Integration of High Residue/No-till and Farmscaping Systems in Organic Production of Broccoli

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ABSTRACT

High-biomass cover cropping enhances marketable yields in organic production of vegetables, linked to the improvement of soil quality and weed control. Although, during transition from chemical to organic cover-cropping production, especially with no-till systems, reduction of nitrogen availability to the main crop and increase in weed and pest pressure may occur. In 2004-2005, summer and fall broccoli (*Brassica oleraceae* L. Botrytis Group) crops were grown in twin rows on permanent (controlled traffic) raised beds (185-cm wide). Before broccoli transplanting, high-biomass cover crops were grown in specific bed areas. Legumes (*Vicia villosa*, *Glycine max* L., and *Crotolaria juncea* L.) on bed tops (grow zones) and grass species (*Secale Cereale* L., *Setaria italica* L., and *Sorghum bicolor* X *S. bicolor* var. *Sudanese*) in the alleyways (bed shoulders and bottoms). Experimental treatments were tillage (conventional, CT; and no-tillage, NT), farmscaping (with and without), and nitrogen sidedressing (with and without, applied 3 weeks after transplanting as a mixture of sodium nitrate - 22 kg N ha^{-1} - and feathermeal - 44 kg N ha^{-1}). Weeds were managed by mechanical cultivation in CT and a spot weeding by hand in NT treatments. High numbers of beneficial insects (*Cotesia glomerata*, *Cotesia orobenae* and *Diadegma insulare*) kept the primary insect pest population (*Pieris rapae, Evergestis rimosalis* (Guenee), and *Plutella xylostella*) at a pest to predator ratio below 4:1. Although the excellent insect pest control was attributed to the farmscape plantings, pest level

and crop yields were not significantly affected by farmscaping (likely due to the close proximity of the farmscaped plots (10-50m from non-farmscaped)). Broccoli yield averaged 62% higher in fall than summer (12.1 vs. 7.5 t ha^{-1}) likely due to cool weather conditions during broccoli head development (October), increasing head size, uniformity, and marketability. In 2004, broccoli yield in CT plots was either equal or slightly higher than NT (9.5 vs. 9.0 t ha^{-1}). However, in 2005, broccoli yield in CT plots was significantly higher in both spring (8.8 vs. 6.8 t ha^{-1}; $p = 0.0258$) and fall crops (13.5 vs. 12.3 t ha^{-1} with $p = 0.0484$). Nitrogen sidedressing improved yield in all plots (9.8. vs. 12.7 t ha^{-1}) and particularly in NT (8.6 vs. 12.1 t ha^{-1}), indicating that availability and/or synchrony of nitrogen was a limiting factor. Incorporating high-N legume residues in the grow zones resulted in a lesser N response in CT.

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Chapter 1

Literature Review

Introduction

In the traditional organic system (tillage intensive), cover crop residues are incorporated, leaving the soil uncovered and prone to soil erosion and proliferation of weeds. Under this traditional system, weed control has become the greatest production problem facing organic growers. According to the Third Biennial National Organic Farmers' Survey, weed management is the top research priority, based on research priority rankings from all respondents (Walz, 1999). Under the subcategory 'pest management,' weed control (mulching/tillage/competition) was listed as the top research priority by the farm respondents. In lieu of modern herbicides, organic growers utilize mechanical cultivation as a major component of their integrated weed management strategies (Regnier and Janke, 1990; Infante and Morse, 1996). While cultivation can effectively control weeds, it may lead to a decline in soil organic matter and erosion losses, especially in sloping fields. Frequent cultivation can accelerate soil moisture losses during dry spells, and promote surface crusting that hinders penetration of rainfall. Organic mulches conserve soil moisture, and can also improve crop nutrient availability (Black, 1973; Tindall et al., 1991; Schonbeck et al., 1993; Schonbeck and Evanylo, 1998). Weed management with reduced or no cultivation is appealing to many organic producers, who want to conserve soil, improve soil quality and prevent nutrient runoff (Regnier and Janke, 1990; Wicks et al., 1994; Gallandt et al., 1999). Soil organic matter and soil quality increase more rapidly when high-residue cover crops are retained intact as surface mulch than when incorporated as green manure (Schomberg et al., 1994).

A second area of concern among organic growers is crop vigor, which may be limited by soil moisture and nutrient availability (Walz, 1999; Phatak et al., 2002). Often nutrient demand by the crop is poorly synchronized with nutrient release, resulting in low plant vigor and increased disease problems (Delden, 2001). Nutrient imbalances tend to be a common problem during transition from conventional to organic systems (Haraldsen et al., 1999).

Focusing predominantly on short-term (current) soil productivity at the expense of long-term production capacity (sustainable soil quality) is a major failing of most tillage intensive systems (Tonitto et al., 2006). Indeed, sustainable soil quality has worsened in most tillage intensive soils because of declining soil organic matter (SOM) levels and enhanced reliance on purchased off-farm production inputs to provide nutrients and control pests (Magdoff and Weil, 2004). Some growers and advocates of tillage intensive agriculture falsely believe that plant tolerance to pests and vegetable produce quality are always worse in high-nitrogen (N) fertilized, high-yielding crops. This myth is based on the belief that high N fertility results in high crop yields at the expense of pest tolerance and vegetable produce quality (Altieri and Nicholls, 2003). Those promoting this myth suggest that high-N fertility creates an unmanageable resource allocation problem within the plant (Phelan, 2004). This high-N myth seems to have occurred because tillage intensive soils are normally not given a steady (timely), adequate and well-balanced supply of both organic matter and mineral supplements (Swift, 1997; Wolf and Synder, 2003; Phelan, 2004). In this unbalanced scenario, heavy applications of high-N fertilizers (either chemical and/or organic) can result in high crop yields but relatively poor pest tolerance and vegetable quality. Of utmost importance, however, when soils are provided an abundant steady well-balanced supply of both organic matter and mineral nutrients—i.e., integrated soil management—they are capable of producing high crop yields and high-quality vegetables with reduced environmental pollution (Swift, 1997; Worthington, 2001). Reduced leaching occurs in high-SOM soils because of their capacity to hold water and buffer nutrient availability (Phelan, 2004). Therefore, a solution to unbalanced low-SOM soils is to develop integrated systems that address both current productivity (P) and long-term production capacity (PC) (Kay and Munkholm, 2004).

No-till mulch

Crop residue mulch associated with no-till systems modifies all aspects of an agroecosystem. Soil chemical, physical and biological properties are altered by organic surface mulch, especially high-residue mulch (6 or more t/ha). Compared to unmulched tilled fields, lower soil temperature and higher soil moisture generally occur in mulched NT fields (Morse et al., 1993; Jalota and Prihar, 1998). Plant-available nutrient levels in the soil are altered considerably in NT systems, depending on the quantity and type of organic mulch present (Schomberg et al., 1994). Of considerable relevance in organic systems, high-residue organic mulch can increase soil quality, suppress weed growth and affect the incidence and severity of phytopathogens and insect pests (Cardina, 1995; Gallandt et al., 1999; Hart and Jarosz, 2000; Renner, 2000).

Soil quality and tillage

Soil organic matter (SOM), and particularly the active SOM fraction, is the principal indicator of soil quality and most other soil quality indicators are dependent on maintaining high levels of active SOM (Islam and Weil, 2000; Weil et al., 2003). Biological management of phytopathogens and harmful insects is enhanced under high-residue NT systems. Biological pest management is based on ecological principles. Where many different types and adequate quantities of organisms coexist, fewer pest problems occur. Although both short-term and long-term improvements in pest management are derived from using high-residue NT systems, in most instances enhanced biological pest management requires buildup over time of active SOM and associated plant-specific beneficial organisms in the soil. Different plant species prefer to associate with a different mix of soil organisms, and their root exudates contain specific chemical signals (chemical cues) that attract the desired organisms. The more diverse and abundant the soil-life, the more likely that most crops can locate and foster the organisms they require to thrive. Generally, pest management problems tend to be more severe early (vs. late) in transition from low SOM conventional tillage to high SOM no-tillage or other minimum tillage systems. Continued use of diverse crop rotations and adding off-site organic materials (compost or aged manure) will increase active SOM and foster taxonomic and functional biodiversity of beneficial soil-life that will result in improved biological pest management (Phatak, 1998; Davis et al., 2002; Phatak et al., 2002).

Cover Crops

Cover crops in general (and particularly mixtures) and rotation of cover crops can contribute to disease management by increasing soil microbial diversity, improving soil health, altering soil physical properties (light and moisture), and acting as a shield to prevent pathogen spores from dispersing into the crop canopy (Linderman, 1994; Creamer et al., 1997; Hart and Jarosz, 2000). In addition, increasing seedling and plant vigor by any means (nutritional, hormonal, environmental) stimulates natural immune mechanisms to resist or tolerate disease pathogens (Boosalis et al., 1986). Cover crops normally reduce soil temperature and thus can be beneficial to plant growth under high-temperature conditions. Selecting cover crops that increase plant vigor by releasing nutrients (especially N) and growth biostimulants can improve plant stand and crop yield in high-residue NT systems (Sims and Slinkard, 1991).

Weed suppression

The presence of surface organic mulch can reduce germination and growth of weeds (Renner, 2000). Several weed ecological principles help explain how no-till mulch can reduce weed biomass. *First,* weed seeds germinate and become established wherever space is available.

By maintaining dense, uniformly distributed non-weed species over the soil surface, weeds have no space to grow. Seeding and optimizing growth of cover crops prior to production of the vegetable crop dramatically reduces weed growth (Radosevich et al., 1997). *Second*, when weed seeds are dormant, they will not germinate, regardless of environmental conditions. High-residue mulch can reduce seed germination by lowering light and buffering diurnal soil temperature changes—a phenomenon known as environmental dormancy (Renner, 2000). *Third*, weed seed persistence is reduced when seeds are retained on or near the surface and the quantity and diversity of seed predators are increased. Growing and maintaining cover crops on the soil surface provide a good habitat for weed seed predators and pathogens and avoidance of tillage retains weed seeds on the surface thus enhancing weed seed predation and decay (Hart and Jarosz, 2000). *Fourth*, weed germination and seedling survival are reduced by allelopathic chemicals released by decomposing residues. High residue cover crops left as a surface mulch release allelopathic substances that inhibit weed growth (Putnam, 1990; Putnam, 1994; Weston, 1996). Incorporation of cover crop residues as green manure dilutes these allelo-chemicals throughout the soil and reduces weed suppression (Brandsaeter and Riley, 1999; Barker and Bhowmik, 2001). Incorporation of leguminous cover crops, like hairy vetch (*Vicia villosa* Roth), releases a burst of nitrogen into the soil, resulting in a proliferation of weed growth (Morse, 2001).

High-residue versus low-residue dead mulch

The higher the level of cover crop biomass, the greater is the potential for physical and chemical obstruction of seed germination and seedling emergence (Teasdale et al., 1991; Morse, 2001). To be effective, organic mulch levels (either *in-situ* or imported) must be high enough to suppress weeds during the minimum weed free period—i.e., the length of time a crop must be free of weeds after planting in order to prevent yield losses (Zimdahl, 1988; Altieri, 1995;

Cardina, 1995). The minimum weed-free period normally corresponds to the first third of the crop cycle (from planting to canopy closure) and weed competition during this time tends to have the greatest effect on crop yield. Therefore, any factor that favors growth of the vegetable crop over weed growth will favor rapid canopy closure and weed suppression.

Experiments using long-term permanent NT systems have shown effective disease suppression as active SOM and microbial disease pathogen antagonists are built up over time in high-residue NT production systems (Linderman, 1994; Phatak, 1998; Magdoff and van Es, 2000; Gracia-Garza et al., 2002). Buildup of active SOM and microbial antagonists will be enhanced faster in continuous (permanent) no-tillage than in rotational tillage (Schomberg et al., 1994). In addition, burying cover crop residues disrupts the soil profile, destroying beneficial insect habitats and increasing weed growth (Phatak, 1998).

Suppression of insect pests through farmscaping

Suppression of insect pests—the term “farmscaping” refers to arrangement or configuration of the main crop plants and insect-attracting plants that promote biological pest management by attracting and sustaining beneficial organisms, with emphasis on beneficial insects(Bugg and Pickett, 1998).

The landscape matrix in which a field and individual crop plants are embedded has substantial impact on the suite of arthropod pests and natural enemies present in the field (Barbosa, 1998; Bugg and Pickett, 1998). Similarly, local practices in field margins and within fields can substantially impact the predator/prey and parasitoid/host dynamics in crop fields. Several field margin manipulations in Europe have been demonstrated to enhance populations of predatory ground beetles, and provide benefits for conservation of habitats. For example, Dennis and Fry (Dennis and Fry, 1992) examined the influence of field margin vegetation on aphid-feeding ground beetles in England and Norway and found clear benefits of maintaining vegetative diversity on the field margin.

Floral plantings that provide nectar and pollen sources for natural enemies also can be used in margin and within fields to help encourage arthropod natural enemy populations. Such plants are referred to as “banker plants,” providing vital resources for natural enemies in the proximity of the garget field. Arthropod predators and parasitoids are known to visit a number of flowering plants and consume nectar and/or pollen (Al-Doghairi and Cranshaw, 1999). Several studies have shown that floral and extrafloral nectar can enhance longevity of parasitoids (Johanowicz and Mitchell, 2000), and may even improve biological control efficacy when provided in fields (White et al., 1995; Hickman and Wratten, 1996). Intercropping of cabbage with clovers (subterranean and white) in the Netherlands provided economic levels of pest control without use of insecticides (Theunissen et al., 1995).

Maintenance of plant residue in the field by reducing or eliminating tillage can enhance the activity of arthropod natural enemies, and improve biological control (Ruberson et al., 1997). However, pest populations also can be increased when tillage is reduced (Gaylor and Foster, 1987; Landis et al., 1987; Turnock et al., 1993). The use of cover crops, however, in conjunction with reduced tillage has been shown to have net pest management benefits in several systems. In Ireland, early-season crops (sown either the previous fall or early in the spring) had greater abundance of natural enemies than crops planted in the spring into bare ground (Purvis et al., 2001), but this difference disappeared later in the season, presumably due to overwhelming metapopulation dynamics throughout the landscape. In cotton, Ruberson et al. (Ruberson et al., 1997) observed fewer pest problems in large plots (one acre each) of conservation-tilled cotton planted in cover crops the previous fall than in conventionally-tilled cotton in a two-year study.

Much of the beneficial activity observed in the cotton system has subsequently been found to be due to ant predation (J. Ruberson, personal communication), which tends to be more prevalent in reduced tillage systems (Ali et al., 1986). In contrast to these examples, Costello and Daane (Costello and Daane, 1998) found that ground cover left in a table grape vineyard increased overall spider diversity, but failed to increase the abundance of spiders that forage up on the vines, so that biological control was unaffected. Thus, each system must be examined separately to determine what the pest management risks or benefits (along with other agronomic elements) (Lewis et al., 1997) might be of increasing surface soil residues through reduced tillage.

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Chapter 2

Field Research

Introduction

Integrated organic vegetable production systems (IOVPS) are established using a "from the soil up" approach (Swift, 1997). Improvement of soil and plant health and development of a nutrient cycling system that supports high yields are the primary objectives of this approach (Welbaum et al., 2004). Both can be successfully accomplished utilizing high biomass cover cropping in a raised-bed/no-till system (Morse and Creamer, 2006). The cover crops deposit organic residues in the soil (root exudates, mucilages and decomposing root biomass), as well as create a well aerated network of micropores that facilitate establishment of disease suppressive soil microbial communities (Sturz et al., 2000; Somers et al., 2004; Welbaum et al., 2004; Compant et al., 2005). They also suppress weeds, conserve water, and provide habitat for invertebrates, arthropods and other organisms (Cardina, 1995; Gallandt et al., 1999; Hart and Jarosz, 2000; Renner, 2000). Under appropriate water and nutrient management conditions such rich ecosystems can minimize other plant growth and development limiting factors by controlling diseases, weeds and insect pests, thus consistently supporting high yields (Swift, 1997; Carter et al., 2004; Phelan, 2004).

Long-term permanent NT system experiments demonstrate effective disease suppression as active SOM and microbial disease pathogen antagonists are built up over time (Linderman, 1994; Phatak, 1998; Magdoff and van Es, 2000; Gracia-Garza et al., 2002). Buildup of active SOM and microbial antagonists will be enhanced faster in continuous (permanent) no-tillage than in rotational tillage (Schomberg et al., 1994). Reduced leaching occurs in high-SOM soils due to the enhanced water holding capacity and capacity to buffer nutrient availability by turnover of microbial biomass (Phelan, 2004). Therefore, a solution to unbalanced low-SOM soils is to develop integrated systems that address both current productivity and long-term production capacity (Kay and Munkholm, 2004).

The high biomass cover crops can be killed either mechanically (by rolling or mowing), or by freezing temperatures (winter killed) (Ref.). Winter killed cover crops provide less mulch and substantially less nutrients than overwintering species. Subsequently, the breakdown of low-N mulches from winter killed cover crops can tie-up nitrogen thus limiting nitrogen availability. The problems associated with nutrient availability result in low yields in organic production, increased pest and disease problems, and poor produce quality (Walz, 1999; Phatak et al., 2002). Inadequate N availability and synchronization coupled with nutrient imbalances are particularly common during the transition from conventional to organic production (Haraldsen et al., 1999).

Farmscaping

Low populations of naturally occurring beneficial insects in vegetable crop stands can be attributed to tillage intensive farming operations that turn under cover crops as green manure (if grown at all), grow a series of monocultures, cultivate on a regular basis and mow around field margins. These practices lower agroecosytem diversity while maintaining a high level of disturbance throughout the growing season that limits food resources and overwintering habitat (Rabb et al., 1976; Powell, 1986; Dutcher, 1993; Landis and Menalled, 1998). Simplification of agroecosystems to monocultures combined with the development of agricultural land and natural landscapes has limited undisturbed natural landscapes to “remnant” patches (Letourneau, 1998). Furthermore, conditions that combine monocultures and intensive disturbance regimes favor the rapid colonization and population growth by pests while hindering the ability of remaining beneficial insects to control them (Price, 1981; Letourneau, 1998).

Dr. Robert Bugg coined the term “farmscaping” which refers to arrangement or configuration of the main crop plants and insect-attracting plants that promote biological pest management by attracting and sustaining beneficial organisms, with emphasis on beneficial insects (Bugg and Pickett, 1998). The configuration of crop plants and insect-attracting plants has substantial impact on the suite of arthropod pests and natural enemies present in the field (Barbosa, 1998; Bugg and Pickett, 1998).

Providing food resources by farmscaping can lower pest populations to acceptable levels by increasing parasitoid fertility, longevity and survival rates (Leius, 1963; Shahjahan and Streams, 1973; Syme, 1975; Foster and Ruesink, 1984; Wäckers and Swaans, 1993; Idris and Grafius, 1995; Olson and Nechols, 1995; Idris and Grafius, 1997; Barbosa and Benrey, 1998). A hungry parasitoid will exhibit a stronger attraction to flower-related scents than to host-related scents thus reducing their efficiency searching for hosts (Wäckers and Swaans, 1993). Additionally, limited food resources around the cash crop lowers the level of parasitism by increasing the amount of time spent searching for food away from the target host (Barbosa and Benrey, 1998).

Effective integration of high residue/no-till and farmscaping systems would facilitate an increase in species richness and abundance of natural enemies (Barfield and Gerber, 1979; Arkin and Taylor, 1981; Risch and Carroll, 1982; Blumberg and Crossley, 1983; Altieri and Schmidt, 1984; Herzog and Funderburk, 1985; Andow and Hidaka, 1989; Stinner et al., 1989; Letourneau, 1998).

Research Outline and Objectives

Our research aimed to show that growing high-biomass cover crops using no-till planting techniques and little or no cultivation would provide ample weed control as well as limiting disturbance effects that suppress natural enemy populations. Broccoli was chosen as the main crop due to its 1) high value, 2) high nutrient requirements, and 3) availability of information on pest control strategies by beneficial insects. Known pests/natural enemies for broccoli commonly found at KARF at levels sufficient for crop damage are imported cabbage worm (*Pieris rapae*)/*Cotesia glomerata*, cross-striped cabbage worm (*Evergestis rimosalis* (Guenee))/*Cotesia orobenae*, and diamondback moth (*Plutella xylostella*)/*Diadegma insulare* (Kok and McAvoy, 1989; Lasota and Kok, 1989; Vail et al., 1991; Gaines, 1992; Kok, 2004). Having a well documented system facilitated accurate assessment of the broccoli system functionality. Plots were farmscaped to determine the efficacy of conservation biological control methods on limiting the need for intervention in the production of marketable broccoli. Objectives were to increase ecosystem function with respect to pest management and reduce reliance on *Bacillus thuringiensis* var. Kurstaki (*Bt*) in case resistance renders this pest management tool ineffective.

Our hypothesis was that by integrating farmscaping with no-tillage (NT) systems, broccoli production can be economically feasible without application of chemical pesticides. Our goal was to demonstrate that high-residue NT systems combined with farmscaping and timely use of the microbial pathogen *Bt* can suppress weed and insect pests to produce a profitable organic broccoli crop. A controlled-traffic raised bed system used in our study limits compaction and allows for precision placement of nutrients in bed tops where vegetables are grown (grow zone) (Morse and Creamer, 2006).

Specific objectives were to develop an improved prototype system for production of organic broccoli by integrating high-residue cover crop NT systems to suppress weeds and supply organic nitrogen with farmscape plantings (insect attracting plants) to attract and sustain beneficial insects.

Approach and Methods

Field experiments were conducted at the Virginia Polytechnic Institute and State University's Kentland Agricultural Research Farm (KARF), near Blacksburg, Virginia, on a Hayter loam soil (fine-loamy, mixed, mesic, Ultic Hapludalf), pH 6.5 - 7.0. The experimental design for each broccoli experiment (summer crops in 2004 and 2005; and fall crops in 2003 and 2004) was a split plot with farmscaping (not farmscaped and farmscaped) as main plots [8 x 50 m] and tillage systems (no-tillage, NT, and conventional tillage, CT) as subplots [8 x 25 m], arranged in four randomized blocks.

Farmscape plantings (main plots).

In farmscaped main plots (8 x 50 m) for each broccoli crop grown, beneficial insect-attracting habitat mixes were established in a separate row (middle row of a 5 row block) for the entire length of the farmscaped main plots. In addition, a living mulch (a mixture of dwarf perennial ryegrass, *Lolium perenne* L., and creeping red fescue, *Festuca rubea* L.) were maintained in the alleyways of the raised beds.

This research focused on utilizing plant species that other researches had previously identified as providing ample food resources (nectar and/or pollen) accessible to a large number of natural enemies (Bugg and Wilson, 1989; Bugg and Waddington, 1994; Bowie et al., 1995; Idris and Grafius, 1995; Idris and Grafius, 1996; Carreck and Williams, 1997; Idris and Grafius, 1997; Idris and Selvi, 1997; Baggen and Gurr, 1998; Long et al., 1998; Colley and Luna, 2000; Dufour, 2000). Characteristics that are desirable in farmscape plants include: (1) long bloom period, (2) high nectar/pollen production, (3) flower structure accessible to natural enemies, (4) easy to grow, (5) tolerant of a wide range of growing conditions, (6) inexpensive seed and (7) not highly invasive.

Some perennial plants are highly desirable as farmscape plants but have limitations due to germination/growth characteristics or high seed cost. These perennial plants are worth the costs associated with greenhouse production or commercial purchase if bloom time (i.e. nectar/pollen production) fills important niches in early summer or late fall.

Summer broccoli

Farmscaping beds (90 – 110 cm wide at the top) were planted with seven rows per bed on June 3, 2004 (broccoli transplanted on June 16th, 2004) containing the following farmscape plants:

1. *Coriandrum sativum* (coriander) and *Calendula officianalis* (calendula)
2. *Phacelia tanacetifolia* (purple tansy), *Centaurea cyanus* (cornflower), *Borago officianalis* (borage), *Cleome hasslerana* (cleome), *Arthemus tinctoria* var. Kelwayi (golden marguerite), *Helianthus annus* (black oilseed sunflower), *Tithonia rotundifolia* (Mexican sunflower) (transplanted)
3. *Achillea millefolium* (yarrow), *Matricaria recutita* (German chamomile), *Lobularia maritima* (sweet alyssum), *Medicago sativa* (alfalfa), *Melilotus officinalis* (yellow sweet clover)
4. *Anethum graveolens* (dill), *Ammi majus* (bishop's weed), *Foeniculum vulgare* (fennel), *Daucus carota* (Queen Anne's lace), *Pastinaca sativa* (parsnips)
5. *A. millefolium* (yarrow), *M. recutita* (German chamomile), *L. maritima* (sweet alyssum), *Petroselinum crispum* (parsley)
6. *P. tanacetifolia* (purple tansy), *C. cyanus* (cornflower), *B. officianalis* (borage), *C. hasslerana* (cleome), *A. tinctoria* var. Kelwayi (golden marguerite), *H. annus* (black

oilseed sunflower), *Agastache foeniculum* (anise hyssop) and *Agastache rugosa* (Korean mint) (transplanted)

7. *Fagopyrum esculentum* (buckwheat)

Plants that bloomed in 2005 consisted of reseeding annuals and perennials/biennials planted in 2004.

Fall broccoli

Farmscaping beds (90 – 110 cm wide at the top) were planted with seven rows per bed on June 20th except for the buckwheat which was sown on July 20th (broccoli was transplanted on August 20th) containing the following farmscape plants:

1. *C. sativum* (coriander) and *C. officianalis* (calendula)
2. *S. virgaurea* (goldenrod), *C. hasslerana* (cleome)
3. *A. millefolium* (yarrow), *M. recutita* (German chamomile), *L. maritima* (sweet alyssum)
4. *A. graveolens* (dill), *A. majus* (bishop's weed), *F. vulgare* (fennel), *D. carota* (Queen Anne's lace), *P. sativa* (parsnips)
5. *A. millefolium* (yarrow), *M. recutita* (German chamomile), *L. maritima* (sweet alyssum)
6. *Tanacetum Vulgare* var. Goldsticks (tansy), *Cosmos bipinnatus* **(**cosmos)
7. *F. esculentum* (buckwheat)

For 2005 only the buckwheat was replanted. Otherwise, plants that bloomed in 2005 consisted of reseeding annuals and perennials/biennials planted in 2004.

High-residue NT plantings (subplots).

For each broccoli crop, cover crops (Tables 1-2) were grown to produce high-biomass *in-situ* mulch for NT production of broccoli. Cover crops were seeded on preformed raised beds (185 cm wide, with five beds per plot), using a NT drill. Liming was not required (average soil test for the study area - 690 ppm Ca and 150 ppm Mg) and chicken manure (3% N, 2% P_2O_5, and

2% P_2O) at a rate of 6 t ha^{-1} was applied before the cover crop was planted for the summer '04 broccoli. Broccoli transplants were grown in plug trays (72 plant, 55 cc cell volume tray) at the Virginia Tech Horticulture Greenhouse and transplanted when they were ~six weeks old. In conventional (CT) subplots, the cover crops were flail mowed and tilled two weeks before transplanting broccoli. In NT subplots for summer broccoli, cover crops were flail mowed (2004) and winter killed (2005) and left as surface mulch before transplanting broccoli (Table 1). For NT fall experiments subplots, the soybean and foxtail millet cover crops, were killed with a flail mower prior to transplanting broccoli, leaving a uniform dense layer of *in-situ* mulch. All plots were planted using a Subsurface Tiller-Transplanter (SST-T) that precision places organic pelleted fertilizer (Harmony 5-5-3) at a rate of 896 kg ha^{-1}. Drip tubing was placed in-row and transplants set in one pass with minimal disturbance of the surface mulch, as described in (Morse et al., 1993).

All plots were monitored weekly for incidence of disease and appropriate organic sprays were applied as necessary. *Bt* (Dipel, Valent USA Corporation) was applied as needed to control broccoli insect pests (1.12 kg ha^{-1}). Collected data included (1) cover crop biomass, (2) broccoli yield, and average head size and (3) incidence of beneficial and harmful insects at weekly intervals during broccoli head formation (Table 1).

Broccoli leaf analysis

At head initiation stage (fall '05 only), young mature broccoli leaves were removed in each subplot, dried at 70°C for 2 weeks, ground with a cyclone mill, and analyzed for organic N content using the Kjeldahl procedure (Peterson and Chesters, 1964).

Broccoli Harvest

Each crop was harvested 3-4 times (Table 1). Immediately after harvest, heads were cut to 20 cm length and fresh weights were recorded.

Pest and Beneficial Insect Scouting

Beneficial insect activity was recorded for these plantings by scouting for pest levels and for signs of beneficial insect activity (e.g. ladybug eggs/larvae/adults, parasite cocoons, parasitized caterpillars, partially eaten pest eggs, pupal skins or cast skins of the beneficial insects). Ten plants were scouted in each treatment (farmscaped and not farmscaped) at a weekly interval during the critical period leading up to and including head formation. The action threshold for augmentative release of beneficial insects was to occur when pest levels rose above a 4:1 ratio of pests to signs of beneficial insect activity. The action threshold for augmentative release of beneficial insects was never reached in this study.

Nitrogen Sidedressing and Fertigation

Sidedressing was applied 2-3 weeks after transplanting, as a mixture of sodium nitrate (22 kg N ha^{-1}) and feathermeal (44 kg N ha^{-1}) on all crops except summer 2004. Both fall crops had sub-subplots with and without sidedressing; all 2005 summer plots were sidedressed. In summer 2004 supplement nitrogen was applied by fertigation in 5 applications (Table 1) of sodium nitrate (4.5 kg N ha^{-1} per application for a total of 22.4 kg N ha^{-1}) along with fish hydrolysate and seaweed (Neptune's Harvest Organic Fish/Seaweed Blend Fertilizer – 2-3-1 at 28 l ha^{-1}). In fall 2004 fish hydrolysate and seaweed (Neptune's Harvest Organic Fish/Seaweed Blend Fertilizer – 2-3-1 at 28 l ha^{-1}) was fertigated in four applications (Table 1) and in summer 2005 soluble powder of enzymatically digested fish protein (Mermaids fish fertilizer at 2.2 kg ha^{-1}) and soluble seaweed (Maxicrop soluble *Ascophyllum nodosum* at 2.2 kg ha^{-1}) was fertigated in two applications (Table 1). In fall 2005 sodium nitrate (1.0 kg N ha^{-1} per application for a total of 3.0 kg N ha^{-1}), soluble powder of enzymatically digested fish protein (Mermaids fish fertilizer at 2.2 kg ha^{-1}) and soluble seaweed (Maxicrop soluble *A. nodosum* at 2.2 kg ha^{-1}) were fertigated in three applications (Table 1).

Statistical Analysis
The data analysis for this paper was generated using SAS software – PROC Mixed with mean separation, Version 9.1.3 of the SAS System for Windows. Copyright © 2006 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.

Results and Discussion

Cover crops

Cover crops for this study provided sufficient biomass (8.8 – 9.9 t ha^{-1}) for weed suppression and considerable N for crop growth (N contribution on bed tops from aerial biomass of 97 – 131 kg N ha^{-1}). The exception (7.8 t ha^{-1} aerial biomass with only 30 kg N ha^{-1}) was the winter-killed sorghum-sudangrass/sunn hemp biculture grown for the summer 2005 broccoli crop (Table 2). The cover crop bicultures and no-till planting techniques provided effective weed control, with the exception of the winter-killed cover crops in summer 2005 where a hand cultivation was required.

Farmscaping / Benefical Insect Activity

As with cover crops, germination rates are higher when farmscape species are drilled in rows. This facilitates cultivation with a hoe and minimizes hand weeding while achieving higher germination rates. Using a row seeder (e.g. the Earthway Seeder) allows grouping seeds that can enable: (1) seeding plant mixes where all species thrive, (2) obtaining desired spatial arrangement of plants and (3) making adjustments for germination characteristics (e.g. light vs. dark germinators). When using a row seeder planting density can be adjusted by adding a seed diluent (i.e. an inert substance that provides a way to precisely control the flow rate of variable sized seed without affecting seed germination) to lower the seeding rate. Whether broadcast seeding or using a row seeder, adjusting the seeding rate can be a big challenge. While there are different plates available for different sized seed and even different plates for a heavy or light seeding rate, these plates work with varying effectiveness. After some experimentation, both corn grits (cg) and soybean meal (sbm) were shown to flow uniformly through plate #22 (beet-chard) of the Earthway Seeder at a rate of approximately 1 gram per foot of row without affecting germination rates. Mixing farmscape seeds with cg or sbm at desirable rates and seeding with a row seeder not only gives excellent uniform spacing and germination of small-seeded farmscape species but also allows for seeding of different sized seed at the same time and allows for all seeding with the same plate.

Brassica production (primarily broccoli and cabbage) has occurred uninterrupted on plots within a 1 km radius at KARF since the late 1980's when it was purchased by Virginia Tech. Extensive research conducted by Dr. Lok Kok and his graduate students reveals that our major broccoli pest at KARF is the imported cabbageworm (Vail, 1988; Lasota and Kok, 1989; McDonald, 1990; Gaines, 1992). Scouting data from 2004 (see Appendices A-C for complete scouting data) reveals the efficacy of our farmscaping plots to control the imported cabbageworm (ICW) (Tables 4-7). These data support the assertion that the early season population of ICW was typical for KARF (see Table 6) but that it dropped precipitously ~2 weeks before harvest of summer broccoli and remained quite low throughout the fall. This drop was brought on by the high population of *C. glomerata* (see Table 6 for numbers of parasitized larvae and Table 7 for numbers of *C. glomerata* cocoons).

Summer broccoli

There was no significant yield difference (p=0.1532) between the conventional and no-till treatments in the 2004 summer experiment, but significant differences occurred in 2005 (p=0.0258); CT yield was higher than NT (Figure 1). From summer 2004 to summer 2005 there was a significant decrease in nitrogen contribution from the cover crops (Table 2). CT yield increased 19.6% from 2004 to 2005 while NT yield decreased 1.3%, indicating that nutrients (particularly N) were tied up in the NT plots in the summer 2005 crop. Synchronization of nutrient availability with crop demand is a major hurtle in organic crop production. Additionally, in summer broccoli production, yield in Virginia is constrained by weather. Ideal temperatures for broccoli production are day temperatures from 15.6-21.1°C and night temperatures from 10.0-15.6°C. In Virginia night temperatures are not so much a limiting factor as are day temperatures. According to Knott's Handbook for Vegetable crops (Maynard and Hochmuth, 1997) the average yield for broccoli is 11,760 Kg ha^{-1} and a good yield is 15,680 Kg ha^{-1}. According to Parsons(Parsons, 2002) organic broccoli yield in Canada is 44% less than commercial broccoli yield. Using this figure to adjust the figures from the Knott's handbook (Maynard and Hochmuth, 1997) average yield would be 6,585 Kg ha^{-1} and a good yield would be 8,780 Kg ha^{-1}. Our yields fall within the later category but further study needs to be undertaken to optimize nutrient synchronization in organic production systems as well as pushing back planting to avoid excessive heat. A lack of significance between the + and – FS plots is due to the lack of adequate separation between plots due to mobile beneficial insects (particularly parasitic wasps) that were controlling the main broccoli pests.

Fall Broccoli

Yields were not significantly different with in 2004 based on tillage (p=0.1929), while CT yield was greater than NT in 2005 (p=0.0484) (Figure 3). Yield increase from fall 2004 to fall 2005 is attributed to a sizable increase in N contribution from the cover crops. There was a 15.4% increase in yield for the CT and an 11.6% increase in yield for the NT. Higher yield increase in CT plots possibly occurred because of greater nutrient availability from the mowed and incorporated cover crops. Using Knott's Handbook (Maynard and Hochmuth, 1997) figures as a benchmark, fall yields are more in line with commercial production figures. Our expectation is that once nutrient synchronization problems are overcome, broccoli yields should be no different for organic and commercial production. There was no significant yield difference between the + and – FS plots.

Nitrogen

In the summer 2004 broccoli crop nitrogen (N) was a major yield limiting factor. Fertigation with sodium nitrate and fish hydrolysate and seaweed (Table 1) over a number of weeks was not sufficient to support high yields. In fall of 2005, a N sidedressing was applied but there was a harvest error during data collection that limited the data to only two complete replications. In the fall of 2005, data was collected on four replications comparing SD and NSD. The N sidedressing sub-subplots were not randomized within the tillage subplots and normally were not equal in size with the plots not sidedressed. However, yield data were adjusted to compensate for differences in plot size and the 2005 data were statistically analyzed (Figure 5). Given those provisos, both tillage ($p=0.0079$) and nitrogen ($p=0.0023$) were highly significant (Figure 5). In 2004, yield response to N sidedressing in 2004 was 32.4% for CT and 62.5% for NT (47.4% overall), while in 2005 was 12% for CT and 27.7% for NT (19.8% overall). In the no-sidedress plots, yield decrease from CT to NT was 26.4% in 2004 and 21.9% in 2005. These data show the lack of N availability in soils transitioning to organic production. In the sidedressed plots, yield decrease from CT to NT was 6.6% in 2004 and 10.6% in 2005. A significant increase in N contribution from the cover crops in fall 2005 explains why the percent increase in yields due to sidedressing was significantly lower in fall 2005. Since the difference between CT and NT in the sidedress plots increased from 6.6% in 2004 to 10.6% in 2005 apparently optimum N availability was not obtained in 2005. This conclusion is supported by the strong correlation between Leaf N and broccoli yield (0.73193 with $p=0.0013$) in fall ’05.

Conclusions

These data indicated that 1) N availability is a major factor limiting broccoli yield in these organic transition systems, and 2) N release (mineralization rate) was higher and/or more synchronous in CT plots than NT. Additional long-term research is needed to determine 1) yield and economic threshold levels derived from applied organic N fertilizers, and 2) the potential interactive (long-term emergent) effects of tillage systems (CT vs. NT) on soil organic matter, pest suppressiveness and crop yield. In closing, these data show that zone establishment of high-biomass cover crops on permanent raised beds, farmscaping, and N sidedressing are an effective combination for producing organic broccoli.

Table 1. Dates of applied cultural practices.

Cultural practice	2004 Summer	2004 Fall	2005 Summer	2005 Fall
Drilled cover crops on raised beds	3 Oct[1]	3-Jun	21-Jun	16-May
Flail mowed cover crops—CT	30-Apr	3-Aug	27-Apr	2-Aug
Rototilled (10-15 cm)—CT	19-May	9-Aug	27-Apr	5-Aug
Rolled cover crops—NT	19-May	3-Aug	-------	2-Aug
Flail mowed rolled cover crops—NT	3-Jun	12-Aug	27-Apr	10-Aug
Transplanted broccoli	4-Jun	17-Aug	4-May	15-Aug
Applied N sidedressing	-------	31-Aug	27-May	30-Aug
Fertigation:	25-Jun	24-Sep	14-Jun	16-Sep
	2-Jul	1-Oct	23-Jun	23-Sep
	9-Jul	8-Oct	-------	30-Sep
	16-Jul	15-Oct	-------	-------
	24-Jul	-------	-------	-------
Cultivation—CT	25-Jun	31-Aug	16-Jun	30-Aug
Cultivation—NT	-------	-------	16-Jun	-------
Bt application	18-Jun	28-Aug	13-May	2-Sep
	23-Jul	14-Oct	27-Jun	11-Oct
Harvest broccoli—first	5-Aug	22-Oct	6-Jul	20-Oct
Harvest broccoli—second	9-Aug	27-Oct	11-Jul	27-Oct
Harvest broccoli—third	13-Aug	1-Nov	14-Jul	30-Oct
Harvest broccoli—fourth	-------	5-Nov	-------	-------

[1] Dates are for year preceding broccoli growing season

Table 2. Cover crop biomass (t ha^{-1}), N content (t ha^{-1}) and N contribution (kg ha^{-1}) at time of transplanting broccoli, 2004-2005.

Broccoli crop	Cover crops[1]			
(date transplanted)	Species	Biomass[2]	N content	N contribution
Summer 04	BT: Rye/HV	4.4	22.0	97
(4 June)	AW: Rye/HV	4.9	22.0	97
	Combined	8.8	-	196
Fall 04	BT: SB and FM	3.9	19.5	76
(17 August)	AW: FM	6.0	15.6	94
	Combined	9.9	-	170
Summer 05	BT: SH and SSG	3.6	8.4	30
(4 May)	AW: SSG	4.2	6.8	29
	Combined	7.8	-	59
Fall 05	BT: SB	5.2	25.2	131
(15 August)	AW: FM	4.5	13.0	59
	Combined	9.7	-	190

[1]Cover Crops: summer 04 – hairy vetch (*Vicia villosa*) (HV) and cereal rye (*Secale Cereale* L.) (drilled 3 October 03), seeded uniformly over bed tops (BT) and alleyways (AW) between beds; fall 04 – soybean (*Glycine max* L.) (SB) and foxtail millet (*Setaria italica* L.) (drilled 3 June 04), SB seeded in two twin rows on BT and FM seeded in AW and the center single row on BT between the two SB twin rows; summer 05 – sunn hemp (*Crotalaria juncea* L.) (SH) and sorghum-sudangrass (*Sorghum bicolor* X *S. bicolor* var. *Sudanense*) (SSG) (drilled 21 June 04), SH seeded in two twin rows on BT and SSG seeded in AW and the center single row on BT; fall 05 – SB and FM (drilled 16 May 05), SB seeded in four center rows of the BT and FM seeded in AW and edges of BT.

[2]Biomass: Before transplanting broccoli each season (19 May 2004, 3 August 2004, 27 April 2005 and 2 August 2005), cover crop samples were taken separately to determine biomass levels on BT and AW. Biomass data are reported based on the area occupied (t ha^{-1}) on BT and AW of the total (BT and AW).

Table 3. Criteria for assessing the probability of weed suppression in organic no-till systems.

Site factor (criterion)	Probability of achieving weed suppression Low	Moderate	High
Mulch quantity[1] – dry wt. (t ha^{-1})	<4	4-8	>8
– soil coverage (%)	<75	75-95	>95
– depth (cm)	<5	5-10	>10
Mulch quality – C/N ratio[2]	<15	15-25	>25
Perennial weeds (% of total weeds)	>20	2-20	<2
MWFP[3] (canopy closure, weeks)	>6	4-6	<4
Monthly in-season rainfall (mm)	>100	40-100	<40
Fertigation[4] method	overhead	furrow	drip

[1]J.R. Teasdale, personal communication, 2004.
[2]C/N ratio = Carbon to nitrogen ratio (weight to weight basis).
[3]MWFP = Minimum weed-free period, defined as the length of time a crop must remain free of weeds after planting to prevent yield loss. Normally, the MWFP coincides with the time of canopy closure.
[4]Fertigation = When water and soluble organic fertilizer are applied in the irrigation system.

Table 4. 2004 Summer Broccoli – imported cabbageworm scouting data (n=10).

	ICW[1] Egg	ICW SL[2]	ICW LL[3]	ICW PSL[4]	ICW PLL[5]	*CG*CM[6]
7-Jul-04	20	8	0	0	0	0
14-Jul-04	26	18	0	0	8	0
22-Jul-04	11	48	2	0	18	5
28-Jul-04	0	5	1	0	0	23

[1] Imported cabbageworm
[2] Small larvae
[3] Large larvae
[4] Parasitized small larvae
[5] Parasitized large larvae
[6] *C. glomerata* cocoon masses

Table 5. 2004 Fall Broccoli - imported cabbageworm scouting data (n=10).

Date	ICW[1] Egg	ICW SL[2]	ICW LL[3]	ICW PSL[4]	ICW PLL[5]	*CG*CM[6]
16-Sep-04	1	0	0	0	0	2
23-Sep-04	2	0	0	0	0	0
30-Sep-04	3	0	0	0	2	0
7-Oct-04	1	1	0	0	1	0
14-Oct-04	0	0	0	1	2	0

[1] Imported cabbageworm
[2] Small larvae
[3] Large larvae
[4] Parasitized small larvae
[5] Parasitized large larvae
[6] *C. glomerata* cocoon masses

Table 6. Average imported cabbageworms scouted per plant.

Month	ICW[1] Egg	ICW Egg	ICW SL[2]	ICW SL	ICW LL[3]	ICW LL
July	4.0 ± 1.0[4]	1.4[5]	1.9 ± 0.2[4]	2[5]	1.2 ± 0.4[4]	0.08[5]
September	1.6 ± 0.4[4]	0[5]	1.2 ± 0.2[4]	0[5]	1.5 ± 0.3[4]	0[5]
October	0.7 ± 0.3[4]	0.05[5]	0.5 ± 0.1[4]	0.05[5]	0.7 ± 0.3[4]	0[5]

[1] Imported cabbageworm
[2] Small larvae
[3] Large larvae
[4] Data collected during 1990 at Kentland Agricultural Research Farm (Gaines and Kok, 1995)
[5] 2004 data

Table 7. *C. glomerata* cocoon masses - numbers scouted per ten plants

Year	Month	*CG*CM[1]
1989	July	0.3 ± 0.3[2]
1990	July	1.1 ± 0.4[2]
2004	July	5.8

[1] *C. glomerata* cocoon masses
[2] Data collected at Kentland Agricultural Research Farm (Gaines and Kok, 1995)

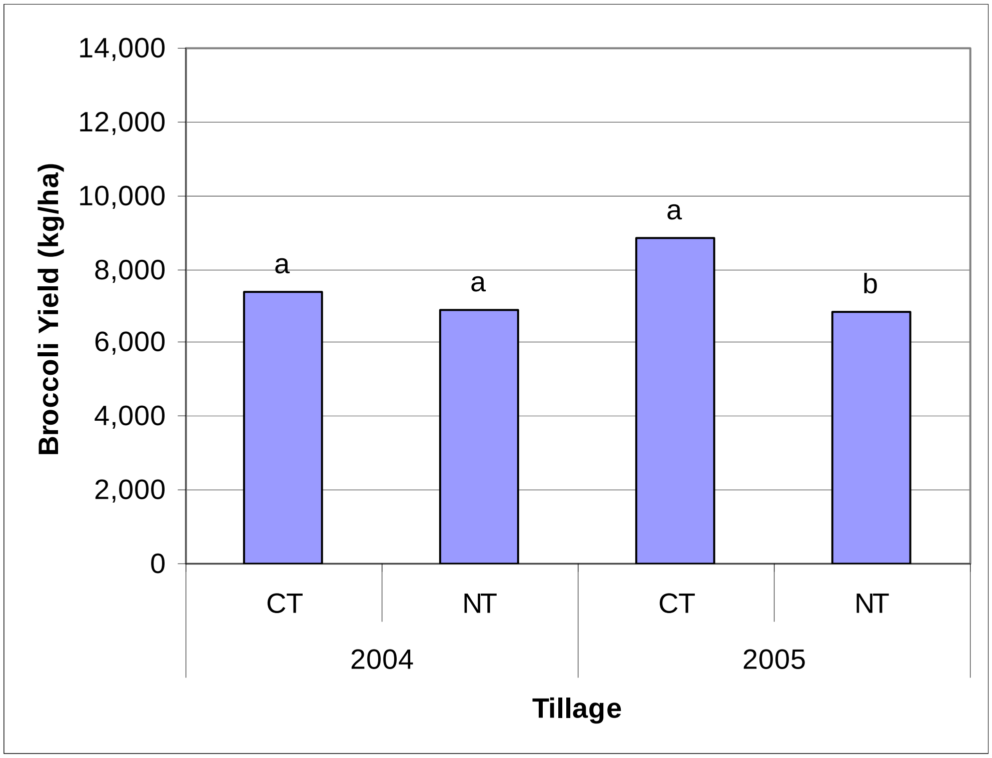

Figure 1. Effect of tillage on summer broccoli yield.
Yield data were averaged for conventional and no-tillage plots with mean separation based on analysis of variance results. Within each year, means with the same lower-case letter were not significantly different (P>0.05).

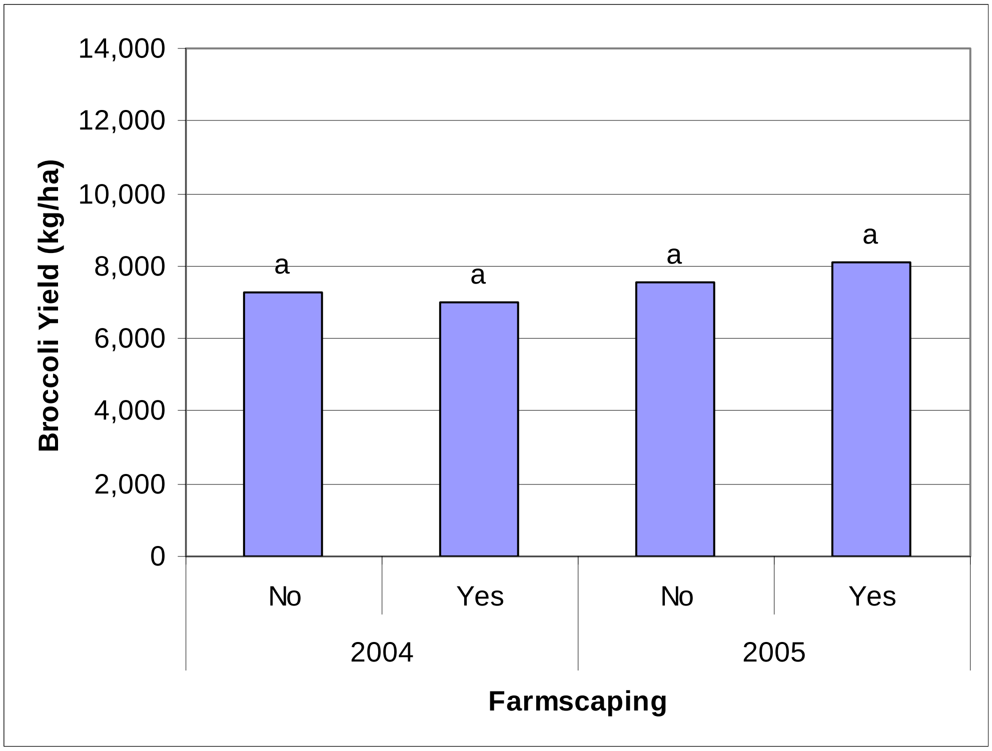

Figure 2. Effect of farmscaping on summer broccoli yield.
Yield data were averaged for plots with and without farmcaping with mean separation based on analysis of variance results. Within each year, means with the same lower-case letter were not significantly different (P>0.05).

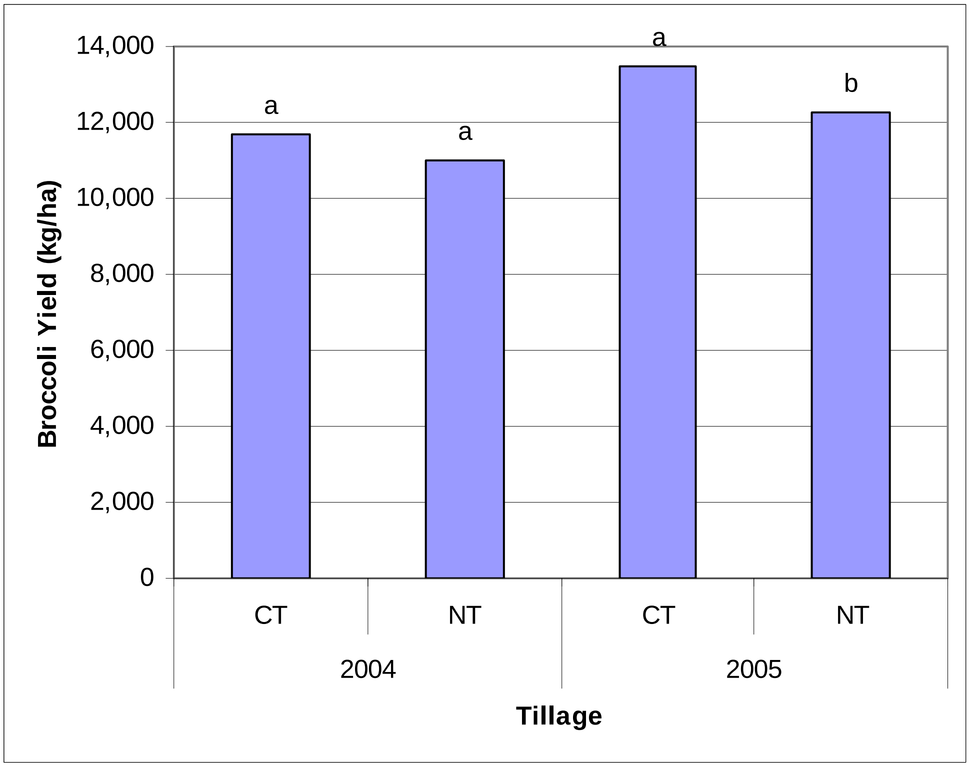

Figure 3. Effect of tillage on fall broccoli yield.
Yield data were averaged for conventional and no-tillage plots with mean separation based on analysis of variance results. Within each year, means with the same lower-case letter were not significantly different (P>0.05).

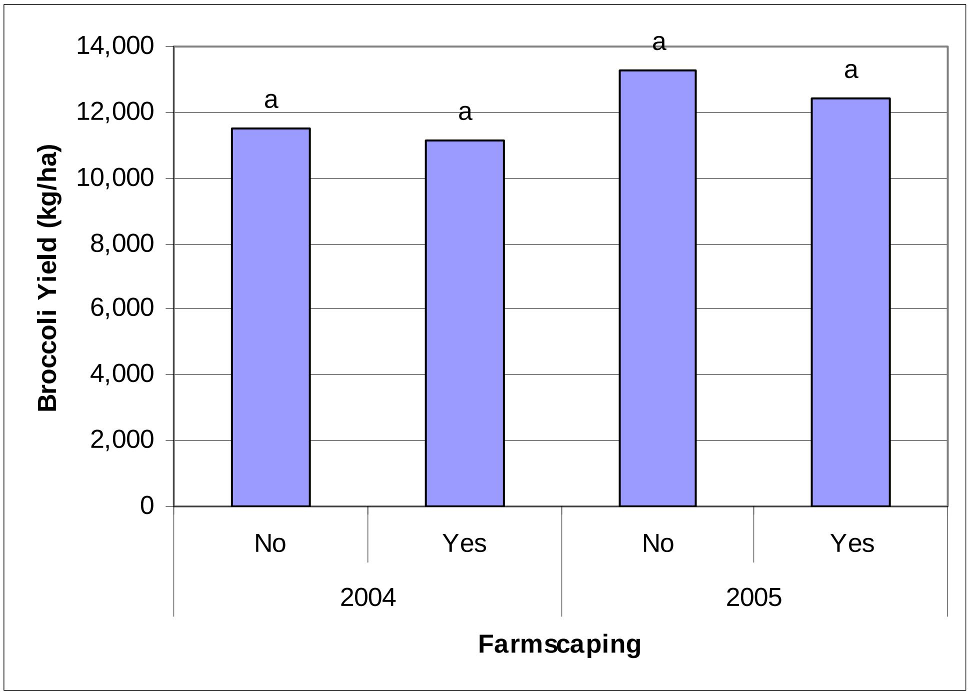

Figure 4. Effect of farmscaping on fall broccoli yield.
Yield data were averaged for plots with and without farmcaping with mean separation based on analysis of variance results. Within each year, means with the same lower-case letter were not significantly different (P>0.05).

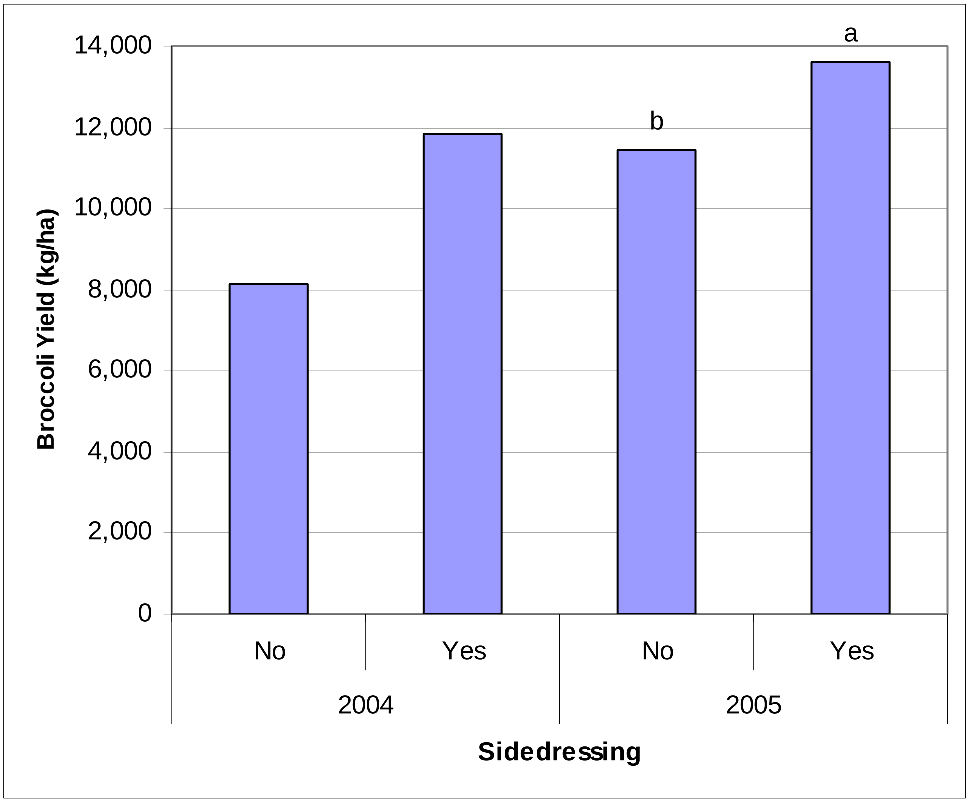

Figure 5. Effect of sidedressing nitrogen on broccoli yield.
Yield data were averaged for plots with and without N sidedressing with mean separation based on analysis of variance results. Within each year, means with the same lower-case letter were not significantly different (P>0.05). The data for 2004 were not analyzed due to harvest error.

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Appendix A

Summer 2004 - complete insect scouting data

		ICW Egg	ICW SL	ICW PSL	ICW LL	ICW PLL	ICW Pupae	ICW PP	CG CM	CG Pupae	CG A	XSCW Egg	XSCW SL	XSCW PSL	XSCW LL	XSCW PLL	XSCW Pupae	CO CM	CO Pupae
7-Jul	-	0	0	0	0	1	0	0	0	0	3	0	0	0	0	0	0	0	0
14-Jul	-	29	15	0	2	5	0	0	0	0	0	0	56	13	0	0	0	0	0
22-Jul	-	6	34	1	22	23	0	0	6	0	4	10	99	0	28	1	0	1	0
28-Jul	-	4	2	0	0	2	1	3	12	0	0	19	0	0	0	1	0	2	0
7-Jul	+	20	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14-Jul	+	26	18	0	0	8	0	0	0	0	6	64	0	3	0	0	0	0	0
22-Jul	+	11	48	0	2	18	0	0	5	0	0	56	77	0	2	0	0	2	0
28-Jul	+	0	5	0	1	0	1	1	23	0	0	0	21	0	0	1	2	0	0

		DBM SL	DBM PSL	DBM LL	DBM PLL	DBM Pupae	DBM PP	LB Egg	LB L	LB A	SP EM	SP A	Aphid	HB Egg	HB L	HB A	LW Egg	LW A
7-Jul	-	0	0	0	0	0	0	22	0	1	3	11	0	0	0	2	6	0
14-Jul	-	14	0	4	0	2	0	0	0	1	5	4	0	0	0	0	0	0
22-Jul	-	1	0	0	0	1	0	40	0	1	3	9	0	0	0	0	0	0
28-Jul	-	1	0	0	0	0	1	124	0	2	1	8	0	12	0	1	0	1
7-Jul	+	0	0	0	0	0	0	82	0	2	6	1	0	0	0	0	2	0
14-Jul	+	3	0	0	0	4	29	0	0	0	2	6	0	0	0	0	0	0
22-Jul	+	4	0	0	0	1	1	45	0	0	6	5	0	0	0	0	0	0
28-Jul	+	0	0	0	0	0	4	122	2	5	4	5	0	12	0	0	0	0

+ = Farmscaped and - = Not Farmscaped

ICW = imported cabbageworm, CG = Cotesia glomerata, XSCW = cross-striped cabbageworm, CO = Cotesia orobenae,
DBM = diamondback moth, LB = lady beetle, SP = spider, HB = harlequin bug.
SL = small larvae, PSL = parasitized small larvae, LL = large larvae, PLL = parasitized large larvae, PP = parasitized pupae,
CM = coccoon mass, A = adult, L = larvae, EM = egg mass.

Appendix B

Fall 2004 - Complete insect scouting data

		ICW Egg	ICW SL	ICW PSL	ICW LL	ICW PLL	ICW Pupae	ICW PP	CG CM	CG Pupae	CG A	XSCW Egg	XSCW SL	XSCW PSL	XSCW LL	XSCW PLL	XSCW Pupae	CO CM	CO Pupae
16-Sep	-	1	0	2	0	0	0	0	0	0	0	0	8	0	0	0	0	0	8
23-Sep	-	2	0	0	0	0	0	0	0	0	0	0	7	0	1	0	0	0	39
30-Sep	-	0	3	0	0	0	0	0	0	0	0	0	7	0	2	0	0	0	16
7-Oct	-	7	5	0	0	0	0	0	0	0	0	0	6	1	0	4	0	0	32
14-Oct	-	0	0	1	1	5	0	0	0	0	0	0	4	7	0	0	0	0	0
16-Sep	+	1	0	0	0	0	0	0	2	0	0	0	10	0	0	0	0	7	0
23-Sep	+	2	0	0	0	0	0	0	0	0	0	0	6	0	0	2	0	0	0
30-Sep	+	3	0	0	0	2	0	0	0	0	0	0	8	1	0	13	0	0	0
7-Oct	+	1	1	0	0	1	0	0	0	0	0	0	5	7	0	9	0	0	8
14-Oct	+	0	0	1	0	2	0	0	0	0	0	0	0	1	0	1	0	0	7

		DBM SL	DBM PSL	DBM LL	DBM PLL	DBM Pupae	DBM PP	LB Egg	LB L	LB A	SP EM	SP A	Aphid	HB Egg	HB L	HB A
16-Sep	-	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0
23-Sep	-	0	0	1	0	0	0	0	0	2	0	0	0	0	0	5
30-Sep	-	2	0	0	0	0	0	0	1	2	1	2	0	12	0	0
7-Oct	-	0	0	2	0	0	0	0	0	1	0	2	0	0	0	8
14-Oct	-	0	0	2	0	0	0	0	0	0	1	2	0	0	0	0
16-Sep	+	0	0	1	0	0	1	0	1	2	0	0	0	0	0	1
23-Sep	+	0	0	1	0	2	0	0	1	2	0	3	0	13	1	2
30-Sep	+	0	0	2	0	0	0	0	1	0	0	1	0	15	2	0
7-Oct	+	0	0	4	0	2	0	0	0	1	1	1	0	0	0	3
14-Oct	+	0	0	5	0	1	0	0	1	1	0	0	0	0	0	1

+ = Farmscaped and - = Not Farmscaped
ICW = imported cabbageworm, CG = Cotesia glomerata, XSCW = cross-striped cabbageworm, CO = Cotesia orobenae,
DBM = diamondback moth, LB = lady beetle, SP = spider, HB = harlequin bug.
SL = small larvae, PSL = parasitized small larvae, LL = large larvae, PLL = parasitized large larvae, PP = parasitized pupae,
CM = coccoon mass, A = adult, L = larvae, EM = egg mass.

Appendix C

Fall 2005 - Complete insect scouting data

		ICW Egg	ICW SL	ICW PSL	ICW LL	ICW PLL	ICW Pupae	ICW PP	CG CM	CG Pupae	CG A	XSCW Egg	XSCW SL	XSCW PSL	XSCW LL	XSCW PLL	XSCW Pupae	CO CM	CO Pupae
30-Sep	-	3	4	0	1	1	0	0	0	0	0	0	34	15	0	4	0	0	155
10-Oct	-	0	2	1	1	3	0	0	0	20	0	0	0	38	0	1	0	0	54
30-Sep	+	0	4	3	1	2	0	0	0	45	0	0	9	40	0	1	0	0	42
10-Oct	+	0	7	3	3	7	0	0	0	21	0	0	0	6	2	0	0	0	94

		DBM SL	DBM PSL	DBM LL	DBM PLL	DBM Pupae	DBM PP	LB Egg	LB L	LB A	SP EM	SP A	Aphid	HB Egg	HB L	HB A
30-Sep	-	0	0	0	0	1	1	0	1	0	2	4	0	11	0	9
10-Oct	-	0	4	1	1	0	0	0	0	0	0	0	0	0	0	11
30-Sep	+	2	0	0	0	1	1	0	1	0	1	0	0	20	0	25
10-Oct	+	0	0	2	0	0	0	0	0	0	0	2	0	0	0	7

+ = Farmscaped and - = Not Farmscaped

ICW = imported cabbageworm, CG = Cotesia glomerata, XSCW = cross-striped cabbageworm, CO = Cotesia orobenae,

DBM = diamondback moth, LB = lady beetle, SP = spider, HB = harlequin bug.

SL = small larvae, PSL = parasitized small larvae, LL = large larvae, PLL = parasitized large larvae, PP = parasitized pupae,

CM = coccoon mass, A = adult, L = larvae, EM = egg mass.

Vita

Gordon Brinkley Benson was born on September 29, 1964. He is the middle of three sons of Gordon and Fran Benson. He is married to Julie Gregonis and has three sons: Kellby, Jared and Tobias. He received his B.S. in Dairy Science from the California Polytechnic State University in San Luis Obispo, California where he was the 1999 Dairy Science Outstanding Senior for Academic Achievement. His work experiences in organic agriculture inspired him to take on this thesis study with Dr. Ron Morse.