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Interdisciplinary Pest Management Potentials of Cover Cropping Systems

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Interdisciplinary Pest Management Potentials of Cover Cropping Systems

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

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Plant Biology

by

Oli Gurmu Bachie

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Oli Bachie

ABSTRACT of THE DISSERTATION

Interdisciplinary Pest Management Potentials of Cover Cropping Systems

by

Oli Gurmu Bachie

Doctor of Philosophy, Graduate Program in Plant Biology
University of California, Riverside, December 2011
Dr. Milton McGiffen, Chairperson

Societal demands are increasing for safe crop production systems because of ecological and health risks of pesticides. Cover crops are an alternative to pesticides that may promote crop production. A three-year experiment was conducted to assess the multidisciplinary pest management potential of selected cover crops. The cover crops were planted during the summer and compared with a no-plant summer fallow system as a control treatment. The cropping treatments were assessed for concurrent suppression of weeds, parasitic nematodes, insect pests and their enhancement of beneficial organisms within the subsequent vegetable crop. The research was conducted at the South Coast Research and Extension Station in Irvine, California. Results indicated that the cover crops suppressed weed population densities and their biomass accumulation. Cover crop weed suppression was stronger against broadleaf weeds than grasses and intensity of suppression increased with increasing years of cover cropping rotations, indicating the buildup effect of the system. The cover crop provided stronger weed suppression when coupled with hand weeding, suggesting the importance of cover crops in an integrated weed management system. The cover crops also reduced the time required for supplemental hand weeding, indicating their potential economic benefits. While the off-season cover crops did not show any benefit for suppression of parasitic nematodes and insect pests in the subsequent vegetable crop, the system had significantly increased saprophytic nematode populations which play a beneficial role in improving soil nutrient status. The off-season cover crops also enhanced parasitoid populations and insect pest parasitization levels in the subsequent broccoli crop. At the same time, the cover crops preconditioned and improved soil and crop nutrition. Overall, the cover crops had combined effects on weed suppression, higher populations of beneficial organisms, enhanced soil and crop nutrition, and increased height, canopy growth, and leaf production of the vegetable crop. These combined effects resulted in higher productivity and marketable yields of broccoli compared to those grown on a summer fallow plot. Therefore the use of off-season cover-cropping rotations can provide multiple concurrent benefits to the productivity of vegetable crops.

TABLE OF CONTENTS

Acknowledgement……………………………..…………………………………..…… iv
Abstract of the Dissertation ………………………..………………………...……. vi
General Introduction……………………………………………………………....…… 1
References………………………………..……………………………..……. 5

Chapter 1: The effect of summer cover cropping systems on weed population densities and biomass……………………..………………………………….……. 7
Abstract……………………………………………………………………………. 7
Introduction…………………………………………..………………………..…. 8
Material and methods……………………………………..…………………….……. 9
Results…………………………………………………………..………………… 13
Discussion and conclusion………………………………………………………...… 25
References………………………………………………………………………… 33

Chapter 2: The effect of summer cropping systems on crop parasitic and saprophytic nematodes. ………………………….………………………..……. 36
Abstract………………………………………………………………………… 36
Introduction……………………………………………………………………..…… 37
Material and methods………………………………………….……………….….…… 38
Results…………………………………………………………….……………… 41
Discussion and conclusion………………………………………………...……… 49
References………………………………………………………………………… 57

Chapter 3: The effect of summer cover cropping systems on vegetable insect pests and beneficial arthropods…………………………………………………… 60
Abstract……………………………………………..…………………….….…. 60
Introduction……………………………………………………………….……..…. 60
Material and methods……………………………………………………….……...… 62
Results…………………………………….………………………….………… 65
Discussion and conclusion…………..…………………………………………...… 80
References……………………..…………………………………………...…… 86

Chapter 4: **S**ummer cropping treatments on soil nutrition, crop growth and marketable yield……………………………………………………………...…… 89
Abstract…………………………………………………………………………… 89
Introduction………………………………………………….……….………… 90
Material and methods………………………………………..…………….……… 92
Results………………………………………………………………….….….…… 94
Discussion and conclusion……………………………………………….…...…… 106
References…………………………..…………………………………..……… 118

GENERAL CONCLUSION……………………………………………………… 122
References……………………………………………………………………...……. 131

List of Tables

Table 1.1: Weed population density per m^2 for the early, mid, and harvest time sampling for 2007………………………………………………………………… 15
Table 1.2: Weed population density per m^2 for the early, mid, and harvest time sampling for 2008………………………………………………………..…….…… 18
Table 1.3: Weed population density per m^2 for the early, mid, and harvest time sampling for 2009……………………………..……………………………… 19
Table 1.4: Weed dry biomass (g/m^2) for the early, mid, and harvest time weed sampling for 2007……………………………………………………….......…… 21
Table 1.5: Weed dry biomass (g/m^2) for the early, mid, and harvest time weed sampling for 2008………………………………………………….……….…… 22
Table 1.6: Weed dry biomass (g/m^2) for the early, mid, and harvest time weed sampling for 2009………………………………………………….…….…… 23

Table 2.1: Plant-parasitic nematode population densities per 100 gram of soil for the three cropping treatments of the three year trial…….…………………..… 42
Table 2.2: Mean plant-parasitic nematode population densities per 100 gram of soil for three trial years and sampling periods of three cropping treatments……..… 43
Table 2.3: Nematode population per g of broccoli root and root gall index……...... 44
Table 2.4: Nematode population per g of tomato root sampled at ABH………..… 46

Table 3.1: Probability levels from ANOVA on total and individual insect pest population densities……………………………………………….……... 66
Table 3.2: Probability levels from ANOVA on broccoli leaf damage, total and individual insect parasitism…………………….………………………… 67

Table 4.1: Effect of summer cropping treatments on soil nutrient concentration under the subsequent vegetable crop……………………………………………….. 96
Table 4.2: Effect of summer cropping treatments on soil nutrient concentrations under the subsequent vegetable crop…………….……………………..………… 97
Table 4.3: Effect of summer cropping treatments on mean broccoli shoot nutrient concentration…………………………………………………………………..… 98
Table 4.4: Effect of cropping treatments on number and Fresh weights of broccoli marketable heads………………………….……………………….………..…… 105

List of Figures

Figure 1a: Cover crop and broccoli field planting procedures …………………… 11
Figure 1.1: Duration (minutes)/plot for hand weed removal within the three cropping treatments…………………………………………………………………… 26
Figure 2.1: Nematode population densities/100 g soil pooled for the sampling periods, year, and the cropping treatments……………………………………………… 44
Figure 2.2: Mean nematode population per g of broccoli root pooled for cropping treatment, and years…………………………………………………………………… 45
Figure 2.3: Saprophytic nematode population densities per 100 g of soil for 2007, 2008, and 2009………………………………………………………………………… 47
Figure 2.4: Mean saprophytic nematode population densities per 100 g of soil pooled for year and cropping treatments………………………………………… 49

Figure 3.1: Total insect population density, leaf damage, and total insect parasitization levels in 2007………………………………………………………… 70
Figure 3.2: Individual insect population densities and individual insect parasitization levels in 2007………………………………………………………… 71
Figure 3.3: Total insect population density, leaf damage, and total insect parasitization levels in 2008………………………………………………………… 73
Figure 3.4: Individual insect population densities and individual insect parasitization levels in 2008………………………………………………………… 75
Figure 3.5: Total insect population density, leaf damage, and total insect parasitization levels in 2009………………………………………………………… 78
Figure 3.6: Individual insect population densities and individual insect parasitization levels in 2009………………………………………………………… 79

Figure 4.1: Organic matter content of soils measured at different sampling periods…………………………………………………………………………………… 95
Figure 4.2: Mean broccoli height throughout the growing seasons for 2007, 2008, and 2009……………………………………………………………………………… 100
Figure 4.3: Mean canopy spread per broccoli plant throughout the growing seasons for 2007, 2008, and 2009……………………………………………………………… 101
Figure 4.4: Mean number of leaves per broccoli plant throughout the growing seasons for 2007, 2008, and 2009………………………………………………………… 103
Figure 4.5: Effect of cropping treatments on broccoli shoot biomass for three years…………………………………………………………………………………… 104

INTERDISCIPLINARY PEST MANAGEMENT POTENTIAL OF SUMMER COVER CROPPING SYSTEMS

GENERAL INTRODUCTION

Vegetable growers rely on pesticides for most of their pest management. However, pesticides in general are ecologically hazardous and can be carcinogenic (USDA IPM Centers 2006). Furthermore, consumers are becoming more concerned about health risks associated with heavy use of pesticides. Current agricultural practices also involve mono-cropping that results in a decline in biodiversity which in turn causes significant economic and environmental loss (Altieri 1999). Some of the shortcomings of the current pest management strategies and the justifications for alternative strategies are outlined below. The proposed research will focus on use of off-season cover crops to promote growth of broccoli.

Management of vegetable insect pests

Four potentially serious lepidopterous pests of brassicaceous plants are *Artogeia rapae*, *Plutella xylostella* L., *Trichoplusia ni* Hübner, and *Hellula undalis* Fabricius (Hooks and Johnson 2002). All these species have multiple generations per year and reduce crop marketable yields (Hooks and Johnson 2001). Managing these specific pests can be costly (Maltais et al. 1998) with annual *P. xylostella* management costs alone estimated at US $1 billion per year worldwide (Talekar 1992). Pest management has heavily relied on broad spectrum pesticides, but has often resulted in pest resurgence and environmental pollution (Idris and Grafius 1993). Although attempts have been made to replace the broad spectrum pesticides by “soft” microbial-based insecticides such as *Bacillus thuringiensis* (Vandenberg et al. 1998), some lepidoptera pests readily developed resistance to them (Liu et al. 1996). These biological-based insecticides are also injurious to parasitoids of *P. xylostella* by competing for or killing their hosts (Chilcutt and Tabashnik 1997). Therefore, there is a still a need for alternative and less risky vegetable insect pest management strategy.

Management of crop parasitic nematodes

About $172 million is spent in the US alone on nematicides (Abawi and Widmer 2000) used for control of crop parasitic nematodes. Nematicides are highly toxic and pose health risks to humans and the environment (Abawi and Widmer 2000). These undesirable features have contributed to a ban or the restricted use of many nematicides, and a look into an alternative nematode management strategies.

Vegetable weed management

With an increased adoption of zero or reduced tillage production systems, farmers became increasingly dependent on herbicides (Enache and Ilnicki 1990). Worldwide, 44% of all pesticide sales are from herbicides, costing about $16.9 billion (Aspelin and Grube 1999). Herbicides contaminate the surface and ground water in many agricultural communities (Barbash et a. 1999). Furthermore, the continuing evolution of herbicide resistance and the lack of herbicides registered for vegetables have created a need for alternative management tactics. Effective weed control is especially challenging to farmers who are interested in sustainable production practices or avoid herbicides (Baker and Smith 1987). The Organic Farming Research Foundation (2002) ranked weed control as the top priority and hence a non-herbicide based weed management is increasingly needed, particularly for organic and sustainable farming (Hutchinson and McGiffen 2000).

Recognizing potential side effects of the conventional pest management strategies, a need arose to develop an ecologically based pest management strategy that can also protect farmers from economic hardship when multiple pest complexes plague their crop fields. Furthermore, the enforcement of rules by the USDA-administered Organic Food Production Act of 1990 and the National Organic Program prohibits the use of synthetic chemicals for organic-labeled produce, indicating the importance of non-pesticide crop production systems. Various researchers have pointed to cover cropping as an effective and ecologically desirable alternative pest management strategy (Ngouajio et al. 2003; Ploeg 2002; Wang et al. 2003; Hooks and Johnson 2002; Kremer and Li 2003). Cowpea cultivars were developed to resists root-knot nematodes (Ehlers et al. 2000). Marigold used as cover crop release nematicidal compounds suppressive to key plant-parasitic nematodes and insect pest populations (Finch and Collier 2000).

Although various researchers suggested the effectiveness of cover crops as a pest management strategy, there is a clear lack of knowledge of their efficiency as a multi-disciplinary pest management strategy. The effectiveness of cover crops may also depend on the cover crop species, methods of cover crop management, the pest it is intended to manage, and soil temperature (Ploeg and Maris 1999; Ploeg 2000; Jagdale et al. 1999) and may vary from region to region. Therefore, it is vital to test the applicability of cover crop pest management potential under local environmental conditions.

This research was intended to investigate the multi-disciplinary pest management potential of selected summer cover cropping and its concurrent suppression of weeds, insect pests, nematodes, and the enhancement of beneficial arthropods, and its ultimate effect on vegetable marketable yield. The specific objectives are subdivided as follows;

Objective 1: Determine the effect of cover crops on weed populations.

Objective 2: Determine the impact of cover crops on population densities of parasitic and saprophytic nematodes. I hypothesized that off season cover crops may reduce parasitic nematodes, but enhance beneficial ones in the subsequent vegetable crop.

Objective 3: Determine the impact of cover crops on population densities of key insect pests. It is hypothesized that pest population densities and associated crop damages can be reduced with off season cover cropping. It is also aimed at assessing effects of cover crops on the activities of natural enemies.

Objective 4: Quantify the impact of cover crops on vegetable growth and yield. I hypothesize that the simultaneous suppression of weeds, nematode and insect pests with cover cropping could enhance vegetable growth and marketable yields.

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CHAPTER 1

EFFECT OF SUMMER CROPPING SYSTEMS ON WEED POPULATION DENSITY AND BIOMASS

Abstract

A three-year field study found that summer cover cropping suppresses weed population densities and their biomass accumulation. Cover crop weed suppression was more prominent for broadleaf than grass weeds. Weed suppression increased in each year of the experiment, indicating that repeated cover cropping is more effective than a single season rotation. Stronger cover crop weed suppression was observed with supplemental hand weeding, suggesting the importance of cover crops as an integrated weed management strategy. Significantly fewer hand weeding hours were required in vegetable crops that had a summer cover cropping rotation than the fallow summer. Lowering supplemental weed control strategy with the use of cover cropping indicates the economic benefit of the cover cropping systems. Broccoli had fewer weeds when it followed cowpea than if the summer cover crop was marigold. Greenhouse trials did not show significant effects of cover cropping and hence were inconclusive to determine the potential of cover crops for weed seed bank suppression. Proper selection of cover crop species, adaptability to local location and suitability with the intended main crop are essential for effectiveness of cover crops as a weed management system.

Introduction

Conventional weed management practices that solely depend on intensive use of herbicides are known to cause ecological and health hazards (Barbash et al. 1999), and have triggered societal demand for alternative weed management strategies (Bond and Grundy 2001). Effective and sustainable weed control is also a top priority for organic agriculture (Organic Farming Research Foundation 2002; Brennan and Smith 2005). The National Organic Regulations and Guidelines prescribe the use of preventive measures as a first line of defense against weeds and other crop pests (USDA–AMS 2006) with no chemical weed control. Because of the lack of effective non-chemical weed management strategies, certified organic croplands in the US faces insignificant increases (Gianessi and Reigner 2007).

One of the fast growing alternative weed management strategies that may fulfill an ecologically desirable pest management alternative is the use of cover crops (Creamer and Baldwin, 2000; Hutchinson and McGiffen 2000; Ngouajio et al. 2003). Cover cropping systems involve the use of live plants or their residues as surface mulches (Dabney et al. 2001; Gavazzi et al. 2010). Cover crops not only suppress weeds, but may also improve growth and productivity of the subsequent crops (Creamer and Baldwin, 2000; Brennan and Smith 2005). Many authors showed the usefulness of cover crops as a weed management strategy, but most were from cover crop inter-planting with the main crop (Brennan and Smith 2005; Akemo et al. 2000; Brainard and Bellinder 2004; Walters and Young 2008). Growers are hesitant to use cover crop inter-planting, as because of competition for resources and yield reduction of the main crop (Peachy et al. 2004). This makes the off-season cover cropping rotation a preferred alternative. However, relatively little evidence exists for the weed management potential of off-season cover crops. Limited resources show that off- season cover crops may provide added economic benefits (Creamer and Baldwin 2000; Ngouajio et al. 2003; Bastiaans and Kropff 2008) including soil preconditioning, and supply of additional nutrient to the subsequent crop (Abdul-Baki and Teasdale 1993).

This research assessed the effectiveness of summer cover cropping systems for weed management in a winter broccoli crop. More specifically, it evaluated the responses of major weed population densities and their respective biomass to two cropping strategies; through a) planting two different cover crops as a summer rotation after which the vegetable crop is planted for growth during the subsequent season and b) planting the primary vegetable crop on a summer fallow (bare land) treatment. In order to assess the additional effects of summer cover cropping, we examined soil weed seed bank and the time it may take for hand weeding in each cropping treatments. It was proposed that cover crops reduce soil weed seed pressure and the need for supplemental weed control.

Materials and Methods

Crop management

A three-year field study was conducted from 2007-2009 at the University of California South Coast Research and Extension Center in Irvine, CA on a loamy-sandy soil. Three summer cropping treatments were employed: 1) French marigold (*T. patula* cv. Single

Gold seeded at 2 kg/ha), 2) cowpea (*Vigna unguiculata* cv. UCR CC 36), seeded at 56 kg/ha, and 3) a summer dry fallow as the untreated control. Cowpea was chosen because it is a drought hardy legume, resistant to weeds and enhances some beneficial organisms (Wang et al. 2001). Marigold was chosen because it is known to control a broad range of nematodes (Ploeg 2002; Wang et al. 2001). Each treatment plot was 12 m long x 10.7 m wide (128 m^2). The cover crops were direct-seeded in the last week of June in the center of 14 planting rows of each treatment plot, watered through drip-tubing and grown for three months. The fallow control plots did not receive water during the summer. Each cover crop treatment plot was planted with the same cover crop in each of the three years of study. Plots were separated from each other with a 3 m wide buffer bare ground. The three treatments were replicated four times in a completely randomized design. At the end of the summer cropping period (first-week of September), the cover crops were mowed at the soil line, chopped, and the residues left on the ground. Concurrently, alternate rows (seven of the 14 rows) of each of the cover crop treatments were incorporated into the soil at about 0.4 m intervals using a hand-pushed rotary tiller in preparation for broccoli transplanting. The fallow plots were not tilled. Plots for cover crop and broccoli planting are shown in Figure 1a.

At the beginning of the subsequent (winter) cropping season (10 days after cover crop incorporation or the second week of September), broccoli seedlings (*Brassica olerace,* cv Marathon) were transplanted in double rows into the tilled strips of the summer cover crop and fallow plots at an inter (between seedlings) and intra-row spacing of 13 and 35 cm, respectively (http://ucanr.org /freepubs/docs /711.pdf). Broccoli transplants were drip irrigated and fertilized with emulsified fish meal (6-2-0 organic fertilizer) at 5 gallons/acre rate. Broccoli was chosen because it is a high-value vegetable crop that is sensitive to weeds, insect pests, nematodes (Potter and Olthof 1993), and requires high soil nutrients (http://anrcatalog.ucdavis.edu/ pdf/7211.pdf). All plot treatments were maintained in the same location for all three years of study in order to assess a cumulative effect of cover crops over time.

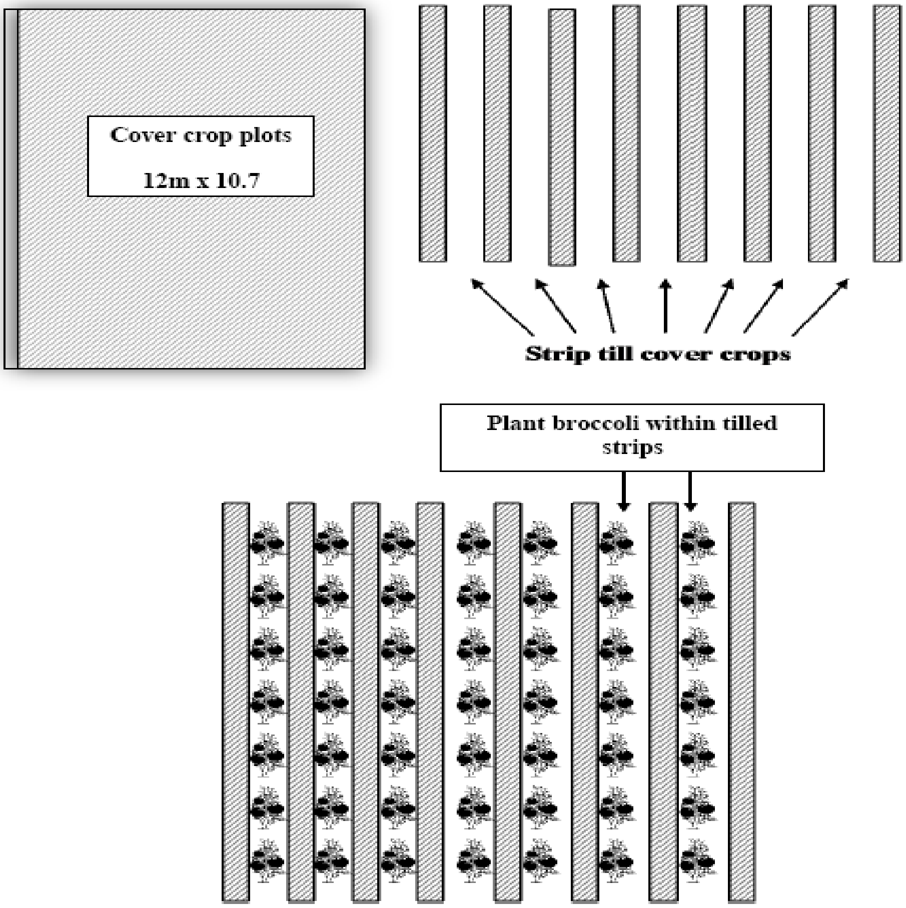

Figure 1a: Cover crop and broccoli field planting procedures

Weed population density and biomass sampling

Weed population density was obtained by sampling at 4 (early), 8 (mid), and 12 (harvest time) weeks after broccoli transplanting. Weed population count was accomplished using a 50 cm x 50 cm quadrat randomly thrown twice within each treatment plot, then counting each weed species that had emerged within the quadrat. The population density of each weed species within a plot was recorded as the average of the two quadrat counts. Following the early and mid sampling periods, all plots were hand weeded, recording the duration of time required for weeding.

Weed dry biomass was determined by clipping the aerial portion of each weed species observed within each quadrat, drying the samples for 7 days at 70^0C, and then weighing. The total weed dry biomass of each weed species was recorded and averaged for the two quadrat samples taken per plot. All weed species population density and dry biomass data were analyzed using ANOVA and the means separated using the student T-test.

Weed Seed-bank analysis

Soil samples were collected three times during each of the three trial years; at the time of cover crop planting (ACCP), at the time of cover crop incorporation (CCI) and at broccoli harvest (ABH). For each treatment plot, a W-shaped pattern was followed to collect twenty soil cores of 10 cm deep each following soil sampling procedures of Forcella et al. (1992). Weed seed populations from each sampling were assessed using a simple greenhouse weed seed germination test. A set of 500 g soil from each of the sampling periods were spread in flats, placed in the greenhouse and kept moist and well drained. The soil was stirred after the 1st two weeks to expose buried seeds to light and trigger germination. Emerged seedlings were counted and removed every two weeks for one month. After one month, the soil was placed in a cold room for 30 days to simulate conditions needed by some weeds for breaking their dormancy and again placed in the greenhouse for one month and germination counted again. Weed seedlings were identified to species and the number of individuals that had emerged from each sample was recorded and pulled from the flats at regular intervals. Flats were checked regularly at 3-4 day interval for newly emerged seedlings to assure that no plants emerged and died between counting.

Assessment of supplemental weeding time

Depending on weed density and the need for weed removal, two supplemental hand weeding were applied each year within the vegetable crop. Weeds were sampled for population densities before each hand weeding. The time required for the hand weeding in the vegetable crop grown on each of the three cropping treatments was assessed with a timed weeding and recorded as time (minutes) from start to finish.

Results

Effects of cover crops on weed population density

The most dominant weed species during all years was *Portulaca oleracea* (common purslane), accounting for 70-85% of all weed populations. Other weed species were

Chenopodium album (common lambsquarters), *Solanum nigrum* (black nightshade), *Amaranthus species* (Amaranth), *Malva nicaeensis* (bull mallow), *Sonchus oleraceus* (annual sowthistle), *Convolvulus arvensis* (field bindweed), *Capsella bursa-pastoris* (shepherd's-purse) and *Erodium cicutarium* (redstem filaree). *Urtica urticaurens* (burning nettle) and *Oxalis corniculata* (creeping woodsorrel) were observed in some plots, but rarely. The grassy weed species *Echinochloa crus-galli* (barnyardgrass) and *Eragrostis barrelieri* (Mediterranean lovegrass) occurred very sporadically. Data on weed population densities were presented in Table 1.1 (for 2007), Table 1.2 (for 2008), and Table 1.3 (for 2009).

Population densities of common purslane at the early sampling of 2007 were significantly lower for the cover crop treatments (P = 0.0008) compared to the summer fallow (Table 1.1). At this sample date, which was just before the initial hand weeding the population density of common purslane within the fallow summer plot peaked at 370 plants per m^2 Therefore, the cover crops reduced purslane populations to one-fifth and less than one-tenth in broccoli that followed either a summer cowpea or marigold cover crops, respectively. All weed population densities following initial hand weeding were generally low for all treatments and did not vary among the cropping treatments. However, the total population density of all weeds combined, mostly accounting for variations in purslane population densities was lower by 5 and 4 times (P = 0.0009) if broccoli followed summer marigold and cowpea, respectively, compared to these on a fallow plot (Table 1.1). Cover crop weed population suppression was more prominent

Table 1.1: Weed population density per m^2 for the early, mid, and harvest time sampling for 2007[*]

Weed species	Weed sampling time and cropping treatments								
	Early			Mid			Harvest time		
	mg	cp	fw	mg	cp	fw	mg	cp	fw
Portulaca oleracea	34^{a}	82^{a}	370^{b}	2	10	36	0	8	36
Chenopodium album	3	3	7	12	4	10	9	3	8
Solanum nigrum	6	5	18	0	0	2	2	0	2
Amaranthus spp[**]	6	2	0	0	1	0	0	0	0
Malva nicaeensis	13	10	10	8	6	3	6	6	7
Sonchus oleraceus	1	1	0	5	3	6	5	1	6
Convolvulus arvensis	0	0	0	0	0	0	0	2	2
Tagetes patula	2	1	1	3	1	0	1	1	0
Other broadleaves	3	2	5	1	2	1	2	2	5
Echinochloa crus-galli	2	0	0	3	2	20	0	0	20
Other grass	20	5	24	2	4	6	2	2	2
All broadleaves	65^{a}	105^{a}	409^{b}	29	26	57	23^{a}	21^{a}	64^{b}
All grasses	22	5	24	5	6	26	2	2	21
All Weeds	87^{a}	110^{a}	433^{b}	33a	32a	82b	25^{a}	23^{a}	85^{b}

[*] Horizontal mean values for each weed species within each sampling time followed by different letter are significantly different from each other. Data not shown with letter values are not significantly different from each other. mg = marigold, cp = cowpea and fw = fallow.

[**] Some of the common *Amaranthus* species were *A. albus*, *A. sinosus* and *A. retroflexus*.

against broadleaves (p = 0.0006) than grass weeds. Grass weeds were generally of low densities and were unaffected by the summer cropping treatments of the first year (2007) (Table 1).

Weed population densities at mid and harvest time sampling were lower than the early sampling period (pre hand weeding) (Table 1.1). The individual weed population densities at the mid and harvest time sampling were not significantly different among cropping treatments (Table 1.1), except for higher total broadleaf (P = 0.0463) and the combined all weed species (P = 0.0291) in the fallow compared to both cover crop treatments (Table 1.1).

Weed population densities for the early sampling of the second year (Table 1.2) resembled that of the first year (Table 1.1), with *Portulaca oleracea* remaining as the most dominant weed. The effect of cover crop weed suppression was also similar. Accordingly, the population density of *Portulaca oleracea* at early sampling of the second year was reduced by 3 or 4 times (P = 0.0251) if broccoli was planted after summer marigold or cowpea respectively, compared to the summer fallow (Table 1.2). The supplemental hand weeding further reduced weed population densities for 2008 as can be seen from the lower weed population densities during the mid and harvest time sampling (Table 1.2). At mid-season and harvest time samplings of 2008, population densities of common purslane were still was significantly lower in the cover crop treatments compared to the fallow (P = 0.0628 and P = 0.0169, respectively). Similar to the 2007 observation, the broadleaved weeds were still more suppressed with cover cropping and hand weeding interactions that the grass weeds.

Weed population densities during the third year (2009) were generally lower than the previous two years. Common purslane was the most abundant weed for early sampling of 2009, but was reduced by 6 and 12 times (P = 0.0727) in marigold or cowpea treatments, respectively compared to the fallow treatment (Table 1.3). Cover crop suppression of *Solanum nigrum* (P = 0.0150), *Amaranthus* species (P = 0.0459) and *Erodium cicutarium* (P = 0.0021) became significant only for this year.

The cover cropping treatment continued to suppress common purslane (P = 0.0943) and *Amaranthus* species (P = 0.0737) at mid sampling (after initial hand weeding) in 2009. The population densities of these weeds at the mid sampling were lower for the summer cover crop than the fallow treatment (Table 1.3). Lower population densities of common purslane (P = 0.0366) and all weeds combined (P = 0.0530) were observed at harvest time for cover crop treatments in 2009 compared to summer fallow (Table 1.3). Among the cover crops, vegetable crops that had cowpea as a summer cover crop had fewer population of weeds than the marigold (Table 1.3). Compared to the previous years, the lowest weed population densities were observed at any sampling date in 2009. There were no significant differences in the population densities of common purslane at the harvest time sampling of 2009 (Table 1.3). Cowpea as a cover crop showed stronger weed suppression capabilities than marigold.

Table 1.2: Weed population density per m^2 for the early, mid, and harvest time sampling for 2008[*]

	Weed sampling time and cropping treatments								
	Early*			Mid			Harvest time		
Weed species	mg	Cp	fw	mg	cp	fw	mg	cp	fw
Portulaca oleracea	96a	85a	331b	7a	10ab	40b	6a	9a	63b
Chenopodium album	7	10	15	0	0	5	0	0	6
Solanum nigrum	1	3	13	0	1	3	0	0	1
Amaranthus spp[**]	0	0	3	0	0	1	0	0	0
Erodium cicutarium	12	0	10	0	0	2	15	0	1
Sonchus oleraceus	6	8	17	0	1	3	2	3	5
Convolvulus arvensis	0	0	3	0	0	0	0	1.5	0
Capsella bursa-pastoris	0	7	3	0	0	0	0	0	0
Other broadleaves	6	4	12	4	3	4	11	4	13
Eragrostis barrelieri	5	15	20	3	0	1	1	1	3
Echinochloa crus-galli	-	-	-	0	0	4	0	0	0
Other grass	5	0	3	0	2	0	5	1.5	4
All broadleaves	128a	115a	415b	11a	14a	58b	33a	17a	87b
All grasses	9	15	23	3	2	5	5.5	2.0	7
All Weeds	137a	130a	437b	14a	16a	62b	39a	19a	94b

[*] Horizontal mean values for each weed species within each sampling followed by different letters are significantly different from each other. Data not shown with letter values are not significantly different from each other. mg = marigold, cp = cowpea and fw = fallow.

[**] Some of the common *Amaranthus* species were *A. albus*, *A. sinosus* and *A. retroflexus*.

Table 1.3: Weed population density per m^2 for the early, mid, and harvest time sampling for (2009)[*]

	Weed sampling time and cropping treatments								
	Early			Mid			Harvest time		
Weed species	mg	Cp	fw	mg	cp	fw	mg	cp	fw
Portulaca oleracea	32a	16a	197b	5a	3a	11b	0.3	0.5	0.0
Chenopodium album	3.0	0.5	6.3	0.3	0.5	2.0	0.0	0.0	0.5
Solanum nigrum	0.0a	0.0a	4.5b	0.0	0.0	1.5	0.3	0.0	0.0
Amaranthus spp[**]	1.3a	0.8a	9.8b	0.0a	0.3ab	2.3b	0.5	0.0	0.0
Malva nicaeensis	9.5	4.8	11.3	8.0	4.8	6.5	1.8	0.5	1.8
Sonchus oleraceus	2.3ab	0.8a	9.0b	1.3	1.8	2.0	0.5	0.0	0.0
Capsella bursa-pastoris	4.3	0.0	11.0	4.8	0.8	3.3	3.5	1.0	1.8
Erodium cicutarium	1.8a	0.0a	6.8b	0.3	0.3	1.8	0.5	0.0	0.0
Urtica urticaurens	1.3	1.3	7.5	2.3	1.8	5.8	4.0	0.8	7.8
Oxalis corniculata	1.5	0.0	1.3	1.3	0.3	1.5	1.5	0.0	3.0
Eragrostis barrelieri	7.3	0.0	16.0	1.3	0.0	0.5	0.3	0.0	0.3
Echinochloa crus-galli	1.0	0.0	5.3	0.8	0.0	0.0	0.0	0.0	0.3
Other grasses	0.0	0.0	1.8	0.3	0.0	1.5	0.0	0.0	0.0
All broadleaves	64a	24a	281b	26ab	14a	44b	13ab	3a	15b
All grasses	1.0	0.0	7.3	2.4	0.0	2.0	0.3	0.0	0.6
All Weeds	65a	24a	288b	28ab	14a	46b	13ab	3a	16b

[*] Horizontal mean values for each weed species within each sampling time followed by different letters are significantly different from each other. Data not shown with letter values are not significantly different from each other. mg = marigold, cp = cowpea and fw = fallow.

[**] Some of the common *Amaranthus* species were *A. albus*, *A. sinosus* and *A. retroflexus*.

Effects of summer cropping system on weed dry biomass

Biomass accumulation of individual weeds was related to the specific weed population densities. During all years, common purslane attained the highest dry biomass accumulation depending on the cropping treatments. At early sampling of 2007, common purslane attained 100 and 36 times higher dry mass in the fallow (P = 0.0422), relative to the marigold or cowpea cover crops, respectively (Table 1.4). Dry mass accumulation from all weeds combined for the early sampling were also reduced by 37 times when the summer cropping was either a marigold or a cowpea compared to the fallow (P = 0.0408) treatment. Similar to the weed population densities, reduction in weed biomass was stronger for the broadleaves than on grass weeds (Table 1.4). Weed biomass accumulation during the mid and harvest time samplings did not vary among the cropping treatments, attributing the cover crops and initial hand weeding that might have already depleted weed seed banks and new weed germination.

Cover crop suppression of purslane biomass accumulation (P = 0.046) and all weed biomass accumulation (P = 0.0057) was also observed for 2008. Cowpea and marigold as cover crops reduced purslane biomass by 6 and 20 times, respectively at the mid sampling (P = 0.0563) compared to the same time sampling on a fallow treatment (Table 1.5). Similarly, dry mass of all weeds at the mid (P = 0.0007) and harvest time sampling (P = 0.010) were significantly lower for the cover crop compared to the Fallow treatment (Table 1.5). Stronger suppression of on biomass accumulation of broadleaves than grasses is consistent for this year as well. The only exception from the first year trial was

Table 1.4: Weed dry biomass (g/m^2) for early, mid, and harvest time weed sampling for 2007[*]

Weed species	Weeding sampling time and cropping treatments								
	Early sampling			Mid sampling			Harvest time		
	mg	cp	fw	mg	cp	fw	mg	cp	fw
Portulaca oleracea	0.1a	0.3a	10.7b	0.0	0.1	0.0	0.0	0.1	4.0
Chenopodium album	0.2	0.0	0.0	0.1	0.0	0.1	0.5	0.4	1.7
Solanum nigrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Amaranthus spp[**]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malva nicaeensis	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.8
Sonchus oleraceus	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.4
Convolvulus arvensis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Tagetes patula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other broadleaves	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.5
Echinochloa crus-galli	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Other grass	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1
All broadleaves	0.3a	0.3a	11b	0.1	0.1	0.1	1.0	1.1	7.6
All grasses	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.6
All Weeds	0.4a	0.3a	11b	0.1	0.1	0.1	1.0	1.1	8.1

[*] Horizontal mean values for each weed species within each sampling time followed by different letters are significantly different from each other. Data not shown with letter values are not significantly different from each other. mg = marigold, cp = cowpea and fw = fallow.

[**] Some of the common *Amaranthus* species were *A. albus*, *A. sinosus* and *A. retroflexus*.

Table 1.5: Weed dry biomass (g/m^2) for the early, mid, and harvest time weed sampling for 2008*

	Weeding sampling time and cropping treatments								
	Early sampling			Mid sampling			Harvest time		
Weed type	mg	Cp	fw	mg	cp	fw	mg	cp	fw
Portulaca oleracea	6a	10a	28b	1.0a	1.1a	4.4b	0.6a	2ab	12b
Chenopodium album	0.3	0.3	0.5	0.0	0.0	4.5	0.0	0.0	2.3
Solanum nigrum	0.0	0.0	0.5	0.0	0.3	0.3	0.0	0.0	0.1
*Amaranthus spp***	0.0	0.0	0.2	0.0	0.0	0.1	0.0	0.0	0.0
Erodium cicutarium	0.2	0.0	0.3	0.0	0.0	0.0	0.2	0.0	0.5
Sonchus oleraceus	0.3	0.5	0.8	0.0	0.0	0.4	0.6	0.8	2.0
Convolvulus arvensis	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.3	0.0
Capsella bursa-pastoris	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Other broadleaves	0.1	0.3	0.3	0.2	0.1	0.2	0.3	0.7	3.3
Eragrostis barrelieri	0.1	0.8	2.0	0.6	0.0	0.0	0.0a	0.1a	0.8b
Echinochloa crus-galli	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
Other grass	0.5	0.0	0.7	0.0	0.1	0.0	1.4	0.6	1.0
All broadleaves	7a	11a	32b	1.1a	1.5a	10b	2a	4a	20b
All grasses	0.6	0.8	2.7	0.6	0.1	0.6	1.5	0.7	1.8
All Weeds	8a	12a	35b	1.7a	1.6a	11b	3a	5a	22b

*Horizontal mean values for each weed species within each sampling time followed by different letters are significantly different from each other. Data not shown with letter values are not significantly different from each other. mg = marigold, cp = cowpea and fw = fallow.

** Some of the common *Amaranthus* species were *A. albus*, *A. sinosus* and *A. retroflexus*.

Table 1.6: Weed dry biomass (g/m^2) for the early, mid, and harvest time weed sampling for 2009*

	Weed sampling time and cropping treatments								
	Early sampling			Mid sampling			Harvest time		
Weed species	mg	mg	Fw	mg	cp	Fw	mg	cp	Fw
Portulaca oleracea	6.3	10.1	19	0.83	0.51	1.46	0.01	0.03	0.0
Chenopodium album	1.4	1.8	0.6	0.36	0.23	1.49	0.0	0.0	0.2
Solanum nigrum	0.0a	0.0a	0.4b	0.0	0.0	0.3	0.02	0.0	0.0
*Amaranthus spp***	3.8	0.19	4.9	0.0	0.07	1.1	0.45	0.0	0.0
Malva nicaeensis	1.4	0.28	1.6	1.02	2.3	6.0	0.06	0.11	3.8
Sonchus oleraceus	1.0	0.60	4.2	0.12	1.30	3.7	0.07	0.0	0.0
Capsella bursa-pastoris	0.32	0.00	4.2	0.71	0.13	2.2	0.96	0.23	0.35
Erodium cicutarium	0.7ab	0.0a	2.1b	0.35	0.04	4.7	0.11	0.0	0.0
Urtica urticaurens	0.04	0.25	1.24	0.34	0.34	1.1	0.49	0.13	1.78
Oxalis corniculata	0.04	0.00	0.15	0.07	0.01	0.13	0.49	0.00	0.61
Other Broad leaf	0.00	0.00	0.00	0.00	0.00	0.6	0.0	0.0	0.61
Eragrostis barrelieri	2.3	0.00	0.97	0.08	0.00	0.12	0.03	0.0	0.09
Echinochloa crus-galli	0.39	0.00	0.70	0.05	0.00	0.00	0.0	0.0	0.01
Other grasses	0.00	0.00	0.61	0.00	0.00	0.69	0.0	0.0	0.0
All broadleaves	15a	13a	38b	5a	5a	24b	3a	1a	10b
All grasses	2.7	0.0	2.3	0.13	0.0	0.81	0.03	0.0	0.10
All Weeds	18a	13a	40b	5a	5a	25b	3a	1a	10b

*Horizontal mean values for each weed species within each sampling time followed by different letters are significantly different from each other. Data not shown with letter values are not significantly different from each other. mg = marigold, cp = cowpea and fw = fallow..

** Some of the common *Amaranthus* species were *A. albus*, *A. sinosus* and *A. retroflexus*.

the suppression of the dry biomass of a grass weed, *Eragrostis barrelieri,* under the cover crop treatments (p = 0.0510) at the second year harvest time sampling (Table 1.5).

Weed biomass was generally lower for 2009 than either 2007 or 2008, suggesting that repeated years of cover cropping rotations and hand weeding may provide increased weed suppression in the subsequent vegetable crop. Greater biomass accumulation in all weeds combined was observed in the fallow plots at early (P = 0.0335), mid (P = 0.0002) and harvest time (P= 0.0167) samplings compared to plots that had summer cover crops (Table 1.6) with stronger suppression on broadleaves than grasses weeds.

Effect of cover cropping on soil weed seed bank

The greenhouse weed seed germination tests showed poor responses for all three years. Even the most dominant weed, *Portulaca oleracea* germinated poorly or failed to germinate at all. Among these germinated, none or only very few weeds showed variation among cropping treatments for both 2007 and 2008 (data not shown). Therefore, this portion of the research finding is inconclusive and has been omitted.

Comparison of summer cropping system and supplemental weeding needs

The time required for the initial (first) weeding in 2007 was not different among the cropping treatments (Figure 1.1), probably due that the cover crops did not provide efficient weed suppression at this initial stage of crop rotation. Differences among cropping treatments (P = 0.0395) on supplemental hand weeding duration appeared at the second hand weeding in 2007 (Figure 1.1) and all other weeding periods of the subsequent years. Longer weeding hours were required for the initial weeding on the fallow plots for 2008 (P = 0.0110) and 2009 (P = 0.0018) compared to the cover cropped plots. The combined initial and second round time spent on hand weeding was higher in the fallow plots of 2007 (P = 0.0559), 2008 (P = 0.0154), and 2009 (P = 0.0005). At all hand weeding periods of all years, longer time was spent weeding in the marigold than in the cowpea treatment, showing stronger weed suppression of cowpea as cover crop than marigold. The relative total weeding time in the fallow plot to the time required in a cowpea plot was about twice in 2007, 2.5 times in 2008, and 2.8 times for 2009, indicating stronger reduction in labor with increasing years of cover cropping rotations.

Discussion and Conclusion

The three consecutive experimentation years revealed that common purslane (*Portulaca oleracea*) was the most prevalent weed both in population density and biomass accumulation. Adler and Chase (2007) states that common purslane is a prolific seed producer that can rapidly colonize warm, moist sites. Either cowpea or marigold used as summer cover crop suppressed common purslane. While individual weeds of the other species were not responsive to the cover cropping treatments, the combined population density and biomass of all weeds was significanly reduced under the summer cover cropping treatments compared to the summer fallow. Hutchinson and McGiffen (2000) also observed sufficient levels of weed suppression with cover crop mulches in desert pepper production.

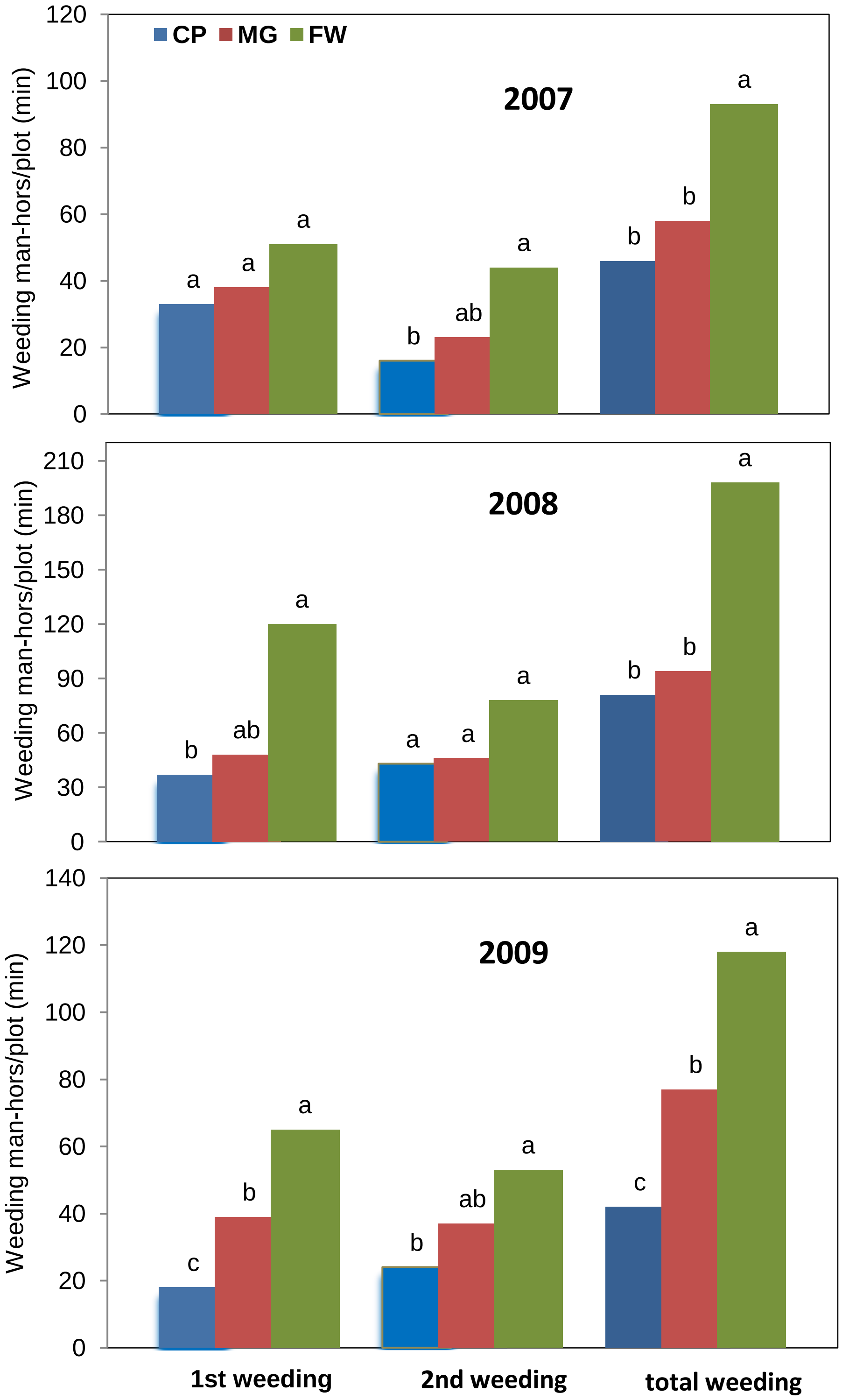

Figure 1.1: Duration (minutes)/plot for hand weed removal within the three cropping treatments for 2007 (top), 2008 (middle) and 2009 (bottom)

Weed suppression with off-season cover cropping treatment was more robust when coupled with supplemental hand weeding, because post-weeding (after the mid and harvest time samplings) population and biomass accumulation of weeds were lower under the cover cropping treatments than the fallow. Therefore summer cover cropping can provide long-term weed suppression, even after the establishment of the vegetable crop. The lower weed population and weed biomass during the subsequent sampling periods of all years (regardless of the cropping treatment) relative to the early sampling stages reveal that supplemetal hand weeding is critical and reduces early stage weed pressure on vegetable crops. It also shows the importance of integrating cover cropping rotations with supplemental hand weeding for more efficient weed management.

Weed suppression during the early growth of a vegetable crop is desirable as most crops suffer serious weed competition during their early growth stages. Eliminating or minimizing early stage crop-weed competition may help a crop to make vigorous growth, develop dense canopy faster and suppress emergence and growth of weeds in the subsequent crop growth season. A long-term weed supression and nitrogen (N) contribution from foxtail millet [*Setaria italica* (L.) Beauv.] and cowpea [V*igna unguiculata* (L.)] cover cropping has been observed to produce greater total marketable yield of bulb onion (*Allium cepa* L.) (Vollmer and Creamer 2010).

Consistent and prominent cover crop weed suppresion was observed against broadleaf than grass weeds, suggesting that cover cropping is more beneficial in agricultural fields dominated by broadleaf weeds. In a similar experiment, Wang et al. (2008) observed a higher suppression of broadleaf weeds than grasses using sun hemp mulches. While cover cropping consistently suppressed weeds during all years, the more cover cropping rotation (years), the stronger was the weed suppression. These findings suggest that cover cropping has incremental effects with increasing years of cover crop rotations. Among the cover crops used, cowpea, if used as a summer cover crop, could provide more weed suppression than if the cover crop was marigold.

Many researchers (Unamma et al. 1986; Hutchinson and McGiffen 2000; and Ngouajio et al. 2003) showed that cowpea provided excellent suppression of weeds when used as an intercrop or organic mulch. The stronger weed suppression and hence less supplemental hand weeding time in cowpea cover crop is probably attributed to the nitrogen fixing ability and more nutrient supply potential, and enhancement of the subsequent vegetable crop growth and facilitating the vegetable crop to suppress weeds on its own at its subsequent growth stages. Enhanced soil quality is one of the reasons contributing to the suppression of weeds within the subsequent vegetable crops (Brainard and Bellinder 2004). The off-season cover cropping that leaves crop residues on soil surfaces increase soil N level and supress weeds in vegetable crops (Teasdale and Pillai 2005; Creamer and Baldwin 2000; Liebman and Staver 2001).

Weed seed greenhouse germination was generally very poor and showed mixed responses among the different weed species. Some weed species germinated more in soil samples collected from the cover crop plots while others were relatively higher in the fallow treatment. Therefore, the effects of cover cropping for the portion of soil weed seed population densities are inconclusive and the “potentially higher” weed seed bank hypothesis within a fallow summer cannot be confirmed. The amount of soil used for germination tests may have not been sufficient enough or our greenhouse conditions might have not provided optimum condition for weed seed dormancy breaking. A further study is recommended to verify the potentials of cover cropping in reducing soil weed seed banks.

The study on effects of cover cropping on supplemental hand weeding duration revealed that cover cropping reduce the time it may take for supplemental hand weeding.   The reduction of supplemental hand weeding time within the cover crop treatments compared to the fallow treatment was consistent for all three years. The total amount of time needed during the whole crop growing season was almost double in the summer fallow plots compared to the summer cover cropped fields. Reducing supplemental weeding needs decreases production costs and provides higher economic return from vegetable crop production.

Although Kumar et al. (2009) suggest that there is no clear mechanism by which cover crop residues may suppress weeds, there are many possible mechanisms listed for weed suppression using off-season by summer cover crops and their residues. Adler and Chase (2007) suggest that cover crop residues suppress weeds through its modification of soil microclimate and physical impedance of weed seed germination or serving as a physical barrier and inhibiting light penetration (Teasdale and Mohler 1993; Liebman and Mohler 2001; Brainard and Bellinder 2004). Others suggest that the exclusion of light is an indirect mechanism by which cover crop residues may suppress weeds and that the actual mechanism is through the reduction of soil temperature fluctuations useful in breaking weed seed dormancy and germination. For example, in the absence of fluctuating soil temperature, *Portulaca oleracea* (Thompson and Grime 1983), *Chenopodium album* and *Amaranthus retroflexus* (Wiese and Binning 1987) failed to germinate. Cover crop residues may also suppress weeds through stimulating or suppressing of soil microbial populations which deplete soil weed seed banks (Conklin et al. 2002; Matthiessen and Kirkegaard 2006).

The off-season cover crop stand may utilize water and nutrients that would otherwise be used by weed species (Teasdale 1998) and hence provides a mechanism by which off-season cover crops could suppress weeds in the subsequent crops. Some cover crops inhibit weeds through allelopathy (Khanh et al. 2005). If there were allelopathic effects from the cover crops used in this trial, the allelopathic compounds must have been more specific to the broadleaved weeds, because the cover crops used were more suppressants to broadleaves. Selective phytotoxicity of allelopathic compounds to broadleaf weeds has been discussed by Ercoli et al. 2007; Jelonkiewicz and Borowy 2005; Hill et al. 2007; Adler and Chase 2007). Selective suppression of weed species with glucosinolate compounds (specific to *Brassica* cover crops) was documented (Haramoto and Gallandt

2005; Norsworthy et al. 2007). Benzoxazinoid compounds specific to rye cover crop mulches suppressed different sets of weed species (Gavazzi et al. 2010). A proper and detailed understanding of allelopathic cover crops may aid scientist to develop effective biological weed control (Khanh et al. 2005) and reduce future reliance on synthetic herbicides (Duke 2010).

Although both marigold and cowpea significantly suppressed weed pressure when used as cover crops in a subsequent vegetable crop relative to the fallow summer, none of the cover crops provided a complete control of weeds without supplemental weed management options. Therefore cover crops may not be considered as the sole control of weeds, but as an integrated component and holistic approach of weed management options. The greater effectiveness of cover cropping as component of integrated weed management strategies was emphasized by Dıaz-Pe´rez et al. (2008). Within the cover crops, the species that possesses rapid growth (Creamer and Baldwin 2000) and large biomass production characteristics (Teasdale and Mohler 2000) may provide more weed suppression.

Finally, weed management using cover crops is ecologically friendly and if coupled with some traditional weed control methods could eliminate or reduce reliance on chemical weed control. In this respect, cover crops may be particularly appealing and useful for organic crop production systems where chemical weed management is not an option. Since the off-season cover crops are not grown simultaneously with the major crop, there would not be a resource competition threat as when the cover crops are inter-cropped with the main crop. To make efficient use of cover crops, growers must also identify the adaptability of cover crops to their local farm condition, the weed species and the economic considerations of agricultural systems. One must also confirm that the specific cover crops and residues could suppress diverse weed species with no or little interfere with the major crop. The USDA–AMS (2006) emphasizes that the screening of cover crops along various crop productions may fulfill the National Organic Regulations and Guidelines that require preventive measures, safe crop production practices and use of competitive crops as a first line of defense against weeds.

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CHAPTER 2

EFFECT OF SUMMER CROPPING SYSTEMS ON PARASITIC AND FREE-LIVING NEMATODE POPULATION DENSITIES

Abstract

The response of nematode population densities to cover cropping treatments was assessed at different times during the cropping period for three consecutive years. At vegetable harvest, root samples were extracted for root knot nematode juveniles (j2 RKN) and evaluated for gall indexing. Nematode population densities were generally low and very patchy. Root-knot nematode (*Meloidogyne incognita)*, cyst nematode (*Heterodera schachtii)*, and pin nematodes (*Paratylenchus* species) were the only species, and none exhibited significant variation among the cropping treatments. Rarely, the root-knot nematode (RKN) and the cyst nematode (SCN) had higher population densities in cowpea than either marigold or fallow treatments. Vegetable root-gall indices were not significant among the cropping treatment and hence cover-cropping treatments cannot be justified. In general, the off-season cover cropping treatments had little or no effect in suppressing soil or crop parasitic nematodes. However, off-season cover cropping treatments significantly increased saprophytic nematode population densities. Saprophytic nematode population densities increased with increasing years of cover cropping rotations, indicating the buildup effect of continuous and long-term cover cropping rotations. The increased population densities of saprophytic nematodes within

the summer cover-cropped plots may be due to the added organic matter accumulation from the cover crops supporting saprophyte nematode food webs.

Introduction

Plant-parasitic nematodes cause severe damage to vegetable crops and cause an estimated annual yield loss of $77 billion to $125 billion worldwide (Abawi and Widmer 2000; Chitwood 2003). Nematicides are used to control plant parasitic nematodes. However, there is health and ecological hazards associated with the use of nematicides, hence the need for risk free, economical, and ecologically desirable alternative methods of managing nematodes (Abdel-Rahman et al. 2008).

Genetic resistance and cultural practices can be alterative nematode management strategies (Ehlers et al. 2002). Another simple and practical alternative is the use of nematode suppressive cover crops (Ploeg and Maris 1999; Wang et al. 2003a; Krueger et al. 2007). Cover crops may suppress nematodes by being a poor host, by having a nematicidal effect, by enhancement of nematode antagonists or beneficial nematodes or serving as a “dead end” trap crop (Ploeg 2000; Wang et al. 2001). However, cover crop nematode suppression is dependent on cultivar of the cover crop, soil temperature (Ploeg and Maris 1999), nematode species (Robinson et al. 1997), and how the cover crop is managed. For example, growing marigold (*Tagetes patula*) as a cover crop consistently lowered root-galling by *M. incognita* on tomato (Ploeg 2002), while incorporation of marigold crop residue failed to do so (Ploeg 2000). Cover crops grown before the main crop can also suppress nematodes and protect a subsequent and susceptible vegetable crop (Krueger et al. 2007). Wang et al. (2001) on the other hand observed that incorporated cover crop residues had no effect on parasitic nematodes, but enhanced population densities of bacterivorous nematodes.

This research is aimed at assessing the effects of summer cover cropping systems on plant parasitic and free-living nematodes in a subsequent vegetable crop. The approach was to use French marigold (*T. patula* cv. Single Gold) and cowpea (*Vigna unguiculata* cv UCR CC 36) as summer cover crops and compare them to a summer fallow (control) treatment. Effects of cover cropping were assessed on nematode species composition and density in broccoli during the winter growing season. Managing nematodes with summer cover crops would provide vegetable growers, particularly organic farmers with an easy and acceptable method for pest management and improve traditional nematode management approaches.

Materials and Methods

Crop management

A three-year field study was conducted from 2007-2009 at the University of California South Coast Research and Extension Center in Irvine, CA on a loamy-sandy soil. The field site was loamy sand with a history of root-knot nematode (*M. incognita)* infestation. Three summer cropping treatments were employed: 1) French marigold (*T. patula* cv. Single Gold seeded at 2 kg/ha), 2) cowpea (*Vigna unguiculata* cv. UCR CC 36), seeded at 56 kg/ha, and 3) a summer dry fallow as the untreated control. Cowpea was chosen because it is a drought hardy legume, resistant to weeds and enhances some beneficial organisms (Wang et al. 2001). Marigold was chosen because it is known to control nematodes (Ploeg 2002; Wang et al. 2001). Each treatment plot was 12 m long x 10.7 m wide (128 m^2) and laid out into 14 planting rows. The cover crops were direct-seeded in the last week of June in the center of the planting rows of each plot, watered through drip-tubing and grown for three months. The fallow control plots did not receive water during the summer. Each cover crop treatment plot was planted with the same cover crop in each of the three years of study. Plots were separated from each other with a 3 m wide buffer bare ground. The three treatments were replicated four times in a completely randomized design. At the end of the summer cropping period (first week of September), the cover crops were mowed at the soil line, chopped, and the residues left on the ground. Concurrently, alternate rows (seven of the 14 rows) of each of the cover crop treatments were incorporated into the soil at about 0.4 m intervals using a hand-pushed rotary tiller in preparation for broccoli transplanting. The fallow plots were not tilled. Plots for cover crop and broccoli planting are shown in Figure 1a.

At the beginning of the subsequent (winter) cropping season (10 days after cover crop incorporation or the second week of September), broccoli seedlings (*Brassica olerace,* cv Marathon) were transplanted in double rows into the tilled strips of the summer cover crop and fallow plots at an inter (between seedlings) and intra-row spacing of 13 and 35 cm, respectively (http://ucanr.org /freepubs/docs /711.pdf). Broccoli transplants were drip irrigated and fertilized with emulsified fish meal (6-2-0 organic fertilizer) at 5 gallons/acre rate. Broccoli was chosen because it is a high-value vegetable crop that is sensitive to weeds, insect pests, nematodes (Potter and Olthof 1993), and requires high soil nutrients (http://anrcatalog.ucdavis.edu/pdf/7211.pdf). All plot treatments were maintained in the same location for all three years of study in order to assess a cumulative effect of cover crops over time. During the third year of the trial I included testing nematode response with susceptible tomato plants. In three of the existing treatment replications, 5-6 tomato seedlings were interplanted into broccoli to observe if cropping treatment differences can be seen on tomato. At broccoli harvest time (ABH), all tomato plants were uprooted and evaluated for tomato root nematode and assayed for gall index.

Nematode assay

Soil nematode population densities were determined by collecting 14 soil cores from 5-25 cm depth from each plot using a 2.5 cm-diameter Oakfield Model L and LS Tube-Type Soil Sampler. Soil samples were collected at cover crop planting (ACCP), at cover crop incorporation (ACCI) and at broccoli harvest (ABH). In each of these years, the 14 soil cores were pooled for nematode analysis. Nematodes were extracted from a 100 gram sub-sample (Byrd et al. 1976) on modified Baermann funnels (Rodriguez-Kabana and Pope, 1981) for 5 days and the number of nematodes (both parasitic and free-living) was counted. Ten broccoli plants were removed at harvest from each treatment plot and rated for root-knot nematode galling on the 0 to 5 scale outlined by Taylor and Sasser (1978). One hundred grams of broccoli roots were placed in a misting chamber for 5 days for nematode extraction and the number of second-stage root-knot nematode juveniles (J2) was counted. All data were analyzed using a one-way ANOVA analysis and means separated used the student T-test.

Results

Soil nematode population levels in the experimental field were generally low in all treatments during all years and all sampling periods. Observed plant parasitic nematodes were root-knot (*Meloidogyne incognita)*, cyst (*Heterodera schachtii),* and pin nematodes (*Paratylenchus* species) only. On any of these nematodes, there were no significant differences among cropping treatments at any sampling period or trial years (Table 2.1). The huge variability of data among replications of each treatment and hence a high standard error made most of the differences statistically insignificant. However, there were some relative variations among the cropping treatments. The root-knot nematode (RKN) population densities were relatively higher for the ACCI sampling of all years in the cowpea treatment compared to either marigold or the fallow treatment (Table 2.1). The sugarbeet cyst nematodes (SCN) were higher at the ABH sampling for the cowpea, relative to the other cropping treatments (Table 2.1).

When pooled (averaged) for the three sampling periods, only RKNs were significantly greater in the cowpea plots (P = 0.0563) for 2007 and 2009, but not 2008 (Table 2.2). Neither the SCN nor the pin nematodes were significant for year or cropping treatments (Table 2.2). If pooled for the cropping treatments (averaged over years and sampling

Table 2.1: Plant-parasitic nematode population densities per 100 gram of soil for the three cropping treatments of the three year trial. RKN (root-knot nematode), SCN (Sugarbeet Cyst Nematode). ACCP = at cover crop planting, ACCI = at cover crop incorporation, ABH = at broccoli harvest, CP = cowpea, Mg = marigold, Fw = fallow

Year	Sampling	Treat	Nematode population level/100 g soil		
			RKN	SCN	Pin
2007	ACCP	CP	0.75a	0.00a	0.25a
		Mg	1.25a	0.00a	0.5a
		Fw	3.50a	0.00a	1.0a
	ACCI	CP	24.0a	0.00a	0.00a
		Mg	2.50a	0.00a	0.00a
		Fw	1.25a	0.00a	0.00a
	ABH	CP	0.00a	0.25a	0.00a
		Mg	0.00a	0.00a	0.00a
		Fw	0.00a	0.00a	1.25a
2008	ACCP	CP	0.00a	0.25a	0.25a
		Mg	0.00a	0.25a	0.00a
		Fw	0.25a	0.00a	0.00a
	ACCI	CP	27.5a	0.00a	2.50a
		Mg	5.00a	0.00a	0.00a
		Fw	2.50a	0.00a	62.5a
	ABH	CP	0.00a	44.0a	7.75a
		Mg	0.00a	0.00a	1.25a
		Fw	0.00a	0.75a	13.0a
2009	ACCP	CP	0.00a	14.5a	1.75a
		Mg	0.50a	12.8a	3.75a
		Fw	0.00a	0.25a	0.50a
	ACCI	CP	56.0a	0.25	7.00a
		Mg	5.00a	0.00	2.75a
		Fw	0.00a	0.00	3.00a
	ABH	CP	10.0a	8.75a	5.00a
		Mg	3.25a	8.25a	0.00a
		Fw	0.75a	5.00a	3.25a

Values in a column within each sampling followed by the same letter are not significantly different from each other at the 95% confidence level.

Table 2.2: Mean plant-parasitic nematode population densities per 100 gram of soil for trial years and sampling periods of three cropping treatments. RKN (root-knot nematode), SCN (Sugarbeet Cyst Nematode). CP = cowpea, Mg = marigold, Fw = fallow

		Nematode population densities per 100 g soil		
Sampling time	Cropping treatments	RKN (j2)	SCN	Pin
2007	CP	8.67a	0.08a	0.08a
	Mg	1.25b	0.00a	0.17a
	Fw	1.58b	0.00a	0.75a
2008	CP	9.34a	14.8a	3.50a
	Mg	1.67a	0.08a	0.42a
	Fw	0.92a	0.25a	25.2a
2009	CP	22.0a	7.83a	4.58a
	Mg	2.9ab	7.00a	2.17a
	Fw	0.25b	1.75a	2.25a

Values in a column within each sampling year of sampling period followed by the same letter are not significantly different from each other at the 95% confidence level.

dates), the RKN were denser for the cowpea treatment (p = 0.0114) compared to marigold or fallow treatments (Figure 2.1). The population density of RKN for the cowpea treatment was about 14 times higher than in the RKN population in the fallow treatment (Figure 2.1). The pooled mean population densities for the other nematode species were not significantly different among the cropping treatments (Figure 2.1).

For the broccoli root analysis, neither of the broccoli nematodes nor the broccoli root gall index was significantly different among the cropping treatments or experimental years (Table 2.3). Nematode root-gall formation on broccoli was generally very rare and only appeared during the first year and none during the subsequent vegetable growing years (Table 2.3). When data were pooled for the sampling periods, and years, there were more RKN population levels on broccoli roots grown on the summer cowpea field than those grown on either marigold or fallow treatments (Figure 2.2).

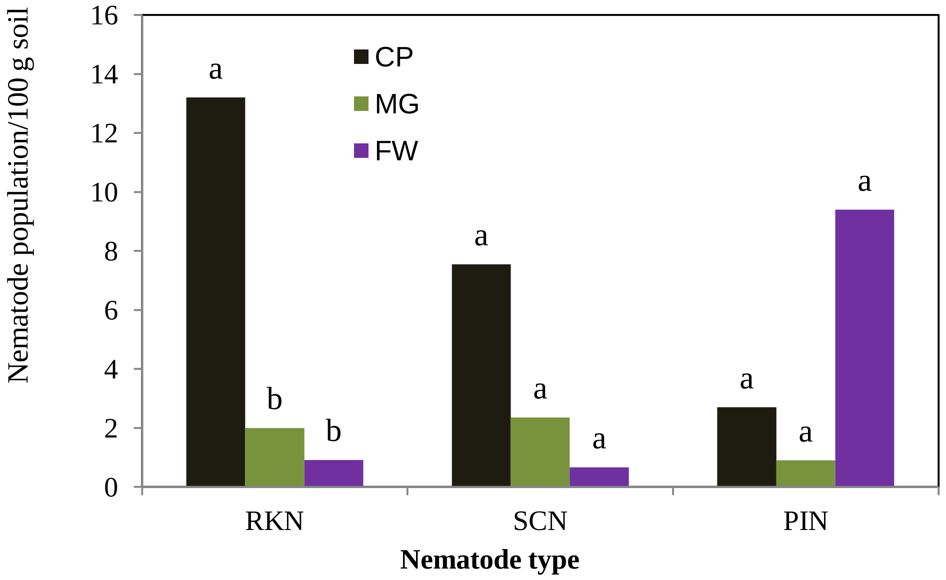

Figure 2.1: Nematode population densities/100 g soil pooled for the cropping treatments CP = cowpea, MG, marigold, and FW = fallow, RKN (root-knot nematode), SCN (Sugarbeet Cyst Nematode). Bar graph within each nematode type represented with same letter are not significantly different from each other at the 95% confidence level

Table 2.3: Nematode population per g of broccoli root and root gall index. CP = cowpea, MG, marigold, and FW = fallow, SCN = Sugarbeet Cyst Nematode, BGI = Broccoli gall index

Trial Years	Cropping system	Broccoli root nematodes		BGI
		j2/g-root	SCN	
2007	CP	2.95a	0.0a	0.05a
	Mg	0.03a	0.0a	0.03a
	Fw	9.40a	0.0a	0.05a
2008	CP	26.2a	4.1a	0.0a
	Mg	0.10a	0.1a	0.0a
	Fw	0.09a	0.2a	0.0a
2009	CP	2.19a	0.85a	0.0a
	Mg	0.00a	1.13a	0.0a
	Fw	1.24a	2.10a	0.0a

Values in a column within each sampling followed by the same letter are not significantly different from each other at the 95% confidence level. SCN (cyst nematode), BGI (broccoli gall index).

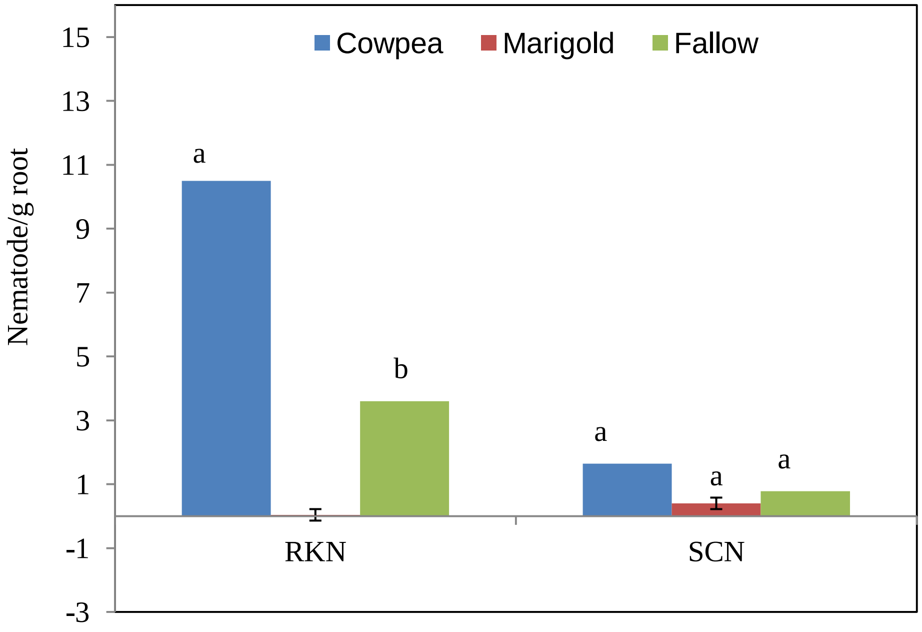

Figure 2.2: Mean nematode population per g of broccoli root pooled for cropping treatments. RKN = root knot nematode, SCN = Sugar beet cyst nematode). Bar graphs within each nematode type represented with same letter are not significantly different from each other at the 95% confidence level

The last year (2009) trial using nematode-susceptible tomato plants inter-planted did not show any significant variation among the cropping treatments on the population density of any of the nematodes (Table 2.4), although there were relatively more j2 RKN in the fallow plots than in either marigold or cowpea cover crop treatments.

In general, the results reveal that contrary to the hypothesis, the use of cowpea and marigold as an off-season cover cropping do not provide suppression to parasitic nematodes, at least to these observed within this experimental field. In most cases the cover cropping treatments had the same effect on parasitic nematode population densities as the fallow treatments. In rare cases, the cover crops enhanced the population densities of some parasitic nematodes compared to fallow treatment.

Table 2.4: Nematode population per g of tomato root sampled at ABH

Summer cropping	Number of j2 g^{-1}root[§]
CP	0.77a
Mg	0.34a
Fw	19.2a

Columns followed by the same letter indicate no significant treatment effects.
[§] data normalized as log (n+1) prior to analysis

Summer cover cropping and saprophytic nematode population densities

While the effects of summer cover cropping treatments were not significant on the crop parasitic nematodes, they had significant effects in enhancing saprophytic (free living) nematode population densities (Figure 2.3). Enhancement of saprophytic nematodes started at the ABH sampling ($p = 0.1046$) in the first year (Figure 2.3a), with no significant differences among cropping treatments for the ACCI sampling. Data on saprophytes was not collected for the ACCP sampling in 2007. At the ABH sampling of 2007, saprophytes were about double on the cowpea treatment compared to the fallow (Figure 2.3a), indicating the stronger enhancement of saprophytes with cowpea cover crop.

Population densities of the saprophytes continued to increase in the second (2008) and third year (2009) compared to the 2007. Higher population were observed in both cover cropping treatments ($P = 0.0003$) at the ACCP sampling of 2008 compared to the fallow (Figure 2.3b), probably accounting for the previous year cover crop and broccoli crop

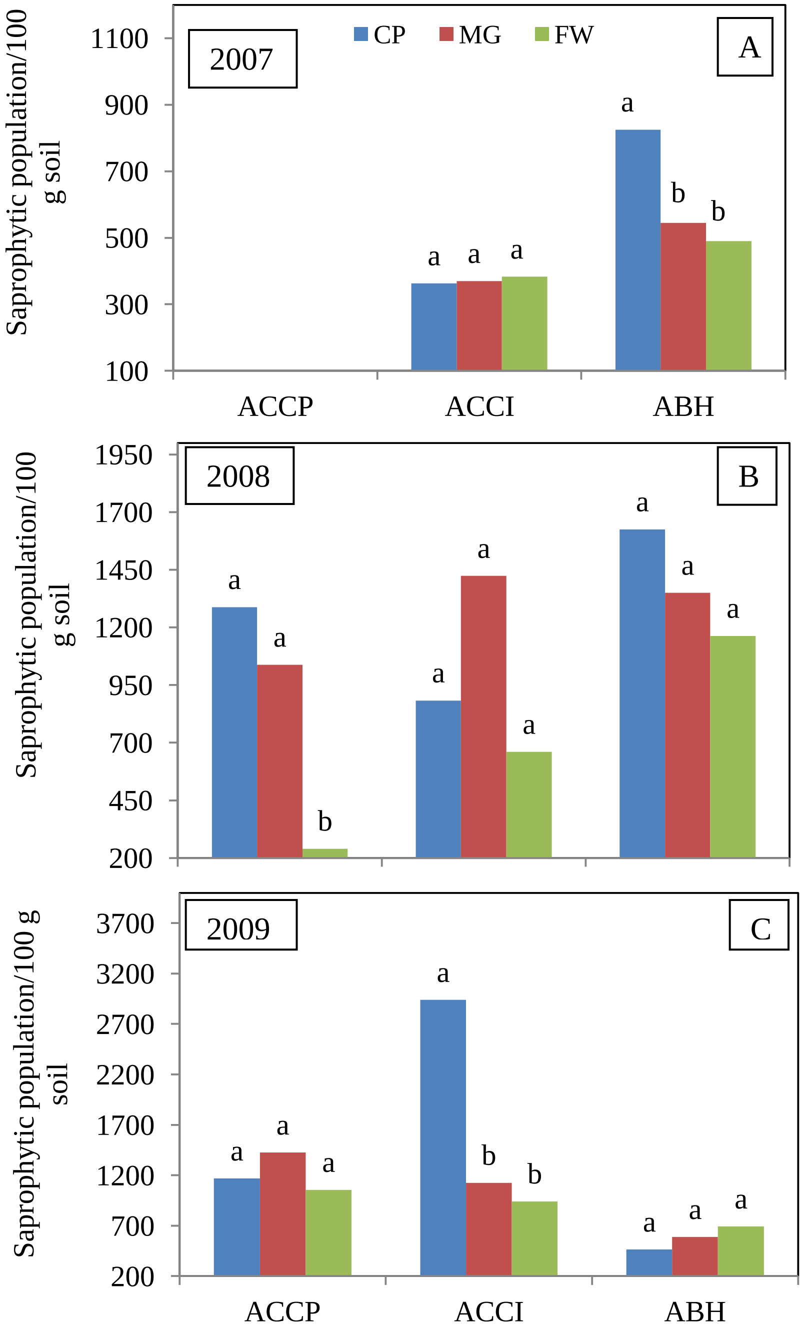

Figure 2.3: Saprophytic nematode population densities per 100 g of soil for 2007 (top), 2008 (middle) and 2009 (bottom). Data not collected for ACCP sampling of 2007. Bar graphs within each sampling period represented with same letter are not significantly different from each other at the 95% confidence level

residues. At this sampling period, saprophyte population were about 5 and 4 times higher in plots that had summer cowpea and marigold, respectively compared to the summer fallow (Figure 2.3b). Regardless of the huge differences in saprophyte population densities among cropping treatments for the ACCI and ABH samplings of 2008, there were no significant differences among the treatments. Saprophyte population densities reached highest peaks following ACCI sampling in 2009 (Figure 2.3c) than any other sampling times of all years. At this sampling saprophyte populations were by far greater on the cowpea ($P = 0.0222$) compared to either marigold or fallow treatments (Figure 2.3c). However, there was a sharp decline in those nematodes for the ABH sampling of 2009 compared to the same time sampling in 2008 (Figure 2.3).

When pooled for the three sampling periods (averaged over the cropping treatments), saprophytic nematode population levels were enhanced by both cover cropping treatments in 2008 and only by the cowpea cover crop in 2009 (Figure 2.4a) compared to the fallow system. Over all, cropping treatments had no significant effect in 2007 (Figure 2.4a), indicating that the influence in cover crops on saprophytic population densities cannot be realized within one year of cover cropping rotations. If mean data are pooled just for the cropping treatments (averaged over the three years and 3 sampling periods), both cowpea and marigold significantly enhanced ($P = 0.0001$) saprophytes (Figure 2.4b) over the fallow treatment.

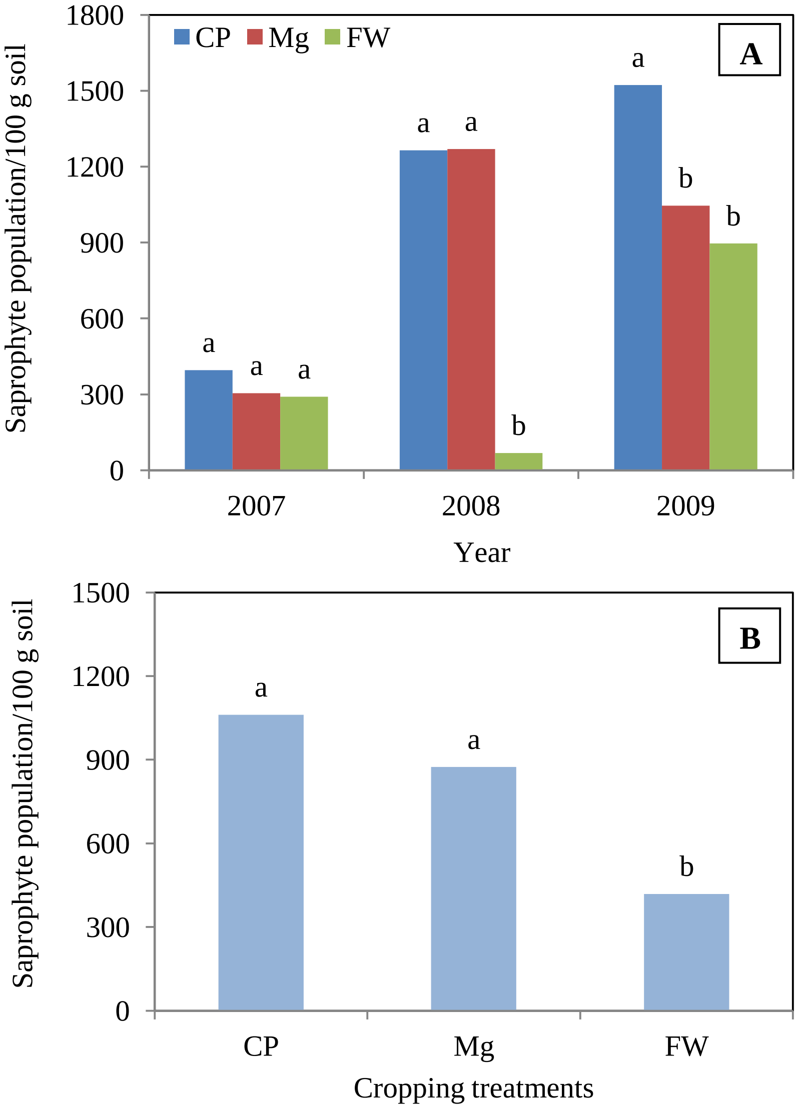

Figure 2.4: Mean saprophyte population densities per 100 g of soil pooled for year (top) and cropping treatments (bottom). Bar graphs within each year or cropping treatment represented with same letter are not significantly different from each other at the 95% confidence level

Discussion and Conclusion

Plant-parasitic nematode population densities in the experimental field were generally low during all years. There were only few species of plant parasitic nematodes, the root-knot (*Meloidogyne incognita),* cyst (*Heterodera schachtii),* and pin (*Paratylenchus* species) nematodes observed. The root knot (*Meloidogyne* spp.) and cyst nematodes

(*Heterodera* spp.) are classified as the most dominant and economically damaging groups of plant parasitic nematodes (Krueger et al. 2007; Oloo et al. 2009).

At all sampling times there was a huge variability in nematode population densities within the treatment replications, resulting in a large standard error and often leading to a non-significant effect in spite of large differences in mean values. Accordingly, the cropping treatments did not show significant differences on most nematode responses. Such problem may probably be minimized by using higher replication treatments . Furthermore, both cowpea and marigold cover crops are non-susceptible crops to nematodes (Ploeg 2002; Wang et al. 2001) and hence the reason for no significant differences among the cropping treatments. Broccoli crop is also a poor host to most nematodes and if planted late in the season when soil temperature is low, the nematode populations would also be low. Although a nematode susceptible crop (tomato) was introduced by intercropping with broccoli at the third year, nematode population densities were still not variable among the cropping treatments.

While cowpea and marigold cover crops are generally regarded as nematode resistant or suppressing plants, their use as off-season cover crop did not guarantee this value under this particular trial conditions. In some cases, RKN population densities were rather higher following cover crop incorporations, particularly cowpea, than under a fallow system. The relatively higher RKN following cowpea residue incorporations may indicate that cowpea still allows some level of nematode multiplication and thus is not resistant against RKN. It is also possible that the cover crops may have suppressed nematodes, but the initial low nematode population level in the field may have made it difficult to make a clear demarcation whether the cover crops suppressed nematode populations or not. Therefore, these responses basically contradict the previous findings that generally regarded cowpea and marigold as resistant and a potential means by which parasitic nematodes can be managed (Ploeg and Maris 1999; Ploeg 2002; Ehlers et al 2002; Wang et al. 2003b). Wand and McSorley (2008) observed that 'Iron Clay' cowpea was susceptible to the same species of nematode it was once identified as suppressing. Chen et al. (2006) also showed that an increase in SCN population density in a former nematode suppressant perennial ryegrass treatment.

The sugar beet cyst nematodes (*Heterodera schachtii*) were not even as much sensitive as the RKN to the cover crop treatments was not variable among the cropping treatments, although were slightly higher in cowpea and marigold cover crops at the ABH sampling of the second year and the ACCP and ABH samplings of the third year. The increase in SCN mainly at the ABH samplings (P = 0.0581) than at other sampling periods, may indicate that broccoli is a host to the SCN. Potter and Olthof (1993) actually show that broccoli is a potential host to the cyst nematodes. Infection of broccoli roots and broccoli root gall formation was very minimum and unaffected by the cropping treatments. Based on my current over all findings therefore, the usefulness of cowpea and marigold as off-season cover crops does not confirm their nematode suppression potentials in the subsequent winter broccoli crop.

There are various reasons documented for variation in nematode suppressing efficiency of cover crops. Ploeg and Maris (1999) state that the life cycle of *Meloidogyne incognita* complete between average soil temperatures of 16°C and 30°C on tomato, but only at 30°C on marigold (Tagetes hybrid). Furthermore, motility of *M. incognita* J2 and its subsequent root penetration may decrease with decreased soil temperatures below 18°C (Roberts 1987). These findings suggest that the effectiveness of cover crops to suppress nematodes depends on the condition under which they are utilized. Ploeg and Maris (1999) further suggested the need for information on thermal-time relationships of plant parasitic nematodes to predict geographical distributions, nematode population dynamics and effects of cover crops on the subsequent crops.

Effectiveness of a cover crop for the purpose of nematode suppression may also depend on the type of target nematode itself. Wang and McSoreley (2008) pointed out that Iron Clay', cowpea failed to suppress root-knot nematodes where there were mixed species of *Meloidogyne.* Ploeg and Maris (1999) also identified nematode suppression of marigold being influenced by crop plant variety, nematode species, and soil temperature. Marigold while suppressive to root-knot nematode, it enhanced the population densities of other nematodes such as stubby-root, spiral and sting nematodes (Krueger et al. 2007) on the other hand. Therefore, the evidence suggests that the type of nematode can determine the effectiveness of a cover crop.

Others observed that nematode suppression of cover crops may depend on how the cover crops were utilized. Wang and McSorley (2008) observed that cover crop mulch was more effective than live crops. On the other hand, Ploeg and Maris (1999) state that live marigold suppress nematodes, because of the release of alpha-terthienyl, a toxic chemical compounds from its live roots (Gommers and Bakker 1988) that have nematicidal characteristics (Siddiqui and Alam 1988). These nematicidal compound (alpha-tertheinyl) released by active, living marigold roots may not be available if marigold is used as an organic mulch (Wang, et.al. 2001). Since my research was based on the off-season cover cropping system and employed their residues as surface mulch and soil incorporation, the observation of poor or no nematode suppression can be justified. Similarly, Ploeg (2000) did not observe any significant suppression from preceding vegetable crops or amending a planting site with marigold plant parts. Furthermore, while cowpea incorporation as a green manure has been observed to suppress *Meloidogyne incognita* (Wang et al. 2004), the suppression was short-lived, and the numbers of *M. incognita* were not different from a fallow treatment (Wang and McSoreley 2008).

Another factor determining cover crop effectiveness was the type of the subsequent vegetable crop that may determine the potential incidence of plant parasitic nematodes. If the subsequent indicator crop is a nematode susceptible plant, it may be possible to detect nematode suppression of cover crops, otherwise, the effects of the cover crops can be masked if the indicator crop is nematode resistant. However, if the vegetable crop is resistant to nematodes by itself, nematode suppression potential of a cover crop could be masked. Accordingly, I may not have observed any significant nematode suppression by the cover crops, because the broccoli used in this research was resistant or a poor host to most nematodes. Most broccoli cultivars contain sulphur compounds such as methanethiol, dimethyl sulphide, methyl thiocyanate, dimethyl disulphide, dimethyl trisulphide, dimethyl tetrasulphide (Vidal-Aragon et al. 2009) that may be toxic to nematodes (Siddiqui 2003). The presence of nematode antagonizing organisms such as bacteria and fungi in a soil may also contribute to the reduction of nematode population densities (Karakas 2007), regardless of nematode suppressive treatments. Kerry (2000) observed that the second-stage juveniles of root-knot nematodes encumbered with spores of the bacterium *Pasteuria penetrans* are less able to invade the roots of host than the unencumbered nematodes.

The most significant outcome of the cover cropping treatment was the enhancement of saprophytic (free living) nematodes. Saprophytic nematode populations were significantly enhanced at ACCP sampling of the second year and the ACCI sampling of the third year in the cover cropped plots, relative to the fallow plots. Since these nematode populations became higher at after cover crop incorporation, the increase in saprophytes may have come from the accumulation and decomposition of cover crop residues. The relatively lower saprophytic nematode populations in the fallow plots may have been associated to the lower input of organic matter from such cropping system.

Therefore, the results confirm that preceding vegetable crops with cover crop could enhance beneficial saprophytic nematode populations.

Saprophytic nematode population density for the first year was not significantly different for the cropping treatments, indicating that a one year cover cropping rotation is not sufficient to enhance populations of free-living nematodes. On the other hand, the increase in saprophyte population with repeated years of cover cropping suggests that there is accumulative effect of the cover cropping treatments. The results clearly demonstrate that cover-cropping rotations must be repeated for several years in order to provide significant contributions to enhance saprophytic populations. The sharp decline in saprophyte populations at the ABH sampling of the third year might have been due to a complete decomposition and degradation of the organic matter to a level that no longer sustained high saprophytic populations at this stage.

An increase in bacterial-feeding nematode population densities following soil treatment with sunn hemp as organic mulch was also observed by Wang and McSorley (2008). Free living bacterial feeding taxa of nematodes constitute more than 60% of the nematode community (Kerry 2000). The presence of high population densities of saprophytic nematodes may provide an added advantage in soil biology (Karakas 2007; Langat et.al. 2008). Saprophytic nematodes are useful in mineralization of plant nutrients and nutrient cycling (Griffiths 1994; Ingham et al.1985) and can be used as sensitive indicators of ecosystem change (Wardle et al. 1995). Langat et.al. (2008) suggested that bacterivorous nematodes respond quickly to increased food supply. Therefore, cover crops play an indirect role of increasing population levels of the beneficial free living nematodes. The structure of the nematode assemblage offers an interesting instrument to assess changes in soil conditions (Leroy et al. 2009). Enhancement of saprophytic nematodes and the mineralization and nutrient cycling benefit that such nematodes can provide (Ingham et al. 1985) to the subsequent crop indicates the profitability of cover cropping rotations.

In general, the use of cowpea or marigold cover crops as an off-season cropping rotation may not provide a viable alternative as a nematode suppression strategy. Hence, the use of cover crops for nematode suppression must be considered carefully, accounting for the target nematode, how the cover crops are to be used, and the environmental conditions of the field. However, these cover crops can be used as off-seasoning cropping rotations to effectively enhance beneficial saprophytic nematode population densities in the subsequent vegetable crop. They do so as their residues decompose supporting nematode food webs. The increase in population levels of saprophytes and feeding on nutrient-immobilizing bacteria and fungi promotes nutrient mineralization and nutrient cycling. It is believed that with more knowledge about the mechanisms stimulating a beneficial nematode community, we may develop cover crop management plans to maximize the desirable effects associated with free living nematodes (Gruver et al. 2010).

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CHAPTER 3

THE EFFECT OF SUMMER COVER CROPPING SYSTEMS ON VEGETABLE INSECT PESTS AND BENEFICIAL ARTHROPODS.

Abstract

A three-year field study (2007-2009) was conducted with off-season cover cropping treatments (2 cover crops; cowpea and marigold and a fallow system) at the University of California, South Coast Research and Extension Station to assess the response of insect pests in a subsequent winter crop of broccoli. Population densities of the larval stage of three major lepidopteran pests, *Trichoplusia ni, Plutella xylostella* and *Artogeia rapae*, were monitored in the field, and levels of parasitism were monitored by rearing field-collected larvae in the laboratory. Total and individual insect population densities and vegetable leaf damage varied throughout the season. Overall, the cover cropping treatments had little effect on populations of these insects in a broccoli crop. However, on some sample dates, higher insect population densities, greater leaf damage and higher parasitization levels were observed in the cover crop treatments than in the fallow treatment. Apparently, preceding vegetable crops with summer cover crops may enhance attractiveness of the vegetable crop to insect pests.

Introduction

Damage by Lepidopteran insect pests is a common constraint to vegetable crop production (Edwards and Singh 2006; Hooks and Johnson 2002; Furlong et al. 2008). Traditional insect pest management approaches utilize pesticides, but these are known to be environmental pollutants (Lim 1986; Idris and Grafius 1993), and in some cases carcinogenic (USDA IPM Centers 2006). Insect pests may also develop resistance to insecticides (Hooks and Johnson 2003; Badenes-Perez et al. 2005; Sarfraz et al. 2005) making them inefficient (Zhao et al. 2002: Broad et al. 2009). Those shortcomings of broad spectrum insecticides, encouraged attempts to replace them by "soft" microbial-based insecticides such as *Bacillus thuringiensis* (Vandenberg et al. 1998; Liu et al. 1996). Yet, insect pests developed resistance to the soft insecticides as well and some "soft" insecticides can be injurious to parasitoids (Liu et al. 1996; Chilcutt and Tabashnik 1997). Therefore, there is an increasing demand for environmentally friendly and economical alternative pest management strategies (Costello 1994; Hooks et al. 1998).

Many researchers have suggested crop diversification and cover crops as alternative insect pest management tactics (Potting, et al. 2005; Yenish et al. 1996; Broad et al. 2009). Cover cropping systems may adversely affect insect pests and, if effective could be used as an alternative insect pest management strategy as they are ecologically benign, minimize reliance on pesticides, reduce chemical exposure, and increase consumer confidence in food production (Agriculture 1998).

Although cover crops could potentially interfere with vegetable insect pests, not all cover crops are equally efficient in suppressing vegetable insect pests. For example, sweet clover cover crop suppressed broccoli pest populations, but not pests of tomato or pepper (Hooks, 2000; Hooks and Johnson 2002). There are also concerns that cover crops used as simultaneous interplanting may compete with the main crop for growth resources and reduce vegetable crop yield (Liebman and Dyck 1993; Broad et al. 2009). Consequently, this research was designed to evaluate the effectiveness of off-season summer cover cropping as an ecologically desirable pest management strategy for the subsequent winter vegetable crop of broccoli. It specifically evaluated the effect of two summer cover crops (cowpea and marigold) on population densities of broccoli insect pests and beneficial arthropods.

Materials and Methods

Crop management

A three-year field study was conducted from 2007-2009 at the University of California South Coast Research and Extension Center in Irvine, CA on a loamy-sandy soil. Three summer cropping treatments were employed: 1) French marigold (T. patula cv. Single Gold seeded at 2 kg/ha), 2) cowpea (Vigna unguiculata cv. UCR CC 36), seeded at 56 kg/ha, and 3) a summer dry fallow as the untreated control. Each treatment plot was 12 m long x 10.7 m wide (128 m^2) and laid out into 14 planting rows. The cover crops were direct-seeded in the last week of June in the center of the planting rows of each plot, watered through drip-tubing and grown for three months. The fallow control plots did not receive water during the summer. Each cover crop treatment plot was planted with the same cover crop in each of the three years of study. Plots were separated from each other with a 3 m wide buffer bare ground. The three treatments were replicated four times in a completely randomized design. At the end of the summer cropping period (first week of September), the cover crops were mowed at the soil line, chopped, and the residues left on the ground. Concurrently, alternate rows (seven of the 14 rows) of each of the cover crop treatments were incorporated into the soil at about 0.4 m intervals using a hand-pushed rotary tiller in preparation for broccoli transplanting. The fallow plots were not tilled. Plots for cover crop and broccoli planting are shown in Figure 1a.

At the beginning of the subsequent (winter) cropping season (10 days after cover crop incorporation or the second week of September), broccoli seedlings (*Brassica olerace*, cv Marathon) were transplanted in double rows into the tilled strips of the summer cover crop and fallow plots at an inter (between seedlings) and intra-row spacing of 13 and 35 cm, respectively (http://ucanr.org /freepubs/docs /711.pdf). Broccoli transplants were drip irrigated and fertilized with emulsified fish meal (6-2-0 organic fertilizer) at 5 gallons/acre rate. Broccoli was chosen because it is a high-value vegetable crop that is sensitive to weeds, insect pests, nematodes (Potter and Olthof 1993), and requires high soil nutrients (http://anrcatalog.ucdavis.edu/pdf/7211.pdf). All plot treatments were maintained in the same location for all three years of study in order to assess a cumulative effect of cover crops over time.

Data collection

1. Broccoli insect pests

Plants were non-destructively sampled for major broccoli insect pests beginning 15 days after broccoli transplanting (DAT) and continuing every two weeks until broccoli harvest. On each sample date, 20 randomly-selected plants per plot were assessed visually for the presence of insect pests following methods used by Costello and Altieri (1995) and Hooks and Johnson (2002). The larvae of the insects actively feeding on the vegetable crop were identified to species level and recorded as the number of individuals per plant. Population density of each species was computed as average number of larvae per broccoli plant.

2) Number of damaged broccoli leaves

Sampling for insect damage to leaves was initiated 21 days after broccoli transplanting (DAT), and continued every two weeks until broccoli harvest. Leaf damage sampling was done in weeks between sequential insect pest sampling. On each sample date, 15 broccoli plants were randomly selected from the interior rows of each plot and the number of damaged leaves counted.

3) Enumeration of beneficial arthropods (parasitism)

Arthropod parasitoids were assessed by rearing field collected broccoli insect pests in the laboratory, beginning at 21 DAT and continuing once every two weeks until broccoli harvest. Five plants from the interior three rows of each plot were randomly selected and searched for insect larvae. Larvae were collected and placed in clear plastic cups with greenhouse grown broccoli leaves as source of food. Individual larvae were reared in the lab and the fate of each larva recorded. Emerging parasitoids from the dead larvae/pupae were identified and the rate of parasitism was calculated as number of insects parasitized divided by total number of insects and multiplying it by 100 (% P =

$\frac{\#IP}{TI} x\ 100$); where #IP = number of insects parasitized, Ti = total insect reared and P = parasitized ((Furlong et al. 2008; Bach and Tabashnik 1990; Johnson et al. 1988).

Statistical analysis

The effect of summer cropping treatments on insect pest population densities, broccoli leaf damage intensities and insect pest parasitism were analyzed using ANOVA for repeated measure analysis. Cropping treatments, sampling weeks and year were the main effects with interaction between cropping treatments and sampling weeks. Mean separation for main effects was conducted using the Tukey studentized mean separation test.

Results

Statistics for the overall model for total and individual insect populations are shown in Tables 3.1. Three broccoli insect pests consistently appeared during crop sampling; cabbage looper (*Trichoplusia ni* Hübner), diamondback moth (*Plutella xylostella* L), and cabbage worms (*Artogeia rapae L*) also known as *Pieris rapae*. Overall, pooled for the three years, total insect population densities for the cowpea cover crop were about 20% higher (P = 0.0263) compared to the fallow plot. Total insect population densities were not significantly different between cowpea and marigold cover crops or marigold and the fallow treatment (Table 3.1). However overall, the cover cropping treatments had no significant effect on the population densities of cabbage loopers and diamondback moth, although the cabbage worms occurred at significantly higher density on the cowpea compared to the fallow treatment (P = 0.0172) (Table 3.1); but cabbage worm generally occurred at very low population densities.

Table 3.1: Probability levels from ANOVA on total and individual insect pest population densities for all three years pooled[1]

Source	Num DF	Pr > F			
		Total insects	Cabbage looper	Diamondback moth	Cabbage worm
CC	2	0.0339	0.0783	0.2647	0.0172
Week	7	<.0001	<.0001	<.0001	<.0001
Year	2	<.0001	<.0001	0.8355	0.0003
CC*year	4	0.4063	0.0647	0.9942	0.0873
CC*week	14	0.0840	0.5978	0.2437	0.4732
Year*week	14	<.0001	<.0001	<.0001	0.0006
CC*year*week	28	0.6198	0.0949	0.6013	0.9049

Multiple comparisons for cropping treatment effect on total insects and cabbage worm for all three years pooled

Source	Total insects			Cabbage worm		
	LSM	comparison	P r> F	LSM	comparison	P r> F
CP	0.53	CP vs FW	0.0263	0.096	CP vs FW	0.0127
MG	0.48	CP vs Mg	0.2785	0.066	CP vs Mg	0.2194
FW	0.44	Mg vs FW	0.5009	0. 044	Mg vs FW	0.4317

[1] CC = cover cropping treatment, CP = cowpea, MG = marigold, and FW = fallow. LSM = least square means.

Statistics for the overall model for leaf damage, total and individual insect pest parasitization are shown in Table 3.2. The overall leaf damage varied among the cropping treatments (P = 0.0133), sampling week (P <0.0001), and year (P <0.0001) and there was a significant interaction between year and sampling week (P <0.0001) as well as a three was significant interaction among cover crop, year and sampling week. Total insect, cabbage looper and diamondback moth parasitization were also significantly different among cover crop treatments, sampling week, and year (Table 3.2), except for the no significant week effect on diamondback moth. There were also some significant interactions as seen in Table 3.2. Since there was a significant year effect for most variables, the data were broken down by year for further analysis.

Table 3.2: Probability levels from ANOVA on broccoli leaf damage, total and individual insect parasitism for all three years pooled[1]

Source	Leaf damage		Insect parasitization				
	Num DF	Pr > F	Num DF	Total	CL	DM	CW
CC	2	0.0133	2	<.0001	0.0061	0.0022	0.3772
Week	6	<.0001	5	0.0004	0.0028	0.2580	0.4489
Year	2	<.0001	2	0.0031	0.0471	0.0003	0.6841
CC*year	4	0.0664	4	0.4526	0.6114	0.9489	0.0991
CC*week	12	0.1283	10	0.1230	0.0596	0.0240	0.4114
Year*week	10	<.0001	8	0.0021	0.0012	0.0311	0.3489
CC*year*week	20	0.0120	16	0.0030	0.0027	0.0162	0.3031

[1] CC = cropping treatment, CL= cabbage looper, DM= Diamondback moth, CW= cabbage worm

Parasitoids that emerged from the larvae or pupa of the parasitized insect pests included Tachnid flies which constituted about 41% of the total parasitoid population and commonly parasitized the cabbage loopers. The other parasitoids were hymenopterous belonging to Chalcid wasps (36%) and parasitized cabbage loopers and diamondback moths, Braconid wasps (13%) parasitized mainly the cabbage worms and other unidentified hymenopterans which constituted 10% of the total parasitoid population.

2007

Insect pest population densities

Total insect population densities in 2007 (pooled for the three species) varied among the sampling weeks ($P < 0.0001$), but not the cropping treatments (Figure 3.1a). The total insect population in all treatments started with low density and then developed early and late season peaks. Although differences were not statistically significant, the total insect populations reached higher levels on the cover crop treatments (sequentially on marigold and cowpea) than on the fallow treatment during the early season peak, but that reversed itself during the late season peak (Figure 3.1a).

All individual insect pest populations fluctuated significantly throughout the growing season but none were significantly affected by the cover crop treatments (Figure 3.2). Cabbage loopers and diamondback moths were the two most dominant species and both had bimodal population peaks, which were especially prominent for diamondback moth. Cabbage loopers and diamondback moths had similar population densities in the early season peak, but the diamondback moth was more dominant during the late season peak. Overall the cabbage worm was at much lower densities than the other two species.

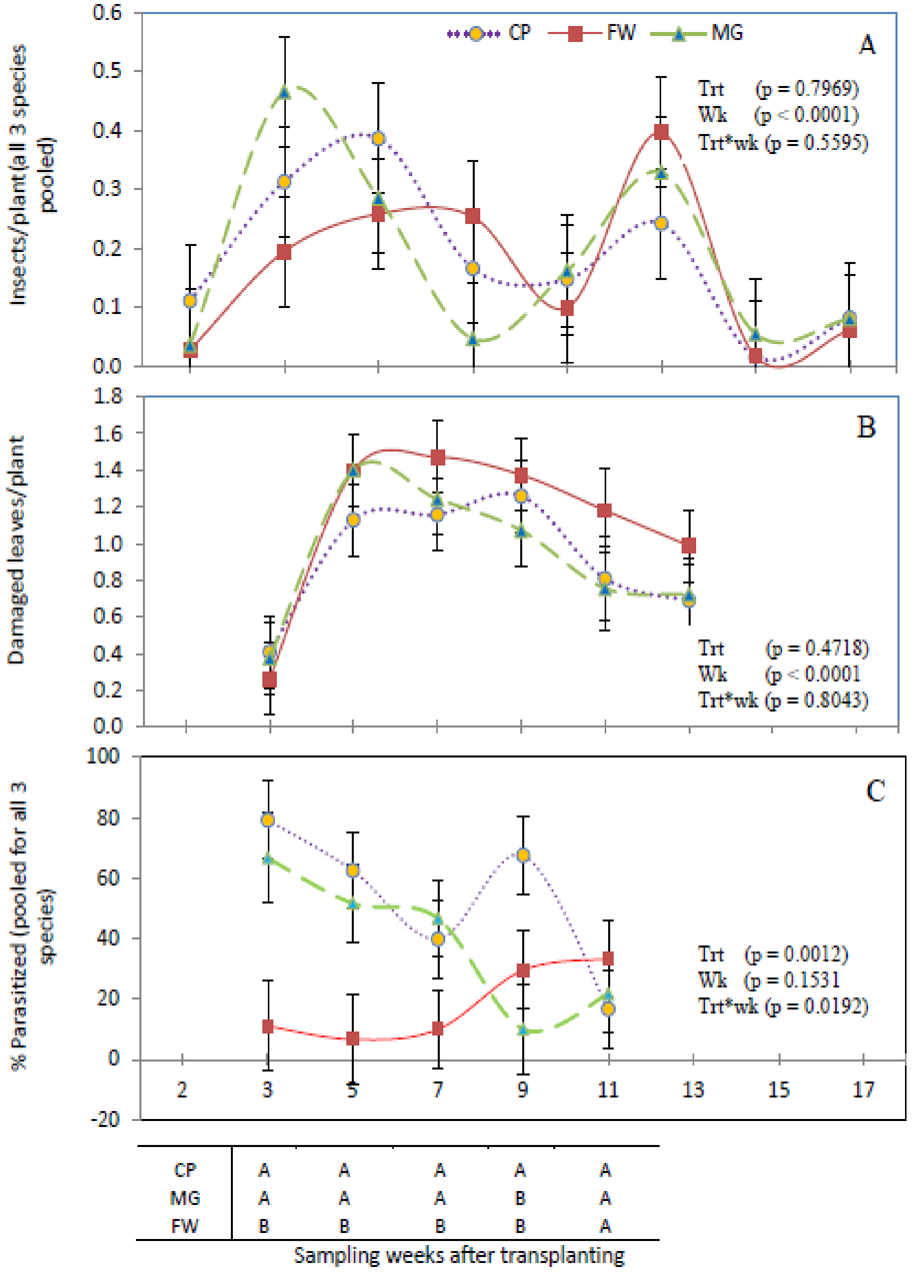
Broccoli leaf damage

Leaf damage in 2007 varied among sampling weeks ($P < 0.0001$), but not among the cropping treatments (Figure 3.1b). Broccoli leaf damage for all treatments increased early in the growing season (Figure 3.1b) peaking in early to mid season as total insect population density increased (Figure 3.1a), and declined shortly from mid to late season (Figure 3.1b). Since cabbage looper and Diamondback moth make the majority of the total insect pests (Figure 3.2), broccoli leaf damage for 2007 must have been caused primarily by those two insect pests.

Insect pest parasitization

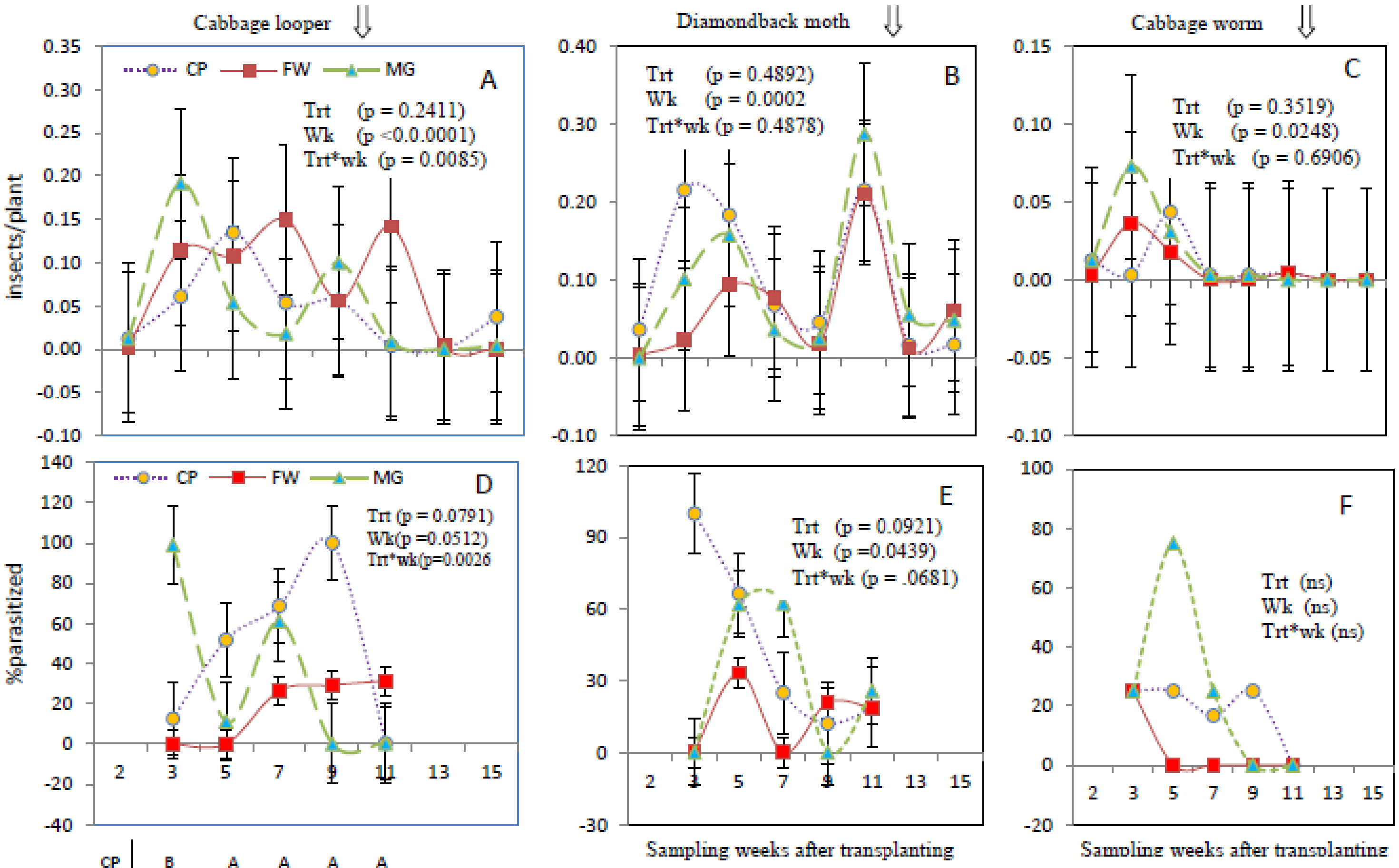
Total insect parasitization for 2007 varied among cropping treatments (P = 0.0012) and there was a significant interaction between cropping treatment and sampling week (P = 0.0192). Total insect parasitization for most of the sampling weeks was significantly higher for the cowpea and marigold treatments, compared to the fallow; however as of the last sample date, there was no significant difference among treatments (Figure 3.1c).

Insect parasitism is species specific. Parasitization rates reached very high levels for all three species on at least some sampling dates (Fig 3.2). Cover crop treatments did not have a significant effect on insect pest parasitism for any of the three species pooled over the season, but the effect for cabbage looper was close to significant (P = 0.0791) (Fig 3.2d). There also was a significant interaction between treatment and sample date for cabbage loopers (P = 0.0026) and cabbage looper had significantly higher levels of parasitism in the marigold plots than in the other plots on the first sample date. Parasitism of cabbage looper was significantly higher in the cowpea plots than in the other plots on the fourth sample date (Figure 3.2d).



CP	A	A	A	A	A
MG	A	A	A	B	A
FW	B	B	B	B	A

Figure 3.1: Total insect population density (A), leaf damage (B) and total insect parasitization level (C) in 2007. In cases where there was a significant interaction between treatment and sample week, means for treatments are compared in a table beneath the graph. Treatments with the same letter within a sample week in the table are not significantly different at $p < 0.05$ using Tukey studentized range test. CP = cowpea, MG = marigold, and FW = fallow, trt = cropping treatment and wk = sampling week.



CP	B	A	A	A	A
MG	A	A	A	B	A
FW	B	A	A	B	A

Figure 3.2: Individual Insect population densiies (above) and individual insect parasitization levels (below) for 2007. In cases where there was a significant interaction between treatment and sample week, means for treatments are compared in a table beneath the graph. Treatments with the same letter within a sample week in the table are not significantly different at $p < 0.05$ using Tukey studentized range test. CP = cowpea, MG = marigold, and FW = fallow, trt = cropping treatment and wk = sampling week

Although parasitism levels for diamondback moths and cabbage worm were numerically lower on the fallow plots compared to the cover crop plots, the differences were not significant (Fig 3.2).

2008

Insect population densities

Total insect population densities for this year varied not only among sampling weeks ($P < 0.0001$), but also among cropping treatments ($P = 0.0035$) with no significant interaction between treatment and sample date (Figure 3.3a). Total insect population was significantly higher in the cowpea treatment than on either the fallow or marigold treatments; there was no significant difference between marigold and fallow. Total insect population at early crop growth season was relatively higher (Figure 3.3a) than at the same time total insect population levels in 2007 (Figure 3.1a), but exhibited a single population peak rather than two. The single seasonal total insect population peak was attained in the middle of the broccoli growing season and then declined (Figure 3.3a). The population peak in 2008 was higher than in either 2007 or 2009. At their peak population levels (8 to 12 weeks after broccoli transplant), total insect pest population was consistently higher for the cowpea treatment ($P = 0.0028$) compared to the fallow treatment with no significant differences between cowpea and marigold and marigold and the fallow treatment (Figure 3.3a).

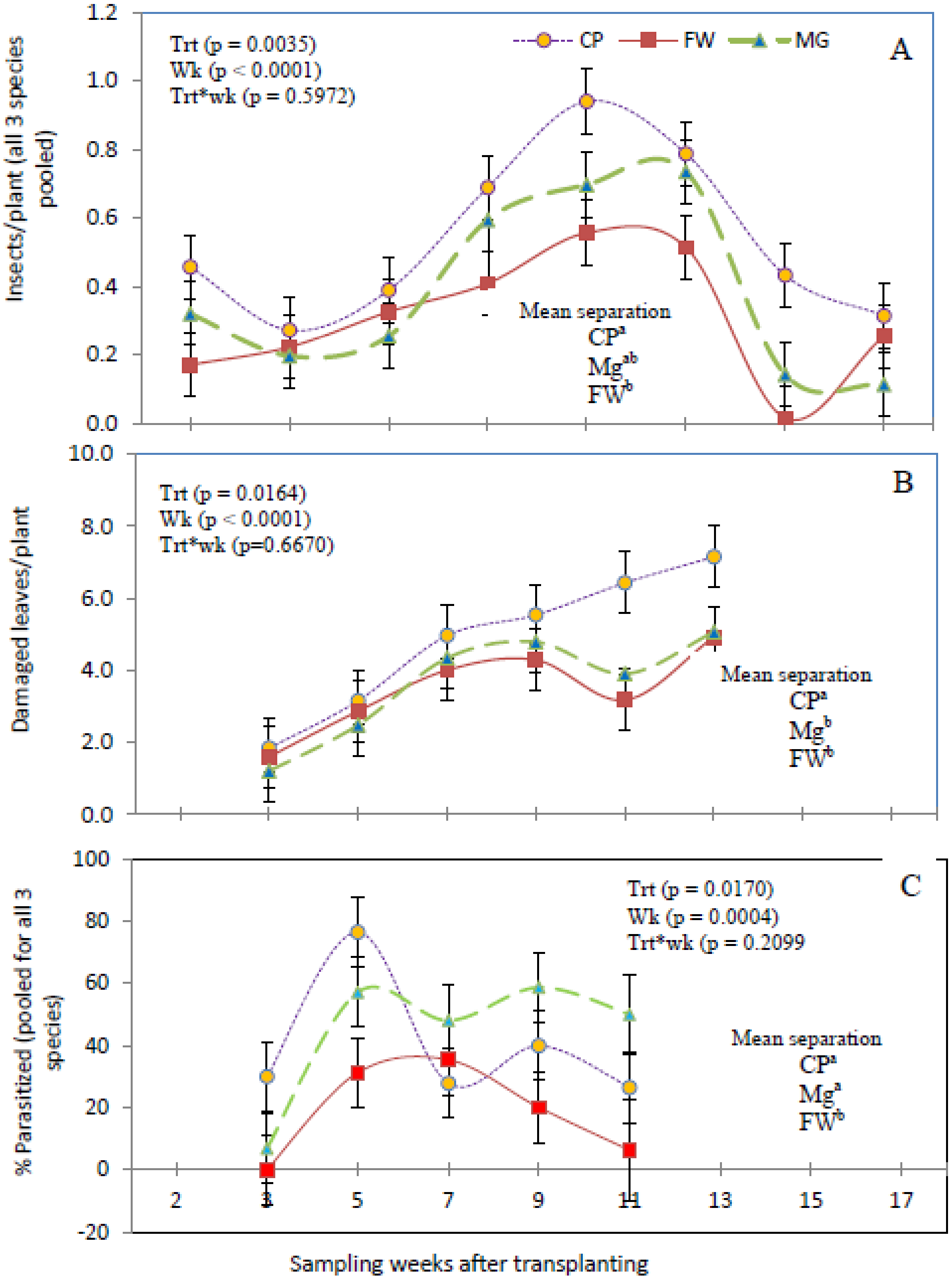


Figure 3.3: Total insect population density (A), Leaf damage (B) and total insect parasitization level (C) in 2008. Where there was no significant interaction between treatment and sample, mean separations are shown within the graph. Treatments indicated by the same letter are not significantly different at $p < 0.05$ using Tukey studentized range test. CP = cowpea, MG = marigold, and FW = fallow, trt = cropping treatment and wk = sampling week.

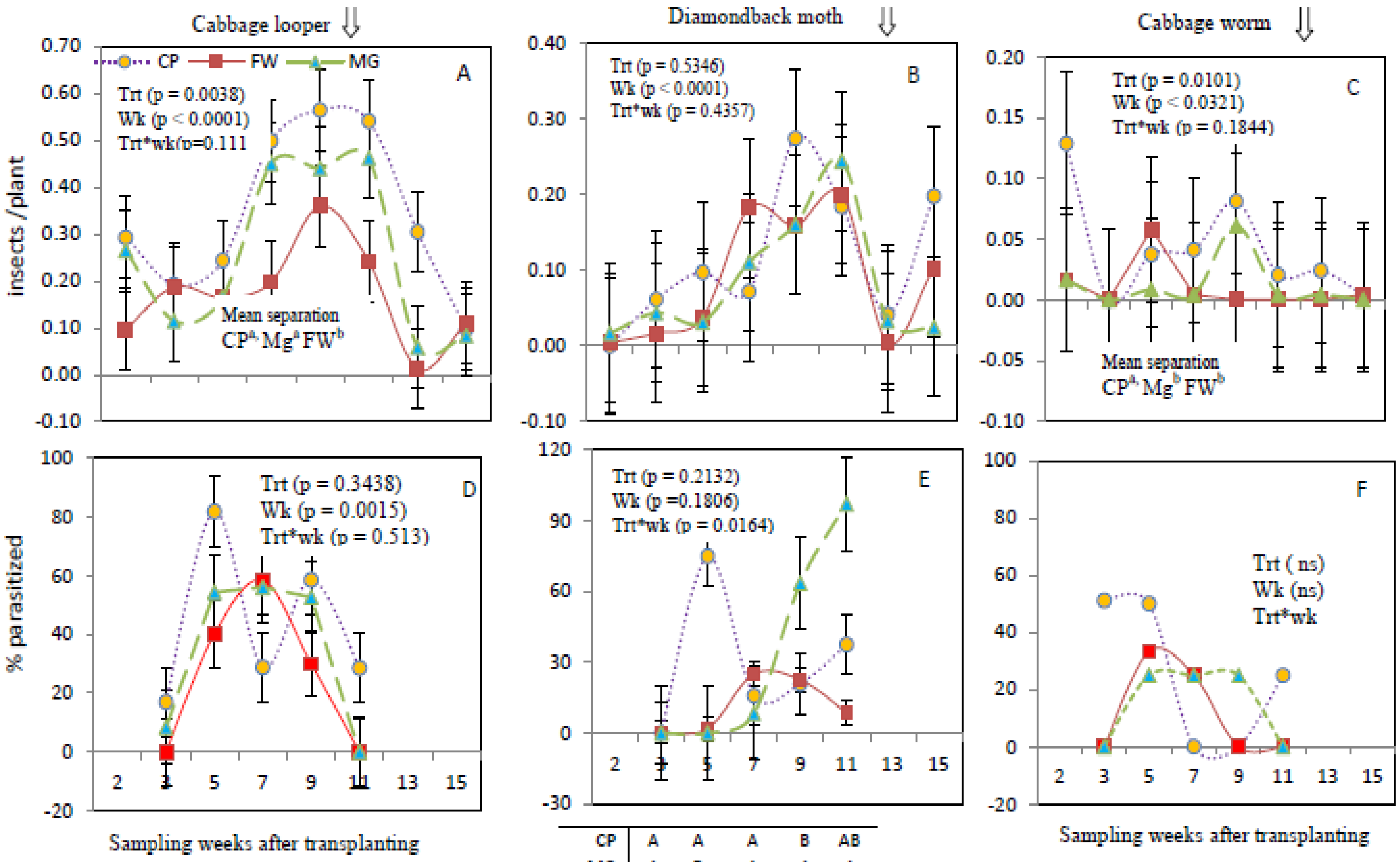
Within individual insect species, both cabbage loopers and cabbage worms responded significantly for the cropping treatments (P = 0.0038 and P = 0.0101, respectively) with populations reaching significantly higher levels on the cowpea treatment than on the other two treatments (Figure 3.4). Cabbage loopers and diamondback moths both exhibited a single mid-season population peak with cabbage loopers reaching a higher peak than diamondback moths (Figure 3.4). As in the previous year, the density of cabbage worm was much lower than the density of the other two species (Fig 3.4c).

Broccoli leaf damage

Broccoli leaf damage for 2008 varied among cropping treatments ($p = 0.0164$) and sampling weeks ($p < 0.0001$) (Table 3.3). Their interaction was not significant. Damage was significantly higher in the cowpea plots than in the fallow plots ($P=0.0028$) and almost significantly higher ($P=0.0632$) in the marigold plots than in the fallow plots (Table 3.3). Leaf damage rose steadily over the first four sample dates in all plots, continued to rise in the fifth and sixth sample dates in the cowpea plots, but flattened over weeks 5 and 6 in the marigold and fallow plots (Figure 3.3b).

Insect pest parasitization

Parasitization rates reached very high levels on at least some sampling dates, especially for cabbage looper (Fig 3.4). Total insect pest parasitization in 2008 differed significantly among cropping treatments ($P = 0.0170$) and sampling weeks ($P = 0.0004$), with no treatment and sampling week interactions (Figure 3.3c). Total insect



CP	A	A	A	B	AB
MG	A	B	A	A	A
FW	A	B	A	B	B

Figure 3.4: Individual Insect population densities (above) and individual insect parasitization levels (below) for 2008. In cases where there was a significant interaction between treatment and sample week, means for treatments are compared in a table beneath the graph. Treatments with the same letter within a sample week in the table are not significantly different at $p < 0.05$ using Tukey studentized range test. CP = cowpea, MG = marigold, and FW = fallow, trt = cropping treatment and wk = sampling week

parasitization levels in 2008 were significantly higher for both cowpea (P = 0.0430) and marigold (P = 0.0204), respectively compared to the fallow treatment (Figure 3.3c).

Among the individual insect species, parasitism did not vary significantly among the treatments for any of the three lepidopteran pests (Figure 3.4), although there was a significant interaction between treatment and week for diamondback moth. Breaking down parasitism by week for diamondback moth revealed that parasitization was significantly higher in the cowpea plots than in the marigold and fallow plots on one early season sampling date and was significantly higher in the marigold plot than in the fallow plots on the last two sampling dates (Figure 3.4e).

2009

Insect population density

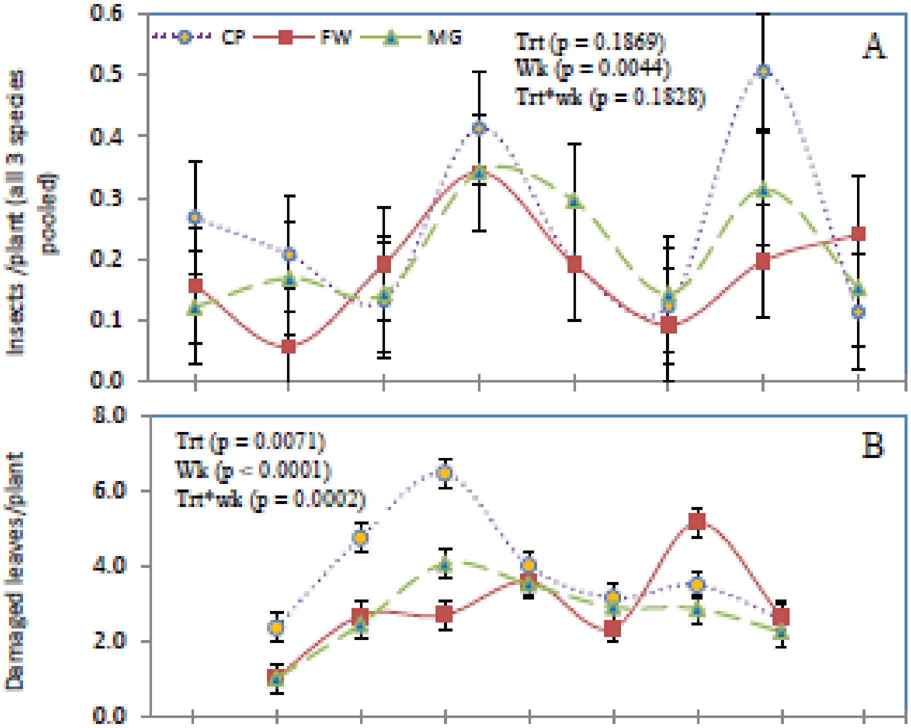
Total insect population for 2009 was not significantly variable among cropping treatments (Figure 3.5), but did vary significantly among sampling weeks (P = 0.0044). The treatment-sample date interaction was not significant. There were two distinct total insect population peaks (Figure 3.5a). Considering the individual insect population densities, none of the three species differed among the treatments (Fig 3.6). Both the cabbage loopers and diamondback moths exhibited distinct mid and late-season population peaks whereas, cabbage worm had only an early season peak and was scarce thereafter (Figures 3.6). However, the diamondback moth had only one population peak in the fallow treatment (Figures 3.6b).

Broccoli leaf damage

Leaf damage in 2009 was significant for the cropping treatments, sampling weeks, and the interaction between cropping treatment and sampling weeks (Figure 3.5b). Early season through the first pest population peak, damage was significantly higher in the cowpea treatment than either marigold or the fallow treatments (Figure 3.5b). On the third sample date, damage also was significantly higher in the marigold plots than in the fallow plots (Figure 3.5b). In mid season there was no significant difference in damage among treatments (Figure 3.5b). Near the beginning of the late season insect pest population peak in 2009, crop damage was significantly greater in the fallow plots than in both the cowpea and marigold plots (Figure 3.5b). There are two peaks of total insect pest density (Figure 3.5a) but only a single peak leaf damage (Figure 3.5b), indicating that crop damages do not correspond to insect population densities. Crop damage patterns do not also correspond to the bimodal population peaks observed for cabbage loopers and diamondback moths in 2009 (Figure 3.6). However, considering the larger individual feeding larval sizes of cabbage loopers, it can be assumed that the cabbage loopers were responsible for most of the broccoli leaf damage. The very low number of cabbage worms indicates that little damage can be attributed to this species.

Insect pest parasitization

The overall model for total insect parasitization for 2009 was significant among the cropping treatments (P = 0.0443), with both the cowpea and marigold plots experiencing



CP	A	A	A	A	A	B	A
MG	B	B	B	A	A	B	A
FW	B	B	C	A	A	A	A

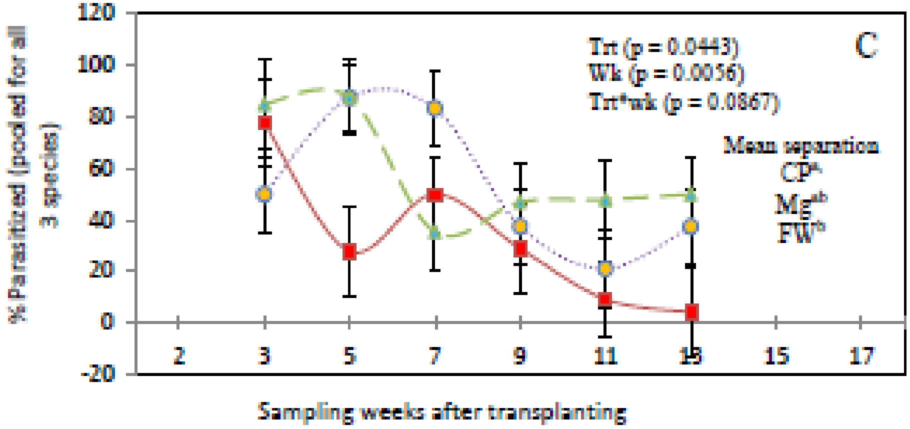


Figure 3.5: Total insect population density (A), Leaf damage (B) and insect parasitization level (C) in 2009. In cases where there was a significant interaction between treatment and sample week, means for treatments are compared in a table beneath the graph. Treatments with the same letter within a sample week in the table are not significantly different at $p < 0.05$ using Tukey studentized range test. CP = cowpea, MG = marigold, and FW = fallow, trt = cropping treatment and wk = sampling week

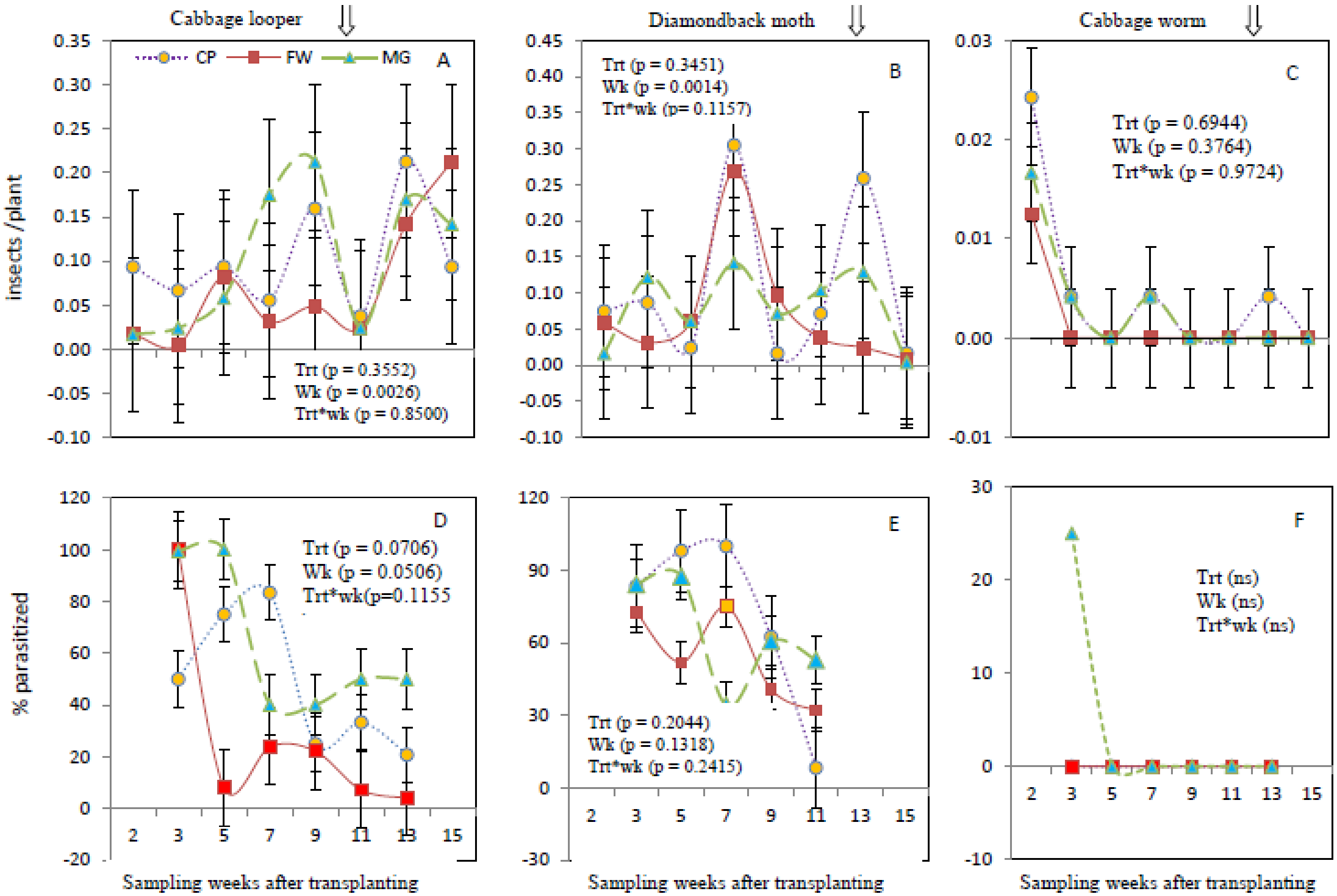


Figure 3.6: Individual Insect population densities (above) and individual insect parasitization levels (below) for 2009. CP = cowpea, MG = marigold, and FW = fallow, trt = cropping treatment and wk = sampling week

significantly higher levels of parasitism than the fallow plots. There was also a significant effect of sampling date (P = 0.0056) and an almost significant treatment-sample date interaction (P=0.0867) (Figure 3.35c). Parasitization was higher early in the season compared to later in the season (Figure 3.5c) The significant difference among treatments was a group effect of all three species pooled as none of them individually showed a significant effect of treatments on parasitism although the effect of treatment on cabbage looper parasitism was almost significant (Figure 3.6d).

Discussion and Conclusion

In general, three lepidopteran insect pests; the cabbage looper (*Trichoplusia ni*), the diamondback moth (*Plutella xylostella*) and cabbage worm (*Artogeia rapae*) were observed as the major broccoli insect pests throughout the study years. Overall pooled for three years, total insect population densities and cabbage worms were higher on the cowpea cover crop compared to the fallow system. However, cropping treatments pooled over the three year study had no significant effect on the overall population density of cabbage loopers and diamondback moths. The overall analysis for data pooled over all three years showed significance levels for the cropping treatment and year. Higher total insect population was observed in 2008 than any other year, probably because broccoli growth for this year was more robust making it more attractive to insect herbivores.

In all years, total or individual insect population started with low levels during early crop growth season, increased over a period of time and attained either single or multiple population peaks. The knowledge of pest population peaks may help plan insect pest management timing and control strategies. Cover cropping treatments had a significant effect on total insect population densities as well as on cabbage loopers and cabbage worm population densities only in 2008. During this year, the higher insect population levels were attained on the cover crop treatments, particularly the cowpea compared to the fallow treatment. In contrast, insect population densities for 2007 and 2009 were not affected significantly by cover cropping treatments. Therefore, considering the three year data, it can be said that the off-season cover cropping treatments had very little or no effect in suppressing either the total or individual insect pests. If at all, the cover crops rather enhanced pest population densities on the subsequent vegetable crop as was observed in 2008. The greater insect population density on the cover crop treatments for 2008 crops may have been due to better growth, higher nutrition and a broader canopy that was observed in the broccoli crop in 2008 (chapter 4).

Based on the three year population dynamics and peaks, the presence of multiple population peaks for the cabbage loopers and diamondback moths may indicate that insect pests are the most important insect pests of broccoli. Sarfraz et al. (2005) considered that *P. xylostella* is a major constraint to brassica crop production, while Furlong et al. (2008) recognizes *A.rapae* as the most devastating pest. These variable categorizations of pest severity could be due to geographic differences and possible year to year variations. In this study, cabbage worms attained far lower population densities that the other lepidopteran pests during all three years.

In this study, off-season cover crops had little or no effect on pest population densities. In studies where cover crops were interplanted with the main crop, reduction in pest populations has been reported from several studies. Broad et al. (2008) detected a reduced colonization of diamondback moth within the diversified cropping systems, indicating that more insect pests under a mono-cropping system. On the other hand, in a mixed broccoli intercropping system, Hooks and Johnson (2002) found higher populations densities of cabbage worm. The more abundant herbivorous insect pest density in monoculture compared to polyculture (Broad et al. 2008) may be attributed to a “resource concentration” hypothesis (Cai et al. 2007) where some specialist herbivores may respond more strongly to homogeneous systems than to mixed cropping. These contrasting observations suggest that the success of cover cropping treatments as insect pest suppressant depends not only on cropping diversification, but also on the scale and the timing of the diversification (Broad, et al. 2008).

The early season increase in broccoli leaf damages in all years could be attributed to the influx of colonizing insects. Broccoli leaf damage varied significantly among cropping treatments in 2008 and 2009 but not in 2007. In 2008, broccoli leaf damage became conspicuously higher in the cowpea cover crop plots compared to the fallow plots only late in the season. In contrast, in 2009 the greater damage on cowpea versus fallow plots occurred only early in the season. Broccoli plants abscise damaged or older leaves very frequently (data not collected) and hence the reason why leaf damages may not progressively increase in each year.

Numbers of insect damaged leaves in 2007 were lower than the peak leaf damage observed in either 2008 or 2009, but the increase in leaf damage does not necessarily synchronize with the dynamics of insect population densities in most of the crop growing years. Within the insect populations, the fact that cabbage looper and diamondback moth were the majority of the total insect pests, suggests that these insect species must have contributed the most to broccoli leaf damage. Yet, since cabbage looper population density accounted most for the total insect population densities and has larger larval sizes, crop damage can be attributed mostly to cabbage loopers and to a lesser extent to diamondback moth and little to the cabbage worm. Nevertheless, crop pest damage is a cumulative effect of all insect pests; hence consideration of total insect pest population should provide a better depiction of insect and insect management decisions.

Similar to the no or little effect of cover crop treatments on insect pest population densities, my research findings cannot confirm that off-season cover cropping reduces crop damage in the subsequent vegetable crop. In contrast, many researchers observed that crop damages can be minimized in a mixed cover and main crop interplanting. These researchers argue that cover crops in a mixed stand interfere with host locating capability and oviposition of insects, masking the main host crop (Andow 1991; Badenes-Perez et al. 2005; Tahvanainen and Root,1972) or obstructing the odor profiles (Couty et al. 2006), hence reducing pest pressure and damage on the main crop. However, Finch and Collier (2000); Finch et al. (2003) argue that there is little support for general masking theory, except when visual cues are restricted (Couty et al. 2006; Broad et al. 2008).

Cover crops in my trial were used as off-season cropping rotation consequently a major masking effect would not be expected.

The most positive effect of the off-season cover crops was enhancement of parasitoids and insect pest parasitization levels, although Furlong et al. (2008) state that the real role of cover crops in manipulating population dynamics of insects and natural enemies still remains unclear. There were greater pest parasitization levels on the cover crop treatments for all years compared to the fallow system. The most likely reason for greater parasitization on cover crop treatments was greater pest population densities on these treatments and that the parasitoids were responding strongly to host population density. It is also possible that natural enemies could be more abundant in diverse vegetation systems because of the continuous variety of microhabitats or food resources (Costello and Altieri 1995). A long season cropping period (be it temporal or spatial cropping sequences) may allow naturally occurring biological control agents to sustain higher population levels on alternate hosts or prey and to persist in agricultural environment throughout the year (Altieri 1999). Within the individual insect pests, parasitization was significant for cabbage loopers and diamondback moths, but not the cabbage worms. However, since insect population density and broccoli leaf damage occurred regardless of the patterns of pest parasitization, such natural pest-parasite relations did not off-set and stabilize broccoli insect pests or its leaf damages. Never the less, tachnid flies, chalcid wasps and braconid wasps are some of the major parasitoids against broccoli insect pests.

Regardless of the occasional greater pest population densities and higher vegetable crop damages on the cover crop treatments, higher broccoli marketable yield was obtained from plots that received summer cover crop treatments than crops from the summer fallow plots (chapter 4). Therefore, growers should consider the holistic contributions from cover crops than their effects on insect pest population density. This study determined that off-season cover crops suppress weeds (chapter 1), enhanced beneficial saprophytic nematode populations (chapter 2), and enhanced the soil environment (chapter 4). Cover crops may provide many benefits; however, they are not do-it-all "wonder crops." (Agriculture 1998). Growers need to make proper selections of cover crops considering many factors that may include benefits to ecosystem biodiversity, contribution to the productivity of agricultural systems (Cai et al. 2007) and compatibility with the main vegetable crop.

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CHAPTER 4

SUMMER CROPPING TREATMENTS ON SOIL AND CROP NUTRITION, GROWTH AND YIELD OF THE SUBSEQUENT VEGETABLE CROP

Abstract

Summer cover cropping and a fallow system were tested for effects on soil and crop nutrition, vegetable growth and yield of broccoli. Soils were analyzed for samples collected at cover crop planting (ACCP), after cover crop incorporation (ACCI) and at vegetable harvest (ABH). Results showed that summer cover cropping increased soil organic matter content, soil and crop nutrient concentrations, crop growth and vegetable marketable yield compared to the summer fallow system. Soil nutrient content is usually low before cover cropping, increases following cover crop incorporation, then is depleted at vegetable harvest. Low soil NO_3 in the initial year and higher soil NO_3 levels in later years are likely indications of N immobilization and mineralization, respectively. Soil nutrients, growth, shoot dry biomass, and marketable yields increased with increasing years of cover cropping rotations, indicating build-up effects of repeated cover cropping. Vegetable crops grown on the cowpea plots were taller, had broader canopy spread and more leaves per plant than if the cover crop was marigold. The ultimate benefit of cover cropping for enhanced vegetable growth and yield may have come from suppression of weeds (Chapter and 3), enhancement of beneficial organisms (Chapters 2 and 3), and increased soil nutrition.

Introduction

Modern agricultural systems involving monocropping have become productive, but only because of their high dependence on external chemical inputs (Oberle 1994). Questions are being raised about the growing dependence of modern farming on chemicals and other non-renewable resources (Altieri 1999). There is also an increasing consumer demand for safe agricultural products and hence, a need for services that may help producers, processors, and distributors adapt to changing consumer preference (www.csrees.usda.gov /ree/strategic plan/htm). Such practices require adoption of alternative management practices (Baligar and Fageria 2007) or enhance functional biodiversity and sustainable production (Altieri 1999).

The use of cover crops is a step towards a sound practice that may accommodate the changing needs of consumers and increase confidence in the quality of agricultural produce. Accordingly, there has been a growing interest in using short-season annual legumes and others as cover crops in vegetable production systems (Creamer and Baldwin 2000). Cover crops in farming systems improve soil health, reduce environmental pollution, and improve crop yields (Fageria et al. 2005; Baligar and Fageria 2007; Singh et al. 2004; Smith et al. 1987; Yenish et al. 1996; Allison 1973. Legume cover crops such as cowpea [*Vigna unguiculata* (L.) Walp.], have been identified as the best candidate for summer cover-crop rotation with winter vegetable crops (Hall and Frate 1996; Aguiar et al. 2001) and improve soil fertility and crop yield (Ngouajio et al. 2003; Baligar and fageria 2007). Farmers may also grow cover crops during the off-season (Campbell et al. 2002). Although several studies have been conducted on cover cropping systems, their use in vegetable crops have rarely been studied (Gallaher 2002) or the research has been mainly on winter annual cover crops with very little research on summer cover crops. However, summer cover crops can produce biomass, contribute nitrogen to cropping systems, increase soil organic matter, and suppress weeds (Creamer and Baldwin 2000), and they are compatible with both organic and conventional farming practices whether incorporated or used as surface mulches (Aguiar et al. 2001; Ngouajio et al. 2003; Baggs et al. 2000). Although cover crops are important components of a sustainable crop production system, their beneficial effects depend on the selection of appropriate cover crops and their management (Baligar and Fageria 2007).

This research is aimed at evaluating the effect of summer cover cropping on the subsequent vegetable crop. It is hypothesized that incorporation of cover crop plant material provides a valuable source of N and enhances crop growth and yield. Summer cover crops are used between spring and fall vegetable crops (Creamer and Baldwin 2000). I hypothesized that cover crops would increase soil nutrition, with subsequent improvement of broccoli yield. Two types of summer cover crops, a legume and a non-legume, were compared with the standard practice of summer fallow in a Mediterranean-type climate.

Materials and Methods

Crop management

A three-year field study was conducted from 2007-2009 at the University of California South Coast Research and Extension Center in Irvine, CA on a loamy-sandy soil. The field site was loamy sand with a history of root-knot nematode (*M. incognita)* infestation. Three summer cropping treatments were employed: 1) French marigold (*T. patula* cv. Single Gold seeded at 2 kg/ha), 2) cowpea (*Vigna unguiculata* cv. UCR CC 36), seeded at 56 kg/ha, and 3) a summer dry fallow as the untreated control. Cowpea was chosen because it is a drought hardy legume, resistant to weeds and enhances some beneficial organisms (Wang et al. 2001). Marigold was chosen because it is known to control nematodes (Ploeg 2002; Wang et al. 2001). Each treatment plot was 12 m long x 10.7 m wide (128 m^2) and laid out into 14 planting rows. The cover crops were direct-seeded in the last week of June in the center of the planting rows of each plot, watered through drip-tubing and grown for three months. The fallow control plots did not receive water during the summer. Each cover crop treatment plot was planted with the same cover crop in each of the three years of study. Plots were separated from each other with a 3 m wide buffer bare ground. The three treatments were replicated four times in a completely randomized design. At the end of the summer cropping period (first week of September), the cover crops were mowed at the soil line, chopped, and the residues left on the ground. Concurrently, alternate rows (seven of the 14 rows) of each of the cover crop treatments were incorporated into the soil at about 0.4 m intervals using a hand-pushed rotary tiller.

The fallow plots were not tilled. Plots for cover crop and broccoli planting are shown in Figure 1a.

At the beginning of the subsequent (winter) cropping season (10 days after cover crop incorporation or the second week of September), broccoli seedlings (*Brassica olerace*, cv Marathon) were transplanted in double rows into the tilled strips of the summer cover crop and fallow plots at an inter (between seedlings) and intra-row spacing of 13 and 35 cm, respectively (http://ucanr.org /freepubs/docs /711.pdf). Broccoli transplants were drip irrigated and fertilized with emulsified fish meal (6-2-0 organic fertilizer) at 5 gallons/acre rate. Broccoli was chosen because it is a high-value vegetable crop that is sensitive to weeds, insect pests, nematodes (Potter and Olthof 1993), and requires high soil nutrients (http://anrcatalog.ucdavis.edu/pdf/7211.pdf). All plot treatments were maintained in the same location for all three years of study in order to assess a cumulative effect of cover crops over time.

Soil and vegetable crop nutrition sampling

Soil samples were collected at the cover crop planting (ACCP), at cover crop incorporation (ACCI), and at broccoli harvest (ABH). Fourteen soil core samples from 5-25 cm depth using a 2.5-cm-diameter Oakfield Model L and LS Tube-Type Soil Samples were collected per plot with a soil auger in a W shape and composited for analysis of soil organic matter content and nutrient concentration. At vegetable harvest time of each trial year, six above-ground broccoli plants were randomly harvested, dried in an oven at 70^{o}C and ground to fine texture. The ground samples (4 replications per treatment) were analyzed for shoot nutrient concentrations (http://www.Al-Labs-west.com).

Crop growth and marketable yield sampling

Fifteen broccoli plants (n = 60 per treatment) were randomly selected from the interior rows of each plot after planting. The selected plants were measured using techniques similar to Hooks and Johnson (2001). Sampling for plant growth parameters, involving broccoli height, canopy spread, and plant leaf number were recorded from 15 randomly selected plants every two weeks starting 10 DAT and until harvest. At harvest, the heads of the broccoli samples were cut and counted per replication and measured for fresh head weights. Another six plants per plot were also randomly selected and harvested per plot, oven-dried for two weeks at 70^{0}C and shoot dry mass was weighed.

Statistical analysis

The effect of treatment type on plant growth parameters was determined using repeated-measure analysis (SAS Proc Mixed). All plant growth and yield data were analyzed using a one-way ANOVA and means separated using Tukey's mean significant differences.

Results

The organic matter contents of soil for most of the sampling periods were higher for the summer cover crop treatments, relative to the fallow system (Figure 4.1), although statistically not significant. Of the three soil sampling periods, significant differences in soil organic matter content between the summer cropping treatments was observed only for the harvest time sampling (ABH) of the 2008 (Figure 4.1a) and just before cover crop planting (ACCP) of the next year (2009) (Figure 4.1b). These soil samples were taken after cover crop incorporation and broccoli harvest for 2008, respectively, indicating that the organic matter detected at these periods must have been from the cover crop and broccoli residues.

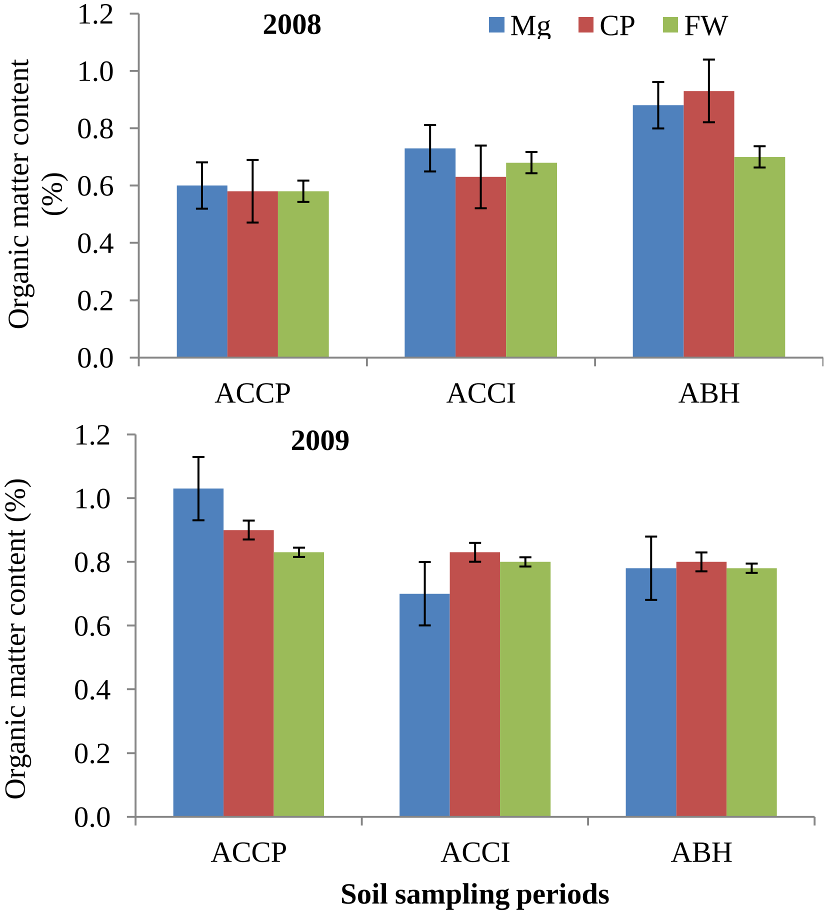


Figure 4.1: Organic matter content of soils measured at different sampling periods (ACCP = at cover crop planting, ACCI = at cover crop incorporation and ABH = at broccoli harvest (p = 0.0851) for 2008 (above) and 2009 (bottom)

Soil nutrient concentrations oscillated between sampling periods and years. During the second year (2008), only soil Ca and Na concentrations and cation exchange capacities (CEC) were slightly higher for the cover crop treatments at ACCP sampling. However, none of the soil nutrition was different between the cropping treatments at ACCI sampling of the same year (Table 4.1). Soil potassium (K), Na, and CEC was higher for

Table 4.1: Effect of summer cropping treatments on soil nutrient concentration under the subsequent vegetable crop[1] (CC = Cropping treatment, Mg = marigold, CP = cowpea, FW = fallow). ACCP = at cover crop planting, ACCI = at cover crop incorporation and ABH = at broccoli harvest

Year	Sample time	CC	K (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)	CEC meq/100g)
2008	ACCP	Mg	198a	428a	3019a	100a	20a
		CP	173ab	383ab	2828a	92ab	18a
		FW	161b	348b	2555b	82b	16b
	P value		*ns*	*ns*	*0.0018*	*0.0387*	*0.0046*
	ACCI	Mg	245a	513a	3053a	153a	20.8a
		CP	219a	414a	2674a	128a	17.8a
		FW	347a	484a	2952a	140a	21.5a
	P value		*ns*	*ns*	*ns*	*ns*	*ns*
	ABH	Mg	225a	616a	2930a	146a	20.9a
		CP	218a	576a	2930a	140a	20.5a
		FW	189b	501a	2743a	118b	18.8b
	P value		*0.0417*	*ns*	*ns*	*0.0094*	*0.0789*
2009	ACCP	Mg	249a	467a	2969a	143a	20a
		CP	257a	473a	3005a	125a	20a
		FW	211a	413a	2705a	100a	18a
	P value		*ns*	*ns*	*ns*	*ns*	*ns*
	ACCI	Mg	195a	465ab	2825ab	136a	19ab
		CP	202a	524a	3154a	139a	21a
		FW	214a	417b	2771b	112b	18b
	P value		*ns*	*0.0329*	*0.0597*	*0.0181*	*0.0551*
	ABH	Mg	169a	486a	2641a	97a	18a
		CP	174a	512a	2726a	93a	19a
		FW	180a	464a	2623a	102a	18a
	P value		*ns*	*ns*	*ns*	*ns*	ns

[1] Mean values in a column within each sampling time followed by the same letter are not significantly different from each other at α = 0.05).

Table 4.2: Effect of summer cropping treatments on soil nutrient concentrations under the subsequent vegetable crop[1] (CC = Cropping treatment, Mg = marigold, CP = cowpea, FW = fallow). ACCP = at cover crop planting, ACCI = at cover crop incorporation and ABH = at broccoli harvest)

Year	Sampling	CC	NO$_3$ (ppm)	SO$_4$-s (ppm)	Mn (ppm)	B (ppm)	soluble salt (ppm)	% Cation saturation	
								Mg	Na
2008	ACCP	Mg	8	48	2	0.53	0.88	18.0	2.23
		CP	7	34	2	0.45	0.83	17.4	2.23
		FW	6	28	2	0.53	0.68	17.4	2.18
	P value		***ns***	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***
	ACCI	Mg	10	36	2.8	0.63	0.75b	20	3.2
		CP	16	33	2.5	0.65	0.9ab	19	3.1
		FW	16	43	2.8	0.63	0.98a	19	2.8
	P value		***ns***	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***
	ABH	Mg	7ab	28	2.3	0.63	0.60	24.2	3.03
		CP	9a	31	2.0	0.53	0.63	23.0	2.95
		FW	5b	23	1.8	0.55	0.55	21.9	2.75
	P value		***0.0326***	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***
2009	ACCP	Mg	24b	26ab	4b	0.58	0.60b	19.2	3.15a
		CP	32a	29a	5ab	0.58	0.78a	19.3	2.70b
		FW	29ab	21b	6a	0.58	0.70ab	18.9	2.48b
	P value		***0.0310***	***ns***	***ns***	***ns***	***0.0236***	***ns***	***0.0104***
	ACCI	Mg	17b	39a	4.3b	0.38b	0.60	20.1a	3.10a
		CP	29a	38a	4.3b	0.4ab	0.60	20.3a	2.83b
		FW	11c	25b	6.8a	0.50a	0.68	18.7b	2.63b
	P value		***0.0009***	***0.0157***	***0.0306***	***0.0550***	***ns***	***0.0383***	***0.0031***
	ABH	Mg	13	10	1.8	0.35	0.30	22.2	2.33
		CP	11	18	2.0	0.33	0.25	22.6	2.15
		FW	10	7	2.0	0.33	0.28	21.4	2.48
	P value		***ns***	***ns***	***ns***	***ns***	***ns***	***ns***	***ns***

[1] Mean values in a column within each sampling time followed by the same letter are not significantly different from each other at α = 0.05).

Table 4.3: Effect of summer cropping treatments on mean broccoli shoot nutrient concentration[1] (CC = Cropping treatment, Mg = marigold, CP = cowpea, FW = fallow). ACCP = at cover crop planting, ACCI = at cover crop incorporation and ABH = at broccoli harvest)

year	CC	% nutrient concentration					
		N	S	K	Mg	Ca	Na
2008	Mg	1.9	0.8	3.1	0.22b	1.8b	0.23b
	CP	2.2	0.9	3.4	0.28a	2.3a	0.34a
	FW	2.1	0.8	3.2	0.23b	1.8b	0.25b
	***P* value**	***ns***	***ns***	***ns***	***0.0146***	***0.0370***	***0.0190***
2009	Mg	1.7b	0.71b	3.0	0.24b	1.8b	0.24b
	CP	2.4a	0.87a	3.6	0.34a	2.4a	0.40a
	FW	1.8b	0.78b	3.1	0.26b	2.1a	0.26b
	***P* value**	***0.0011***	***0.0163***	***0.0138***	***0.0006***	***0.0485***	***0.0033***

[1] Mean values in a column within each sampling time followed by the same letter are not significantly different from each other at $\alpha = 0.05$).

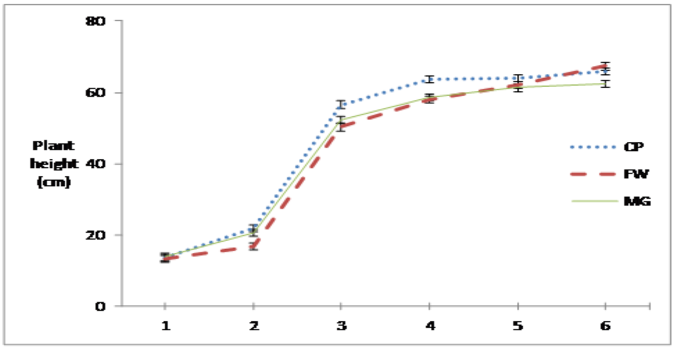
cover crop treatments at ABH sampling for 2008, relative to the fallow treatment (Table 4.1). In 2009, the only time soil nutrient contents were visibly different for the cropping treatments was at the ACCI sampling (Table 4.1) and all soil nutrients were at the same level for all cropping treatments at other sampling periods of 2009. The pH of the soil for both study years ranged from 7.9 to 8.2 and was not different among the cropping treatments.

In addition to the above nutrient types, soil NO_3 showed unique responses based on cropping treatments (Table 4.2). Soil NO_3 was consistently higher for the cover crop treatments relative to the summer fallow, but not until after cover crop incorporation of

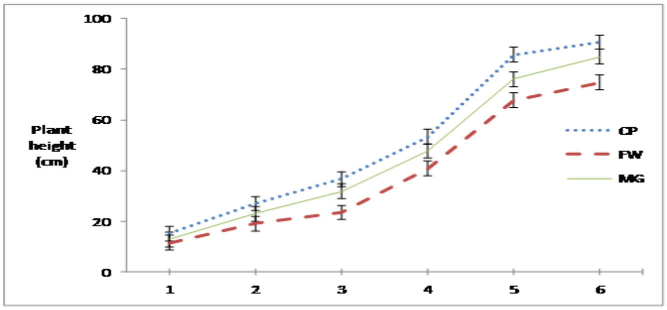
2008. Soil NO_3 level declined and was not different among the cropping treatments at ABH sampling of 2009 (Table 4.2). In relative comparisons soil NO_3 levels were higher in 2009 than in 2008. Soil SO_4, and percent cation saturations were higher for the cover crop treatments, compared to the fallow, but not until 2009. Mn and B were higher in the fallow than in the cover cropped plots at ACCI. Soil nutrient concentrations, particularly NO_3 and SO_4 were generally greater when the cover crop was a cowpea than marigold (Table 4.2).

Some, but not all of the soil nutrient enrichment from cover cropping is reflected in the nutrient uptake of the vegetable crop (Table 4.3). As for the plant nutrients, higher N, S and K were detected in the shoots of broccoli grown on the summer cowpea plots compared to the fallow treatments. However, these nutrient increases were only in the 2009 crops, but not in 2008 (Table 4.3). Other nutrients such as Mg, Ca, and Na showed higher levels in broccoli shoots that were grown on the summer cowpea plots as early as 2008 and also in the shoots of the 2009 crops. Al and B were also higher in broccoli shoots from the summer cowpea treatments, compared to the marigold and fallow treatments (Table 4.3). In general broccoli benefitted from higher nutrient uptakes from treatments that had a summer cowpea than marigold and least when broccoli was grown on summer fallow plots.

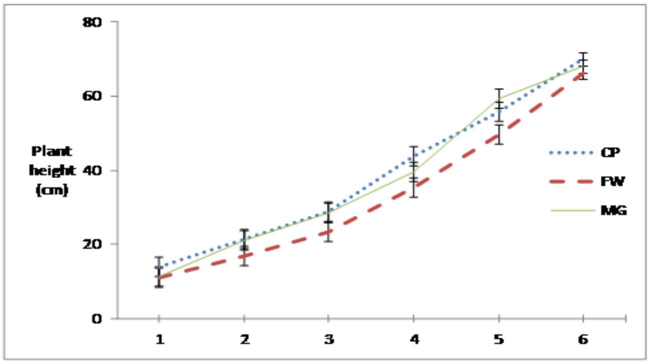
As with the soil and vegetable crop nutrient conditions, broccoli growth differed depending on the summer cropping systems. Broccoli grown on the summer cover crop plots were taller and had more vigorous growth than those on the summer fallow plots



CP	A	A	A	A	A	A
FW	A	A	B	B	A	A
MG	A	A	B	B	A	B

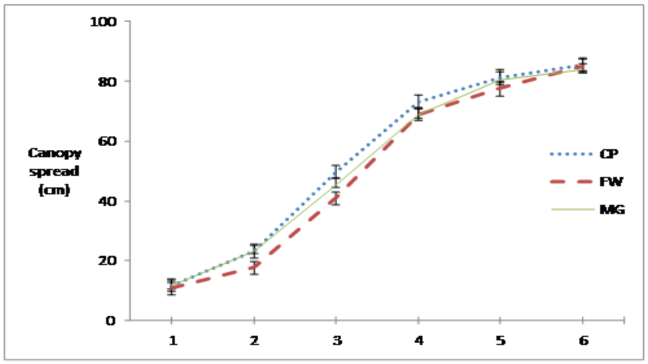


CP	A	A	A	A	A	A
FW	A	A	B	B	B	B
MG	A	A	AB	AB	AB	AB

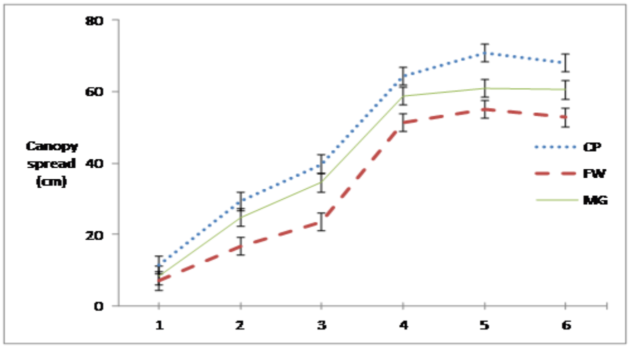


CP	A	A	A	A	A	A
FW	A	A	B	B	B	A
MG	A	A	AB	AB	AB	A

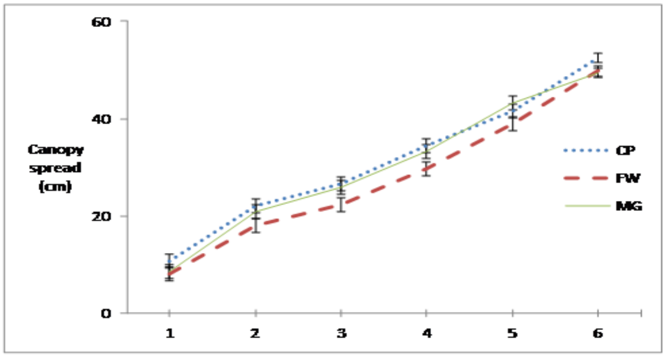
Figure 4.2: Mean broccoli height throughout the growing seasons for 2007 (top), 2008 (middle) and 2009 (bottom). CP = cowpea, FW = fallow, and MG = marigold (sampling for plant height started two weeks after broccoli transplant and continued bi-weekly until broccoli harvest). Mean values followed by different letters in a column under each graph are significantly different from each other at α = 0.05



CP	A	A	A	A	A	A
FW	A	A	B	B	A	A
MG	A	B	B	B	A	B



CP	A	A	A	A	A	A
FW	A	B	B	B	B	B
MG	A	AB	AB	AB	AB	AB



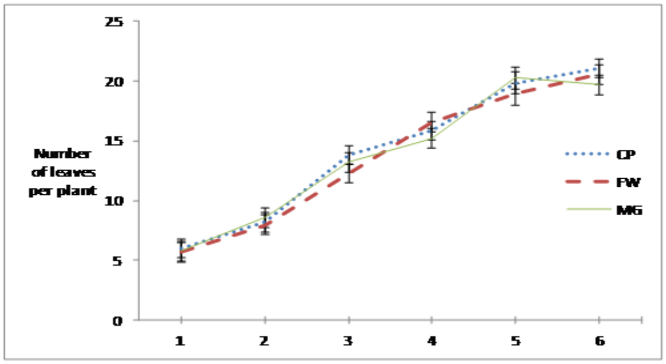
CP	A	A	A	A	A	A
FW	A	B	B	B	B	A
MG	A	AB	AB	AB	AB	A

Figure 4.3: Mean canopy spread per broccoli plant throughout the growing seasons for 2007 (top), 2008 (middle) and 2009 (bottom). Mean values followed by different letters in a column under each graph are significantly different from each other at α = 0.05

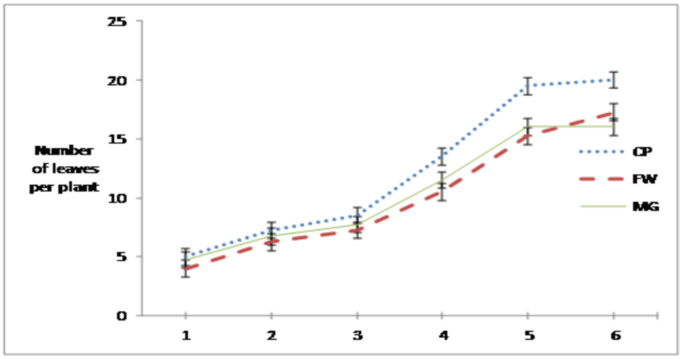
(Figure 4.2). During almost all sampling weeks, broccolis crops were consistently taller for the two cover crops than the fallow treatments. Consistent with nutrient status, crop height growth was highest for those from cowpea, followed by marigold and least for crops grown on the summer fallow (Figure 4.2). The increase in height of broccoli grown on the cover crops is more prominent after the third week of sampling for all study years and more pronounced for the 2008 crops. Broccoli canopy spread was similar to the crop's height responses in that broccoli on the summer cover crop treatments for all years had relatively broader canopy, but were most significant for the 2008 cropping year (Figure 4.3).

The mean number of leaves per individual plant was also variable. Once again these crop growth parameters differed based on sampling years and cropping treatments (Figure 4.4). During all trial years, broccoli grown on the summer cowpea fields had relatively higher mean leaf numbers per plant than any other cropping treatments, particularly at about 8 weeks after broccoli transplant. Mean leaf number production and variation between cropping treatments were clearly visible for the 2008 and 2009 cropping seasons than for the 2007 broccoli (Figure 4.4).

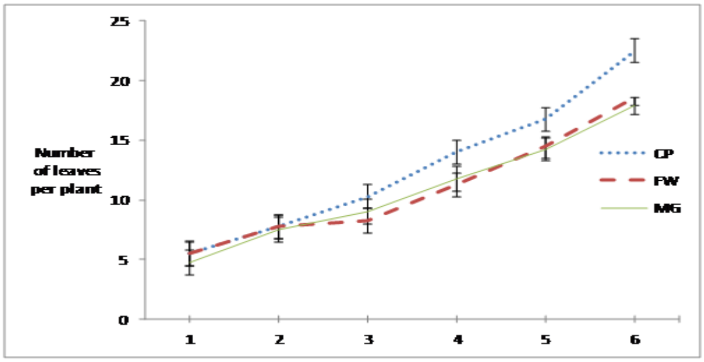
Broccoli shoot biomass determination from destructive crop sampling at harvest time showed that there was no significant broccoli shoot biomass gain from cover cropping for the first year (2007) rotation, although broccoli grown on the summer cowpea were relatively heavier than the other two cropping treatments (Figure 4.5). Vegetable crops



CP	A	A	A	A	A	A
FW	A	A	B	AB	B	A
MG	A	A	AB	B	A	B



CP	A	A	A	A	A	A
FW	A	A	A	B	B	AB
MG	A	A	A	AB	B	B



CP	A	A	A	A	A	A
FW	A	A	A	B	B	B
MG	A	A	A	AB	B	AB

Figure 4.4: Mean number of leaves per broccoli plant throughout the growing seasons for 2007 (top), 2008 (middle) and 2009 (bottom). Mean values followed by different letters in a column under each graph are significantly different from each other at $\alpha = 0.05$

of heavier shoot biomass from cover cropping were observed for 2008 (p= 0.0008) and 2009. During those latter two years, broccoli shoot biomass was heavier for those from cowpea followed by marigold and least for crops grown on the summer fallow (Figure 4.5). The 2008 broccoli shoot biomass for crops from summer cowpea and marigold were about 43% and 23% higher, respectively than these grown following a summer fallow treatment. Although broccoli shoot biomass for 2009 was generally lighter than the 2008 crops, similar trends as for the 2008 crops was observed for treatment effects. Accordingly, broccoli grown on cowpea, followed by those on marigold had heavier biomass than crops grown on the summer fallow field.

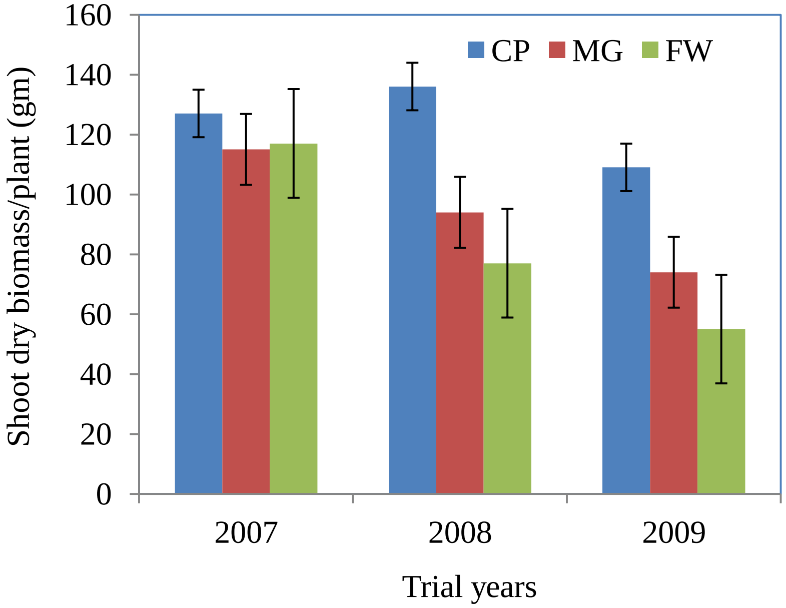


Figure 4.5: Effect of cropping treatments on broccoli shoot biomass for three years

Finally, all effects of cropping treatments is expected to show the benefits of cover cropping with the evaluation of the marketable yields of the vegetable crop. The results clearly demonstrated that the marketable yield responses of broccoli closely matched the responses in soil and crop nutrient, crop growth and biomass accumulations. Considering the marketable yields, there was no significant yield difference between cover cropping and fallow treatments for the first year cropping (Table 4). During this year, the number of marketable heads (MH) and fresh weights of the marketable heads (FWMH) from the first, second and total crop harvest were not significantly different from each other for all cropping treatments (Table 4.4).

Table 4.4: Effect of cropping treatments on number and Fresh weights of broccoli marketable heads*

Trial yr	CCs	**1st harvest**		**2nd harvest**		**Total harvest**	
		MH	FWMH (kg)	MH	FWMH (kg)	MH	FWMH (kg)
2007	CP	115	22.1	142	39.1	257	61.2
	MG	94	19.0	143	32.2	237	51.3
	FW	81	16.3	121	27.3	202	43.6
P value		***ns***	***ns***	***ns***	***ns***	***ns***	***ns***
2008	CP	99	26a	127	49	226	74a
	MG	101	12b	132	31b	233	44ab
	FW	84	10b	128	28b	212	38b
P value		***ns***	***0.0188***	***ns***	***0.0050***	***ns***	***0.0027***
2009	CP	100a	19a	70a	3.7a	169a	23a
	MG	91a	12b	84a	3.8a	175a	16b
	FW	66b	10b	43b	2.3b	109b	12b
P value		***0.0189***	***0.0377***	***0.0018***	***0.0425***	***0.0002***	***0.0163***

*MH and FWMH are number and fresh weight of marketable heads, respectively. Values followed by the same letter in column within each trial year is not significantly different from each other at $\alpha = 0.05$

Differences between cropping treatments in vegetable marketable yield commenced in the second year (2008) cropping year. Interestingly, broccoli gain from cover crops even for the second year study was only with fresh weights of the marketable heads, but not the number of heads (Table 4.4). Higher fresh broccoli marketable heads were observed from the first and second harvest from the 2008 crops. Broccoli crops produced higher number of marketable heads and fresh weights of the marketable heads during the third year (Table 4.4). The total number and fresh weights of marketable heads from the two harvest periods of crops from a summer cowpea plots for 2008 and 2009 were about 36% and 48% higher, respectively compared to these grown on the summer fallow (Table 4.4). The findings in general, suggest the long-term buildup and additive effects of cover cropping rotations on the subsequent vegetable crop.

Discussion and Conclusions

The cover cropping treatments increased soil organic matter contents within the subsequent vegetable crop. However, statistically significant differences in soil organic matter component of the soil was not detected until at the broccoli harvest time of 2008 and following cover crop incorporation in 2009. Since these samplings were both after cover crop or broccoli incorporation, the higher soil organic matter contents must have been from the decomposition of the cover crop residues as well as broccoli. A continued practice of cover cropping becomes an investment in building healthy soil over the long term, builds organic matter and by serving as food source to soil organisms (Agriculture 1998), and increasing soil productivity (Hartwig and Ammon 2002).

The initial year similarity in organic matter content levels of cover cropped and fallow plots is probably due to the fact that soil organic matter buildup takes place very slowly.

Organic matter of a soil is important in improving soil structure, increase infiltration and cation exchange capacity and serves as efficient storage of nutrients (Hartwig and Ammon 2002; Wilhelm et al. 2004). Upon its breakdown soil organic matter releases available nutrients to plants (Carter and Stewart 1996). However, soil contents of organic matter frequency and type of cultivation (Heenan et al. 1995), cropping and residue management (Grace et al. 1995; Webb et al. 2003), or fertilizer N input (Bhogal et al. 1997; Fageria et al. 2005) may also affect soil nutrient status.

The soil organic matter contents from cropping treatments were reflected in variation of some soil nutrient contents. As has been shown from soil nutrient analysis, nutrient enhancement from cover cropping was more visible following cover crop residue incorporation. Wagger (1989) and Creamer and Baldwin (2000) suggest that higher contents of soil nutrients were associated either manure applications or cover crop incorporations. While soil nutrient concentrations oscillated between sampling periods and years, Ca and Na concentrations and soil cation exchange capacities (CEC) were higher for the cover crop treatments of the second year (2008) ABH sampling and at ACCP sampling in the third year. The higher soil nutrient concentration and CEC from the cover crop plots of the 2008 must have been from the accumulation from the previous year crop residue decomposition (there was no soil analysis for the first year trial).

However, most of the soil nutrient concentration right after cover crop incorporation (ACCI sampling) of 2008 was not different among the cropping treatments, indicating the probability of nutrient immobilization following residue incorporations. The latter increase in soil nutrition must have been from the mineralization process following cover crop residue decomposition. The trend suggests that it is possible to buildup up soil nutrient contents with the use of summer cover cropping and allow the subsequent vegetable crop to make use of accumulated soil nutrients. It also suggests that the process of cover cropping rotations must be continuous in order to achieve a continuous improvement in nutrient availability for the subsequent vegetable crop.

Similarly, soil NO_3 was consistently higher for the cover crop treatments relative to the summer fallow, but not until after cover crop incorporation of 2008. Soil NO_3 level declined and was not different among the cropping treatments at ABH sampling of 2009. The decline in NO_3 at broccoli harvest was probably depletion due to nitrogen uptake by broccoli. In relatively higher soil NO_3 levels in 2009 than in 2008, suggests a nutrient build-up effect from repeated cover cropping and a higher N mineralization with increased years of residue accumulation. Soil SO_4, and percent cation saturations were higher for the cover crop treatments, compared to the fallow, but not until 2009. Mn and B were higher in the fallow than in the cover cropped plots at harvest. My results demonstrated the importance of preceding cultivation of vegetable crops with summer cover cropping instead of leaving the land fallow. Following broccoli production after summer cover cropping benefitted the crop in enhancing and increasing soil nutrient availability, enhancing crop growth and marketable yield. The ultimate benefit of cover cropping may also come from pest suppression, enhancing beneficial organisms, increased biodiversity and other indirect benefits of cover cropping.

Since soil nutrition is particularly critical for organic food production practices, the use of cover crops could help fulfill this need. I observed that not all soil nutrients are equally enhanced with the use of cover cropping. Besides, not all cover crops are equal contributors to added soil nutrition. Increases in soil nutrient content, particularly soil NO_3 was greater when the cover crop was cowpea than when it was a marigold, probably relating to the nitrogen fixing capability of cowpea. Leguminous cover crops with a biological nitrogen-fixing capability play a much more important role and may reduce dependence of the subsequent crop on synthetic nitrogen fertilizers (Aguiar, et al. 2001; Fageria et al. 2005; Hartwig and Ammon 2002). However, Franzluebbers et al. 1994; Fageria et al. 2005) all suggest that N supply from the decomposing residues must coincide with the subsequent crop N demand and proper management of residue in order to provide increased efficiency of cover crop use.

The N supply from legumes could reduce N application rates below the recommended rate for subsequent vegetable crops (Burket et al. 2003). The contribution of N is the primary benefit of leguminous crops (Singh et al. 1992; Smith et al. 1987) resulting in increased crop yields (Fageria et al. 2005). Therefore, my findings of variable nutrient contribution from different cover crops suggest that the extent of soil nutrient build up is dependent on the type of the cover crops and that proper cover crop compatibility and selection be made based on the requirement of a farm and residue management practices. Although legumes could release fixed N to the soil, leguminous cover crop residues may also transport a large portion of their biomass nitrogen into the seeds if allowed to flower and mature, because the N-fixing symbiosis of the legume shuts down when the crop stops active growth. Therefore, a good management that benefits the subsequent vegetable crop is to kill the legume cover crops in the early- to mid-blossom stage and plant the following cash crop without delay, aside from any period for residue decomposition (Agriculture 1998).

Since soil nutrition is somewhat related to soil organic matter accumulations, such benefits must depend on a balanced interaction of organic matter, soil organisms that break down crop residues and nutrient cycling and selection of the cover crop and residue management practices (Aguiar, et al. 2001). The increased microbial immobilization of soluble N may require modified fertility management practices (Paoletti et al. 1994) that increases nutrient availability to coincide with plant demand (Jackson et al. 1993). Immobilized nutrients may be subsequently available through mineralization after incorporation (Baggs et al. 2000). On the other hand, the pattern and timing of mineralization of nutrients depends on the residue quality, soil type, temperature, soil moisture content and timing and method of incorporation (Baggs et al. 2000). The higher soil Ca and Na under cover crop treatments may also be due to the fact that cover crops may help bring nutrients such as calcium and potassium back into the upper soil profile from deep soil layers and then release them back into the active organic matter when they die and decompose (Agriculture 1998).

As for the soil contents, higher N, Mg and Na were detected in the shoots of broccoli grown on the summer cowpea plots compared to the fallow treatments. However, these nutrient increases were only in the 2009 crops, but not the 2008, indicating a need for repetitive and multiple-year cover cropping rotations to provide increased nutrient supply to the subsequent vegetable crop. In some cases, while some soil nutrients were higher for the cover crop treatments (such as K, SO_4, and Ca) than in the bare soil, the subsequent crop does not seem to have made full benefit of the improved soil nutrition. My findings were consistent with Baggs et al. (2000) where no significant effect of cover cropping was observed on the N content or yield of the subsequent oats crop, regardless of the release of N from decomposing cover crop tissues. These observations were attributed to non-limiting N in this soil for any benefits to become apparent immediately. It is also possible that mineralization of some nutrients from incorporated residues may be delayed (Rayns and Lennartsson1995), resulting in conflicting evidence over the ‘fertilizer value’ of cover crops (Baggs et al. 2000) showed that recovery of N by the subsequent crop is typically less than 30–40%. Cover crops may also reduce available soil NO_3 compared with the fallow treatment by 18–44% (Baggs et al. 2000) as a result of low mineralization rates.

My observation of low nutrient content in shoots of crops and the many other previous findings suggest that crop nutrient contents do not necessarily match soil N contents. Baggs et al. (2000) showed that crop N alone is an adequate indicator of the quality of a cover crop. In some cases a higher N content in crops was observed following a bare ground treatment than the cover crops, suggesting that N was not available for crop uptake following cover crop incorporation and may be delayed until after complete mineralization (Baggs et al. 2000). Nutrient immobilization from incorporation of residues is short-lived immobilization for soils with comparatively high C:N ratio (Baggs et al. 2000). Cover crops can provide N to subsequent crops in two ways 1) non-legume cover crops recover and recycle residual fertilizer N, and 2) legume cover crops fix atmospheric N for the later crops (Burket et al. 2003). In general while cover crops have the potential to supply nutrients to the subsequent crops, synchronization of N supply from decomposing residues and crop nutrient demands must govern the timing of cover crop kill Creamer and Baldwin, 2000). If not properly managed cover crops create nutrient deficiency as a result of immobilization (Fageria et al. 2005). This is probably the reason why Schroeder et al. (1998) rejected the use of cowpea crop residues as fertilizer N inputs for broccoli.

Consistent with nutrient status, crop height growth was highest for those from cowpea, followed by marigold and least for crops grown on the summer fallow. The increase in height of broccoli grown on the cover crops is more prominent after the third week of sampling for all study years, but no height differences were observed between cropping treatments for the initial growth stages (weeks). This initial stage indifference in crop height could be due to a growth lag phase and that crops are not able to make immediate use of the added resources. Broccoli canopy spread was similar to the crop's height responses in that broccoli on the summer cover crop treatments for all years were relatively of broader canopy, but were most significant for the 2008 cropping year. Canopy growth differences between the study years may have been due to the variation in weather conditions of the different experimentation years. Mean leaf number production and variation between cropping treatments were clearly visible for the 2008 and 2009 cropping seasons than for the 2007 crops. These visible increases in number of broccoli leaves with increasing cover cropping rotations indicate the benefits of multiple cover cropping rations and their buildup effects with increasing use of the system. The mean number of leaves per individual crop could be a reflection of the quality of the vegetable crop. Regardless of some differences in various growth progressions of the vegetable crop, there were some similarities in their responses to the cropping system treatments. First, crop growth is most enhanced by preceding it with summer cowpea than marigold. Secondly, the taller and the greater the canopy spread of the crops are, the higher are the number of leaves per plant.

The growth benefits in height, canopy formation and leaf numbers per plant is a reflection of the nutrient use efficiency from the cover cropping treatments. In contrast, some previous researchers have observed higher mean number of leaves and heavier stem dry weight from a bare soil than when a rye cover crop used (Broad et al. 2009)

suggesting that rye cover cropping treatments resulted in broccoli marketable yield losses. The negative consequences from cover cropping may have been from cover crop-vegetable intercropping, hence live competition for available resources. In this experiment I did not observe any negative consequences of cover cropping on any of the three year growth or yield components of the subsequent vegetable crop.
Broccoli shoot biomass determination from destructive crop sampling at harvest time showed that there was no significant broccoli shoot biomass gain from cover cropping for the first year (2007) rotation. The observation once again suggests that a single year cover cropping rotation is not sufficient enough to benefit drymass accumulation by a subsequent vegetable crop. Shoot biomass gain from cover cropping of the latter years was consistent with the observation of increased soil and crop nutrition. The increase in crop biomass with increasing years of cover cropping reveals that repeated cover cropping results in the buildup of cover crop effects.

As for crop shoot dry biomass, broccoli marketable yields were not significantly different between the cover cropping and fallow treatments for the first year cropping. Such responses were seen in almost all broccoli growth parameters and suggest that a one-year cover cropping rotation is of no net and ultimate benefit to broccoli. Increase in marketable yield from cover cropping was significant in the subsequent study years. Similar to the higher marketable yield observed from cover crop residue supplemented tomatoes (Kumar et al. 2005), I observed vigorous growth, higher shoot biomass accumulation and higher marketable yield of cover crop residue supplemented broccoli.

In contrast, Hoyt (1999) observed a reduction in yield of broccoli planted into desiccated barley (*Hordeum vulgare* L) cover crop and attributed it to lower soil temperatures in the cover crop treatment.

The reduction of soil temperature with the use of cover crop mulches and residues has been discussed (Teasdale and Mohler 1993) as a possible limitation delaying crop harvest for several days (Broad et al. 2009). However, I observed that broccoli crops grown following summer cover cropping were heavier and had vigorous crop appearances compared these on a fallow field. These benefits however were more eminent after the second year of cover cropping rotations, indicating a buildup effect of the cover crops. Broccoli seems to have benefited from previous summer cover cropping during its second and third year trials. Higher fresh broccoli marketable heads were obtained during the second year from both harvest times and the total marketable heads. An increase in marketable yields starting the second year indicates the necessity of repeated cover cropping rotations to be beneficial. The increase in both marketable head numbers and fresh weights of the marketable heads occurred during the third year, further revealing the importance of longer and repetitive cover cropping rotation. The generally lower yield for the 2009 trial, relative the previous year, however was due to crop damage by other herbivorous pests and unexpected flowering, reducing number and fresh weights of marketable broccoli heads. Yet relative yield comparisons were valid.

The more inclusion of the cover crops in the cropping rotations, the higher was the crop yield benefit both in number and weights of marketable broccoli yield. These findings confirm the recommendations that vegetable farmers can grow cover crops during the off-season (Campbell et al. 2002) and benefit from the harvest of the subsequent crop. Ngouajio et al. (2003) suggests that cover crops can be used in diverse cropping conditions as they are compatible with both organic and conventional farming practices by either incorporating or using them as surface mulches. Improvements in soil physical, chemical, and biological environment from the use of cover crops are the reasons for the improved yields of subsequent crops, although crop yields may vary from crop to crop and agroecological regions. The positive response of the subsequently grown crop is also attributed to the transfer of nutrients from cover cropping and less immobilization nutrients (Chalk 1998). Similar to our findings, Hively and Cox (2001); Fageria et al. 2005) observed a higher corn yield following white clover (*Trifolium repens* L.) and red clover (*Trifolium pratense* L.) cover crops. Marketable yield of sweet corn was approximately doubled by hairy vetch in 2 of 3 years compared to an unfertilized, no-cover crop control (Teasdale et al. 2008). Burket et al. (2003) observed a 58% higher average broccoli yield when grown with no fertilizer N, but following a legume cover crop.

In general, the response of broccoli as a vegetable crop to cover cropping rotations was positive associated with nutrient, growth and yield output of the crop. If properly managed, then it is most likely that the cover cropping system can sponsor its own soil fertility, crop protection and productivity. Such low input farming systems with improved crop productivity and profitability can be easily adopted by farmers (Brewer 1999; Leavitt et al. 2011) and becomes very useful in organic farming systems where the use of synthetic fertilizers in not acceptable. Cover crops in farming systems improve soil health, reduce environmental pollution, and improve crop yields (Fageria et al. 2005: Baligar and Fageria 2007) and maintain sustainability of crop production (Singh et al. 2004). Such sustainable production of agricultural products achievable through cover cropping must be based on holistic agricultural management that encourages interdependent and diverse properties. For higher cover crop use efficiency farmers should also deal with selection of appropriate cover crop species with desirable socioeconomic considerations and ultimate vegetable crop yield improvement. It must also involve lower production costs with no adverse effect on crop health and the environment.

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GENERAL DISCUSSION AND CONCLUSION

Although various studies exist on cover crops as pest management strategy, most were isolated and lack data to show their multi-disciplinary pest management potentials. This research was conducted to assess the interdisciplinary and concurrent pest management potentials of summer cover cropping systems. It was designed to specifically assess the effect of cover cropping on weed population density, population density of key vegetable insect pests, insect pest parasitization, on population density of parasitic and saprophytic nematodes, and then quantify the impact on vegetable productivity and marketable yields.

To answer these responses, results were presented in four chapters;

- Chapter 1 deals with weed population density and biomass accumulation
- Chapter 2 deals with parasitic and saprophytic nematode population density
- Chapter 3 deals with key vegetable insect pest, crop leaf damage, and insect pest parasitization levels
- Chapter 4 deals with nutrition, growth, and marketable yield of the subsequent vegetable crop

Under weeds, results showed that summer cover crops suppressed population density and biomass accumulation of weeds within the subsequent vegetable crop. Cover crop weed suppression was most effective against broadleaf weeds than grasses, suggesting that cover cropping may be more effective in agricultural fields predominated with broadleaf weeds. The intensity of cover crop weed suppression increased with increasing years of cover cropping rotations, indicating that their effects buildups over longer cover cropping rotations. Weed suppression was also stronger when coupled with hand weeding. Therefore, cover-cropping systems may be more effective if used as an integrated weed management strategy. Cover cropping as alternative weed management strategy is on the rise (Creamer and Baldwin 2000; Hutchinson and McGiffen 2000) and therefore results from this research may provide a better understanding of the off-season cover crop weed suppression potentials.

Among the cover crops, cowpea provided stronger weed suppression than marigold, probably relating to its N fixing capability, and its more enhanced nutrient supply to the subsequent vegtable crop. Hutchinson and McGiffen (2000), and Ngouajio et al. (2003) showed that cowpea provided an excellent suppression of weeds when used as an intercrop or as organic mulch. The cover crops may have suppressed weeds through modification of soil microclimate, physical impedance to light penetration and weed seed germination (Adler and Chase 2007; Brainard and Bellinder 2004) or through cover crop residue stimulation of soil microbial populations (Matthiessen and Kirkegaard 2006), depleting soil weed seed bank. Those cover crops may also been allelopatic to some weed species (Khanh et al. 2005). Using cover crops for weed suppression is ecologically desirable as it could eliminate reliance on herbicides, hence is particularly useful for organic crop production systems where chemical weed management is not an option. However, to appreciate the usefulness of cover crops, it is necessary to make sure the cover crops are adaptable to a local environment, not negatively interfere with the main crop and fulfill the social and economic considerations of an agricultural system.

With regards to nematodes, the summer cover cropping treatments were in disparity with my hypothesis. Although cowpea (Ehlers et al. 2000) and marigold (Finch and Collier 2000; Ploeg 2002) were known to suppress crop parasitic nematodes, these qualities were not observed in this finding. There were only three parasitic nematode species; the root-knot (*Meloidogyne* spp), the sugar beet cyst nematode (*Heterodera schachtii*) and the pin nematodes (*Paratylenchus* spp) observed in the research field, although the field has previously been used for nematode research and was expected to be loaded with nematode population densities. The low initial nematode population densities may have made it difficult to detect nematode suppression potentials of the cover crops. There were instances where the cover crops were either not different from the fallow system or even enhanced parasitic nematode population densities. Similar response, where incorporated cover crop residues had no effect on parasitic nematodes was also observed by Wang et al. (2001).

A cover crop may suppress parasitic nematodes when used as an intercrop, but not as a surface mulch or residue incorporation. Although Wang et al. (2004) observed cowpea incorporation as green manure to suppress *Meloidogyne incognita*, such suppression was short-lived, and at the end the numbers of *M. incognita* were not different from a fallow treatment (Wang and McSoreley 2008). Ploeg (2000) also pointed out that there was no benefit to a subsequent crop from amending a planting site with marigold plant parts. Therefore the type of cover crop and how the cover crops are utilized; whether live or as mulch (Wang and McSorley 2008), the target nematode (Wang and McSoreley 2008; Krueger et al. 2007), and the species or cultivar of the cover crop (Ploeg and Maris 1999) play an important role in determining the effectiveness of a cover crop against parasitic nematodes.

On the other hand, summer cover cropping treatments were effective in boosting the population densities of free-living (saprophytic) nematodes. Saprophyte population densities were higher following cover crop incorporations, indicating the importance of increased input of organic matter from the decomposition of cover crop residues. My findings in this particular area is consistent finding was consistent with the findings of Wang et al. (2001), Wang and McSorley (2008) who observed an increase in bacterivorous (bacterial-feeding) nematode population densities following soil treatment with sunn hemp as organic mulch. Enhanced population densities of saprophytic nematodes play an important role in soil nutrient cycling (Wang et al. 2001), provide added advantage in soil biology (Langat et.al. 2008), and help nutrient mineralization (Griffiths 1994). In doing so, saprophytic nematodes can be regarded as sensitive indicators of ecosystem change (Wardle et al. 1995). With knowledge of the mechanisms stimulating beneficial nematode community, researchers could develop cover crop management plans to maximize the desirable effects associated with free living nematodes (Gruver et al. 2010).

While testing cover cropping treatments with insect pest population density responses, I observed three major broccoli pests, the cabbage loopers (*Trichoplusia ni)*, Diamondback moths (*Plutella xylostella)* and cabbage worms (*Artogeia rapae*). The cabbage loopers and diamondback moths occurred consistently at higher population densities during all years than the cabbage worms, indicating that those insects must be the most dominant insect pests of broccoli. Sarfraz et al. (2005) listed *P. xylostella* as the major constraint to brassica crop, although Furlong et al. (2008), suggest *A rapae* as the potentially devastating pest in cooler temperate regions regardless of its usually less spread population.

Insect population levels usually start with low at the beginning of vegetable growing season, rose and declined towards the end of the growing season with some peak levels. Except at rare instances, the cropping treatments were seldom significant on population densities of the total or individual insect pest population densities. Difference in insect pest population densities were rather varied among sampling weeks which more probably is related to the vegetable growth conditions. Within the pest sampling weeks, there were some population peak levels. The peak population levels are probably indications of a multiple generations of insect pests within the broccoli growing season. The insect pests observed in here have multiple generations per year and hence more damaging to vegetable crop yields (Hooks and Johnson 2001) than insect pests with a single generation.

Although not statistically significant, relatively higher insect population levels were observed on broccoli grown on the summer cover cropped plots, than on the fallow, indicating that the multiple cropping attracts more insect pest population. Similarly, Hooks and Johnson (2002) found higher populations of cabbageworm in the broccoli intercropping systems. On the other hand, Broad et al. (2008) assessed reduced colonization of diamondback moth with a diversification of cropping systems. The relatively higher insect pest population densities on the cover crop treatments may be as a result of cover crop enhanced vegetable growth making the vegetable more attractive for insect foraging. The peak insect population density was usually higher during the early vegetable growth than the latter, probably serving as a warning signal for timing of preparations to control insect pests.

Broccoli leaf damage in most cases rose and declined following total insect population densities. The damages were generally lower in 2007 than the other two years, suggesting that it takes a long time for the insect pests to migrate from elsewhere, locate the host crop and cause significant damages. Crop damage in most cases also started with low levels, progress to a high peak, except in 2008 and declines near crop maturity. This close synchronization between insect population densities and crop leaf damages indicates that insect pests were responsible for broccoli leaf damages. The decrease in pest population levels with crop maturity indicates that insect pests capable of identifying crop quality and palatability and are of high population levels on actively growing stages crops. Both cabbage loopers and Diamondback moths were consistently higher than the cabbage worms. Considering the larger larval sizes of the cabbage loopers and the higher population densities that matched crop leaf damages, those two insect pests must have been more responsible for broccoli leaf damages.

In the mean time, the cover cropping treatments enhanced parasitoid population and had increased insect pest parasitization levels. Although the enhanced insect pest parasitization did not necessarily offset crop damages, it must have provided a check and balance between insect population and potential crop damages. According to the enemies' hypothesis the natural enemies were more abundant in diverse vegetation systems because of the continuous variety of microhabitats or food resources (Costello and Altieri 1995). The combination of enhancement of vegetable growth and the increased natural enemies by cover cropping rotations may have been the reason (s) for the tolerance of the vegetable crop to insect pests, regardless of the initially higher insect population densities and leaf damages.

In addition to the suppression of weeds, enhancement of insect pest parasitization, the summer cover crops increased soil organic matter contents of soil within the subsequent vegetable crop, particularly after cover crop incorporation. Soil organic matter improves soil structure, increases infiltration and cation exchange capacity and serves as efficient storage of nutrients (Hartwig and Ammon 2002; Wilhelm et al. 2004). Following cover crop residue incorporation, there was higher soil nutrient concentrations, but only after the second year. The delay in soil nutrient concentration may be due to immobilization into the cover crop residues, which requires sometime to mineralize after complete residue decomposition.

Soil NO_3 was consistently higher for the cover crop treatments relative to the fallow, but also not until after cover crop incorporation of the second year (2008). Soil NO_3 levels was not different among the cropping treatments at ABH in 2009, probably due to depletion because of broccoli uptake. Soil NO_3 level was higher under cowpea than marigold, reflecting the N fixing capability of cowpea. Leguminous cover crops with nitrogen fixing capability could supply N needs of vegetable crops and reduce dependence on synthetic nitrogen fertilizers (Broad et al., 2008; Hartwig and Ammon 2002). The N supply from the decomposing residues must however coincide with the subsequent crop N demand (Franzluebbers, et al. 1994). The higher soil Ca and Na under the cover crop treatments is because of the cover crops bringing such nutrients back into the upper soil profile from deep soil layers (Agriculture 1998).

Broccoli height growth, canopy spread, and mean leaf numbers per plant were all greater for the cover crop treatments compared to the fallow during all years, although the differences were more pronounced for the 2008 crops. Broccoli with heavier shoot biomass was harvested from the summer cover crop plots compared to the fallow. Shoot biomass increased with increasing years of cover cropping, indicating the buildup effect of the cover crops. Higher numbers of broccoli marketable heads were obtained after the second year of cover cropping. However, both higher number of broccoli marketable heads and higher fresh weights of the marketable heads were achieved after the third year cover cropping rotations, once again revealing the importance of extended years of cover cropping rotations.

In general, cover cropping is a desirable practice that can provide multiple pest suppression or enhance crop pest tolerance opportunities in the subsequent vegetable crop. The suppression of crop pests and the enhancement of beneficial organisms are causes for the ultimate higher yield of the vegetable crops. Such practice reduces or eliminates the need for synthetic chemicals, hence fulfill the USDA Organic Food Production Act and the National Organic Program. Never the less, cover crops may not provide complete suppression of all pests, hence are more realistic to be used as integrated pest management strategies. Cover crops are compatible with both organic and conventional farming practices (Ngouajio et al. 2003). The findings from this research could serve to promote cover crop awareness of growers and increase their knowledge of what cover crops could do. Such low input farming systems can be easily adopted by farmers (Leavitt et al. 2011). For more effectiveness, farmers should make proper selection of appropriate cover crop species with desirable socioeconomic considerations, such as lower production costs with no adverse effect on crop health and the environment, maintain ecosystem biodiversity and contribute to the productivity of agricultural systems (Cai et al. 2007). One must also realize that cover crops may provide many benefits, but are not do-it-all “wonder crops” (Agriculture 1998).

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