Enhancing Sustainability of Organic Broccoli Production through Integration of No-till and Farmscaping

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Project Information

Abstract:

This project sought to develop an improved organic production system for broccoli and other crucifer crops by integrating high-biomass no-till (NT) systems to suppress weeds with farmscape plantings as food and habitat for beneficial insects. In 2004 and 2005, a total of four crops (two summer and two fall) and ten on-farm demonstration trials (five summer and five fall) were conducted, using in-situ high-biomass cover crop mulch and NT production systems to produce organic broccoli.

Research - High-biomass cover cropping systems are considered ideal to simultaneously build soil quality and achieve high marketable yields of organic vegetables. However, nitrogen availability and weed and pest management are often problems during transition form chemical to organic cover-cropping systems, especially with no-till. In 2004-2005, two summer and two fall broccoli (Brassica oleraceae L. Botrytis Group) crops were grown in twin rows on permanent (controlled traffic) raised beds (185-cm wide). Before transplanting broccoli, high-biomass cover crops were established in specific bed areas (zones), namely legume species on bed tops (grow zones) and grass species in the alleyways (bed shoulders and bottoms). Experimental treatments were tillage (conventional, CT; and no-till, 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) and feathermeal (44 kg N/ha). Weed growth was held below yield-limiting levels with cultivation in CT plots and by periodic spot weeding to remove pesky perennial weed species in NT. High levels of beneficial insects kept broccoli insect pests low in all plots. Although the excellent insect pest management was attributed to the farmscape plantings, pest level and crop yield were not affected by farmscaping, possibly because the distance between + and - farmscape plots was insufficient to prevent migration of beneficial insects. Broccoli yield averaged 72% higher in fall than summer, probably because cool weather conditions during broccoli head development (October) favorably impacted both head size and quality (marketability). Broccoli yield in CT plots was either equal or slightly higher than NT. Nitrogen sidedressing improved yield in all plots and particularly in NT, indicating...
that availability and/or synchrony of nitrogen was a major factor limiting broccoli yield. Lower N response in CT probably occurred because incorporating high-N legume residues in the grow zones resulted in greater N availability. Yield in both CT and NT N-sidredesed fall broccoli was excellent, averaging 11.9 t/ha in 2004 and 13.6 t/ha in 2005. 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.

Outreach - A total of seven on-farm trials with organic no till (NT) broccoli were conducted in Virginia and three in western North Carolina, during 2004-05. Mixed results illustrated several potential constraints to organic no-till brassicas, including insufficient cover crop biomass or incomplete mow-kill, heavy weed pressure, drought, and grower lack of knowledge of best crop and nutrient management practices for these crops. Supplemental trials at Virginia Tech’s Kentland Agricultural Research Farm identified soybean, sunnhemp and three species of millet as most suitable cover crops to precede NT fall broccoli (high biomass generation between June and August, and susceptible to mow-kill). Other trials clarified but did not resolve problems with insufficient mulch persistence and winter weed control in winterkilled cover crops preceding early spring vegetables.

During the two-year period from early 2004 through early 2006, the project’s outreach component reached about 450 people through presentations at winter conferences and workshops, and about 125 through a three farm field days. In addition to presenting integrated minimum-till systems for organic brassicas, outreach efforts emphasized key components that can be adopted individually to considerable benefit, including high biomass cover crops to protect and build soil quality, farmscaping for biological insect pest control, and best management practices for organic brassicas. A survey showed that participants gained useful knowledge from these events, that a majority of farmers, market gardeners, home gardeners and agricultural professionals are adopting components of these systems in their crop production or education/outreach endeavors, and that at least several growers are adopting or experimenting with organic no-till. Two Virginia farmers who hosted field trials are in the process of acquiring no-till planting aids in order to implement these systems at a larger scale on their farms.

Project Objectives:

Objectives—Our hypothesis was that by integrating farmscaping with NT systems, broccoli production can be economically feasible without application of chemical pesticides. Our goal was to demonstrate that high-biomass cover crop mulch combined with farmscaping and timely use of the microbial pathogen Bt can suppress weed and insect pests to produce a profitable organic broccoli crop. Specific objectives were to (1) develop an improved prototype system for production of organic broccoli by integrating high-residue NT cover crop mulch to suppress weeds and supply organic nitrogen with farmscape plantings to attract and sustain beneficial insects; (2) evaluate the need for application of Bt in farmscaped systems for broccoli to control insect pests; and (3) facilitate the adoption of high-biomass NT production systems and farmscaping and other education and outreach methods.

Performance targets—By December 2005, four fact sheets and a comprehensive leaflet on organic NT-farmscaping broccoli production will be available in both electronic and printed form. Within one year after completion of the project, (1) two of the five organic growers hosting on-farm demonstrations will adopt NT-farmscape systems, and (2) ten of the 200 or more growers who will attend workshops and field days will explore NT-farmscape systems for production of organic broccoli or other crops.
Introduction:

Integrated organic vegetable production systems (IOVPS) strive to achieve a higher level of ecosystem function that will increase the resilience of an agroecosystem. This “from the soil up” approach develops disease suppressive soils and nutrient cycling that can support high yields. Yield limiting factors are minimized and ecosystem function improves as soil quality is improved (Carter et al., 2004; Phelan, 2004b).

Broccoli was grown in this trial because of its 1) high economic potential, 2) high nutrient requirements, and 3) well documented pest beneficial complex. A controlled-traffic raised bed system limits compaction and allows for precision placement of nutrients in bed tops where vegetables are grown (grow zone). This provides the framework for improving soil quality through implementation of no-till practices. High biomass cover crops are grown and killed either mechanically or by freezing temperatures (winter killed). Research has shown that high biomass cover crops left as surface mulch build up soil quality at a faster rate than when mowed and incorporated (Schomberg et al., 1994). High-biomass cover crop provides ample weed control until broccoli closes canopy and nutrients. Of considerable relevance in organic systems, high-biomass organic mulch can not only increase soil quality and suppress weed growth but also affects the incidence and severity of phytopathogens and insect pests (Cardina, 1995; Gallandt et al., 1999; Hart and Jarosz, 2000; Renner, 2000). Winter killed cover crops provide substantially less mulch and nutrients than overwintering species. Proper weed control and nutrient tie-up are important issues to consider when using winter killed cover crops in organic no-till systems. Nitrogen deficiency can be minimized by using starter fertilizer and side dressing with additional N fertilizers.

Although not the aim of the original study, N side dressing revealed the need to address nitrogen synchronization in organic systems. The problems associated with nutrient availability (Walz, 1999; Phatak et al., 2002) result in low yields in organic production, increased pest and disease problems, and poor produce quality. Poor N availability, synchronization and nutrient imbalances are common when transitioning to organic production (Haraldsen et al., 1999) and constitute substantial hurdles for fledgling organic growers. 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 (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). 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, 2004a). 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).

Known pests/natural enemies for broccoli are imported cabbage worm (Pieris rapae)/Cotesia glomerata, cross-striped cabbage worm (Evergestis rimosalis (Guenee))/Cotesia orobenae, and diamondback moth (Plutella xylostella)/Diadegma insulare. 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 thurengensis var. Kurstaki (Bt) in case resistance renders this pest management tool ineffective.

**Farmscaping** - The failure of natural enemies in vegetable crops is due primarily to the effects of disturbance (e.g. tillage and pesticides) and a lack of adequate food resources (e.g. pollen and nectar), and insufficient overwintering habitat (Rabb et al., 1976; Powell, 1986; Dutcher, 1993; Landis and Menalled, 1998). The simplification of agroecosystems to monocultures combined with the development of agricultural land and natural landscapes has limited undisturbed natural landscapes to “remnant” patches. Generalist natural enemy populations are no longer supported by the natural landscapes that once surrounded agricultural landscapes. Furthermore, conditions that combine monocultures and intensive disturbance regimes favor the rapid colonization and population growth by pests while hindering the ability of natural enemies 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. 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; Pickett and Bugg, 1998).

Providing food resources by farmscaping increases parasitoid fecundity, longevity, survival and levels of parasitism (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) as well as influences the foraging behavior of searching parasitoids (Lewis and Takasu, 1990; Wäckers and Swaans, 1993). Wackers (1993) compared the response of starved and satiated parasitoids to the odors produced by flowers and host-infected leaves. Food deprived individuals chose flower odors, while sugar-fed individuals preferred host-associated odors. Thus, wither or not food is available for adult parasitoids in the areas where their hosts are located may determine, in part, tenure time and levels of parasitism and thus their efficiency as biological control agents (Barbosa and Benrey, 1998).

This research aimed to show that growing high-biomass cover crops using no-till planting techniques and little or no cultivation would effect similar changes in natural enemy populations as those observed by other researchers. The resulting species richness and abundance of natural enemies would be similar to those observed in less disturbed, perennial agroecosystems (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).

**Literature Cited:**


Symposia in Agricultural Research, Beltsville, MD.
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Cooperators

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  Organic Farmer
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- **Anthony Flaccavento**
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Research

Materials and methods:

Research - Field experiments were conducted at the Virginia Polytechnic Institute and State University’s Kentland Agricultural Research Farm, near Blacksburg, Virginia. The soil was a Hayter loam (fine-loamy, mixed, mesic, Ultic Hapludalf) with a pH varying from 6.5 to 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.

As with cover crops, germination is much higher when farmscape species are drilled in rows. This facilitates cultivation with a hoe and minimizes hand weeding while achieving significantly 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.

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. 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 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.

What comprised the Virginia Tech farmscaping plots - Summer broccoli - Farmscaping beds (90-112 cm wide at the top) were planted with seven rows per bed on June 3, 2004 (broccoli transplanted on June 16, 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 (90-112 cm wide at the top) were planted with seven rows per bed on June 20, 2004 except for the buckwheat which was sown on July 20, 2004 (broccoli was transplanted on August 20, 2004) 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 (Table 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 four beds per plot), using a NT drill. Lime was not needed in the experimental plots and chicken manure at a rate of 6 t ha-1 was applied before the cover crop was planted for the summer '04 broccoli crop. Broccoli transplants were grown in plug trays 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, the cover crops were killed mechanically or rolled (cover crops were winter killed for summer 2005 broccoli). For NT fall broccoli subplots, the soybean and foxtail millet cover crops were killed mechanically prior to transplanting broccoli, using a flail mover, 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 (5-5-3 at a rate of 896 kg ha-1) and drip tubing in-row and sets the transplants in one pass with minimum disturbance of surface mulch(Morse et al., 1993).

All plots were monitored regularly for incidence of disease and appropriate organic sprays were applied as necessary. Likewise, all plots were irrigated as needed and organic fertilizer (pelleted at planting and liquid soluble or sidedressed fertilizer during the growing season) was applied to ensure optimum plant growth and development. Bt was applied as needed to control broccoli insect pests. Data collected included (1) cover crop biomass, (2) broccoli yield, and (3) incidence of beneficial and harmful insects at weekly intervals at critical times leading up to broccoli head formation.

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 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 plants by scouting for pest levels and for signs of natural enemy activity (ladybug eggs/larvae/adults, parasite cocoons, parasitized caterpillars, partially eaten pest eggs, pupal skins or cast skins of beneficials). The action threshold for releasing beneficial insects occurs when pest levels rise above their specific action threshold (e.g. four small imported cabbageworm caterpillars/plant), coupled with a drop below 25% of sampled plants showing signs of beneficial insect activity.

Nitrogen sidedressing and fertigation - Sidedressing was applied 2-3 weeks after transplanting, as a mixture of sodium nitrate (22 kg 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 while all summer 2005 plots were sidedressed. In summer 2004 supplement nitrogen was applied by fertigation in 5 equal applications (Table 1) of sodium nitrate (totaling 22.4 kg N ha-1) and liquid fish and kelp (totaling 2.8 kg ha-1). In fall 2004 liquid fish and kelp (2.25 kg N ha-1) was fertigated in four equal applications and in summer 2005 soluble fish powder (0.81 kg N ha-1) and soluble kelp (0.06 kg N ha-1) was fertigated in two applications primarily for micronutrients and growth stimulants rather than supplemental nitrogen which was supplied by sidedressing. In fall 2005 sodium nitrate (3.0 kg N ha-1), fish powder (0.5 kg N ha-1), soluble kelp (0.04 kg N ha-1) in three equal applications primarily for micronutrients and growth stimulants but also a small amount of supplemental nitrogen.

Outreach - Three Virginia farms participated in the project during its first year, and planted cover crops in 2003 for no-till broccoli planting in spring 2004. Grazing by deer, heavy weed pressure and/or poor soil conditions compromised the cover crop and/or broccoli so severely that the trials could not be completed, and the farms withdrew from the project.

Three new farms, two in the Appalachian region and one in the Tidewater region, were recruited to conduct field trials in no-till production of broccoli and other brassicas during the 2004 and 2005 growing seasons. An additional trial was conducted at the outreach coordinator’s homestead garden. Soil conditions, cover crops, vegetable crops, planting and harvest dates for these four sites are shown in Table 1.

For spring brassicas, non-winter-hardy cover crops were planted in July or August of 2004, and grown until killed by frost, forming an in situ mulch. In one trial, the cover crop was planted in May, mowed in July, rolled in August, and allowed to regrow until frost. Vegetables were transplanted early the next spring, with plants set directly through the cover crop residue (NT) or after residues were rototilled into the top 4 to 5 inches of the soil (CT).

For fall broccoli, summer cover crops of foxtail millet and cowpea (cv. ‘Iron-Clay’) were planted in May or June, and either tilled in (CT) or managed no-till by mowing and/or rolling in August (NT), just prior to planting fall broccoli.

In five trials, farmscape plantings were established between the NT and CT plots to provide habitat for natural enemies of Imported Cabbageworm (ICW), aphids and other brassica pests. The other two trials were conducted either within 30 ft of an established farmscape strip (Trial 2 at Dayspring Farm) or a weedy field border (homestead garden) that provided habitat. Farmscape plantings consisted of a 3 ft wide strip seeded to Beneficial BlendTM (Rincon Vitova), plus additional flowering plants known to support beneficial insects, such as buckwheat, sunflower, coriander, kenaf, parsnip, carrot or Jerusalem artichoke.

 Marketable yields of broccoli, cauliflower and cabbage were recorded. In addition,
pest and beneficial insect counts were done at least once for each of the fall broccoli trials. Ten plants from each treatment were examined, and numbers of eggs and larvae of ICW, aphids, ladybugs, spiders and other pest and beneficial arthropods were recorded.

The original plan included weekly insect counts, differential insect pest control treatments (Bt applications), targeted releases of beneficial insects on an as-needed basis, and an economic analysis of inputs and proceeds for the two treatments. However, this protocol was far too complex and time consuming for busy farmers to complete, and the procedure was simplified to marketable yield, mean head size, and Bt application on an as-needed basis (generally, 1 application for fall crops, and 0 or 1 for spring crops).

Research results and discussion:

Research - Cover crops - Cover crops for this study provided sufficient biomass for weed suppression and considerable N for crop growth. The exception was the winter-killed sorghum-sudangrass/sunn hemp biculture grown for the summer 2005 broccoli crop (Table 2). Using Table 3 to assess the probability of weed suppression, those factors related to mulch quantity were all in the high range and quality factors were in the moderate to high range except for several factors from the winter-killed cover which were in the low to moderate range. Weeds were not a limiting factor. With the exception of occasional spot weeding due to perennial weed problems, hand weeding was necessary only in the winter-killed cover crops in summer 2005.

Summer broccoli - Broccoli yields for the 2004 summer plantings were not significantly different, while the CT yield was higher than NT in summer 2005 (Figure 1). From summer 2004 to summer 2005 soil quality had probably increased; however there was a significant decrease in nutrient 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 hurdle 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 are controlling the main broccoli pests.

Fall Broccoli - Yields were not significantly different with in 2004, while CT yield was greater than NT in 2005 (Figure 3). Yield increase from fall 2004 to fall 2005 is attributed to the combination of an increase in soil quality and a significant 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. This difference from CT to NT is due to the increase in nutrient availability from the mowed and incorporated cover crops. Using Knott’s (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. Again there was a lack of significance between the + and – FS plots. In the summer crops there was a slight increase in yield in the + FS plots over the – FM plots (~110 Kg ha−1 –Figure 2) while in the fall crops there was a decrease in yield in the +FS plots (~620 Kg ha−1 –Figure 4). The difference in the fall is most likely due to shading by the tall farmscape plants (2m tall) in the fall FS plots.

Nitrogen - The summer 2004 crop sidedressing showed that nitrogen (N) was a major yield limiting factor and that fertigating with a combination of fish, kelp and sodium nitrate over a number of weeks was not sufficient for high broccoli 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 on the comparison between SD and NSD. 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 and nitrogen were highly significant (Figure 5). Yield increase due 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 transition 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 6.6% 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 = .0013) in fall ’05. 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.

Outreach - Cover crops in the season prior to spring brassicas generated two to four tons dry biomass per acre (data not shown), but by the following spring, their winterkilled residues provided less coverage and weed suppression than expected. Significant weed cover and bare soil (empty niche for additional weed growth) at the time of vegetable planting increased the likelihood of significant weed competition in the NT treatment (Table 2). Residues of the frost-tender summer were partly decomposed during the five to six months between frost-kill and spring planting. At Waterbear Farm, the semihardy oats, bell beans and peas grew through November before frost-kill, but deer consumed legume residues and oat seed heads, resulting in poor mulch coverage.

At Dayspring Farm, broccoli and cabbage grew more slowly in NT than in CT during the first five weeks after planting, possibly because of lower soil temperatures and/or slower mineralization of soil organic nitrogen (N). In trial 1, where weed pressure was relatively light, broccoli plant diameter was about 10% less in NT than CT at 35 days after planting (DAP), but yields in the two treatments were similar (Table 2). In trial 2, high weed pressure in the NT treatment significantly depressed
plant growth (plant diameter 30% lower than in CT), and cut crop yield by half. Surprisingly, NT cabbage recovered from the early-season growth deficit to outyield CT cabbage in this trial.

At Waterbear Farm, diligent early-season weeding reduced weed impact on the broccoli, and the CT and NT treatments had similar broccoli yields and similar weed levels at time of harvest. The grower attributed the relatively low yields to cool spring weather and inadequate levels of available soil N.

At the homestead garden, the broccoli crop failed due to late planting of low-quality starts. One hand weeding followed by an application of supplemental mulch minimized weed competition against the other crops, but significant slug damaged occurred, especially in the NT treatment. Cauliflower yields were lower in NT than CT, but cabbage yield were similar in the two treatments.

With the exception of slugs at one site, pest pressures were light (below economic thresholds), and insect counts were not taken.

Cabbage may have performed better in NT than broccoli and cauliflower because its edible portion matured two to three weeks later, during hotter weather. Similar per-head weights in CT and NT suggest that the higher yield in NT resulted from a higher percentage of plants producing marketable heads. Early in the season, the cooler, wetter conditions in the NT treatment might be expected to retard soil N mineralization and head growth in the broccoli and cauliflower, whereas the mulch effect of NT might become advantageous for cabbage maturing in summer conditions.

In 2004, foxtail millet + cowpea yielded substantial mulch for NT broccoli planting; however the NT treatment tended to depress yield and head size, especially at Dayspring Farm, where caterpillar pest pressure was heavy (Table 3). Significant regrowth of mowed cowpea was observed at both sites, and may have contributed to yield depression in broccoli. In 2005, the millet + cowpea cover crop established poorly and became infested with the annual weed horseweed. It is likely that the cover crop was planted too early (April 27) when the soil was still too cool for these heat-loving crops. When the weedy cover crop was mowed in July, it formed a thin mulch, but little regrowth of either cowpea or weeds took place. Hot dry conditions during September and October, combined with heavy caterpillar pest pressure, resulted in very small heads, high plant mortality especially in CT, and low yields.

The limited insect data showed trends toward larger numbers of aphids and eggs of imported cabbageworm (ICW) in CT than in NT. However, ICW larvae counts tended to be higher in NT, suggesting lower egg/larval mortality in NT. At the Flaccavento farm, harlequin bug occurred in NT but not CT broccoli. At Dayspring, percent defoliation by insect pests was higher in NT than CT in 2004, but similar in the two treatments in 2005. In 2004, the combination of competition or allelopathy from regrowing cowpea and heavy pest pressure may have worked together to cause the sharp reduction in NT broccoli yield. The farmscape plantings apparently did not support sufficient beneficial populations to provide effective pest control, possibly because the diversity of farmscape species that were successfully established was not sufficient to provide season-long nectar and pollen. At the Virginia Tech Kentland Agricultural Research Farm, high quality farmscape plantings have provided consistent and excellent pest control in brassicas.

Overall, the farm field trials gave NT broccoli yields about 24% lower than the CT yields, whereas spring planted cabbage yielded 41% more in NT than CT. The trials also illustrated several challenges in organic no till brassica production:

• cooler, wetter soil and sometimes slugs under residues in spring brassicas
• N limitation for NT spring broccoli or cauliflower planted into cool soil under mulch
• inadequate mulch persistence and weed suppression from winterkilled cover crop residues
• cowpea regrowth competing against fall NT broccoli
• unfavorable (hot, dry) conditions and heavy pest pressure on fall broccoli in the Tidewater
• small-scale producers need effective, affordable equipment and practical methodology for planting and managing high biomass cover crops for NT vegetable production
• farmers need reliable sources of high quality organic brassica starts, and/or reliable and affordable potting mixes and cultural practices for producing them.

These challenges illustrated necessary new directions for our research and outreach work, some of which were pursued during the 2005 growing season, and some of which are discussed under the “Areas Needing Additional Study” section.

Overall, the outreach on-farm trials in North Carolina were beset with unavoidable difficulties, including extreme weather conditions (Hurricane Ivan) and deer damage to both cover crop and broccoli plants. However, three trials were salvaged enough to obtain data. In two of the three trials, broccoli yield and beneficial insect levels were highest in NT plots. In the third trial, higher yields in the CT plots were attributed to heavy incidence of fescue regrowth and lack of sufficient available nitrogen in the no-till plots.

Participation Summary

Educational & Outreach Activities

PARTICIPATION SUMMARY:

Education/outreach description:

Outreach - Outreach/increased grower awareness—Many organic growers in Virginia, North Carolina and elsewhere have expressed interest in our project. Examples of outreach activities by the project coordinator and outreach participants include:

Presentations were given by Ron Morse on organic NT vegetable production, at the annual conferences of (1) Maryland Organic Food and Farming Association (MOFFA) (January 8, 2005); (2) Southern Sustainable Agriculture Workers Group (SSAWG) (January 20-23, 2005); and (3) Richmond Area Vegetable and Fruit Program (February 1, 2005). Presentations were given by Mark Schonbeck on cover cropping systems for organic NT systems, at the annual conferences of (1) Southern Sustainable Agriculture Workers Group (SSAWG) (January 20-23, 2005); (2) Appalachian Sustainable Development (ASD) (February 5, 2005); and (3) Virginia Association for Biological Farming (VABF) (February 19, 2005). All presentations were well attended, totaling just under 300 participants.

A Grant was awarded to Mark Schonbeck and Ron Morse by the Organic Farming Research foundation (OFRF) to conduct supplemental experiments comparing cover crops as winter-killed mulch for spring organic NT broccoli and other crops (Award amount = $8,600).

Ron Morse has initiated a project to develop and evaluate NT planting aids (NTPAs) for small-scale farmers. This project is being undertaken to address a critical dilemma—small-scale organic farmers have the desire and need to adopt
NT cropping systems; however, they lack the equipment and experience to make it succeed.

Information sheets were written and duplicated on (1) Farmscaping Techniques for Managing Insect Pests; (2) Selection of Cover Crops for Organic No-till Vegetable Production; (3) Integration of No-till Systems and Farmscaping for Production of Organic Broccoli; (4) Proactive Weed Management for Production of Organic Vegetables—Emphasizing Cover-Cropped No-till Systems; (5) Preliminary Evaluation of Cover Crops for Organic No-till Applications in Virginia and North Carolina; (6) Impacts of High-Residue No-till Systems on Soil Quality; (7) Developing Low-cost Equipment and Techniques for No-till Cover Cropping Systems on Small Farms.

Richard McDonald updated a organic transition website/manual for burley tobacco growers that is used to train growers and extension personnel. The website features organic broccoli production techniques, soil health basics, broccoli enterprise crop budgets, farmscaping plants for all four seasons, and organic pest management. The website is free and open to anyone (www.drmcbug.com). Richard McDonald assisted transitioning tobacco growers who desire to explore organic broccoli production. In demonstration plots at the Mast store, he showed that incorporating cover crops doubled broccoli yield from 3,500 to 7,000 lb/acre. He provided BIPM expertise to the New River Organic Growers Association (NROG) to further their transition to organic broccoli production, as specified in the grant proposal. He also assisted the NROG members to become certified.

Richard McDonald conducted educational and demonstration projects for organic farmers. He helped establish NT/farmscaped plots for 2005 plantings at two sites. He assisted Lily Patch Farms in producing certified organic broccoli transplants. Richard presented eight farmscape training programs in which there were over 400 attendees.

Information sheets developed during 2004-05 were updated and modified in winter 2005-06 to incorporate additional project findings and to attempt to address the outreach needs identified above. Survey feedback indicates that revisions may have improved the usefulness and accessibility of the information provided. The following information sheets were distributed at presentations in January-February 2006:

Cover Crops for All Seasons - Expanding the cover crop tool box for organic vegetable producers, by Mark Schonbeck and Ron Morse, 4 pp.
Summer Annual Cover Crops for Organic No-Till Fall Brassicas - results of a cover crop variety trial conducted near Blacksburg, VA in 2005, by Mark Schonbeck and Ron Morse, 4 pp.
Late Summer and Fall Cover Crops for Early Spring Vegetables - a summary of field trials in 2004 and 2005, by Mark Schonbeck and Ron Morse, 4 pp.
Using a Manually-Pushed Garden Seeder for Precision Cover Crop Plantings on the Small Farm, by Mark Schonbeck and Ron Morse, 2 pp.

Semiannual updates on the project have been published in The Virginia Biological Farmer, the quarterly newsletter of Virginia Association for Biological Farming. The most recent articles, entitled Cowpeas and Relatives: a Valuable and Versatile Genus of Legumes, and Research Update - Organic Minimum-Till Vegetables, both by Mark Schonbeck, appeared on pages 8-10 of Volume 29 No. 1 (First Quarter
2006) of The Virginia Biological Farmer. In addition, a 2000-word article on organic no-till vegetable production was published in spring of 2004 on the New Farm website (www.newfarm.org), which has elicited several telephone and e-mail inquiries about these production systems from producers and agricultural professionals around the nation and in southeastern Canada.

One additional significant outcome of the project is that two of our Virginia farmer cooperators – Richard Ursomarso of Waterbear Organic Farms, and Charlie Maloney of Dayspring Farm - have become sufficiently interested in implementing no-till methodology on their farms that they plan to acquire no-till planting aids at the beginning of the 2006 season. Charlie has realized substantial yield increases in summer vegetables with no-till cover crop management on his warm, sandy, fast-drying soils. Richard is particularly interested in no-till cover crop management for soil conservation and soil improvement in his sloping fields.

Project Outcomes

Project outcomes:

Research—Research data on integrating organic no-till and farmscaping were positive and we are very optimistic regarding future impacts leading to more sustainable and profitable methods of organic production of broccoli and other crops. Our research shows that zone establishment of high-biomass cover crops on permanent raised beds, farmscaping, and N sidedressing are an effective combination for producing organic broccoli. Over time, growers and agricultural professionals will become more knowledgeable and capable of implementing these recommended organic best-management practices for production of broccoli and many other vegetable and agronomic row crops. We also anticipate that a major impact of our studies will be development of NT equipment and associated technology for small (1/2-2 ha) organic farms. This equipment will include cost-effective light-weight roller crimpers for killing high-biomass cover crops and NT planting aids to facilitate plant establishment into thick dead cover crop mulch.

Outreach—Results from ten on-farm trials conducted on organic farms in Virginia and North Carolina were inconsistent, ranging from very successful to complete failures because of extreme weather conditions and/or lack of grower-participant know how and available equipment. However, good NT broccoli yields were always achieved whenever high-biomass cover crops were properly grown and managed, and recommended growth inputs (nutrients and water) were applied.

In the process of conducting on-farm trials and giving presentations to growers, we encountered the following constraints to the successful adoption of this integrated, state-of-the-art production system:

• Excellent weed control is a prerequisite for successful no till without chemical herbicides, and weed management is often the most serious challenge for all organic producers. The presence of tall fescue (as in recently-plowed pasture), noxious perennial weeds like nutsedge, or large seed banks of annual weeds can lead to poor yields or crop failures in organic brassicas planted no till into cover crop mulches.
• In practice, continuous no-till is not feasible for organic producers, as perennial weeds eventually increase, requiring some tillage. Normally, at least one tillage operation is required annually, just before planting the cover crop. In some cases, the cover crop residue may need to be tilled in shallowly because of heavy weed pressure or inadequate mulch cover. These systems can still confer substantial
benefits in soil quality and net returns, and are more aptly called organic minimum tillage. We are adopting this terminology in our outreach materials and presentations.

• An information gap exists regarding best management practices for organic brassica production, particularly N nutrition. Broccoli requires considerable N within a short period of time, and low broccoli yields on many organic farms may be related to inadequate N or poor synchrony between soil N mineralization and crop N needs. Reliable and affordable irrigation (preferably drip) is also essential in the event of drought. These constraints must be addressed within the context of cover crop based organic no-till production systems.

• Small-scale producers need access to simple, affordable equipment for no till cover crop management and vegetable planting.

• Many growers in our region possess only a rudimentary knowledge of cover cropping, including the range of cover crop species available, their uses and benefits, effective planting and establishment practices, and strategies to maximize cover crop benefits including erosion control and organic matter inputs to the soil.

• Many growers understand the concept of providing habitat for natural enemies of vegetable pests, but can benefit from more in-depth information on farmscaping to provide effective, season-long, farm-wide habitat. Highly successful farmscaping at Kentland, where vegetable crops required at most one pesticide (Bt) application, impressed many participants with the power of this sustainable technology.

Farmer Adoption

Outreach - Participant address lists from the presentations at the Southern Sustainable Agriculture Working Group conference (January 2005) and the two farm field days in 2005 were used to distribute a survey to 90 participants to assess potential impact of our project on vegetable production practices in our region. In addition, participants in the November 2005 Small Farm Family Conference were surveyed by the conference organizers, and participants in our session at the 2006 Virginia Biological Farming Conference received our survey.

Despite the hurdles to full implementation of these systems on working organic farms, interest in our project and in implementation of key components remains high. Of the 39 survey responses from participants in the three 2005 events, 12 are farmers or market gardeners, 10 are Extension personnel, consultants, educators and other agricultural professionals, and 17 are home gardeners. Thirty-three respondents (85%) indicated that their knowledge and understanding of cover crops had been enhanced “considerably” or “a great deal” as a result of attending the event. Similar numbers reported considerably or greatly enhanced understanding of farmscaping (33) and no till planting and management (32). Twenty one respondents (54%) reported enhanced knowledge about small-scale no-till equipment, and 17 (44%) for best management practices for organic brassicas. On a scale of 0 (poor) to 4 (excellent), respondents rated oral presentations and visual aids at an average of 3.4, field demonstrations at 3.6, and written materials (information sheets) at 3.3.

Of the 12 farmers and market gardeners, four reported changing their production practices “considerably” or “a great deal” as a result of attending the event, and five reported changing practices “somewhat.” Three are in the process of adopting organic no-till practices, four plan to experiment with no-till in the near future, and one reported successfully phasing out of methyl bromide fumigation through the use of soil building cover crops, including brassica cover crops as a “biofumigant.” Of the 10 agricultural professionals and educators, five are changing the content or approach of their educational efforts “considerably” or “a great deal,” and two are changing “somewhat” as a result of attending these events. Four plan to promote
cover crop based organic no-till planting as a viable production strategy. A majority of both home gardeners and farmers reported adopting or planning to adopt cover crop and/or farmscaping components into their production systems.

In the Small Farm Family Conference survey, 74% of respondents who had attended our workshop indicated that their knowledge of organic no till vegetable production was “very improved” and the remaining 26% indicated that their understanding was “improved.” A clear majority of the 13 survey respondents from the 2006 VA Biological Farming conference reported “considerably” or “greatly” enhanced understanding of cover cropping (10), no till planting and management (10) and best management practices for brassicas (9). The figures were lower for farmscaping (4) and small scale equipment (3) which were not as thoroughly covered in this short (1 hour) workshop. The quality of the session was rated highly: 3.5 for oral presentation, 3.7 for visual aids and 3.8 for written materials. All five of the agricultural professionals who responded indicated their intention to incorporate some aspects of the material presented into their education and outreach efforts. All three farmers and four of the five home gardeners plan to modify their practices in some ways based on what they learned.

Recommendations:

Areas needing additional study

Based on project findings to date, the following topics merit additional study:

• Given uneven results with winterkilled cover crop residues for no till spring brassica plantings, what are optimum management practices for minimum till spring vegetables planted after winterkilled cover crops? Options include shallow incorporation of residues over the entire bed or field, deeper non-inversion tillage (chisel plow or reciprocating spader), and strip tillage (shallow or deep/noninversion) in crop rows or “grow zones” only.

• Best management practices for organic spring and fall broccoli, especially regarding N nutrition, synchrony of soil N availability with crop uptake needs, cover crop selection and management to optimize soil N mineralization, and organic N fertilizer sidedressing. We have applied for additional funding to explore the soil chemical and biological dynamics governing crop nutrient availability in conventional till and minimum till organic vegetable agroecosystems.

• Cover crop zone planting – sowing the legume in the “grow zone” and the grass between rows or beds – concentrating legume N in crop rows and persistent grass mulch and weed suppression between rows. A number of zone-planted cover crop trials were planted at Kentland in 2005, to be followed by no-till or reduced-till vegetable planting in 2006.

• Further evaluation of cover crops that might be best suited for no-till spring or fall brassica production. In particular, we plan to evaluate proso millet, pearl millet and sunnhemp as summer cover crops before fall broccoli. For spring broccoli, we will also evaluate lablab bean in the “grow zone” as an allelopathic, low-residue cover crop to provide a clean seedbed by the next spring.

Based on feedback received through the outreach program, we are taking the following steps to improve dissemination of this approach to brassica production:

• Develop and make available to small scale producers a series of no-till planting aids. These low-cost, tractor-drawn implements slice through cover crop residues and prepare a narrow (2-inch) but deep (6-8 inch) “slot” of soil for transplanting or direct seeding large seeds or seed potatoes. Planting aids will be provided to two participating growers for the 2006 season.

• Focus initial education and outreach on key components of the system: best cover
cropping and weed management practices, farmscaping for season-long beneficial habitat, and best nutrient and crop management practices for organic brassicas. Only when these are in place can no-till cover crop management and vegetable planting be successfully implemented.

- Expand the “cover crop toolbox” – identify and disseminate practical information on additional cover crop species or varieties that are not yet widely in use as cover crops, but are available, affordable, and well suited to no till brassica production systems.
- Expand the number of Extension and NRCS personnel and other agricultural professionals in our region who are familiar and comfortable with organic minimum-till vegetable production systems and their key components – cover crops, weed control, farmscaping, nutrient management and scale-appropriate equipment. We have applied for additional funding to carry out a professional development training program intended to reach 30 professionals in our region during 2006-07.