 2.5 m by 7.5 m were used in 1996, while raised beds measuring 1.2 m by 12 m were used in 1997 and 1998 to facilitate undercutting. Cover crops winter rye 'Wheeler' (*Secale cereale* L.) and field peas (*Pisum sativum* L.) were sown by hand on 18 April 1996, 24 April 1997, and 23 April 1998. Treatments were as shown in Table 2.1 for all three years and were laid out in a randomized complete block design with four replications and 18 treatments in each replicate.

There were two main cover crop factors; rye:pea proportion (RP) and overall cover crop seeding rate (SR). The rye:pea proportions had five levels including pure rye (RR), pure field pea (PP), ¾rye + ¼pea (Rp), ½rye + ½pea (rp), and ¼rye + ¾pea (rP). Seeding rate levels consisted of high (H), medium (M), and low (L). High seeding rates for pure rye and pure field peas were 114 and 142 kg ha^{-2} respectively. Medium and low seeding rates were 50% and 25%, respectively, of the high rate for each cover crop. Seeding rates (Table 2.1) were adjusted each year based on germination tests carried out prior to sowing. Three additional treatments were included as controls to determine the efficiency of the cover crops in weed suppression. Control plots received no cover crop seed and included a weedy, no-tilled check (WNT) which was mowed or undercut at transplanting, a weedy check tilled at transplanting then left un-weeded (WT), and a tilled hand-weeded control (WFT). Tilled and no-till weedy checks were included to compare weed pressures from weeds germinating at transplanting to weeds germinating at cover crop sowing that may re-establish after mowing or undercutting.

Percent (%) ground cover by weeds (assessed visually), dominant weed species, and weed counts were recorded randomly within each plot before undercutting in a 1 m^2 area 68-69 days after seeding (DAS) cover crops in 1996, and in a 0.5 m^2 area in 1997 and 1998 60-61 DAS. Cover crop shoot biomass was taken randomly within each plot 70 DAS from each cover cropped plot in 1996, 60 DAS in 1997, and 62 DAS in 1998. A 1 m^2 quadrant was used in 1996, while quadrants measuring 0.5 m^2 were used in 1997 and 1998. Rye and pea foliage

were put in separate bags and oven-dried at 57C for 72 hours prior to dry weight determination. Cover crop plots and the WNT check were mown 74 DAS in 1996 using a sickle bar mower which deposited the intact residue evenly across the mowed width. Cover cropped plots and the WNT were undercut 61 DAS in 1997 and 63 DAS in 1998, while control plots WT and WFT were cultivated 83 DAS in 1996, 61 DAS in 1997, and 73 DAS in 1998. In 1998 above-ground weed biomass was collected from all plots using a 0.5 m^2 63 DAS and 45 days after undercutting cover crops. Weed samples were put in separate bags and oven-dried at 57C for 72 hours prior to dry weight determination. After undercutting cover crops soil temperatures at midday were recorded for all 72 plots in 1996, 1997, and 1998, at a 15 cm depth using Taylor Bi-therm thermometers (A.M. Leonard, Inc., 241 Fox Drive, Piqua, OH).

Extraction of allelochemicals.

To determine if activated charcoal can be used under field conditions to collect allelochemicals produced by cover crops, and to determine if in fact the cover crops were producing inhibitory compounds, bags of activated charcoal were buried in field plots in 1998. They were retrieved and extracted of any compounds adsorbed to the activated charcoal. Activated charcoal (120 g) (Matheson, Coleman, and Bell, Cincinnati, OH) was thoroughly moistened with 20 ml of distilled water and placed in Nitex nylon fabric bags (Tetko Inc, Kansas City, Mo) measuring 450 cm^2 on each flat surface. The nylon fabric had 5 micron openings and 1 % open area. The bags were sealed and buried 1 cm under the

soil and mulch on 24 July in RRH, PPH, and WFT treatments. After 27 days the bags were taken out of the field and stored in a freezer to preserve any compounds adsorbed by the activated charcoal. To extract the compounds, half the charcoal from each bag was mixed with an equal volume of HPLC grade acetone (Fisher Scientific, Fairlawn, NJ), and stirred on a Nuova II stir plate (Barnstead Thermolyne, Dubuque, IA) for 1h. The mixture was then filtered through a Buchner funnel lined with a Whatman No.1 filter paper into a side-arm flask attached to a suction pump. The charcoal was re-extracted with the same volume of fresh acetone to extract as much of the compounds as possible. Each filtrate was then put in a round-bottomed flask and the acetone evaporated in a Buchi 461 water bath and rotary evaporator (Buchi Laboratoriums-Technik Ag, Switzerland) until the volume remained constant. The remaining extract in each flask was brought up to a standard 50mls with distilled water. An amount of 17.4 ml (1x) of pure extract was applied to a 10 cm D petri dish. The ratio of extract to the surface area of the petri dish approximated the ratio of the total extract 950 ml) to the surface area of the bag (225 cm^2). This was done to reproduce the concentration of allelochemicals that would have been present during this time period per unit field surface area. In addition, the pure extract was diluted by a factor of 10 (0.1X), 100 (0.01x), and 1000 (0.001x) to obtain 1.74, 0.174, and 0.0174 ml respectively to obtain a dose-response. For each extract the four volumes were pipetted onto 2 circles of germination paper in 10 x 1.5 cm petri dishes. The 17.4 ml samples were set out 36 h earlier to let the solvents evaporate to avoid flooding the seed. The controls included (1) an extract from

the equivalent weight of moistened activated charcoal not buried in the field, and (2) distilled water. Fifteen lettuce (*Lactuca sativum* L.) seeds were evenly spaced in each petri dish, given 8 ml of water, then placed in a germination chamber set at 20C with 24 h of light. The bioassay was repeated once using the same extracts under the same conditions. Lettuce seeds were considered germinated when a healthy radicle emerged from the seed coat. Rate of germination, total germination, and final lettuce seedling fresh weights were recorded.

Data for all experiments were analyzed using SAS (GLM and PROC ANOVA). Data for the cover crop experiment were analyzed in a factorial model with the control no cover crop plots excluded. Significantly different means were separated by LSD. Weed data were combined for 1996, 1997, and 1998 and subjected to analysis of variance in a factorial model with significantly different means separated by LSD. To determine the relationship between cover crop and weed populations before undercutting, percent (%) ground cover by weeds in 1996, 1997, and 1998 was regressed against rye, field pea, and total cover crop above-ground biomass. Weed dry weight 63 DAS and 45 days after undercutting were also plotted against rye, field pea, and total cover crop above-ground biomass in 1998.

RESULTS AND DISCUSSION

Weed populations before cutting cover crops.

Weeds had established by the time the cover crops were mown or undercut. Observations on weeds before undercutting showed more broadleaf weed species than grass species in all treatments (Appendix A,B). Grass weeds were very few or non-existent. There was no consistent effect of treatment on weed species make-up over the three years of this study. In 1996 and 1997 treatments without cover crops had the greatest diversity of weed species. Ladysthumb (*Polygonum persicaria* L.) was prevalent in all treatments in 1997 and was not completely killed by the undercutter. Although the weed pressure was much higher in the experimental plots in 1998 compared to the previous two years, there was less diversity of weed species in all treatments. The dominant broad-leaf species in 1998 were smallflower galinsoga (*Galinsoga parviflora* Cav.), smooth pigweed (*Amaranthus hybridus* L.), and common lambsquarter (*Chenopodium album* L.).

Analysis of the 3-year pooled data (3YP) revealed significant effects of year and seeding rate on broadleaf and grass density, and % ground cover by weeds (WGC) (Table 2.2). Broadleaf weed density and WGC were greatest in 1998 compared to previous years and grass weed density was greatest in 1997 (Table 2.3). Grass and broadleaf weed density, and WGC decreased with increased SR, as expected (Table 2.2). Combined analysis showed that the proportion of rye to pea had no effect on broadleaf weed density, but affected both grass weed density and WGC (Table 2.2). With the exception of 1998, in

which RP had no effect on grass weed density, both grass weed density and WGC were reduced by cover crops containing rye compared to a pure pea cover crop. The RP x SR interaction had a significant effect on WGC in all three years and 3YP.

The three cover-crop-free controls had the largest weed sizes and highest WGC in all three years and the 3YP (Table 2.3, 2.4). Most of the weed species were flowering at the time of cover crop kill. Variation in WGC was not always related to weed size. In 1996 and 1997 broad and grass weed densities in the three controls were similar to those in RRH, and yet WGC was 9 to 10 times less in RRH compared to the three controls (Table 2.3). Grass weed density for all three years was transformed using $\sqrt{(x+ ½)}$ before analysis of data of all 18 treatments, so LSD is not shown (Table 2.3).

Only RRM and RpM had less than 100 weeds per m^2 in 1998 (Table 2.3). Weeds also grew much more this year, with weeds growing in treatments with higher rye ratios also reaching heights of 35 to 70 cm. In 1996 and 1997 weed heights were reduced in treatments with higher rye ratios and in PPH compared to the controls. Weed heights were not statistically analyzed because they were recorded between ranges for each treatment. Much of the month of May remained dry after the cover crops were sown (Appendix C). Cover crops were slow to germinate and establish, allowing already germinating weeds in the soil to grow ahead of the cover crops. In addition, in 1998, many pea seedlings were eaten by migrating geese, reducing the potential pea plant population and eventual mulch yield. Higher weed pressure in 1998 resulted in less weed

suppression, and more uniform WGC in the cover cropped treatments. Pooled data showed RpH, RpM, and rpH suppressing weeds most compared to the pooled controls (Table 2.4).

Cover crop dry weights.

Analysis of 3-year pooled (3YP) data revealed significant effects of Y x RP, year, RP, and SR on rye, field pea, and total cover crop dry weight, and significant effect of Y x SR on rye and total cover crop dry weight only (Table 2.5). Rye, pea, and total cover crop biomass were highest in 1998, decreasing from high to low seeding rates (Table 2.5). Rye biomass decreased with decreasing rye ratios in RP, while field pea biomass increased as expected. Total cover crop biomass increased with increasing field pea ratios in RP only in 1996, with no consistent effect of pure rye, pure pea, or bicultures in 1997, 1998, and 3YP on total cover crop biomass (Table 2.5). In treatments with both rye and pea (Rp, rp, and rP), greater rye growth suppressed pea growth in 1997 compared to 1996, but not in 1998 (Appendix D).

Spring 1996 and 1998 were drier than spring 1997 (Appendix C). May 1997 was cold and wet and the cover crops were delayed in becoming established, however after establishment cover crops grew vigorously in June. Kessavalou and Walters (1997) reported that cold temperatures from autumn 1991 into early spring 1992 resulted in seedling injury and retarded rye seedling growth and therefore reduced dry matter yield. In our study 1997 cover crop dry weights were greater than those obtained in 1996 (Appendix D). In 1998 as well much of the cover crop

growth took place in June. The greatest cover crop biomass was obtained in 1998, with more than 4 MT. h^{-1} in some treatments. Rye did not produce as much biomass in 1996 as in 1997 in all treatments, while in 1998 with more than 4 MT. h^{-1} of biomass was obtained in RRH and RRM.

Higher tonnage of cover crop residues than those recorded in this study have been reported, especially for autumn-grown wheat and rye (Wilkins and Bellinder, 1996). For rye, 2.0 to 4.4 MT. ha^{1} were obtained when cut at 1st node, and 1.8 to 4.4 MT. ha^{1} at 2nd node. For wheat 9.2 to 15.5 MT. ha^{1} were obtained at 2nd node. Rye at the boot stage yielded 3.7 to 6.9 MT. ha^{1}. Earlier studies showed 4.0 to 4.5 MT. ha^{1} of dry wheat and rye residue suppressing weed emergence and growth up to 12 weeks (Crutchfield et al., 1986; DeAlmeida, 1985; Lanfranconi et al., 1993). These tonnage figures were approached by the cover crops in our 1998 plots in rpH and rPH, both of which had 4.6 MT. ha^{1} of dry cover crop biomass (Appendix D). In the same year RRH, RRM, and RpH also had 4 to 4.4 MT. ha^{-1} of dry cover crop biomass.

Weed dry weight before and after undercutting cover crops in 1998.

For weed dry weights taken at undercutting (63 DAS) and 45 days after transplanting (DAT) in 1998 there were significant effects of RP and SR on weed biomass, but there was no RP by SR interaction (Table 2.6). Generally weed biomass increased with decreasing rye ratios in the cover crops, and from high to low seeding rates for both sampling dates. Before undercutting, weed biomass was highest in WNT, WT, and WFT where no cover crops were sown (Table 2.7).

Weed dry weight at undercutting ranged from as low as 0.35 MT ha^{-1} (RRH) to 6 MT ha^{1} (WFT), which was more than twice for most of the cover cropped treatments. This showed that the presence of cover crops suppressed the potential weed population. Highest weed biomass among cover cropped treatments was in PPM and PPL.

Forty-five days after undercutting in 1998, all treatments had greater weed biomass than before undercutting, except for WNT (Table 2.7). Weeds did not die after undercutting due to rain that same evening and for several days afterwards. The weeds received enough moisture to stay alive, re-establish, and accumulate more biomass. From visual observation in 1997 at least 3 days of dry and sunny weather are necessary for undercut weeds and rye to desiccate. Pea cover crop killed was much better than that of rye, but weeds were killed least at undercutting. The least weed biomass 45 DAT was collected in RRH, RpH and WT, (the control that was tilled at transplanting, then left un-weeded for the rest of the season) (Table 2.7). Weeds were suppressed by the greater rye biomass in RRH and RpH, while weeds in WT germinated after the plots were tilled before tomatoes were transplanted. The weedy no-till check, WNT, had the greatest weed biomass as it had the most weeds re-establishing after undercutting. From visual observation, there was little germination and establishment of new weeds in treatments with originally high weed biomass after undercutting in the plots. RRH, RpH, and WT had 29 to 32 % of the weed biomass of WNT, while the rest of the treatments had 40% to 80%.

Relationship between cover crop biomass and percent ground cover by weeds.

Percent weed ground cover (WGC) in cover cropped treatments at time of cover crop kill decreased with increasing cover crop biomass in 1997, 1998, and 3YP, as shown by regression analysis (Figure 2.1b, c, d). In 1996, there was no correlation between total cover crop dry weight and WGC because similar weed densities were obtained in RR treatments (with lowest cover crop biomass) and in PP treatments (with highest cover crop biomass).

WGC at undercutting and field pea dry weight had very weak correlations in 1996, 1997, and the 3YP (Figure 2.2), with a number of outlying points. Field pea was not a strong determinant of WGC in the different treatments (Figure 2.2). Weeds under the canopy of the pea cover crop before mowing or undercutting were visibly etiolated, a sign of competition for light. The highest pea biomass (PPH) in 1996 and 1997 suppressed weeds by more than 90 % (Appendix D). The denser the field pea mulch, the greater the weed suppression (PPH in Table 2.3).

In all three years and 3YP, WGC decreased with increasing rye biomass (Figure 2.3), with slightly stronger correlations in 1998 and 3YP. Weeds in RR plots were stunted, but higher weed numbers resulted in slightly greater WGC than in rp (H, M, L) , rPH, and rPM, and this is most evident in 1996 and 1997 (Table 2.3).

Relationship between cover crop biomass and weed dry weight.

Similar to effects of cover crops on WGC, weed dry weight measured immediately before undercutting the cover crops (63 DAS) in 1998 was negatively

affected by rye and total cover crop biomass, but was unaffected by increasing pea biomass (Figure 2.4). Weed dry weight measured 45 days after undercutting in 1998 decreased with increasing rye biomass and increased, though weakly, with increasing pea biomass (Figure 2.5). The positive effect of pea on weed biomass may be attributable to nitrogen released into the soil by the decomposing field pea mulch resulting in a corresponding biomass accumulation by the weeds. Weed biomass decreased with increasing total cover crop dry weight (Figure 2.5c), but with a weaker correlation than for pre-undercutting data. This is probably due to the fast decomposition of the field pea component of the cover crop mulch and the re-establishment of the undercut weeds which thereafter overcame suppression by the mulch. Rain that fell immediately after undercutting and for several days thereafter accelerated the decomposition of the field pea mulch and the release of nitrogen into the soil.

Influence of cover crop mulch on soil temperature.

Germination of weed seeds in the soil is affected by soil temperatures, which are in turn affected by the amount of cover crop mulch on the soil surface. Soil temperatures were recorded at noon at a depth of 15 cm, for several June-August dates in 1996, 1997, and 1998 after the transplanting of the tomato crop (Table 2.8). Cover crop mulch alone did not determine soil temperatures. In addition to the thickness of mulch on the soil surface, soil temperatures varied depending on the soil moisture in each plot, the air temperature, and intensity of sunshine on the day the readings were recorded. Field plots were not evenly flat in all three years

so-low lying spots or sections tended to remain wetter and therefore have lower soil temperatures than other sections which drained off and dried faster. Soil temperatures ranged between 16C and as high as 34C in 1996 which was a dry year. The highest temperatures were recorded in RRL and WT in 1996, RRL and WT in 1997, while rpH had the lowest temperature in both years (Table 2.8). Early August 1996 was very dry and hot resulting in the much higher temperatures in treatments with little mulch cover left on the soil surface. Soil temperatures were lower in WNT in 1996 and 1997 probably because the weeds were dense enough to shade out much of the solar radiation. Soil temperature did not vary much among treatments in 1997 probably because of greater soil moisture in that year. In both 1996 and 1997 soil temperatures rose as the cover crop mulch decomposed and exposed the soil surface, but also depended on the air temperatures. Summer temperatures were mild and less fluctuating in 1998, the driest of the three years, but cover crop mulch on the soil surface was also much more than that obtained in 1996 and 1997 (Appendix D). Most of the soil temperature readings in 1998 fell between 20 and 25 C compared to the 18 to 35 C range in 1996 (Table 2.8). Lowest soil temperatures in 1998 were recorded in rPM, and the highest were recorded in RpM, RpL, RRH, PPM, and WFT.

Activated charcoal extractions.

In the comparison of the effect of four levels of extracts from RRH, PPH, and WFT on lettuce seed germination, undiluted extract of activated charcoal buried beneath RRH decreased germination by 85% compared to undiluted extracts from

PPH and WFT (Table2.9). The 0.1x, 0.01x, and 0.001x dilutions of extracts from charcoal buried beneath RRH, PPH, and WFT, together with the fresh activated charcoal extracts, and distilled water had a final germination of 14 or 15 seedlings. After 7 DAS seedling fresh weights were significantly affected by the 0.1x dilutions of extracts from activated charcoal buried beneath RRH, PPH, and WNT treatments in the field (Table 2.9). Seedling fresh weight decreased with reducing extract concentration, with the weight of one seedling being 18 or 19 mg in 17.4ml samples, and 15 or 16 mg in the 0.0174 ml samples. Fresh weight of seedlings in the clean charcoal extract samples and the water control were 14 or 15 mg, less than for the extracts from the field. The field extracts may also have contained some growth promoting compounds, (e.g. IAA), which resulted in greater biomass accumulation by the seedlings in those samples.

Total lettuce seed germinated in the four concentrations of the three field and the fresh activated charcoal extracts, and distilled water were plotted for 2, 4, and 6 DAS. The greatest variation was in the 17.4 ml samples 2 DAS (Figure 2.6a), with least number of seeds germinated in rye and field pea extracts, followed by WFT extracts. Lettuce seed germination was suppressed most in 17.4 ml rye extract treatment, followed by 17.4 ml field pea and WFT extract treatments 4 DAS. By 6 DAS weed germination was most suppressed in the 17.4 ml rye extract treatment. In 1.74 ml samples, seed germination was slowest in the field pea extract 2DAS, but 3 DAS onwards, additional germination was similar to the fresh activated charcoal and water controls. Germination rate was slowed down most by the 17.4 ml samples of the rye and pea extracts compared to the controls,

indicating that a compound or compounds with allelopathic effects were adsorbed by the activated charcoal in the field. Apparently some were also picked up in WFT, since there was a difference in germination from the extract of the clean activated charcoal. Compound from WFT may have come from decomposing weeds which were incorporated into the soil when the plots were tilled.

Several factors including soil temperatures, rate of tomato plant growth, and kind and density of cover crop mulch on the soil surface determined the germination, growth, and eventual density of weeds after the tomato crop was established. Weather conditions following mowing or undercutting can affect weed suppression by the cover crop. In 1998, the cover crop biomass at undercutting was quite high, but it rained the same evening (after undercuttting) and for several days after. Thus many of the weeds which were present before the plots were undercut did not die and became re-established. Most of the weeds, (especially the broadleaf species like lambsquarter, smooth pigweed, ladysthumb, and galinsoga), had already advanced in growth such that they were not suppressed by the cover crop mulch. Thus the weeds growing before undercutting re-infested the plots after the tomatoes were transplanted, especially those plots with higher ratios of field peas.

These results showed that if cover crops sown and killed in the spring or in warm seasons accumulate enough biomass for mulch they may suppress weeds just as well as those sown in autumn then killed in spring which is the current practice in the northern parts of the USA. However, only RRH and RpH had similar weed suppression to WT when weed dry weights were compared (Table 2.7).

There must also be at least three dry days after undercutting to allow the weed' and cover crop' roots to dry out. Re-establishment may also adversely affect the growth and development of the primary crop. The greatest cover crop biomass was obtained in two of the bicultures, a factor in favor of identifying the right mixtures for weed control.

The extract study, though done only in 1998, showed that activated charcoal could be used to trap compounds with allelopathic effects, and therefore another option to use in such studies. The study also re-affirmed that 'Wheeler' rye produces allelopathic compounds, and field peas possibly do the same, though weeds were not suppressed to the same degree in PPH as in RRH (Table 2.7). Peas have been reported to produce compounds with allelopathic activity (Schneck and Werner, 1991).

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Treatments	Abbreviation	1996		1997		1998	
		Kg ha^{-1}					
		Rye	Peas	Rye	Peas	Rye	Peas
Pure rye	RRH	126.0		141.8		129.3	
Pure rye	RRM	63.0		70.9		64.6	
Pure rye	RRL	31.5		35.4		32.3	
¾ rye + ¼ field peas	RpH	94.5	43.6	106.3	48.6	97.0	56.7
¾ rye + ¼ field peas	RpM	47.3	21.8	53.1	24.3	48.5	28.4
¾ rye + ¼ field peas	RpL	23.3	10.9	26.6	12.2	24.3	14.2
½ rye + ½ field peas	rpH	63.0	87.3	70.9	97.3	64.6	113.4
½ rye + ½ field peas	rpM	31.5	43.6	35.4	48.6	32.3	56.7
½ rye + ½ field peas	rpL	15.8	21.8	17.7	24.3	16.2	28.4
¼ rye + ¾ field peas	rPH	31.5	130.8	35.4	145.8	32.3	170.0
¼ rye + ¾ field peas	rPM	15.8	65.4	17.7	72.9	16.2	85.0
¼ rye + ¾ field peas	rpL	7.9	32.7	8.9	36.4	8.1	42.5
Pure field peas	PPH		174.5		194.5		226.8
Pure field peas	PPM		87.3		97.3		113.4
Pure field peas	PPL		43.6		48.6		56.7
Weedy control, mowed or undercut, untilled	WNT						
Weedy control, tilled	WT						
Weed-free control, tilled	WFT						

Table 2.1. Cover crop treatments and seeding rates for three years of field trials in Columbus, OH. H, high (100%); M, medium (50%) seeding rate; L, low (25%) seeding rate. No cover crops were sown in the controls WNT, WT, and WFT.

Table 2.2. Analysis of variance of main factors for 1996, 1997, 1998, and 3-year pooled weed data before cover crop kill in Columbus, OH. Means with the same letter are not significantly different at the 0.05 probability level. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, M, L, 100, 50 and 25% seeding rates, respectively. RP, cover crop combination; SR, seeding rate; Y, year; brdleaf, broadleaf. *, **, ***, significant at 0.05, 0.01, and 0.001 probability levels, respectively. Ns, not significant at 0.05 probability level.

Factor	1996			1997			1998			3-year pooled data		
	Brdleaf weeds (no m^{-2})	Grass weeds (no m^{-2})	% weed ground cover	Brdleaf weeds (no m^{-2})	Grass weeds (no m^{-2})	% weed ground cover	Brdleaf weeds (no m^{-2})	Grass weeds (no m^{-2})	% weed ground cover	Brdleaf weeds (no m^{-2})	Grass weeds (no m^{-2})	% ground cover
RR	40	5 a	10 b	88 a	12 b	10 bc	146	4	27 c	91	7 b	15 c
Rp	30	2 a	9 b	78 a	8 bc	8 bc	144	0	25 c	84	3 b	15 c
rp	21	1 a	4 b	56 bc	4 c	6 c	180	2	33 b	86	2 b	15 c
rP	32	2 a	11 b	48c	4 bc	12 b	228	2	42 a	105	3 b	24 b
PP	32	14 b	28 a	72 ab	48 a	38 a	246	10	40 a	116	24 a	36 a
H	22	2	4 b	48 c	8 b	6 c	130	0	23 c	68 b	4 b	12 c
M	34	8	11 b	68 b	18 a	12 b	198	2	34 b	100 ab	10 a	20 b
L	38	4	22 a	90 a	20 a	26 a	238	8	43 a	122 a	10 a	32 a
1996										31 c	5 b	16 b
1997										69 b	15 a	15 b
1998										189 a	4 b	33 a
RP	Ns	*	***	***	***	***	Ns	Ns	***	Ns	***	***
SR	Ns	Ns	***	***	***	***	Ns	Ns	***	**	**	***
RP x SR	Ns	Ns	*	***	*	***	Ns	Ns	***	Ns	Ns	***
Y										***	***	***
Y x RP										Ns	***	***
Y x SR										Ns	Ns	Ns
Y x RP x SR										Ns	Ns	Ns

Table 2.2.

Table 2.3. Weed data taken before killing cover crops in 1996, 1997, and 1998, at Columbus, OH. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea; WNT, un-tilled weedy control; WT, tilled weedy control; WFT, tilled weed-free control. H, M, L, 100, 50 and 25% seeding rates, respectively. Controls did not differ in their preparation before cover crop kill. Height was not analyzed and LSD for grass weed numbers is not reported because data was transformed before statistical analysis.

Treatment	1996				1997				1998			
	Broad leaf weed D (no m^{-2})	Height (cm)	Grass weed D (no m^{-2})	% weed ground cover	Broad leaf weed D (no m^{-2})	Height (cm)	Grass weed D (no m^{-2})	% weed ground cover	Broad leaf weed D (no m^{-2})	Height (cm)	Grass weed D (no m^{-2})	% weed ground cover
RRH	56	<5	1	10	122	<7	6	12	100	45	0	15
RRM	34	<5	9	12	70	<9	14	8	94	<5 to 35	4	20
RRL	32	<5	4	10	70	<10	16	9	248	30 to 70	10	45
RpH	14	<3	1	2	40	<10	4	4	118	<5 to 35	2	17
RpM	39	<5	1	2	90	<11	2	8	86	<5 to 45	2	15
RpL	39	3 to 50	5	22	102	<13	16	11	228	70	0	42
rpH	9	<5	0	2	26	<7	0	3	112	<5 to 55	0	18
rpM	30	<7	2	5	70	<10	6	7	214	30 to 60	4	40
rpL	24	<10	2	5	74	8 to 30	4	8	216	<5 to 80	0	40
rPH	14	<7	0	2	20	<10	0	2	212	70	2	40
rPM	39	<9	4	8	52	<15	4	5	232	<5 to 70	2	43
rPL	44	3 to 60	2	26	74	3 to 60	8	30	240	<5 to 70	4	44
PPH	16	<5	9	6	30	<5	28	8	116	<5 to 85	2	25
PPM	29	3 to 60	26	31	58	5 to 60	62	33	362	<5 to 80	4	50
PPL	51	30 to 50	8	48	126	20 to 60	54	73	230	30 to 90	24	46
WNT	43	40 to 60	16	95	116	40 to 60	32	98	666	<5 to 95	0	100
WT	53	40 to 60	29	98	130	40 to 60	46	99	732	85	0	100
WFT	50	40 to 50	52	98	126	40 to 60	66	100	658	5 to 100	4	100
LSD	Ns			15.4	31.0			6.88	74.7			4.99

Table 2.3

Treatment	Data pooled over 3 years		
	Broad leaf weeds (no. m^{-2})	Grass weeds (no.m^{-2})	% ground cover by weeds
RR(H)	93	2	11
RR(M)	66	9	12
RR(L)	117	10	21
Rp(H)	57	2	9
Rp(M)	71	3	9
Rp(L)	123	9	24
rp(H)	49	0	8
rp(M)	105	4	20
rp(L)	105	2	18
rP(H)	82	1	16
rP(M)	107	3	23
rP(L)	119	5	36
PP(H)	54	12	13
PP(M)	150	37	32
PP(L)	142	29	52
Means of controls	285	26	99
LSD	98.6		7.9

Table 2.4. Weed data taken before killing cover crops pooled for 1996, 1997, and 1998, at Columbus, Ohio. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea; WNT, un-tilled weedy control; WT, tilled weedy control; WFT, tilled weed-free control. H, M, L, 100, 50 and 25% seeding rates, respectively. Controls did not differ in their preparation before cover crop kill. LSD for grass weed numbers not shown because data was transformed before statistical analysis.

Factor	1996			1997			1998			3-year pooled data		
	MT. Ha^{-1}											
	Rye	Peas	Total	Rye	Peas	Total	Rye	Peas	Total	Rye	Peas	Total
RR	1.0 a		1.0 c	2.0 a		2.0	3.6 a		3.6 a	2.2 a		2.2 b
Rp	0.9 a	1.0 c	1.9 b	1.7 ab	0.4 c	2.1	2.5 b	1.2 b	3.7 a	1.7 b	0.9 d	2.5 a
rp	0.8 a	1.3 bc	2.1 b	1.4 b	0.8 b	2.2	1.8 c	2.0 a	3.8 a	1.4 c	1.3 c	2.7 a
rP	0.6 b	1.6 b	2.2 b	0.8 c	1.6 a	2.4	1.1 d	2.6 a	3.8 a	0.8 d	2.0 b	2.8 a
PP		3.1 a	3.1 a		1.9 a	1.9		2.7 a	2.7 b		2.6 a	2.6 a
H	0.8	2.1 a	2.3 a	1.9 a	1.6 a	2.8 a	2.8 a	2.5 a	4.3 a	1.8 a	2.1 a	3.1 a
M	0.8	1.9 a	2.2 a	1.5ab	1.1 b	2.1 b	2.5 a	2.1 ab	3.7 a	1.6 a	1.7 b	2.7 b
L	0.8	1.3 b	1.7 b	1.1b	0.8 b	1.5 c	1.5 b	1.7 b	2.6 b	1.1 b	1.3 c	1.9 c
1996										0.8 a	1.7 b	2.1 b
1997										1.5 b	1.2 c	2.1 b
1998										2.3 a	2.1 a	3.5 a
RP	***	***	***	***	***	Ns	***	***	*	***	***	**
SR	Ns	***	**	***	***	***	***	*	***	***	***	***
RP x SR	Ns	Ns	Ns	Ns	*	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Y										***	***	***
Y x RP										***	**	***
Y x SR										***	Ns	**

Table 2.5. Anialysis of variance of main factors for 1996, 1997, 1998, and 3-year pooled cover crop data at time of cutting in Columbus, OH. Means with the same letter not significantly different at 0.05 probability level. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, M, L, 100, 50, and 25% seeding rates, respectively. RP, cover crop combination; SR, seed rate; Y, year; *. **, ***, F-tests significant at 0.05, 0.01, and 0.001, probability levels. Ns, not significant at 0.05 probability level.

Factor	Weed biomass 63 DAS (MT ha^{-1})	Weed biomass 45 DAT (MT ha^{-1})
RR	1.0 b	2.5 c
Rp	0.9 b	2.7 bc
rp	1.3 b	3.5 b
rP	1.4 b	3.4 b
PP	2.0 a	4.3 a
H	0.8 c	2.8 b
M	1.3 b	3.4 ab
L	1.8 a	3.7 a
RP	***	***
SR	***	*
RP x SR	Ns	Ns

Table 2.6: Analysis of variance and mean separation of weed biomass for cover crop main factors cover crop combinations (RP) and seeding rates (SR) for 1998 field trials. DAS, days after sowing cover crops; DAT, days after transplanting tomatoes. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, M, L, 100, 50 and 25% seeding rates, respectively. Means with the same letter not significantly different at p=0.05. *, ***, significant at 0.05 and 0.001 levels of probability, respectively.

Treatment	Weed biomass 63 DAS (MT ha^{-1})	Weed biomass 45 DAU (MT ha^{-1})
RR(H)	0.3	1.7
RR(M)	1.0	2.5
RR(L)	1.5	3.2
Rp(H)	0.6	1.9
Rp(M)	0.5	3.3
Rp(L)	1.7	3.0
rp(H)	0.6	3.0
rp(M)	1.4	3.4
rp(L)	1.8	4.0
rP(H)	0.9	2.7
rP(M)	1.4	3.5
rP(L)	1.7	4.1
PP(H)	1.5	4.7
PP(M)	2.1	4.1
PP(L)	2.3	3.9
WNT	5.7	6.1
WT	5.0	1.8
WFT	6.0	0.0
LSD	0.96	1.3

Table 2.7: Weed dry weights at cover crop undercutting (63 DAS) and 45 days after undercutting (DAU) in Columbus, OH, in 1998. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. WNT, un-tilled weedy control; WT, tilled weedy control; WFT, tilled weed-free control. H, M, L, 100, 50 and 25% seeding rates, respectively.

Treatment	1996				1997				1998			
	Jul-23	Jul-26	Jul-29	Aug-5	Jun-30	Jul-7	Jul-14	Jul-21	Jul-17	Jul-22	Jul-27	Jul-31
RRH	20.5	22	19	24	20	20	21	19.5	23	25	23	21
RRM	22	24	20.5	26	21	21	22.5	21	22	23	22	22
RRL	25	27	25	31	24	24	24	23.5	22	24	22	21
RpH	22.5	23.5	22	27.5	21	21	23	22	23	24	23	22
RpM	21	22	19	24	20	21	22	20	23	25	23	22
RpL	22	23	21	25	22	20	23.5	22	22	25	22	22
rpH	17.5	19	17	20	20	17	19	18	22	24	21	22
rpM	22	23	19	25	21	19	21.5	20	22	24	22	21
rpL	22	23	21	25	22	20	23	21	22	23.5	22	21
rPH	22.5	24	22.5	27	19	21	21	19	22	24	23	22
rPM	22.5	24	21	27	21	21.5	22.5	21	21	22.5	21	19.5
rPL	22	23	22	25	22	22	23	21.5	21	23	22	22
PPH	22.5	24	22	27	22.5	21.5	24	22	22	24	22.5	22
PPM	23.5	25	22	28	23	21	25	23	23	25	23	21
PPL	22.5	25	23	26	24	22.5	23.5	22	23	24	21	22
WNT	21.5	22	21	25	21	20	22	20	22	24	22	21
WT	25	27.5	25	34	22.5	22	22.5	21	22	24.5	23	22
WFT	24.5	27	25	28	24	24	24	23	24	25	23	22

Table 2.8. Soil temperatures (C) recorded at midday at a 15 cm depth in 1996, 1997, and 1998 in Columbus, OH. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, M, L; high, medium, and low seeding rates, respectively. WNT, un-tilled weedy check; WT, tilled weedy check; WFT, tilled weed-free check.

Source of extract	concentration of extract applied on lettuce seed			
	1x	0.1x	0.01x	0.001x
	Total lettuce seed germinated			
Rye	11a	14	14	14
Field pea	13b	14	15	14
Weeded contr	13b	14	14	14
	Lettuce seedling fresh weight (mg)			
Rye	19	18ab	17	16
Field pea	18	19a	16	15
Weeded contr	18	17b	16	15

Table 2.9: Total germination and fresh weight of lettuce seedlings in 4 concentrations of extracts from rye, field pea, and conventionally weeded plots in 1998 field trials, in Columbus, OH. x = 17.4 ml of fresh extract.

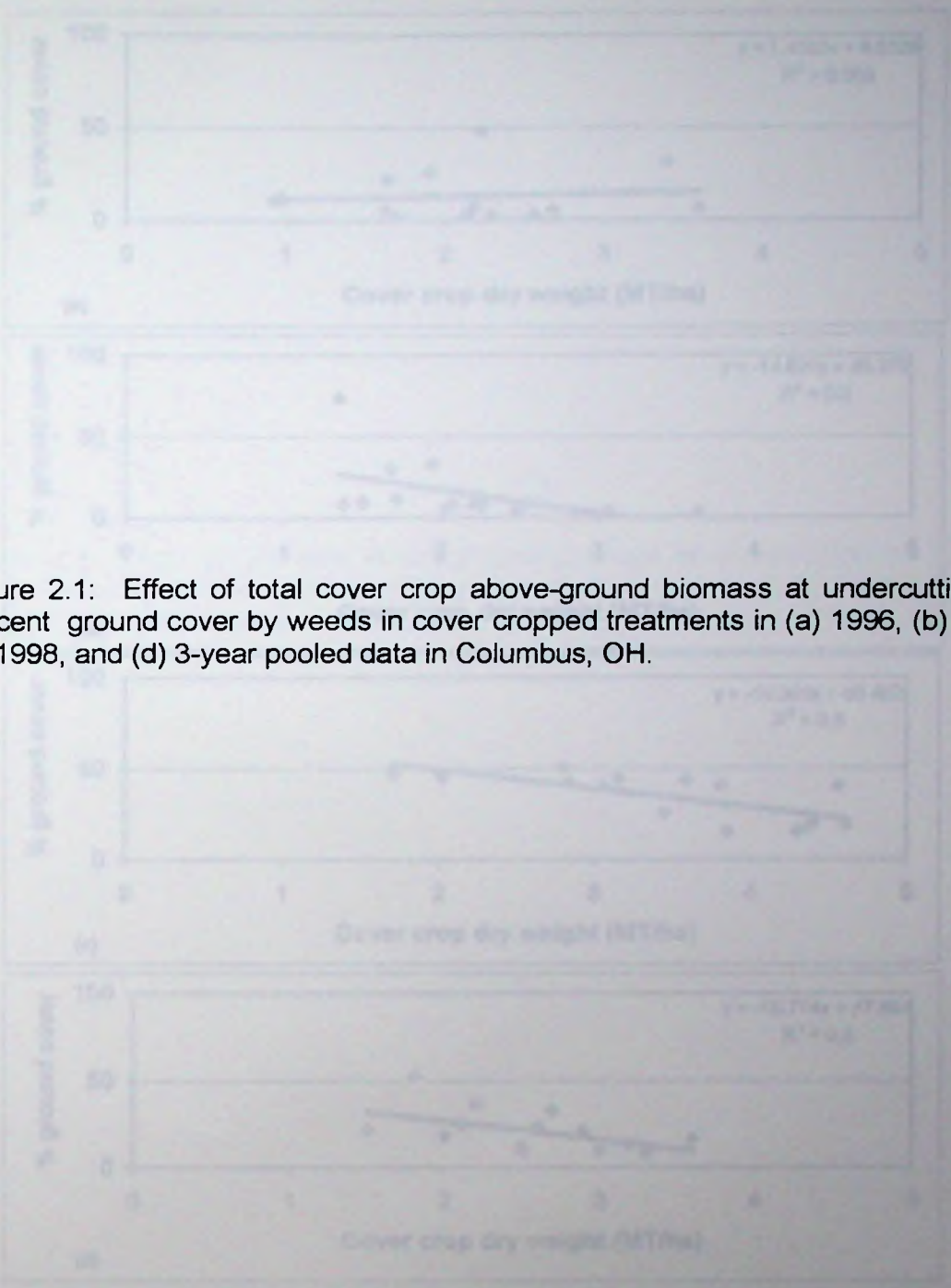

Figure 2.1: Effect of total cover crop above-ground biomass at undercutting on percent ground cover by weeds in cover cropped treatments in (a) 1996, (b) 1997, (c) 1998, and (d) 3-year pooled data in Columbus, OH.

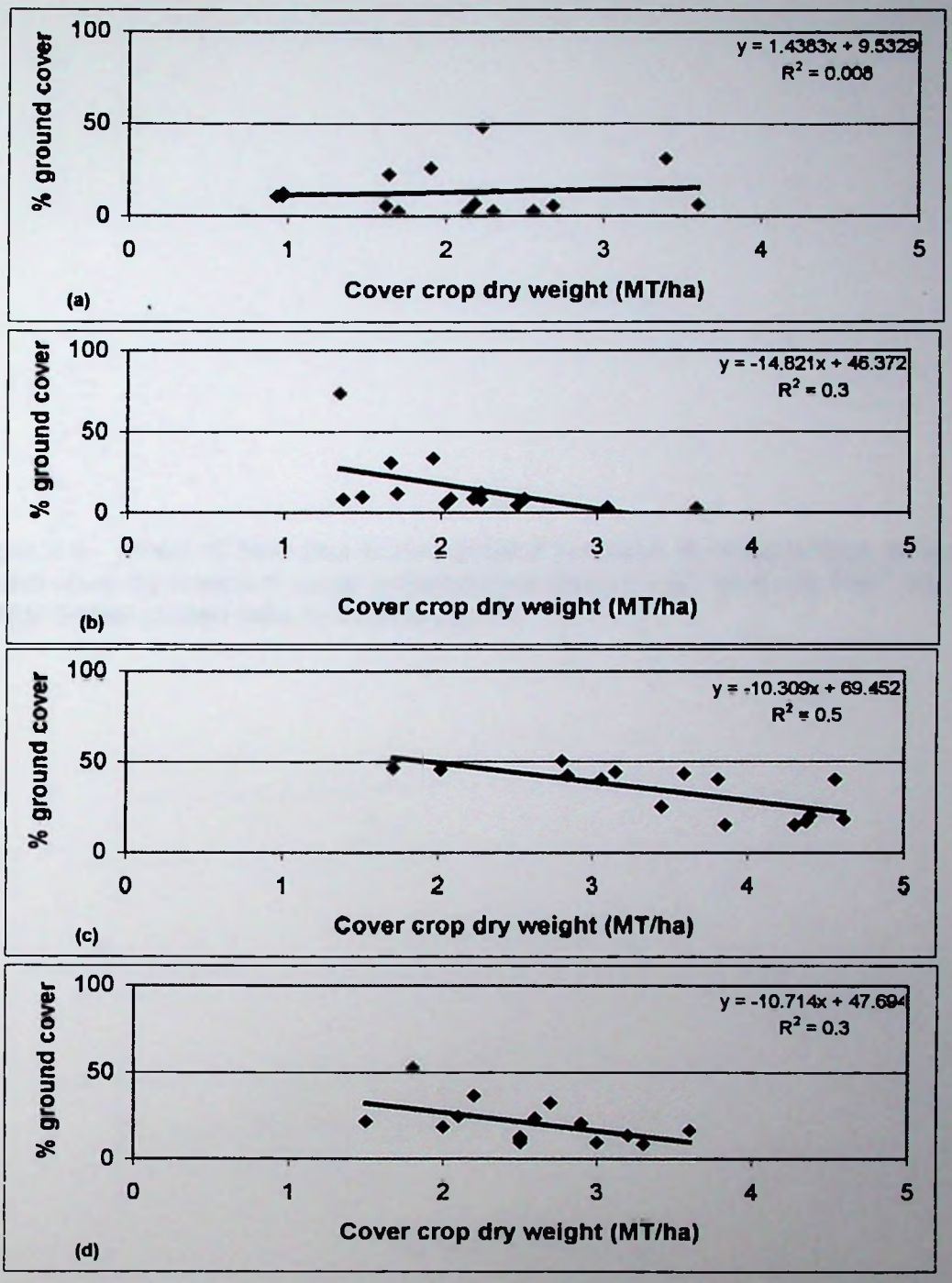
% ground cover
100
50
0
0
1
2
3
4
5
y = 1.4383x + 9.5329
R² = 0.008
Cover crop dry weight (MT/ha)
(a)
% ground cover
100
50
0
0
1
2
3
4
5
y = -14.821x + 46.372
R² = 0.3
Cover crop dry weight (MT/ha)
(b)
% ground cover
100
50
0
0
1
2
3
4
5
y = -10.309x + 69.452
R² = 0.5
Cover crop dry weight (MT/ha)
(c)
% ground cover
100
50
0
0
1
2
3
4
5
y = -10.714x + 47.694
R² = 0.3
Cover crop dry weight (MT/ha)
(d)

Figure 2.1.

Figure 2.2: Effect of field pea above-ground biomass at undercutting on percent ground cover by weeds in cover cropped treatments in (a) 1996, (b) 1997, (c) 1998, and (d) 3-year pooled data in Columbus, OH.

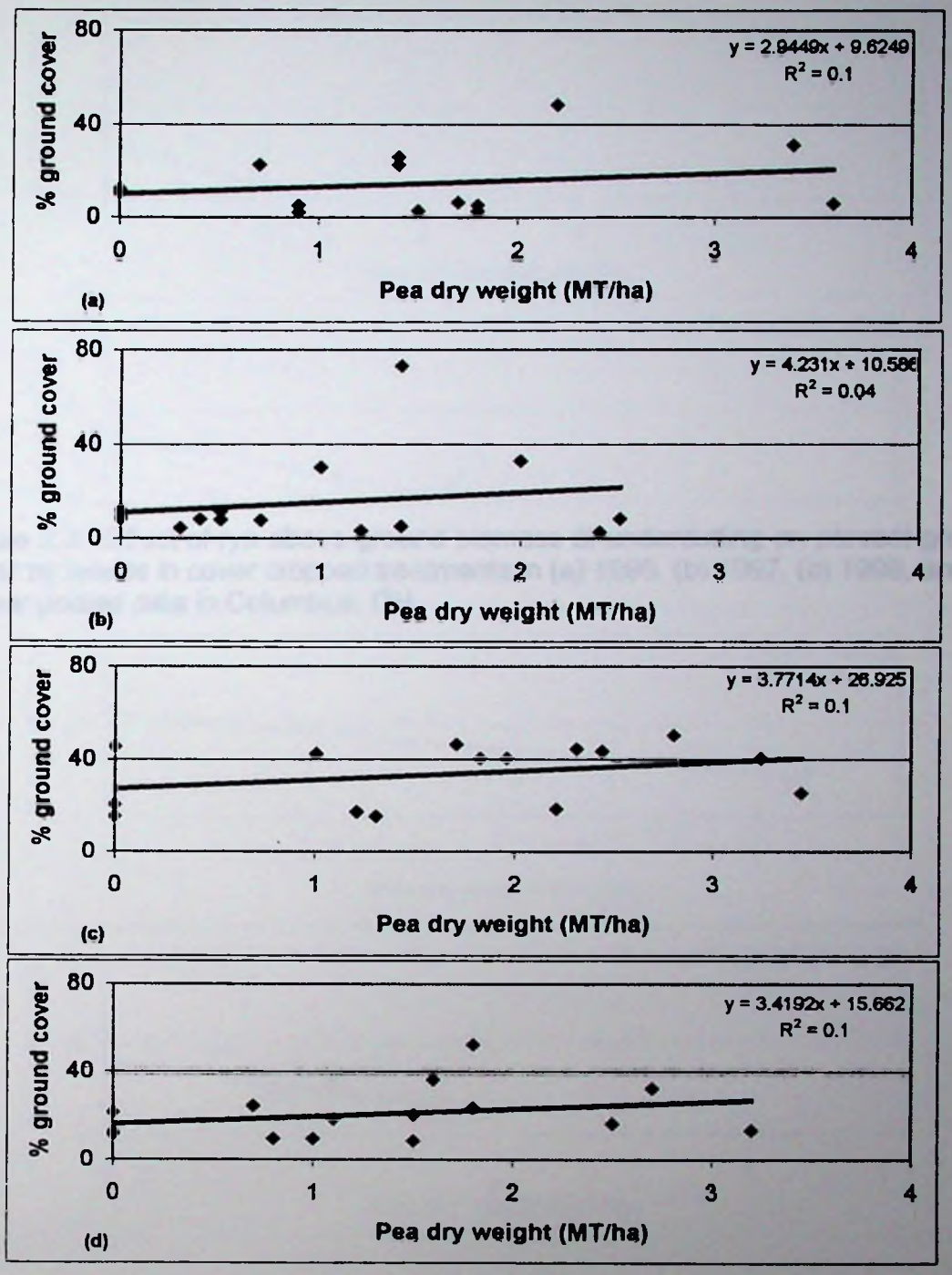
% ground cover
80
40
0
0
1
2
3
4
y = 2.9449x + 9.6249
R² = 0.1
Pea dry weight (MT/ha)
(a)
% ground cover
80
40
0
0
1
2
3
4
y = 4.231x + 10.586
R² = 0.04
Pea dry weight (MT/ha)
(b)
% ground cover
80
40
0
0
1
2
3
4
y = 3.7714x + 26.925
R² = 0.1
Pea dry weight (MT/ha)
(c)
% ground cover
80
40
0
0
1
2
3
4
y = 3.4192x + 15.662
R² = 0.1
Pea dry weight (MT/ha)
(d)

Figure 2.2.

Figure 2.3: Effect of rye above-ground biomass at undercutting on percent ground cover by weeds in cover cropped treatments in (a) 1996, (b) 1997, (c) 1998, and (d) 3-year pooled data in Columbus, OH.

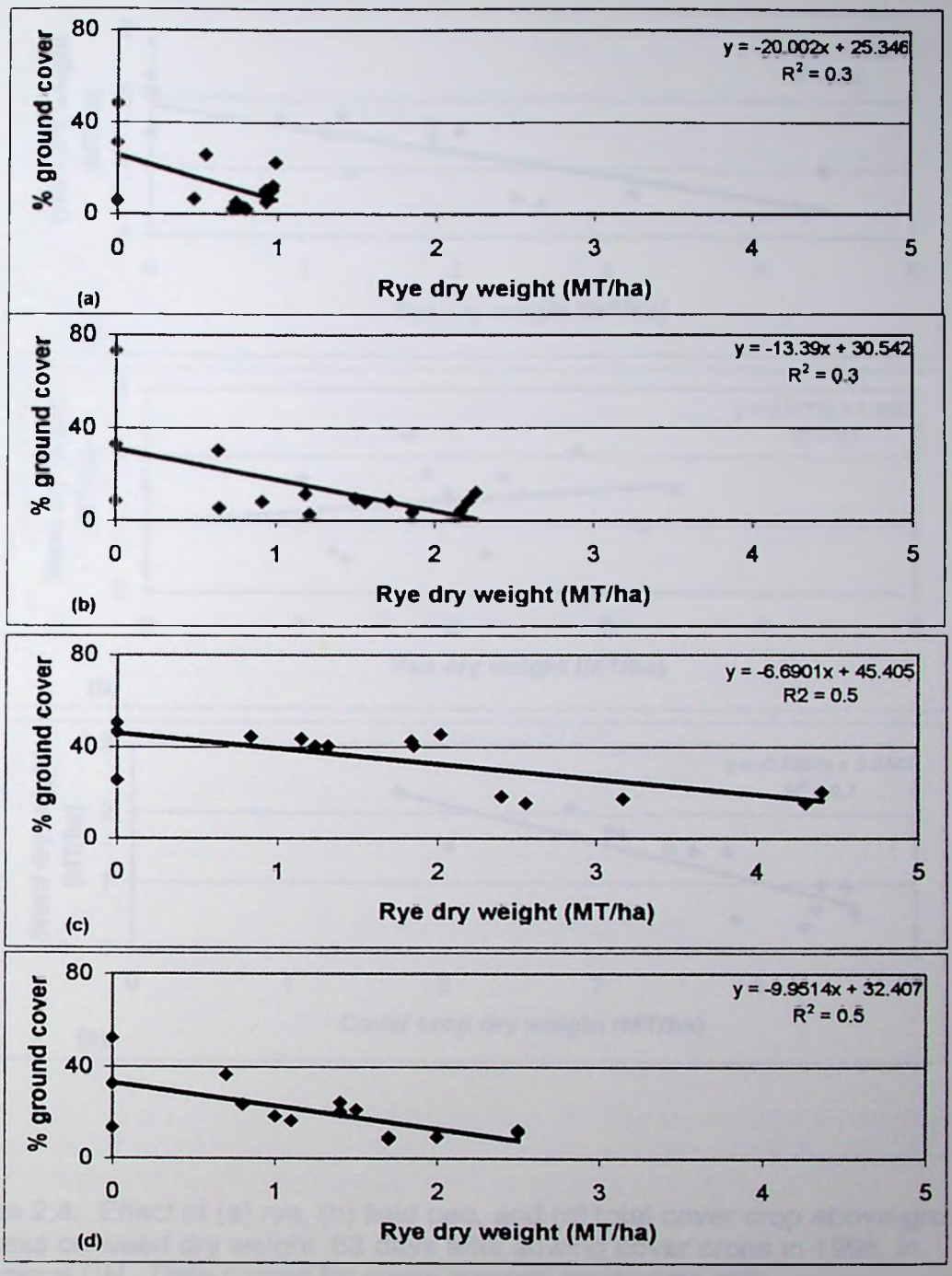
% ground cover
80
40
0
0
1
2
3
4
5
Rye dry weight (MT/ha)
y = -20.002x + 25.346
R² = 0.3
(a)
y = -13.39x + 30.542
R² = 0.3
(b)
y = -6.6901x + 45.405
R2 = 0.5
(c)
y = -9.9514x + 32.407
R² = 0.5
(d)

Figure 2.3.

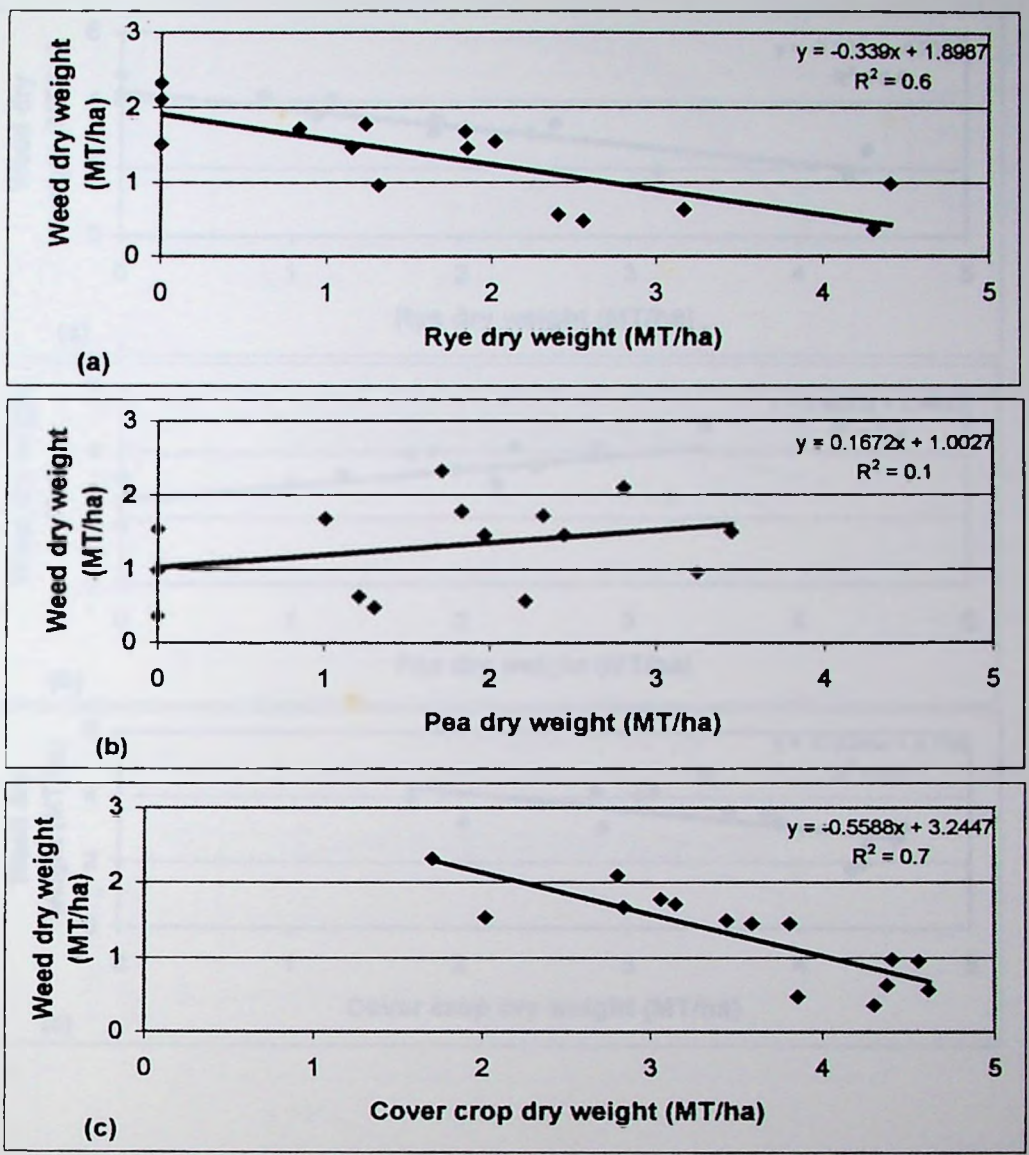

Figure 2.4: Effect of (a) rye, (b) field pea, and (c) total cover crop above-ground biomass on weed dry weight 63 days after sowing cover crops in 1998, in Columbus,OH. Data plotted for cover cropped treatments only.

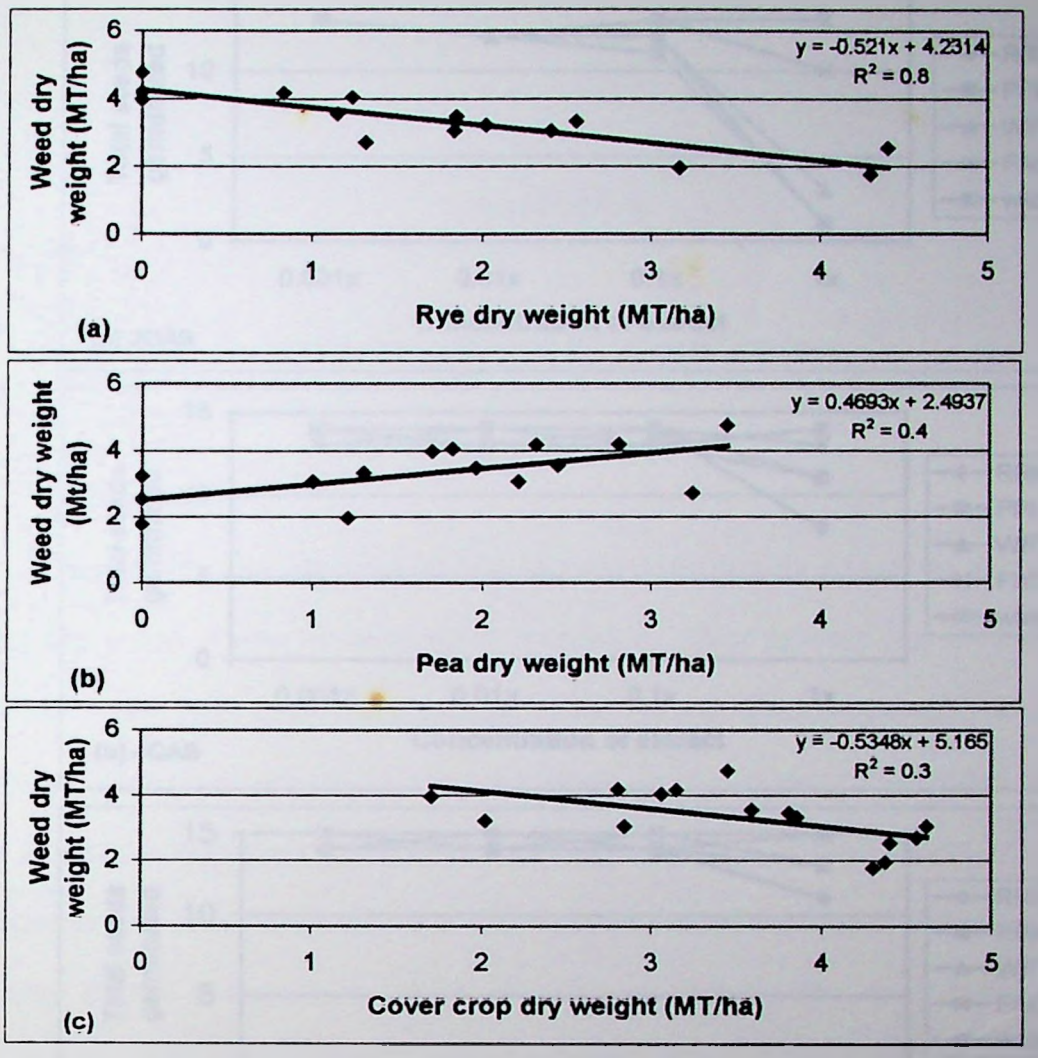

Figure 2.5: Effect of (a) rye, (b) field pea, and (c) total cover crop above-ground biomass on weed dry weight 45 days after undercutting in 1998, in Columbus, OH. Data plotted for cover cropped treatments only.

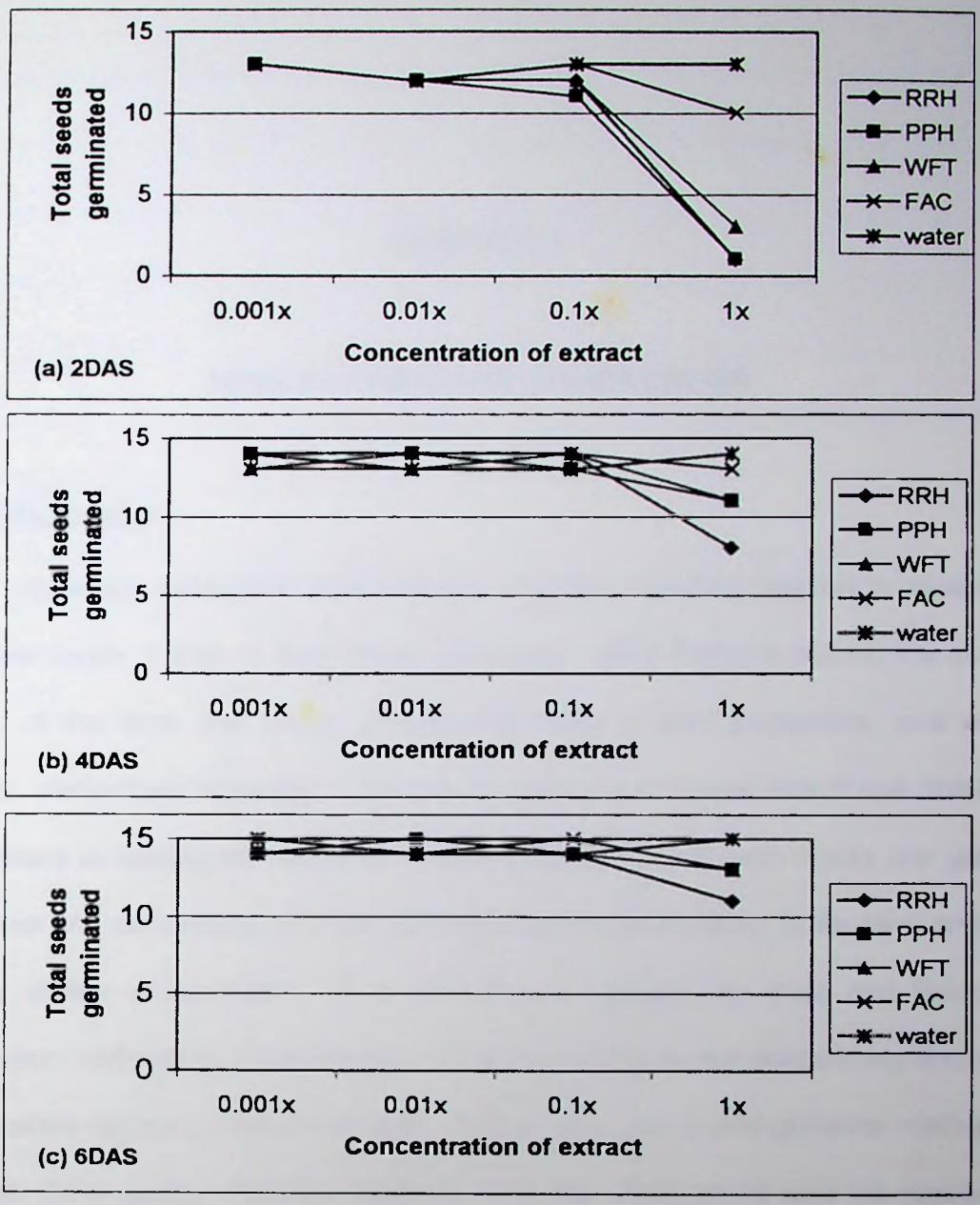

Figure 2.6: Total lettuce seed germinated (a) 2 DAS, (b) 4 DAS, and (c) 6 DAS when treated with 4 concentrations of from activated charcoal buried in three treatments in the 1998 field trial in Columbus, OH. x = 17.4 ml of pure extract; RRH, pure rye; PPH, pure pea; WFT, tilled weed-free check; DAS, days after sowing. Controls were extracts from fresh activated charcoal (FAC), and distilled water.

CHAPTER 3

TOMATO GROWTH IN COVER CROPS

INTRODUCTION

Vegetable production in developing countries including Uganda is done with very low levels, if any, of agricultural chemicals. Most farmers rely on the innate fertility of the land, and invest considerable labor in land preparation and weed control. Yields from vegetable and other crops are much lower than those obtained by farmers in developed countries where considerable off-farm inputs are used. Intensive and continuous land use has reduced the productivity of the land and the quality of the environment. It is desirable to identify low cost and low-input production methods to maintain and, if possible, improve soil productivity and crop yields while reducing production costs. Cover crop use is one potential method to achieve these goals. Results obtained from this study could also be applied to home gardeners in developed countries, and also in commercial situations where the autumn crops are harvested too late to establish over-wintering cover crops.

Some studies involving over-wintered cover crops for vegetable production in temperate climates have yielded positive results (Abdul-Baki and Teasdale, 1993; NeSmith et al., 1994). A few studies have already shown the possibility of

using cover crops sown in the spring for weed control, but not all reported the effect on the primary crops (Ateh and Doll, 1996; Barnes and Putnam, 1983; Bordelon and Weller, 1997; Nelson et al., 1991). This raised our interest in exploring cover crop use for crop production in tropical climates while taking into account some pertinent differences. One possible option for the tropics would be to sow the cover crops at the beginning of the rainy season, kill them 1.5 to 2 months later, then establish the vegetable crops.

There is a possibility of primary crops being negatively affected by cover crops, for example, through the production of allelochemicals which are otherwise desirable for weed suppression (Creamer et al., 1996; Lehle et al., 1993; Putnam, 1988; White et al., 1989). Cover crops could also use up soil nutrients and soil moisture thus limiting availability to the subsequent primary crops. It has also been reported that plant mulches delayed tomato fruit maturity by approximately 10 days, but total tomato yield in the hairy vetch mulch was more than 2 times that of the unmulched control, and higher than that from plants mulched with black polyethylene (Abdul-Baki and Teasdale, 1993). Some bioassays have also shown allelopathic effects of cover crop extracts on both weed and primary crop seed germination and seedling growth (White et al., 1989; Lehle et al., 1983). Potential cover crops have to be assessed for their effect on primary crop growth and yield before they are recommended to farmers. Research geared towards tropical conditions has to be carried out to determine the effect of cover crops on the establishment, growth and eventual yield of vegetable crops.

The use of legume/monocot cover crop combinations could result in better vegetable crop yields as opposed to using pure legume or monocot stands, as the two cover crop families have several complimenting characteristics (Mohler and Teasdale, 1993; Walker, 1993). Monocots could offset the rapid decomposition of legumes which in turn fix and add nitrogen to the soil. Nitrogen leaching is also less in legume/monocot mixtures than in a pure legume stand (Agboola and Fayemi, 1972; Clark et al., 1994; Sainju and Singh, 1997). With the right legume/monocot cover crop combination the vegetable crop would benefit both from the weed control and the nitrogen fixation.

The overall goal of this study was to evaluate how a vegetable crop would perform in cover crops sown in the early spring and killed prior to its establishment. This was to emulate establishing a cover crop at the onset of the rains in a tropical situation, document some of the problems that might be met, and come up with ways to solve them before adapting the practice. The specific objectives were to (a) study the performance of the tomato crop when planted into the different cover crop proportions and seed rates in the field, and (b) study the effect of the different cover crop treatments on soil fertility before and after the crop trial.

Results obtained would help define further research on cover crops for vegetable production in the tropics and for home gardeners in the temperate regions. Results can also be extrapolated to other vegetable crops. Data were analyzed using SAS and significantly different means of main factors were separated by LSD.

MATERIALS AND METHODS

The field trials were conducted at The Ohio State University Waterman Agricultural and Natural Resources Farm, Columbus OH, on a Miami silt loam (Mesic Typic Hapludalf) soil, in 1996, 1997, and 1998. The field plots chosen for the trials were not treated with herbicides to maximize the weed pressure and in keeping with minimizing the use of agricultural chemicals. The land was plowed and then rototilled to obtain a fine seedbed. Flat seedbeds measuring 2.5 m x 7.5 m were used in 1996, while raised beds measuring 1.2 m x 12 m were used in 1997 and 1998. Cover crops winter rye 'Wheeler' (*Secale cereale* L.) and field peas (*Pisum sativum* L.) were sown by hand on 18 April 1996, 24 April 1997, and 23 April 1998. Treatments were as shown in Table 2.1 (Chapter 2) for all three years and were laid out in a randomized complete block design with four replications and 18 treatments in each block.

The tomato (*Lycopersicon esculentum* Mill.) cultivar 'Marglobe' from the Ohio Seed Company (127 Jackson St., West Jefferson, OH) was used as the test vegetable crop. After weed observations were taken, the cover crops and WNT (the weedy check) were mown down 74 days after sowing (DAS) in 1996, and undercut 61 DAS and 63 DAS in 1997 and 1998 respectively. The tilled, un-weeded (WT) and the tilled and weeded (WFT) checks were cultivated 83, 61, and 73 DAS in 1996, 1997 and 1998 respectively. One-month-old tomato seedlings were hand-transplanted on 11 and 12 July 1996, 26 and 27 June 1997, and 6 and 7July 1998. The seedlings were planted in 3 rows per plot, with 15 plants per row

spaced 45 cm between plants and 75 cm between rows in 1996. Spacing in 1997 and 1998 was 60 cm between rows and 45 cm between plants, with 50 plants per row, and two rows per raised bed. Each seedling received 200 mls of 10N-52P-10K Plantex starter solution (PlantCo Inc., 314 Orenda Rd, Brampton, Ontario, Canada) at transplanting. No other fertilizer amendments were made in the trial plots for the duration of the experiments.

Diseases and pests were controlled based on scouting and spraying was carried out when necessary following recommendations for the State of Ohio (Ohio State University Extension, 1998). To gauge the effect of the different cover crop treatments on tomato growth, tomato plants were destructively harvested from all treatments 31 days after transplanting (DAT) in 1996, 34 DAT in 1997, and 50 DAT in 1998. Tomato plant growth was very slow in 1998 due to low soil moisture and high weed pressure. Most recent fully expanded leaflets from the top of the tomato canopy were picked for tissue nutrient analysis 33 DAT in 1996 and 53 DAT in 1997. Data was collected on flowering, fruiting and fruit ripening of tomato plants. WFT was hand weeded whenever required. Ten plants were tagged for harvesting from the central row of each plot in 1996, and from the central parts of both rows in 1997 and 1998. Tomato fruit were picked and weighed as they ripened at 4-7 day harvest intervals. Soil was sampled before sowing cover crops and at the end of the growing season in 1997 and 1998 for nutrient analysis at OARDC labs. Soil was also sampled at time of tomato transplanting in 1998.

RESULTS AND DISCUSSION

Effect of cover crop treatments on tomato growth and development.

Spring and summer of 1996 and 1998 were drier than in 1997 (Appendix C). The tomato crops had to be watered with overhead sprinkler irrigation several times after transplanting. Summer 1998 was especially dry after transplanting and severely affected the establishment of the tomato transplants. On the other hand no additional watering was necessary the whole of the growing season in 1997.

Tomato plant growth was much greater in 1997 than in 1996 and 1998 (Table 3.1). Tomato plants were destructively harvested much later in 1998 because differences in growth due to cover crop treatments after transplanting were manifested slower than in 1996 and 1997. More leaves per plant were recorded for treatments in 1997 than in the other two years except for rPH, PPH, WT, and WFT in 1996, and WT and WFT in 1998 (Table 3.1). When data was pooled for the three years (3YP) rPM, WT, and WFT had the most leaves per plant (Table 3.2). Rye:pea proportions (RP) significantly affected leaf numbers of tomato plants in 1996 only (Table 3.3), with leaf numbers increasing with increasing field pea ratios in the cover crop. Leaf numbers decreased with decreasing cover crop seed rates (SR). Tomato plants in RRH to RRL and WNT had the least number of leaves per plant. For 3YP data leaves per plant increased significantly from RR to PP (Table 3.4). There were significant differences in tomato leaf numbers among the pooled SR, and among the three

years (Y), with highest numbers being recorded in 1997. The Y by RP interaction was significant.

The most branching (>5 branches) in 1996 was observed for rpH, rPH, rPM, PPH, and PPM, while no branching was seen in RRH and WNT (Table 3.1). Tomato plants in WT and WFT had the most branches in 1996 and 1998. Rye: pea proportions had an effect on number of branches in 1996 and the 3YP data only (Table 3.3, 3.4). Branching increased with increasing proportions of field peas in the cover crops. Branch numbers were significantly different among the 18 treatments in 1996 and 1998, but LSD is not shown because data was transformed before statistical analysis.

Tomato plants in all treatments in 1997 had greater leaf area than in the other two years except for WT and WFT in 1996, and WFT in 1998 (Table 3.1). Only in 1997 did tomato plants in the controls WT and WFT have smaller leaf areas than in some of the cover cropped treatments. When data was pooled rPH, PPH, WT, and WFT had larger leaf areas than the other treatments (Table 3.2). In 1996 and 1998 tomato leaf areas increased with increasing field pea ratios in the cover crop, and decreased with decreasing SR in all three years and 3YP (Table 3.3, 3.4). Tomato leaf areas were significantly different among both RP and SR in 1996, but with no interaction between the two factors. There were highly significant differences in tomato leaf areas among RP in 1997, and significant differences among SR in 1998. For the pooled data there were very significant differences among RP, SR, Y, and an interaction between Y and RP

(Table 3.4). Mean leaf areas in 1997 were more than twice those in 1996, and more than 15 times those in 1998.

Tomato plants in all 18 treatments were taller in 1997 than in 1996, while in RRH to WNT they were almost twice as tall 34 DAT in 1996 compared to 50 DAT in 1998 (Table 3.1). For the pooled data the tallest tomato plants were in PPH, PPM, WT, and WFT (Table 3.2). Tomato plant heights among the 18 treatments were significantly different in 1996, 1998, and 3YP when compared with ANOVA. Tomato plant heights increased with reducing proportions of rye in the cover crops in 1996, 1997, and 3YP, and decreased with reducing SR in 1996 and 3YP (Table 3.3, 3.4). There were significant differences in tomato plant heights among RP in 1996, 1997, and 3YP, and among SR in 1996 and 3YP. There were no significant differences between tomato plant heights for any variable in 1998. Tomato plant heights were highly significantly different between years, but there was no interaction between Y and RP or SR (Table 3.4).

Except for rPH and PPH, tomato plants had greater dry weights in 1997 compared to 1996 (Table 3.1). Dry weights of tomato plants in cover cropped treatments and WNT in 1998 were much lower than in 1996 and 1997 due to the dry spell and the weed pressure that built up. In 1996 tomato plants in WT, PPH, and rPH, were heavier than those in the conventionally hand weeded control (WFT). Tomato plants in WT and WFT were heavier than all the other treatments in 1998. When data was pooled the heaviest plants were in rPH, PPH, WT and WFT (Table 3.2). When subjected to ANOVA there were

significant differences between the 18 treatments for 1996, 1997 and 3YP. Tomato dry weights increased with increasing proportions of pea in cover crop combinations in all three years and 3YP, and fell with reducing SR in 1996, 1998, and 3YP (Table 3.3, 3.4). There were significant differences in tomato dry weights among RP in 1996, 1997, and 3YP, and among SR in 1996, 1998, and 3YP. Tomato plants grew better with higher proportions of pea probably because of the soil nitrogen fixed by the legume. At higher cover crop seeding rates weeds were suppressed sufficiently to allow greater tomato growth and yield compared to lower seeding rates where weed pressure was higher.

Macro-nutrient analysis of tomato leaf tissue.

At the time young tomato leaves were picked in 1996 and 1997 for nutrient analysis, most of the treatments had flowering plants, and some fruit set. Growth of tomato plants in 1998 was very poor due to drought and weed pressure, thus leaves were not picked for nutrient analysis. Nitrogen (N) levels ranged between 1.9 to 2.5 % in 1996, and between 2.6 to 3.7 % in 1997 (Appendix E). Phosphorus (P) levels ranged from 6,500 to 10,800 parts per million (ppm) in 1996, and between 5,575 to 6,900 ppm in 1997. Potassium (K) levels ranged between 20,600 to 30,200 ppm in 1996, and between 29,700 to 35,700 ppm in 1997. Tomato plants in 1997 had higher N and K levels, but lower P levels than tomato plants in 1996. There was no consistent relationship between levels of the nutrients and cover crop treatments from year to year. The only significant

differences were among P levels of cover crop combinations and among K levels for seed rates in 1996 (data not shown). Contrary to our expectations increasing proportion of pea in the cover crop had no effect on N level in tomato leaves. This could be because most of the N was at this time being diverted to the flowering and fruiting tissues of the tomato plants. There were significant differences among the 18 treatments in tomato tissue P, but none for N and K in 1996. There were significant differences in N levels among treatments, while for P and K there were highly significant differences among replicates only in 1997.

Analysis of soil samples.

There were no significant differences in soil pH, CEC, and macro-nutrient levels among cover cropped treatments and between cover cropped treatments and the three controls in 1997 (Appendix F). However P and K levels were higher in all treatments in end-of season soil samples, which is not easily explained for WNT, WT, and WFT. All Ca, Mg, and CEC levels were lower in end of season soil samples. In 1998 N, P, K, Ca, MG, and CEC levels were higher in all treatments at cover crop kill with no significant differences among all 18 treatments. End-of-season N levels were lower in all treatments except RpH, indicating that N was used up during the season, more likely by the dense weed population. Since locations were shifted each year it is not be possible to draw conclusions on the effect of cover crops on soil nutrients in this study.

Effect of cover crop treatments on flower and fruit set of tomato plants.

Additional growth and development data for tomato plants in 1996, 1997, and 1998 are shown in Figure 3.1, 3.2, and 3.3. Flowering started 24 DAT in 1996, 25 DAT in 1997, and 35 DAT in 1998, and was much faster overall in 1997 than in 1996 and 1998 (Figure 3.1). Tomato plants flowered slower in pure rye (RR) in 1996 (Figure 3.1a), but in 1997 the higher and constant soil moisture helped in overcoming the stunting effect of rye (Figure 3.1b). By the last day of recording in 1996, RRH and RRM had not achieved 60 % plants in bloom, while in 1997 RRH to RpM had 90% or more plants flowering. Fifty percent flowering was achieved earliest by tomato plants in rPH, PPH, WT, and WFT in 1996, and by tomato plants in RpH, rpH, and rPH in 1997. Tomato plants in WNT were the slowest in flowering in both years, barely achieving 50 % by the last day of recording in 1996. Flowering was very poor in 1998 in the cover cropped treatments, with the controls WT and WFT outperforming the rest of the treatments. By the last day of recording tomato plants in all cover cropped plots and WNT had not achieved 20% flowering. Still even under these stressful conditions tomato plants in rpH, rPH, and PPH flowered faster than the rest of the cover cropped treatments (Figure 3.1c). Having peas in the cover crop mulch helped to some extent in overcoming the unfavorable weather and weed pressure.

The fruiting of tomato plants followed a similar pattern as that of flowering (Figure 3.1, 3.2). Tomato plants in rPH, PPH, WT, and WFT achieved 50% fruiting earlier than the other treatments in 1996 (Fig. 3.2a), while plants in rpH, rPH, PPM,

and WFT did so in 1997 (Figure. 3.2b). By the last day of recording WT and WFT had the most number of plants fruiting in 1996, while in 1997 it was RRH, RpM, rPH, and PPM (Figure 3.2a, 3.2b). Among cover cropped treatments, tomato plants in pure rye were slowest to fruit in 1996 but not in 1997. Adequate soil moisture together with less weed pressure overcame the suppressive effect of the rye on the tomato crop. The controls WT and WFT fruited slower than some of the cover cropped treatments in 1997, but not in 1996 and 1998. Tomato plants in the weedy WNT fruited slowest in 1996 and 1997. Fruiting of tomato plants in 1998 was very slow in cover cropped treatments and WNT, while rates of fruiting in WT and WFT were comparable to those in 1996 and 1997 (Figure 3.2c)

Rate of ripening of tomato fruit was recorded only in 1997 (Figure 3.3). Tomato fruit in RpH, rpH, and WFT started ripening earliest. Five days later rate of fruit ripening in RRM and PPM had accelerated. Despite the faster rate of flowering and fruiting in RRH, rate of fruit ripening was one of the slowest together with WNT, rpL, and RpM. Abdul-Baki and Teasdale (1993) found plant mulches delaying tomato fruit maturity by about 10 days compared to black polyethylene mulch. Even conventionally weeded controls had earlier fruit maturity than plant mulched treatments. In this study WT was comparable to the slower ripening cover cropped treatments, while WFT was comparable to the earlier and faster ripening cover cropped treatments.

Tomato fruit yield.

Tomato fruit were weighed and counted in 1996, 1997, and 1998, and the data was pooled across the three years (Table 3.5, 3.6). Among cover cropped treatments in all three years and 3YP, rPH and PPH had the most fruits harvested from 10 plants (Table 3.5). WNT had the least number of fruits while WFT had the most. There were significant differences in number of fruits between the 18 treatments when subjected to analysis of variance. There were significant differences among RP in 1996 and 3YP, with fruit numbers increasing from RR to PP (Table 3.6). Differences in number of fruits among SR were significantly different for all three years and 3YP, with number of fruits falling with decreasing SR. There were no interactions among RP and SR for all years and 3YP. There were highly significant differences in numbers of fruits among Y, with mean numbers recorded in 1997 being 43 times those in 1998. There was interaction between Y and SR, but none between Y by RP, or Y by SR by RP (Table 3.6).

Except for RRH, RRM, RRL and WNT, treatments in 1998 yielded less tomato fruit than in 1996 (Table 3.5). Highest yields in cover cropped treatments were recorded in rpH, rPH, PPH, and PPL in 1996, while in 1998 highest yields were in rpH, rPH, and PPH. Yields in 1997 ranged from 13 MT. ha^{-1} in the weedy check to 52 MT. ha^{-1} in rPH and were less varied. There was adequate soil moisture to overcome potential suppressive effects from weed pressure or rye mulch. Fruit weights ha^{-1} differed significantly among RP in 1996 and 3YP, with yields increasing from RR to PP (Table 3.6). Fruit weights were significantly

different among SR in 1996, 1998 and 3YP, with fruit weight falling with decreasing SR in 1998 and 3YP. There was no interaction between RP and SR in all three years and 3YP. There were highly significant differences in tomato yield among years, with yields in 1997 35 times those in 1998. There were no interactions between Y, RP_1 and SR for the 3YP (Table 3.6).

Tomato fruit yield (MT ha^{-1}) was plotted against total cover crop, field pea, and rye dry weights recorded at undercutting for all three years and the pooled data (Figure 3.4, 3.5, 3.6). Though the correlations were not strong, tomato yield increased with increasing cover crop dry weight (Figure 3.4a, b, c, d). The strongest correlation was in 1996, followed by the 3YP, 1998, and weakest in 1997 in which the highest tomato yields were recorded. Tomato yield was positively correlated with pea dry weight (Figure 3.5), but the correlation was very weak in 1998 when the lowest tomato yields were recorded (Figure 3.5c). Higher field pea biomass did not help tomato plants to overcome the high weed pressure and soil moisture deficit. Tomato fruit yield was negatively but very weakly affected by rye dry weight (Figure 3.6a, b, c, d), thus the stronger correlations obtained for total cover crop biomass resulted from the presence of field peas.

Overall the presence of adequate soil moisture tended to overcome the suppressive effect of weed pressure and rye on tomato growth and yield. Tomato plants grew faster, larger and yielded more fruit in 1997 when there was much more rainfall than in 1996 and 1998 (Appendix C). Supplementary irrigation in 1996 and 1998 was infrequent and uneven, not availing enough moisture to tomato plants for

normal growth. Under limited precipitation and high weed pressure, the presence of field peas in the mulch promoted the growth and development of tomato plants compared to those in rye mulch among cover cropped treatments. Generally as the ratio of field peas increased and that of rye decreased leaf numbers, branching, plant height, leaf area, and dry weight of tomato plants increased. This supported the theory that rye produces allelochemicals that suppress the growth of the tomato plants, and field peas fix N available to tomato plants for growth and development. Fruit yield was positively correlated to total cover crop and field pea biomass. The thicker the cover crop mulch, the greater the weed control, and the better the tomato crop growth. The higher the field pea ratio in the cover crop biculture, the greater the amount of N fixed, which should translate into better tomato plant growth. Among cover cropped treatments the highest yield were recorded in the highest seed rates of ½ rye + ½ pea, ¼ rye + ¾ pea, and pure pea cover crop treatments.

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Treatment	1996					1997					1998				
	Leaves (no. / plant)	Brans. (no. / plant)	Lf area (cm^2 / plant)	Height (cm / plant)	Dry wt (g / plant)	Leaves (no. / plant)	Brans. (no. / plant)	Lf area (cm^2 / plant)	Height (cm / plant)	Dry wt (g / plant)	Leaves (no. / plant)	Brans. (no. / plant)	Lf area (cm^2 / plant)	Height (cm / plant)	Dry wt (g / plant)
RRH	9	0	117	36.5	2.3	36	3	992	60.3	11.8	7	0	79	41.9	1.5
RRM	12	1	219	44.6	3.6	54	4	1017	61.3	12.0	6	0	43	31.4	0.7
RRL	13	1	162	40.1	2.7	44	4	1113	65.3	13.8	6	0	28	27.8	0.4
RpH	16	2	316	45.5	5.0	40	4	945	63.7	10.6	9	1	92	37.3	1.4
RpM	25	4	347	47.9	5.7	34	3	580	64.3	9.4	6	0	36	28.3	0.6
RpL	13	1	238	43.4	4.3	31	3	894	66.5	11.4	7	0	46	32.5	0.9
rph	35	6	610	59.5	11.8	46	3	1382	71.5	16.7	7	0	73	40.3	1.5
rpM	23	3	651	52.6	9.3	38	3	1117	72.0	13.1	7	0	51	32.5	0.9
rpL	21	3	270	42.8	4.0	32	3	973	61.5	11.8	6	0	46	31.1	0.8
rPH	49	6	1459	58.9	17.7	40	3	1496	68.8	15.9	11	1	126	37.0	2.4
rPM	33	5	537	52.9	9.0	66	5	1601	68.3	17.8	7	0	76	34.8	1.4
rPL	29	4	366	45.4	6.5	41	3	1183	72.5	13.6	7	0	66	34.5	1.0
PPH	47	7	1504	62.4	20.6	44	4	1625	72.0	18.0	10	1	137	40.0	2.5
PPM	38	5	717	55.0	9.9	50	4	1530	77.5	17.1	13	3	187	39.0	2.9
PPL	21	3	626	55.5	9.9	48	5	1385	71.0	14.3	6	0	38	25.8	0.7
WNT	9	0	127	41.3	2.5	19	1	561	59.8	6.4	7	0	50	32.5	0.7
WT	63	10	1870	60.1	23.5	42	3	1182	68.5	13.8	43	4	857	67.0	23.8
WFT	80	12	2041	63.1	16.6	33	2	1181	72.8	12.9	61	6	3159	79.5	52.9
LSD	28.5		712.1	11.77	9.08	18.1		532.1	Ns	5.17	7.9		355.4	12.44	4.98

Table 3.1: Destructive harvest data of tomato plants one month after transplanting for 1996 and 1997, and two months after transplanting for 1998. Means separated by LSD. Brans, branches; Lf, leaves; wt, weight. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; ¼rye + ¾pea; PP, pure pea. H, high(100%) seeding rate; M, medium (50%) seeding rate; L, low (25%) seeding rate. WNT, untilled weedy check; WT, tilled weedy check; WFT, tilled weed-free check. LSD not shown for branches because data were transformed before analysis of variance.

Treatment	3-year pooled data				
	Leaves (no. / plant)	Branches (no. / plant)	Leaf area (cm^2/ plant)	Height (cm / plant)	Dry weight (g / plant)
RRH	17	1	396	46.2	5.2
RRM	24	2	426	45.7	5.4
RRL	21	2	434	44.4	5.6
RpH	21	2	451	48.8	5.7
RpM	22	2	321	46.8	5.2
RpL	17	1	393	47.5	5.5
rpH	29	3	688	57.1	10.0
rpM	23	2	606	52.4	7.8
rpL	20	2	430	45.1	5.5
rPH	33	3	1027	54.9	12.0
rPM	35	3	738	52.0	9.4
rPL	26	2	538	50.8	7.0
PPH	34	4	1089	58.1	13.7
PPM	34	4	811	57.2	10.0
PPL	25	3	683	51.4	8.3
WNT	12	0	246	44.5	3.2
WT	49	6	1303	65.2	20.4
WFT	58	7	2127	71.8	27.5
LSD	13.6		426.4	8.58	6.21

Table 3.2. Destructive harvest data of tomato plants (from Table 3.1) pooled over 1996, 1997, and 1998. Means separated using LSD. RR, pure rye; Rp; ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, high (100%) seeding rate; M, medium (50%) seeding rate; L, low (25%) seeding rate. WNT, untilled weedy check; WT, tilled weedy check; WFT, tilled weed-free check. LSD not shown for branches because data was transformed before analysis of variance.

Table 3.3. Analysis of variance of main factors for 1996, 1997, and 1998 tomato destructive harvest data. Means with the same letter not significantly different with LSD separation. Brans, branches; Lf, leaves; wt, weight. RR, pure rye; Rp; ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, high (100%) seeding rate; M, medium (50%) seeding rate; L, low (25%) seeding rate. RP, cover crop combination; SR, seeding rate; *, **, ***, significant at 0.05, 0.01, and 0.001 probability levels, respectively. Ns, not significant at 0.05 probability level.

Factor	1996					1997					1998				
	Leaves (no. / plant)	Brans (no. / plant)	Lf area (cm^2 / plant)	Height (cm / plant))	Dry wt (g / plant)	Leaves (no. / plant)	Brans (no. / plant)	Lf area (cm^2 / plant)	Height (cm / plant))	Dry wt (g / plant)	Leaves (no. / plant)	Brans (no. / plant)	Lf area (cm^2 / plant)	Height (cm / plant))	Dry wt (g / plant)
RR	11 b	1 b	166 c	40.4 c	2.9 c	44	4	1041 c	62.3 b	12.5 bc	6	0	50	33.7	0.9
Rp	18 b	2 ab	301 c	45.6 bc	5.0 bc	35	3	806 c	64.8 b	10.4 c	7	0	58	32.7	1.0
rp	26 ab	4 a	510 bc	51.6 ab	8.4 ab	39	3	1157 bc	68.3 b	13.9 ab	7	0	57	34.6	1.0
rP	37 a	5 a	787 ab	52.4 ab	11.1 a	49	4	1427 ab	69.8 ab	15.8 ab	8	0	90	35.4	1.6
PP	35 a	5 a	949 a	57.6 a	13.4 a	48	4	1513 a	73.5 a	16.5 a	10	1	120	35.6	2.0
H	31	4	801 a	52.5 a	11.5 a	41	3	1289	67.3	14.6	9	0	101 a	39.3	1.8 a
M	26	3	494 ab	50.6 ab	7.5 ab	48	3	1169	68.7	13.9	8	1	79 ab	33.2	1.3 ab
L	19 a	2	332 b	45.4 b	5.5 b	39	4	1109	67.4	13.0	6	0	45 b	30.7	0.7 b
RP	**	*	**	***	***	Ns	Ns	***	*	**	Ns	Ns	Ns	Ns	Ns
SR	Ns	Ns	*	*	*	Ns	Ns	Ns	Ns	Ns	Ns	Ns	*	Ns	*
RP x SR	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns

Table 3.3.

Factor	Leaves (no. / plant)	Branches (no. / plant)	Leaf area (cm^2/ plant)	Height (cm / plant)	Dry weight (g / plant)
RR	21 b	1 b	419 bc	45.4 c	5.4 c
Rr	20 b	2 b	388 c	47.7 bc	5.5 c
rp	24 b	2 ab	575 b	51.5 ab	7.8 b
RP	31 a	3 a	768 a	52.6 a	9.5 ab
PP	31 a	3 a	861 a	55.6 a	10.6 a
H	27 a	3	730 a	53.0 a	9.3 a
M	27 a	3	581 b	50.8 ab	7.6 b
L	22 b	2	495 b	47.8 b	6.4 b
1996	25 b	3 a	543 b	49.5 b	8.2 b
1997	43 a	4 a	1188 a	67.8 a	14.8 a
1998	8 c	0 b	75 c	34.4 c	1.3 c
RP	***	**	***	***	***
SR	*	Ns	**	*	**
PR x SR	Ns	Ns	Ns	Ns	Ns
Y	***	***	***	***	***
Y x RP	*	*	*	Ns	*
Y x SR	Ns	Ns	Ns	Ns	Ns
Y x RP x SR	Ns	Ns	Ns	Ns	Ns

Table 3.4. Analysis of variance of main factors for 3-year pooled tomato destructive harvest data. Means with the same letter are not significantly different by LSD(0.05). RR, pure rye; Rp; ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, high (100%) seeding rate; M, medium (50%) seeding rate; L, low (25%) seeding rate. RP, cover crop combinations; SR, seed rates; Y, year. *, **, ***, significant at 0.05, 0.01, 0.001 probability levels. Ns, not significant at 0.05 probability level.

Treatment	1996		1997		1998		3-year pooled data	
	Fruits (no. / plant)	Fruit weight (MT/ha)	Fruits (no. / plant)	Fruit weight (MT/ha)	Fruits (no. / plant)	Fruit weight (MT/ha)	Fruits (no. / plant)	Fruit weight (MT/ha)
RRH	7	0.6	138	38.8	2	2.9	49	14.1
RRM	7	0.6	150	40.9	3	1.3	53	14.3
RRL	10	0.9	96	31.1	2	1.5	36	11.2
RpH	16	2.8	121	36.2	2	0.8	46	13.2
RpM	12	1.9	133	41.3	2	0.7	49	14.7
RpL	11	1.4	96	32.1	2	0.3	36	11.3
rpH	27	5.2	137	44.3	5	2.6	56	17.4
rpM	20	3.5	114	34.7	3	0.4	45	12.9
rpL	18	2.9	122	40.5	1	0.3	47	14.6
rPH	55	14.8	163	52.5	7	1.8	75	23.0
rPM	21	2.9	127	40.3	1	1.3	49	14.8
rPL	12	2.7	114	39.0	0	0.6	42	14.1
PPH	49	15.0	157	41.8	6	2.0	71	19.6
PPM	19	3.9	143	48.2	2	0.2	55	17.4
PPL	20	6.5	117	45.3	1	0.1	46	17.3
WNT	0.3	0.02	26	13.2	0	0.2	9	4.5
WT	83	21.3	97	31.6	43	9.5	74	21.0
WFT	111	34.0	158	50.0	92	31.4	120	38.4
Lsd (0.05)	25.28		36.64	11.91		3.243	46.31	6.45

Table 3.5. Tomato fruit harvest data for 1996, 1997, 1998, and pooled over the three years in Columbus, OH. Means of the 18 treatments separated by LSD. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, high (100%) seeding rate; M, medium (50%) seeding rate; L, low (25%) seeding rate. WNT, untilled weedy check; WT, tilled weedy check; WFT, tilled weed-free check. LSD not shown for fruit weight in 1996 and fruit number in 1997 because data were transformed before analysis of variance.

Table 3.6. Analysis of main factors for 1996, 1997, 1998, and 3-year pooled tomato fruit harvest data. Means with the same letter are not significantly different at 0.05 probability level. RR, pure rye; Rp; ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, high (100%) seeding rate; M, medium (50%) seeding rate; L, low (25%) seeding rate. RP, cover crop combinations; SR, seed rate; Y, year. *, **, ***, significant at 0.05, 0.01, 0.001 probability levels. Ns, not significant at 0.05 probability level.

Factor	1996		1997		1998		3-year pooled data	
	Fruits (no. / plant)	Fruit weight (MT/ha)	Fruits (no. / plant)	Fruit weight (MT/ha)	Fruits (no. / plant)	Fruit weight (Mt/ha)	Fruits (no. / plant)	Fruit weight (MT/ha)
RR	8 b	0.7 c	128	36.9	2	1.9	46 bc	13.2 b
Rp	13 b	2.0 bc	117	36.5	2	0.6	44 c	13.1 b
rp	22 ab	3.9 abc	128	39.9	3	1.1	50 abc	14.9 ab
rP	29 a	6.8 ab	135	43.9	3	1.2	55 ab	17.3 a
PP	30 a	8.4 a	139	45.1	3	0.8	57 a	18.1 a
H	31 a	7.7 a	143 a	42.7	4 a	2.0 a	59 a	17.5 a
M	16 b	2.6 b	133 a	41.1	2 ab	0.8 b	50 b	14.8 b
L	14 b	2.9 b	109 b	37.6	1 b	0.5 b	42 c	13.7 b
1996							20 b	4.4 b
1997							129 a	40.5 a
1998							3 c	1.1 c
RP	*	*	Ns	Ns	Ns	Ns	*	**
SR	**	*	**	Ns	*	*	***	**
RP x SR	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
Y							***	***
Y x RP							Ns	Ns
Y x SR							**	Ns
Y x RP x SR							Ns	Ns

Table 3.6.

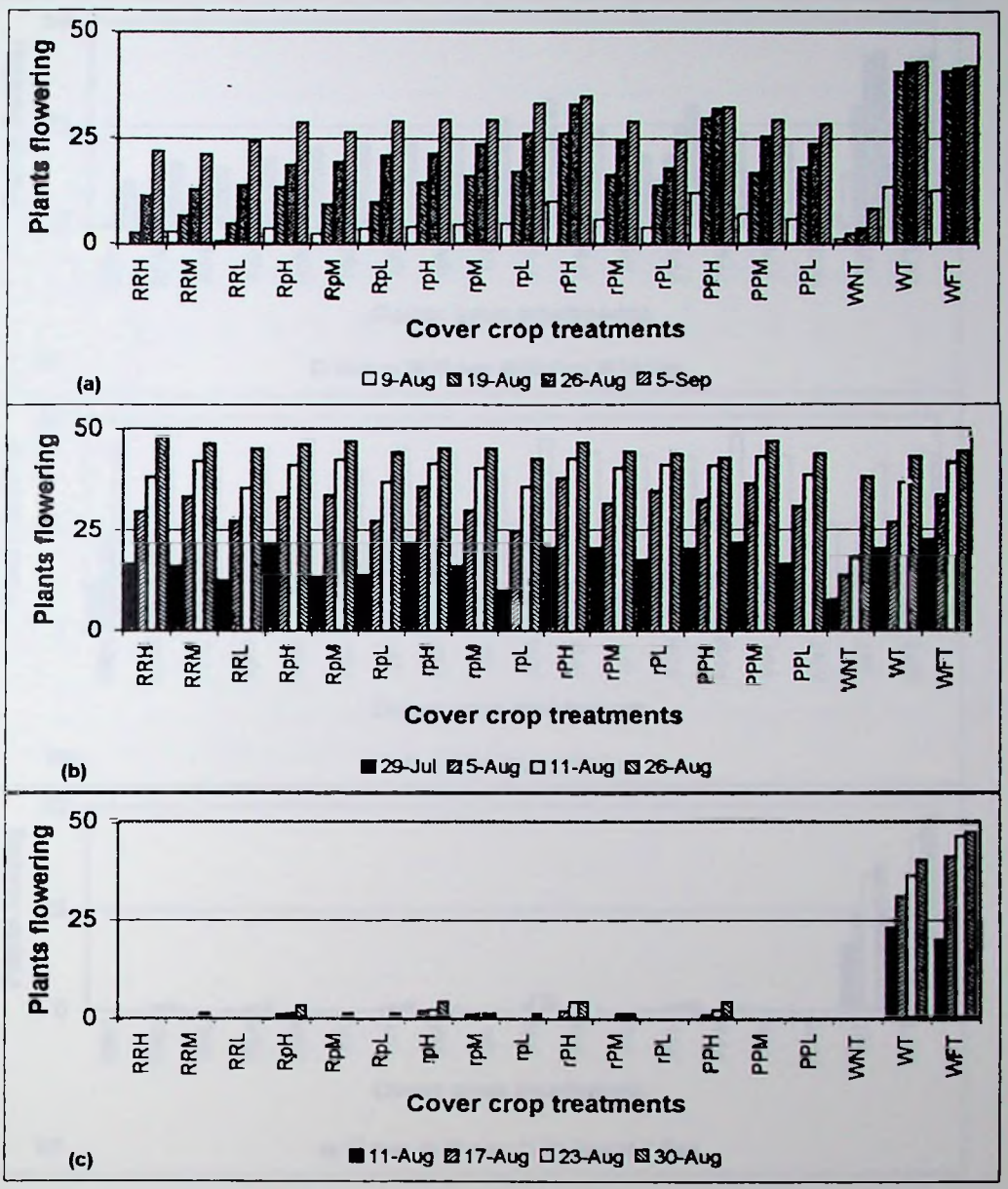

Figure 3.1: Effect of cover crop treatments on rate of flowering of tomato plants in (a) 1996, (b) 1997, (c) 1998, in Columbus, OH. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, high (100%) seeding rate; M, medium (50%) seeding rate; L, low (25%) seeding rate. WNT, untilled weedy check; WT, tilled weedy check; WNT, tilled wed-free check.

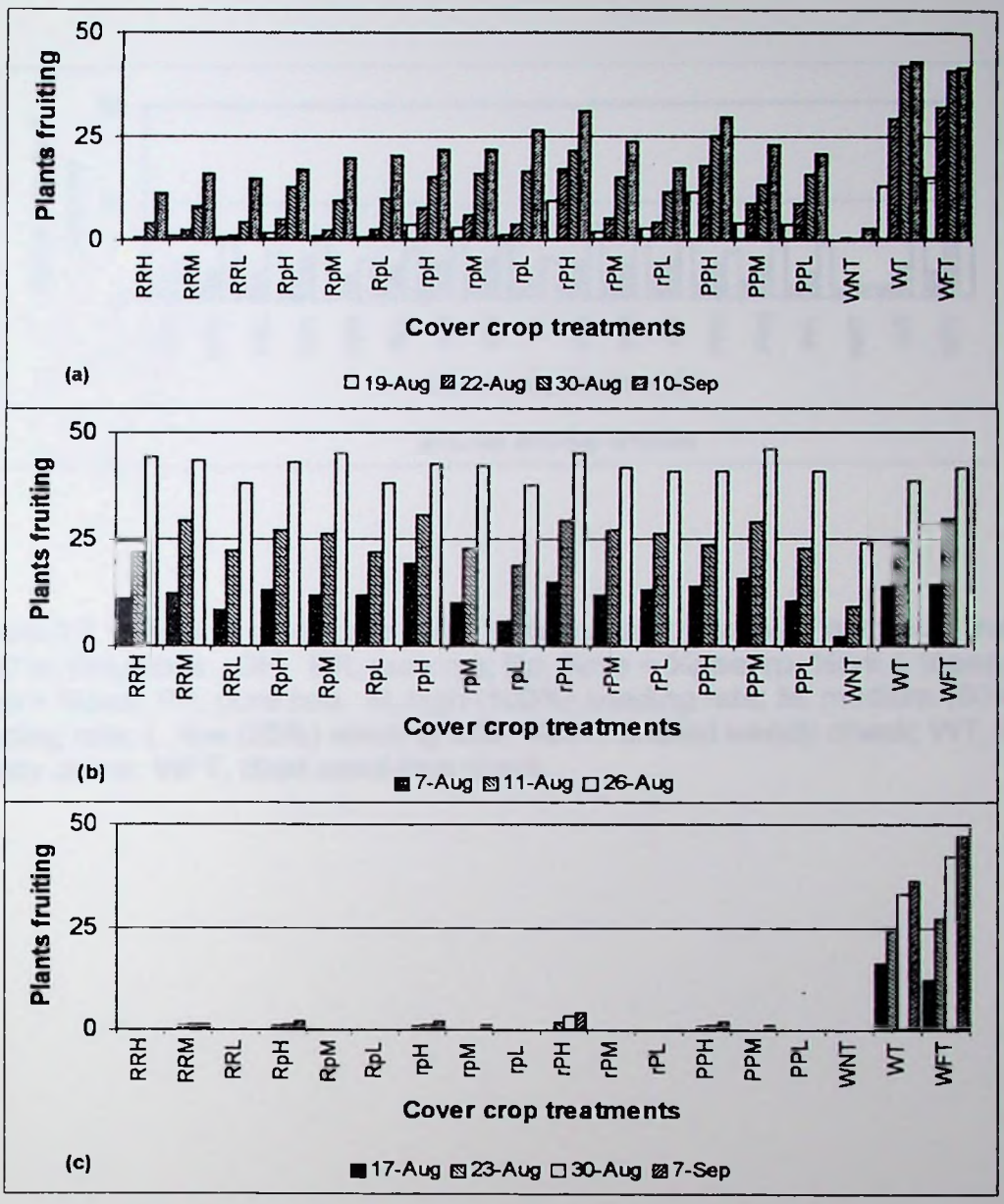
Plants fruiting
50
25
0
RRH
RRM
RRL
RpH
RpM
RpL
rpH
rpM
rpL
rPH
rPM
rPL
PPH
PPM
PPL
WNT
WT
WFT
Cover crop treatments
(a)
19-Aug
22-Aug
30-Aug
10-Sep
(b)
7-Aug
11-Aug
26-Aug
(c)
17-Aug
23-Aug
30-Aug
7-Sep

Figure 3.2

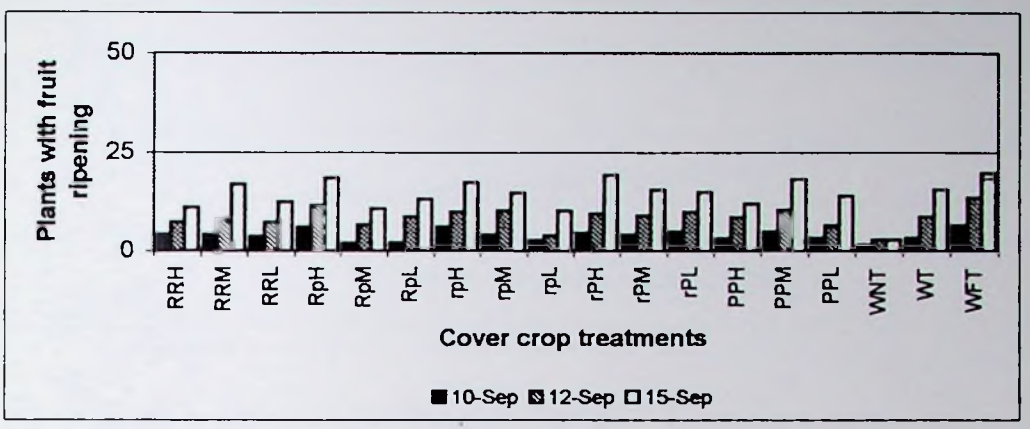

Figure 3.3: Effect of cover crop treatments on rate of ripening of tomato fruit in 1997 in Columbus , OH. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, high (100%) seeding rate; M, medium (50%) seeding rate; L, low (25%) seeding rate. WNT, untilled weedy check; WT, tilled weedy check; WFT, tilled weed-free check.

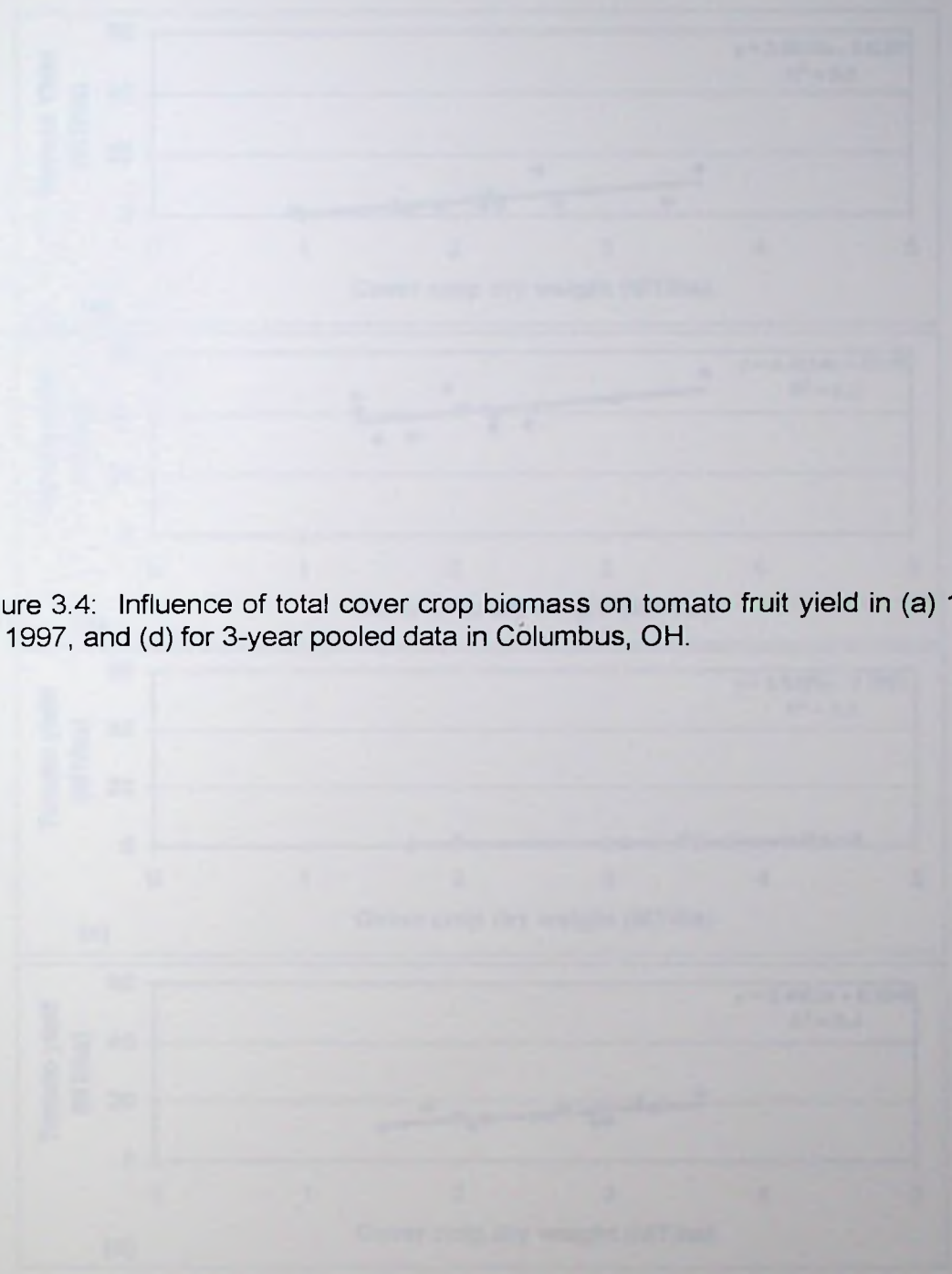

Figure 3.4: Influence of total cover crop biomass on tomato fruit yield in (a) 1996, (b) 1997, and (d) for 3-year pooled data in Columbus, OH.

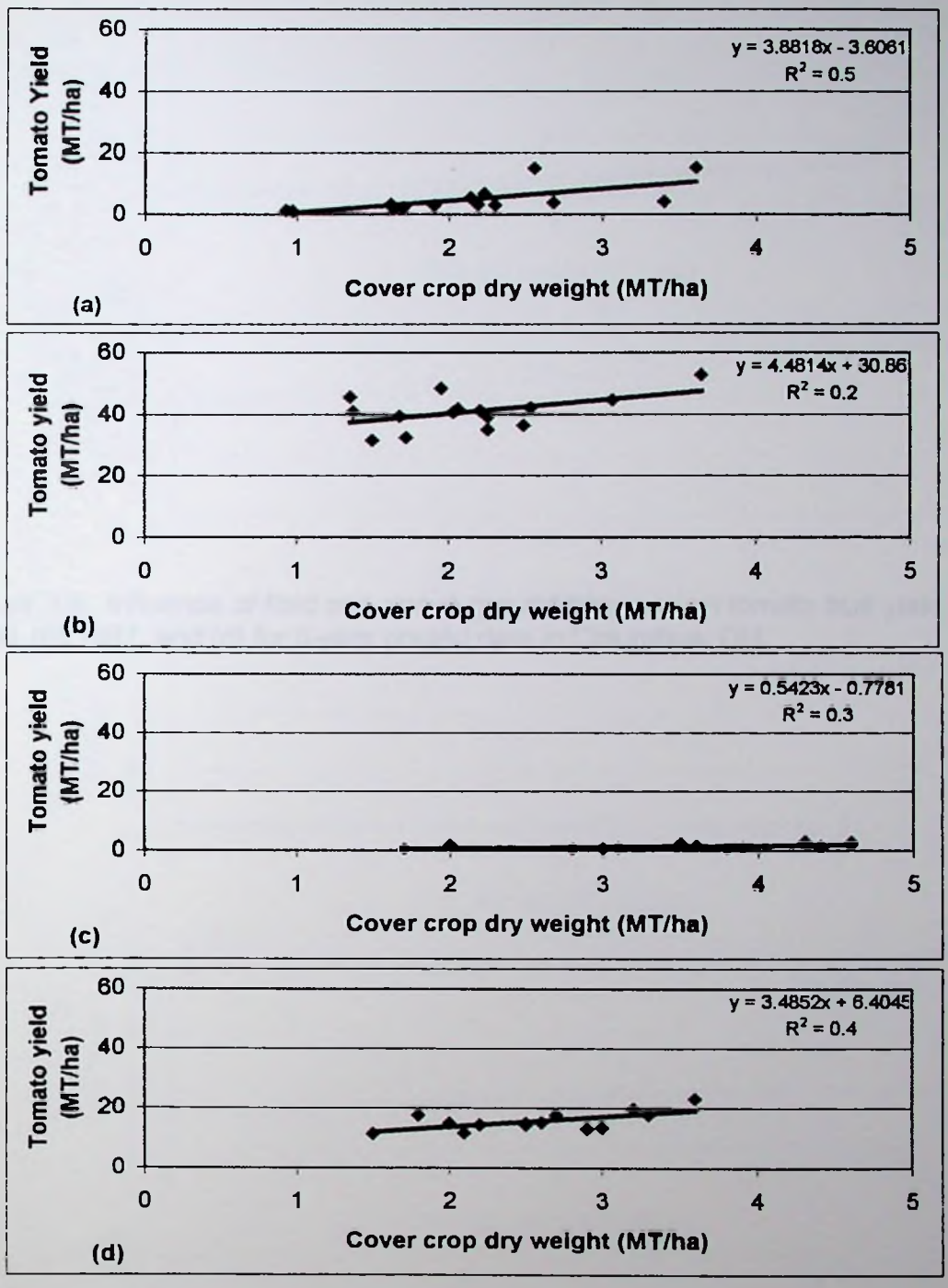
Tomato Yield (MT/ha)
y = 3.8818x - 3.6061
R² = 0.5
Cover crop dry weight (MT/ha)
(a)
Tomato yield (MT/ha)
y = 4.4814x + 30.86
R² = 0.2
Cover crop dry weight (MT/ha)
(b)
Tomato yield (MT/ha)
y = 0.5423x - 0.7781
R² = 0.3
Cover crop dry weight (MT/ha)
(c)
Tomato yield (MT/ha)
y = 3.4852x + 6.4045
R² = 0.4
Cover crop dry weight (MT/ha)
(d)

Figure 3.4.

Figure 3.5: Influence of field pea above-ground biomass on tomato fruit yield in (a) 1996, (b) 1997, and (d) for 3-year pooled data in Columbus, OH.

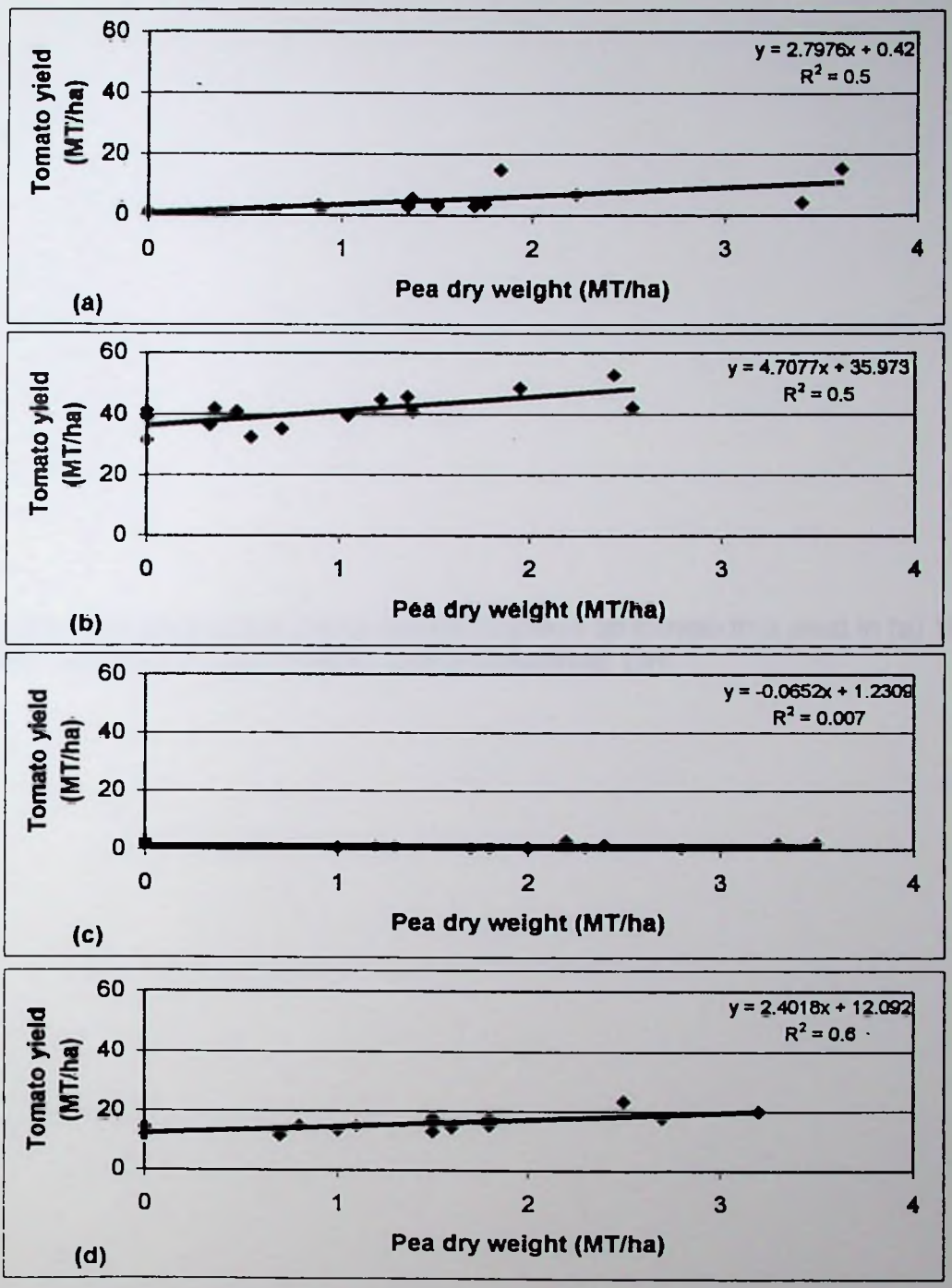
Tomato yield (MT/ha)
60
40
20
0
0
1
2
3
4
Pea dry weight (MT/ha)
y = 2.7976x + 0.42
R² = 0.5
(a)
Tomato yield (MT/ha)
y = 4.7077x + 35.973
R² = 0.5
Pea dry weight (MT/ha)
(b)
Tomato yield (MT/ha)
y = -0.0652x + 1.2309
R² = 0.007
Pea dry weight (MT/ha)
(c)
Tomato yield (MT/ha)
y = 2.4018x + 12.092
R² = 0.6
Pea dry weight (MT/ha)
(d)

Figure 3.5.

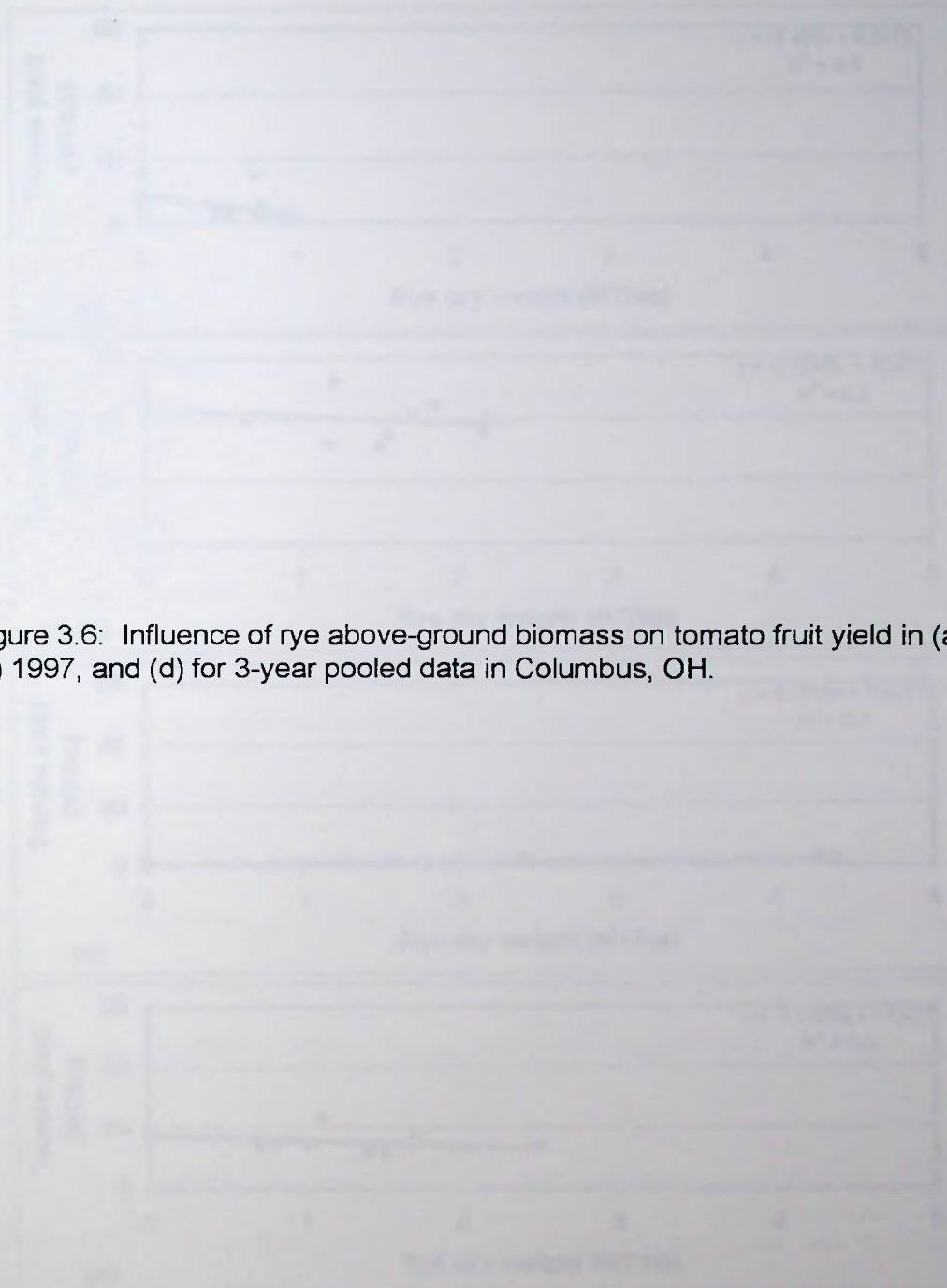

Figure 3.6: Influence of rye above-ground biomass on tomato fruit yield in (a) 1996, (b) 1997, and (d) for 3-year pooled data in Columbus, OH.

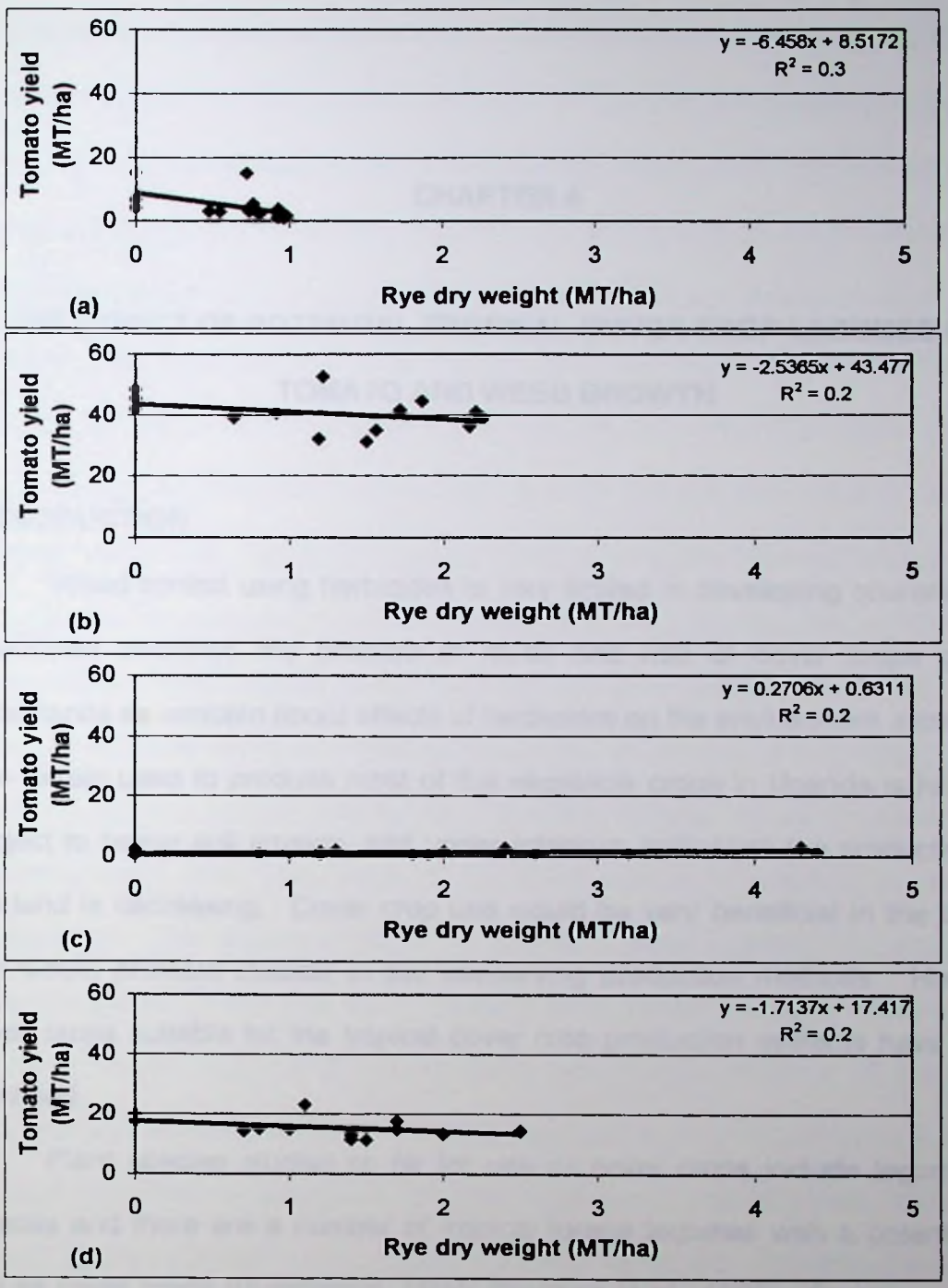
y = -6.458x + 8.5172
R² = 0.3
Tomato yield (MT/ha)
Rye dry weight (MT/ha)
(a)
y = -2.5365x + 43.477
R² = 0.2
Tomato yield (MT/ha)
Rye dry weight (MT/ha)
(b)
y = 0.2706x + 0.6311
R² = 0.2
Tomato yield (MT/ha)
Rye dry weight (MT/ha)
(c)
y = -1.7137x + 17.417
R² = 0.2
Tomato yield (MT/ha)
Rye dry weight (MT/ha)
(d)

Figure 3.6

CHAPTER 4

THE EFFECT OF POTENTIAL TROPICAL COVER CROP LEGUMES ON TOMATO AND WEED GROWTH

INTRODUCTION

Weed control using herbicides is very limited in developing countries. In developed countries the practice of no-till and use of cover crops gained acceptance as concern about effects of herbicides on the environment increased. The terrain used to produce most of the vegetable crops in Uganda is hilly and subject to heavy soil erosion, and under intensive cultivation the productivity of the land is decreasing. Cover crop use would be very beneficial in the tropics and would promote interest in soil conserving production methods. However cover crops suitable for the tropical cover crop production systems have to be identified.

Plant species studied so far for use as cover crops include leguminous species and there are a number of tropical forage legumes with a potential for use as cover crops (Humphreys, 1994; Skerman et al., 1988). Some examples are siratro (*Macroptilum atropurpureum*), lablab bean (*Lablab purpureus*), velvet bean (*Mucuna sp.*), centro (*Centrosema pubescens*), tick clovers (*Desmodium*

sp.), soybean (*Glycine max*), and kudzu (*Pueraria* sp.). All these species differ in growth habit and in the amount and rate of biomass accumulation over time. With limited documented research in this area, researchers are challenged to identify the species most suitable for use in tropical crop production systems.

Many studies have documented that cover crops suppress weeds through physical and allelochemical mechanisms, but which mechanism is the most effective for which cover crop is not always known. Allelochemicals may be produced by shoot residue, root residue, or both types of residue of a particular cover crop species. Some researches have investigated the mechanisms used by cover crop species in weed suppression both in the field and in the greenhouse. Rye (*Secale cereale* L.) residue was found to suppress weeds better than poplar excelsior (*Populus* sp.), which was used as a non-toxic mulch cover on the soil surface (Barnes and Putnam, 1983). It was concluded that allelochemicals were also involved in weed control in addition to physical suppression. The effects of rye shoot and root tissue together and separately were compared in another study together with poplar excelsior (Barnes and Putnam, 1986). Rye shoots suppressed weeds independently of rye roots. Leached and un-leached root and shoot residues of sorghum (*Sorghum bicolor* L.) and rye were investigated for their combined and separate effects on barnyardgrass (*Echinochloa crusgalli* L.) and velvetleaf (*Abutilon theophrasti* Medik.) (Hoffman et al., 1996b). Poplar excelsior was also included as a treatment. Rye root residue and poplar excelsior significantly affected the growth of the two weed species. These studies showed that weed suppression by a

particular species may be by physical suppression, but may also primarily be by allelochemicals which may be produced by the roots.

The objective of the first study was to observe the growth habit and biomass accumulation of three tropical legumes, a soybean cultivar, and a ¼ rye + ¾ pea combination. (The rye + pea combination had shown promising results in field trials weed control in a tomato crop in 1996 and 1997 compared to 4 other rye + pea combinations (Chapter 2, 3).). Their effect on weed and tomato growth was also documented. The objective of the second study was to investigate the effect of root and shoot tissue, together and separately, on the growth of weeds and tomato plants. A suppressive effect by shoot residue alone or together with root residue could be due to either or both physical and allelochemical mechanisms. A suppressive effect by root tissue with no effect by the corresponding shoot tissue could be attributed to allelopathy.

MATERIALS AND METHODS

Seed of three tropical legume species, siratro (*Macroptilum atropurpureum*), lablab bean (*Lablab purpureus*), and velvet bean (*Mucuna sp.*) were obtained from Kawanda Agricultural Research Institute (KARI), Uganda, in 1997. Plants of the three species were assessed in two greenhouse trials to determine their potential in weed control and effect on tomato growth. In the first trial a Miami silt loam (Mesic Typic Hapludaf) soil from the Waterman Laboratory Farm at Ohio State University (Columbus, OH) was mixed with Krum horticultural

perlite (Hummert International, Earth City, Mo) in a 3 : 1 ratio by volume. Forty liters of the soil mixture was placed in 57 liter plastic Rubbermaid tubs, with 40 holes, each 5mm in diameter, drilled in the bottom for drainage. Five weed species found in the tropics were used to test weed control potential of the cover crops. These were smooth pigweed (*Amaranthus hybridus* L.), purslane (*Portulaca oleracea* L.), lambsquarters (*Chenopodium album* L.), fall panicum (*Panicum dichotomiflorum* Michx.), and green foxtail (*Setaria viridis* (L.) Beauv.). Before sowing the cover crops, seeds (5g) of each weed species were sown separately and shallowly in a line across the shorter width of the tub, the species being allocated random positions in each tub on 24 October 1997. This was because if the trial was in the field, weed seeds in the soil seed bank would certainly germinate among the cover crops, possibly being suppressed to different degrees. In addition to the three tropical legume species from Uganda, soybean (USDA Vegetable Lab, Beltsville, MD), a ¼ rye (*Secale cereale* L.) + ¾ field peas (*Pisum sativum* L.) combination, and a control without cover crops were included for a total of six treatments replicated three times. The rye and field peas were included because they were being used in cover crop field trials in Columbus, Ohio, and the ¼ rye + ¾ pea ratio produced high cover crop biomass in the field. The seeding rates used are shown in Table 4.1. Siratro was scarified using a Hoffman SC50 air driven scarifier, then the seed from Uganda were inoculated with the appropriate *Bradyrhizobium* sp. (Urbana Laboratories, St. Joseph, Missouri). The experimental design was a randomized complete block with three replicates. The cover crops were sown 25 October

1997 and the tubs put in a greenhouse room heated to 30C though temperatures fell at night to about 25C. Extra lighting was provided by 400 watt HPS lamps (CISCO, Columbus, Ohio) for two h in the morning and evening for a total of 12 h of daylight. Hand watering was carried out as required. The cover crops and weeds were cut just under the soil surface 51 days after sowing (DAS) and left to dry for one week. On 22 December seeds (5g) of each species were sown as before in each tub and the next day one-month-old 'Marglobe' tomato (*Lycopersicon esculentum* Mill.) seedlings were transplanted, 2 per tub. A weed count was taken 16 DAS and tomato growth data was recorded 45 days after transplanting (DAT). Fruit harvest data was also recorded.

Besides seeking to confirm results from the first greenhouse study, the second study was also done to determine the effect of shoots and roots together and separately on weed suppression and tomato growth. A suppressive or stunting effect, especially by the roots, could be attributed to the production of allelochemicals. Tomato plants and weed seeds were also grown in separate pots to eliminate any effect they might have on each other interfering with the effect of the cover crops. From observations in the first greenhouse study, two of the species from Uganda, lablab and velvet bean, were not used in the second study.

Field soil from the same location was again mixed with Krum horticultural perlite, this time in a 2 : 1 ratio for a lighter and more porous mixture. The 19 L plastic pots used in this study had 20 holes, each 5mm in diameter, drilled in the bottom for better absorption of water from a capillary mat. Hoffman et al. (1996a,

1996b) drilled 23 holes in the bottom of pots to better form a capillary column when they were placed on moistened capillary matting. The drain holes in the sides of the pots were sealed off with duct tape to prevent possible excessive drainage of water. Soil mixture (15L) was put in each 19L pot. Vattex capillary matting (Hummert International, Earth City, Mo) was laid out on black plastic sheeting (O.S. Plastic Inc., Norcross, GA) on benches in a greenhouse chamber, watered thoroughly by hand, and thereafter watered by a timed drip system to keep it constantly wet. Some holes were punched in the plastic sheeting to drain off excess water. As opposed to hand watering, capillary matting provided each pot with similar amounts of water, eliminating the effects of differences in soil moisture on plants growing in the pots. In a greenhouse study Hoffman et al. (1996a) determined that sub-irrigation from a capillary mat eliminated moisture differences between treatments with and without cover crop residue on the soil surface. The potted soil was watered thoroughly before the pots were placed on the mats, then watered again until water ran out of their holes to ensure the establishment of a capillary column of water from the mats to the plants. The pots were left on the moist mats for five d to ensure that they had established a capillary column. Pots that dried out were watered again or replaced before any seeds were sown.

Siratro, soybean, rye + field pea, and pure rye seeds were the sown in the pots on 2 March for the tomato plant study, and 18 May for the weed study. Pure rye was included because it is known to have allelopathic activity (Barnes and Putnam, 1983, 1986; Barnes et al., 1987). In each of the three replicates, two

pots each for tomatoes and weeds were sown with the same cover crop with the seeding rates in Table 4.1. Cover crops for the tomato study were killed 65 DAS, and those for the weed study 72 DAS, then left on the soil surface to dry. To separate the effect of shoots and roots, shoots from one pot each of the cover crops in each replicate were removed and put on soil in a fresh pot of soil mix, leaving the roots in the original pot. Both shoots and roots were left in the second pot. Including the control without cover crops there were all together thirteen pots or treatments each for the tomato and weed studies in each replicate. Soil was taken from the pots in which cover crops had been grown and from the controls and analyzed at Ohio Agricultural Research and Development Center (OARDC, Wooster, OH), for total nitrogen.

'Marglobe' tomato seedlings were transplanted 13 May 1998, and the experiment was terminated 125 DAT. Green foxtail, purslane, and smooth pigweed seeds (3g each) were sown in three lines each radiating from the center of each pot on 10 August 1998. Germination and establishment of weeds were recorded 8 and 14 DAS respectively. Each weed species was then thinned down to 10 plants per pot where necessary to reduce competition. Weeds were destructively harvested 41 DAS and their fresh weight recorded. The chamber was getting additional lighting from 400 watt HPS lamps for a 12 h day, and heating to 32C from March to the end of May when these were terminated. Results were analyzed using the SAS system and significant differences between means were compared using lsd (0.05).

RESULTS AND DISCUSSION

The cover crops showed differences in growth habits and rates of biomass accumulation (data not shown). Lablab and velvet bean had large seeds which grew into large vines with widely spaced leaves which did not cover the soil enough to suppress weed growth. These two species had sturdy stems which grew vertically for about a month before becoming prostrate on the soil surface. In the field this would allow weeds to germinate and establish in large numbers before the cover crop is killed. Even the dry mulch was not thick enough, leaving more than 70% of the soil bare. Siratro and soybean (bred for high foliage production) produced dense foliage, had a prostrate growing habit and fast growth rate and had 100% soil cover 45 DAS. Both suppressed the weeds sown in the tubs, especially the soybean mulch which had 0% weed growth in two replicates. After sowing the second time weed counts were taken 16 DAS (Table 4.2). The only significant difference was between green foxtail numbers ($p= 0.05$), with the least germination recorded in tubs with lablab bean and the control. Fall panicum hardly germinated in any of the treatments. Soybean and siratro mulch tended to suppress pigweed, lambsquarters, and purslane better than the other mulches, and pigweed was suppressed by velvet bean more than lablab bean and rye + peas. There were no significant differences between any of the tomato plant growth and yield parameters recorded in the first greenhouse study, although fruit yield tended to be greater in the soybean cover crop treatment (Table 4.3).

Plant growth parameters taken at termination of the second greenhouse study and harvest data on the tomato crop are shown in Table 4.4. Tomato plants branched most in the siratro root and shoot (Mrs), siratro shoot (Ms), soybean root and shoot (Srs), and rye shoot (Rs) treatments, and the least branching was in the rye root (Rr) treatment. There were no significant differences between tomato plant heights and leaf areas (Table 4.4). However the tallest plants were in the Srs and siratro root (Mr) treatments and the shortest in the rye + field pea shoot (RPs) treatment. Largest leaf areas were recorded in Rs, Srs, and Mrs. There were significant differences ($p= 0.05$) between tomato plant dry weights, with the greatest biomass being accumulated in Mrs and Srs, and the least in Rr (Table 4.4). There were no significant differences in the tomato fruit harvest data, but tomato plants in Srs and Mrs had the best yields by weight, and Rs the least. Overall, Srs and Mrs had the best effect on tomato growth and yield, Rr depressed growth most, while Rs depressed yield most (Table 4.4).

There were highly significant differences ($p= 0.05$) between germination percentages for pigweed, purslane, and green foxtail 8 DAS (Table 4.5). Pigweed and purslane (the two broadleaf species) germinated 100% in Rr, and 0% under the mulch in Srs and Ss. Purslane also did not germinate in Mrs. At this date some seedlings had already damped-off, especially purslane (up to 70% in RPr). Damping off of pigweed and purslane was prevalent in the pots with roots only and the control, then under the mulch in Ms for purslane. Germination percentages of the grass weed (green foxtail) were much lower than

those of the broadleaf weeds (Table 4.5). Green foxtail germinated most in Sr and Rs, and least in Mrs, Srs, and RPr. No damping off was observed for this species.

There were significant to highly significant differences between weed populations 14 DAS (Table 4.5). Damping-off reduced weed populations for both pigweed and purslane in the treatments where it occurred. However the greatest suppression of these two species was in Srs, Mrs, Ss, and Ms. A substance produced by the roots in RPr, Sr, and Mr could have contributed to the damping off, but still the presence of thick mulch on the soil surface caused a greater suppression of weeds. Except for Mr and RPrs, green foxtail populations either remained the same or increased slightly indicating additional germination.

Differences between weed fresh weights were significant ($p=0.05$) for pigweed and highly significant ($p=0.05$) for green foxtail (Table 4.6). Ms stunted weed growth most, with the average weed fresh weight being less than 0.1g for the three weed species. The two broadleaf weeds were equally suppressed in Srs. However percent germination and establishment of green foxtail in Srs was very low, thus the few plants that grew through the mulch had enough resources for growth. Rr was second in suppressing average weed fresh weight of all three weed species, followed by Mrs. RPrs and Ss treatments suppressed average weed fresh weight the least, but then they also had the least weeds established 14 DAS. Reduced weed seedling establishment allowed greater biomass accumulation by individual weed seedlings. With the exception of siratro, weeds in the root treatments accumulated less biomass than those in the root + shoot

treatments and the shoot treatments (Table 4.6). This is not easy to explain as soil in all pots was equally moist all the time. Maybe the shoot tissue in contact with the soil surface decomposed and released nutrients into the soil which then became available to weeds in treatments with cover crop shoots on the soil surface.

At time of transplanting tomato seedlings in the second greenhouse study, treatments sown with siratro had an average of 0.19 % N, rye+ pea and soybean 0.18 % N, and rye 0.17 % N. Treatments without any cover crop, including those with cover crop shoots on the soil surface had an average of 0.16 % N.

Considering the results from both greenhouse studies, Mrs (Siratro roots + shoots) and Srs (soybean roots + shoots) were the outstanding treatments for both tomato growth and yield, and suppression of weed growth. Siratro and soybean rapidly accumulated enough above-ground biomass to form a mulch thick enough for 90% or more suppression of both the broadleaf and grass weeds in the second greenhouse study (Table 4.5). Tomato plants also grew and yielded best in these two treatments. The studies would have to be repeated to confirm these results, but the consistency over the tomato and weed parameters measured allow for a preliminary conclusion in their favor. Rr suppressed tomato and weed growth the most. In another study rye root residue was also observed to suppress the growth of two weed species (barnyard grass, velvetleaf) compared to rye shoot residue or a combination of the two residue types (Hoffman et al., 1996). Although the roots of the tropical legumes formed viable nodules indicating nitrogen fixation, tomato growth and yield was not as

high in treatments with siratro and soybean roots as in treatments with both root and shoot residues in the same pot. Therefore separating the residues reduced the positive effects they had on tomato and weed control in Mrs and Srs. These studies showed a potential for the use of siratro and the soybean cultivar used in these studies for weed control in tropical tomato production. They show that the best effect would be obtained by killing the cover crops and leaving the shoots on the soil surface where they were grown. Additional studies in the greenhouse and in the field are needed to confirm or negate these results before any recommendations are made.

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Cover crop	Seeding rate (kg ha^{-1})
Rye + peas	28 + 102
Soybean	136
Siratro	170
Lablab bean	50
Velvet bean	60
Rye	113

Table 4.1: Seeding rates for cover crops in the two greenhouse studies.

Cover crop	Plants per container				
	Pigweed	Purslane	Lambsqtr	Foxtail	Fallpanic
Rye + peas	13	3	6	17	0
Soybean	7	0	1	12	0
Siratro	10	0	3	10	0
Lablab bean	18	3	6	8	0
Velvet bean	10	5	4	14	0
Control	11	2	4	8	0

Table 4.2: Effect of six cover crop treatments on the germination of five weed species. Lambsqtr, lambsquarter; fallpanic, fall panicum.

Cover crop	Tomato plant growth data (45 DAT)				Tomato fruit harvest	
	Plant height (m)	Number of leaves	Flower cluster number	Fruit number	Fruit number	Total fruit weight (g)
Rye + peas	1.15	41	7	2	3	266.9
Soybean	1.13	48	5	2	6	469.1
Siratro	1.13	54	6	2	4	172.8
Lablab bean	1.97	45	8	1	3	201.2
Velvet bean	1.23	43	4	1	5	358.8
Control	1.30	45	7	1	3	135.2

Table 4.3: Effect of six cover crop treatments on tomato plant growth 45 days after transplanting (DAT), and on tomato yield through 125 DAT in greenhouse study one.

	Tomato plant growth data				Tomato fruit harvest	
Treatments	Branches (no./plant)	Height (m/ plant)	Leaf area (cm^2/plant	Dry wt (g / plant)	Fruits (no/plant)	Fruit wt (g / plant)
Rye roots (Rr)	1	1.90	1171	34.2	2	177.7
Rye shoots (Rs)	6	1.93	3662	105.1	0	24.0
Rye roots and shoots (Rrd)	2	2.02	1430	48.9	2	155.1
Rye + pea roots (RPr)	2	1.79	1418	52.1	3	176.7
Rye + peas shoots (RPs)	4	1.66	1740	58.2	4	211.6
Rye + peas roots & shoots (RPrs)	3	1.68	1103	58.1	1	116.8
Soybean roots (Sr)	2	1.82	1334	47.6	2	159.4
Soybean shoots (Ss)	5	2.10	2692	99.8	1	56.8
Soybean roots and shoots (Srs)	6	2.22	3398	107.1	4	328.0
Siratro shoots (Ms)	7	2.03	2298	101.0	2	136.9
Siratro roots (Mr)	4	2.22	2009	76.7	2	80.7
Siratro roots and shoots (Mrs)	7	1.90	3164	111.2	4	211.7
Control (C)	2	1.97	1871	58.7	2	146.8
Lsd (0.05)		Ns	Ns	46.89		Ns

Table 4.4: Effects of cover crop treatments on tomato plant growth and yield in the second greenhouse study. *,***, significant at 0.05 and 0.001 probability levels respectively; Ns, not significant at 0.05 probability level; wt, weight. LSD of number of branches and fruit number not shown because data was transformed before statistical anaysis.

Treatments	Pigweed		Purslane		Green foxtail	
	% germination 8 DAS	% establishment 14 DAS	% germination 8 DAS	% establishment 14 DAS	% germination 8 DAS	% establishment 14 DAS
Rye roots	100	93	100 (10% d.o)	92	6	7
Rye shoots	27	17	17	13	23	44
Rye roots & shts	52	57	23	14	2	2
R+P roots	77 (30% d.o)	38	97 (70% d.o)	20	1	3
R+P shoots	50	36	37 (6% d.o)	33	3	29
R+P roots & shts	22	9	4	1	4	2
Soybean roots	82 (25% d.o)	43	92 (55% d.o)	33	37	50
Soybean shoots	0	0	0	0	2	7
Soy roots & shts	0	0	0	0	1	3
Siratro roots	62 (2% d.o)	24	92 (45% d.o)	38	8	7
Siratro shoots	4	1	33 (100% d.o)	0	4	4
Sirat roots & shts	7	1	0	0	0	1
Control	92 (30% d.o)	18	80 (67% d.o)	1	15	23
Lsd (0.05)	37.2	41.8	40.0	37.5	10.3	32.7

Table 4.5: Effect of cover crop treatments on germination and establishment of three weed species. *, **, ***, significant at p= 0.05, 0.01, and 0.001 respectively. DAS, days after sowing; d.o, damping off; R+ P, rye + pea; shts, shoots; sirat, siratro.

Treatments	Average weed fresh weight (g)		
	Pigweed	Purslane	Green foxtail
Rye roots	0.4	0.6	0.4
Rye shoots	1.8	4.3	0.9
Rye roots and shoots	1.1	1.9	0.7
Rye + peas roots	0.9	1.7	0.7
Rye + peas shoots	1.7	2.7	1.0
Rye + peas roots &shoots	3.1	3.7	1.1
Soybean roots	0.8	1.2	0.6
Soybean shoots	5.2	4.0	1.3
Soybean roots &shoots	0	0	1.6
Siratro roots	0.5	1.3	0.6
Siratro shoots	0	0	0
Siratro roots and shoots	1.6	0	0.5
Control	1.8	2.5	0.6
Lsd (0.05)	2.50	Ns	0.55

Table 4.6: Effects of cover crop treatments on weed fresh weights in second greenhouse study. *,*** significant at 0.05 and 0.001 probability levels respectively; Ns, not significant at 0.05 probability level.

CHAPTER 5

DISSERTATION SUMMARY

Cover crops have regained importance as a method of weed control in sustainable agriculture, reduced or no-till agriculture, and in organic farming. They have potential applications in many crop production systems, but must be investigated thoroughly prior to adaption for specific crops in various parts of the world. This research was carried out to explore the possibility of using spring-sown cover crops for vegetable production in the northern temperate regions, especially by growers interested in reduced herbicide use. Research information will be extrapolated to the tropical situation where cover crops have 1½ to 2 months to accumulate biomass before being killed and the primary crop established. Tomato was the test crop, but results can be applied to other vegetable crops. While some questions were answered by this research, many more have been raised and further research will be carried out in the tropical situation designed to improve on the results obtained so far.

The use of varying combinations and seed rates of the cover crops in this study was important in determining how much biomass could be accumulated and how much weed suppression could be obtained. The 15 cover crop

treatments were repeated in the three years of field trials so as to draw decisive conclusions, which was important as the weather differed from year to year. Having both wet and dry summers in the three years of this field research allowed observations on how well the cover crops would control weeds in a range of environmental situations. Three controls, one left weedy, the second tilled then left un-weeded, and the third tilled and conventionally hand-weeded, provided comparisons of weed pressure in three scenarios to the results from the cover cropped treatments. Two bicultures, ½ rye + ½ field pea, and ¼ rye + ¾ field pea at their highest seeding rates accumulated more than 4 MT ha^{-1} above ground biomass and can potentially suppress weeds under moderate weed pressure. However, a high population of broadleaf weed species like lambsquarters and pigweed that become established before cover crop kill may overcome the suppressive effect of the cover crop mulch if weeds are not killed at the same time as the cover crop. This happened in 1998 when weed suppression was the poorest of all three years. The cover crop mulch for fresh market tomatoes should be thick enough and last at least 30 days after kill to allow the crop to establish and the canopy to close. This would cover the critical period of weed control in tomatoes determined by Weaver and Chin (1983). When there was adequate moisture (1997), the plants established canopies which assisted in weed suppression under the plants. It is crucial also to have at least two days of dry weather after the cover crops and weeds growing among them are killed prior to planting the primary crop to minimize re-establishment.

The greenhouse studies to test the imported tropical legume species against some others showed two promising species, siratro and soybean, which will be investigated further in Uganda. From the promising results obtained with the two bicultures, some monocot species will also be included in the studies to maximize the benefits of the cover crops in vegetable crop production. The monocot species will reduce the rate of decomposition of the cover crop mulch on the soil surface and reduce leaching of nitrate from the soil.

Tomato yield and weed control increased with increasing cover crop biomass, emphasizing the need to establish seeding rates of cover crops which provide adequate mulch on the soil surface. Tomato growth was also outstanding in the two bicultures mentioned above, especially in 1997, so additional work can be done with these combinations, perhaps varying the seeding rates and better timing the cover crop kill time. Other grain species (wheat, oats, barley) have been investigated for spring-sowing and have shown promise. Hairy vetch could be used in place of field peas, as it is already being used as an over-wintering cover crop in the northern temperate regions. There is a potential for spring-sown cover crops in the northern temperates and in the tropics as long as the right cover crop combinations are identified.

Some recommendations can be drawn from this research. Cover crop species for spring-sowing and tropical situations should be able to establish rapidly to accumulate above-ground biomass and smother any weeds that may grow before the cover crop is killed. The siratro and soybean tested in this research showed these qualities and need to be explored further in the field. In

these field research trials the tomato crop was established after killing the cover crop, but instead of waiting that long, strip tillage could be used to establish the primary crop about one month after sowing the cover crop, which can then be killed later on in the growing season. This would give the primary crop more growing time within the season. However, primary crops should be planted as soon as possible after cover crop kill for faster establishment and growth within the critical weed-free period for each crop species (Masiunas, 1998). The tomato crop in 1997 was transplanted one day after cover crops were undercut and performed well with yields up to 50 MT ha^{-1} despite the weed pressure that built up later. For weed sensitive crops additional weeding may be carried out later in the season when the cover crop mulch decomposes and weeds grow through (Masiunas et al., 1995; Mwaja, 1994; Teasdale, 1993), but this should not be a limitation to the use of cover crops. Cover crop mulches can control weeds from 30 to 75 days after cover crop kill depending on the species, location, weather, and time of sowing (Creamer et al., 1996; Barnes and Putnam, 1983; Masiunas et al., 1995; Smeda and Weller, 1996). Cover crop mulch degrades faster in warmer climates.

Cover crops are not without some negative attributes. They may deplete soil nutrients and moisture, or are hosts to the same diseases and hosts as the primary crop. They may also be difficult to kill just by undercutting or mowing, thus herbicides may have to be applied to ensure maximum cover crop kill. Weeds not suppressed by the growing cover crop may later become a problem if they are not killed at the time the cover crop is cut.

This research provided an insight into the problems and cover crop requirements for tropical situations. With the demand for chemical-free crops on the increase in the European markets, especially in the winter, and for organically grown produce in the USA, cover cropping will have an important role in the production package to meet these needs (Collins et al., 1992; Misra et al., 1991). Cover cropping also has potential in spreading out the growing season in the tropical regions, where cold storage and food processing facilities are limited. Some of the crops could be established later in the growing season to stretch out the harvest period and the availability of perishable produce like vegetables.

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APPENDIX A

DOMINANT WEED SPECIES IN 1996

Summary of weed species in cover crop treatments before mowing in 1996, arranged in decreasing order of number of replicates they were observed in. *indicates dominant species. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye+ ½pea; rP, ¾rye + ¼pea; PP, pure pea. H, high (100%) seeding rate; M, medium (50%) seeding rate; L, low(25%) seeding rate. WNT, untilled, weedy control; WT, tilled weedy control; WFT, tilled weeded control.

Treatments	Weed Species
RRH	Green foxtail, common mallow, ladysthumb, *Galinsoga* sp., chickweed
RRM	Ladysthumb, sowthistle*, common mallow, green foxtail, chickweed, *Galinsoga* sp.
RRL	Sowthistle*, ladysthumb, lambsquarter, pigweed, velvetleaf, shepherd's purse, common mallow
RpH	Ladys thumb, common mallow, amaranthus, green foxtail
RpM	Ladysthumb*, green foxtail, common mallow, purslane, chickweed, pigweed, velvetleaf, sowthistle
RpL	ladysthumb, amaranthus, sowthistle, green foxtail, lambsquarter, common mallow
rpH	Green foxtail, ladysthumb, common mallow, pigweed, sowthistle, *Galinsoga*
rpM	Common mallow*, green foxtail*, ladysthumb, lambsquarter, pigweed, *Galinsoga*
rpL	pigweed*, green foxtail, common mallow, ladysthumb, black nightshade, lambsquarter
rPH	Ladysthumb, pigweed, common mallow, green foxtail, lambsquarter, sowthistle, *Panicum*
rPM	Ladysthumb, common mallow, pigweed*, *Galinsoga**, purslane, green foxtail
rpL	Ladysthumb*, pigweed, *Galinsoga***, lambsquarter, common mallow, black nightshade, *Panicum*, shepherd's purse, green foxtail
PPH	Ladysthumb, green foxtail, black nightshade*, lambsquarter, common mallow, pigweed
PPM	Ladysthumb, pigweed, lambsquarter, green foxtail, *Galinsoga*, common mallow, velvetleaf, purselane
PPL	*Galinsoga**, lambsquarter*, green foxtail, smartweed, sowthistle, black nightshade, purselane, pigweed
WNT	Ladysthumb*, *Galinsoga**, velvetleaf*, sowthistle*, lambsquarter*, common mallow*, green foxtail, pigweed, *Panicum**, black nightshade, purslane, shepherd's purse, dandelion
WT	Lambsquarter*, amaranthus*, smartweed*, *Galinsoga**, green foxtail*, black nightshade*, purslane, *Panicum*, green foxtail, common mallow, chickweed, dandelion, sowthistle, velvetleaf,
WFT	Green foxtail*, lambsquarter, sowthistle*, *Galinsoga**, purslane*, *Panicum**, smartweed*, pigweed, velvetleaf, chickweed*, shepherd's purse, common mallow, black nightshade,

APPENDIX B

DOMINANT WEED SPECIES IN 1998

Summary of weed species observed in 1998 before undercutting cover crop treatments. * indicates dominant species. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye+ ½pea; rP, ¾rye + ¼pea; PP, pure pea. H, high (100%) seeding rate; M, medium (50%) seeding rate; L, low(25%) seeding rate. WNT, untilled, weedy control; WT, tilled weedy control; WFT, tilled weeded control.

Treatments	Weed Species
RRH	Sow thistle*, pigweed, *Galinsoga**, bindweed
RRM	pigweed, *Galinsoga* , bindweed, green foxtail,
RRL	pigweed*, sowthistle, *Galinsoga**, lambsquarter, green foxtail, *Panicum*
RpH	*Galinsoga**, pigweed, sow thistle, green foxtail
RpM	*Galinsoga*, pigweed*, lambsquarter, green foxtail
RpL	*Galinsoga*, lambsquarter, pigweed*
rpH	*Galinsoga*, pigweed*, sow thistle
rpM	*Galinsoga**, pigweed*, lambsquarter, green foxtail
rpL	Amaranthus*, *Galinsoga**, lambsquarter*, green foxtail
rPH	*Galinsoga**, pigweed, sow thistle, lambsquarter*, *Panicum*
rPM	*Galinsoga**, pigweed*, ladysthumb, lambsquarter, velvetleaf, green foxtail
rpL	pigweed*, *Galinsoga**, lambsquarter*, green foxtail, *Panicum*
PPH	*Galinsoga*, pigweed*, lambsquarter*, ladysthumb, sow thistle, *Panicum*
PPM	pigweed*, *Galinsoga*, lambsquarter*, *Panicum*
PPL	*Galinsoga**, pigweed*, sow thistle, lambsquarter*, red foxtail, *Panicum*
WNT	*Galinsoga**, pigweed*, lambsquarter*
WT	pigweed*, *Galinsoga*, lambsquarter*
WFT	pigweed*, *Galinsoga**, lambsquarter*, velvetleaf*, green foxtail

APPENDIX C

WEATHER DATA

Rainfall and air temperature data recorded for the duration of the field trials in Columbus, OH. C, Celcius; min., minimum temperature for the month; max., maximum temperature for the month; ins, inches; n. avb, not available. Rainfall recorded April 22 to 30 in 1996, April 20 to 30 in 1997, and April 19 to 30 in 1998.

Month	1996			1997			1998		
	Air temp. (C)		Rain fall (ins.)	Air temp. (C)		Rain fall (ins.)	Air temp. (C)		Rain fall (ins.)
	Min.	Max.		Min.	Max.		Min.	Max.	
April	3	16	4.83	-7	26	0.49	-3	23	2.2
May	10	21	6.43	1	29	6.16	7	32	3.45
June	16	28	4.15	9	34	6.95	6	33	0.51
July	16	28	5.88	9	33	6.16	12	33	0.35
Aug.	16	29	0.89	12	34	5.35	9	34	1.31
Sept.	13	24	4.99	6	30	0.78	n. avb	n. avb	n. avb
Oct.	6	18	n. avb	0	26	3.26	n. avb	n. avb	n. avb

APPENDIX D

COVER CROP ABOVE-GROUND BIOMASS

Cover crop biomass at mowing (1996) or undercutting (1997, 1998), and pooled over the three years in Columbus, Ohio. RR, pure rye; Rp, ¾rye + ¼pea; ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, M, L, 100, 50, 25% seeding rates, respectively. Checks not included because no cover crops were sown in check plots.

Treatments	1996			1997			1998			3-year pooled data		
	Metric tons ha^{-1}											
	Rye	Peas	Total	Rye	Peas	Total	Rye	Peas	Total	Rye	Peas	Total
RRH	1.0		1.0	2.3		2.3	4.3		4.3	2.5		2.5
RRM	1.0		1.0	2.2		2.2	4.4		4.4	2.5		2.5
RRL	0.9		0.9	1.5		1.5	2.0		2.0	1.5		1.5
RpH	0.8	1.5	2.3	2.2	0.3	2.5	3.2	1.2	4.4	2.0	1.0	3.0
RpM	0.8	0.9	1.7	1.7	0.4	2.1	2.6	1.3	3.9	1.7	0.8	2.5
RpL	1.0	0.6	1.6	1.2	0.5	1.7	1.8	1.0	2.8	1.4	0.7	2.1
RpH	0.8	1.4	2.1	1.9	1.2	3.1	2.4	2.2	4.6	1.7	1.5	3.3
RpM	0.9	1.8	2.7	1.6	0.7	2.3	1.9	2.0	3.8	1.4	1.5	2.9
RpL	0.7	0.9	1.6	0.9	0.5	1.4	1.2	1.8	3.0	1.0	1.1	2.0
rPH	0.7	1.8	2.5	1.2	2.4	3.6	1.3	3.3	4.6	1.1	2.5	3.6
rPM	0.5	1.7	2.2	0.6	1.4	2.0	1.2	2.4	3.6	0.8	1.8	2.6
rpL	0.5	1.4	1.9	0.6	1.0	1.6	0.8	2.3	3.1	0.7	1.6	2.2
PPH		3.6	3.6		2.5	2.5		3.5	3.5		3.2	3.2
PPM		3.4	3.4		2.0	2.0		2.8	2.8		2.7	2.7
PPL		2.2	2.2		1.4	1.4		1.7	1.7		1.8	1.8

Appendix D

APPENDIX E

TOMATO TISSUE ANALYSIS

Analysis of young tomato leaf tissue for macro nutrients in 1996 and 1997. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, high seeding rate; M, medium seeding rate; L, low seeding rates. WNT, un-tilled weedy check; WT, tilled weedy check; WFT, tilled weed-free check.

Treatment	1996			1997		
	N (%)	P (ppm)	K (ppm)	N (%)	P (ppm)	K (ppm)
RRH	2.4	6891	26214	3.4	6938	33271
RRM	2.5	6494	23808	3.4	6133	33285
RRL	2.0	5270	20595	2.7	6793	31421
RpH	2.1	8559	26343	3.3	6187	32581
RpM	2.4	9601	27445	3.6	6514	34676
RpL	1.9	9020	23971	3.3	6400	34025
rpH	2.4	8621	30225	3.2	6066	30915
rpM	2.3	9082	29005	3.3	6369	31921
rpL	2.1	7386	24727	3.6	6325	33121
rPH	2.2	8495	25041	3.0	5875	32195
rPM	2.3	9113	26962	3.1	5939	32192
rPL	2.4	9974	28168	3.1	5896	32430
PPH	1.8	10239	25146	3.1	5888	31335
PPM	2.2	9915	26698	3.2	5575	30205
PPL	2.1	8592	20837	3.1	5707	30440
WNT	2.2	10394	28480	3.0	5696	29771
WT	2.1	10813	26010	3.3	6020	33587
WFT	2.5	8578	24514	3.7	6855	35698

APPENDIX F

1997 SOIL ANALYSIS

Soil nutrient analysis results for two sampling dates in 1997. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, high seeding rate; M, medium seeding rate; L, low seeding rates. WNT, un-tilled weedy check; WT, tilled weedy check; WFT, tilled weed-free check.

Treat	Before sowing cover crops							End of season					
	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	CEC (meq)	N (%)	pH	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	CEC (meq)
RRH	6.7	194	252	1783	344	13	0.14	6.7	223	288	1528	320	12
RRM	7.0	178	247	1873	358	13	0.13	7.1	182	271	1893	353	14
RRL	7.1	171	235	1913	369	14	0.13	7.2	204	255	1855	366	14
RpH	7.2	133	204	2125	394	14	0.13	7.3	179	236	1860	369	13
RpM	7.2	184	245	1845	362	13	0.14	6.9	218	255	1618	344	12
RpL	7.2	165	242	1895	377	13	0.14	7.2	215	261	1658	347	12
rpH	7.3	151	219	1948	373	14	0.13	6.9	199	271	1650	341	12
rpM	7.4	147	206	2038	387	14	0.13	7.1	177	271	1840	364	13
rpL	7.3	166	246	1990	362	14	0.13	7.2	192	265	1708	338	12
rPH	7.2	179	254	1945	362	14	0.13	7.2	195	268	1725	349	12
rPM	7.1	162	214	1945	383	14	0.13	7.2	189	233	1763	355	12
rPL	7.0	176	254	1855	348	14	0.14	7.1	197	331	1625	348	12
PPH	7.1	155	250	1983	384	14	0.13	7.1	189	264	1813	382	13
PPM	7.2	157	227	2063	390	15	0.14	7.0	198	262	1758	375	13
PPL	7.3	158	217	2305	382	15	0.13	7.3	188	258	1823	369	13
WNT	7.4	152	215	2025	395	14	0.14	7.2	194	222	1765	358	12
WT	7.1	181	236	1833	359	13	0.13	7.2	197	258	1660	354	12
WFT	7.3	179	214	1798	354	13	0.14	7.2	204	254	1633	344	12

Appendix F.

APPENDIX G

1998 SOIL ANALYSIS

Soil nutrient analysis results for three sampling dates in 1998. RR, pure rye; Rp, ¾rye + ¼pea; rp, ½rye + ½pea; rP, ¼rye + ¾pea; PP, pure pea. H, high seeding rate; M, medium seeding rate; L, low seeding rates. WNT, un-tilled weedy check; WT, tilled weedy check; WFT, tilled weed-free check. Ns, not significant at 0.05 probability level.

Treat	Before sowing cover crops							At transplanting							End of season
	PH	N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Cec (meq)	pH	N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Cec (meq)	N (%)
RRH	6.8	0.12	212	189	1520	305	11	6.5	0.14	217	238	1603	334	13	0.13
RRM	6.8	0.12	220	204	1480	304	11	6.5	0.13	209	232	1500	327	13	0.13
RRL	6.4	0.13	212	197	1340	281	11	6.3	0.13	209	212	1548	333	13	0.12
RpH	6.5	0.12	198	198	1343	285	11	6.5	0.13	217	228	1663	332	13	0.14
RpM	6.4	0.12	187	197	1375	292	11	6.5	0.14	226	231	1643	349	12	0.12
RpL	6.2	0.12	204	192	1270	273	11	6.7	0.13	217	211	1638	347	13	0.12
rpH	6.2	0.13	177	200	1243	265	11	6.5	0.13	217	244	1590	338	13	0.13
rpM	6.1	0.13	198	210	1250	264	11	6.2	0.14	226	240	1493	327	14	0.14
rpL	6.1	0.13	198	209	1350	287	12	6.3	0.14	212	229	1555	339	14	0.13
rPH	6.2	0.13	173	203	1473	293	12	6.5	0.14	226	240	1608	350	14	0.13
rPM	6.2	0.13	176	209	1343	284	11	6.4	0.14	217	227	1588	355	13	0.13
rPL	6.1	0.13	192	223	1403	295	13	6.4	0.14	201	227	1603	354	14	0.14
PPH	6.2	0.14	198	228	1390	284	12	6.6	0.15	217	244	1725	368	13	0.13
PPM	6.3	0.13	179	231	1498	312	12	6.6	0.16	209	227	1628	336	13	0.14
PPL	6.4	0.14	184	230	1543	324	12	6.5	0.14	206	230	1633	335	13	0.13
WNT	6.5	0.14	176	234	1668	356	13	6.4	0.15	226	236	1548	326	13	0.13
WT	6.5	0.14	195	236	1553	329	12	6.4	0.15	223	262	1593	330	13	0.14
WFT	6.9	0.14	172	236	1378	298	11	6.5	0.15	215	273	1538	335	13	0.13
LSD	0.4	0.01	Ns	17.4	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns	0.01

Appendix G.