ORGANIC FARMING RESEARCH FOUNDATION

Project report submitted to the Organic Farming Research Foundation:

Project Title:

Evaluation of Frost-Killed Cover Crop Mulches for Organic No-Till Production of Spring Vegetables on Small Farms

FINAL PROJECT REPORT

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Evaluation of Frost-Killed Cover Crop Mulches for Organic No-Till Production of Spring Vegetables on Small Farms

A Final Report to the Organic Farming Research Foundation on research conducted between July 2004 and June 2006.

Mark Schonbeck
October 1, 2006

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The research project covered in this report is part of a larger research, demonstration and outreach program, directed by Dr. Ron Morse of Virginia Tech, on sustainable organic vegetable production systems for the southeastern United States. This program integrates cover crop based minimum-tillage systems, farmscaping for biological insect management, and nutrient management for organic vegetable crops.

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  - *Late Summer and Fall Cover Crops for Early Spring Vegetables*, 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.

1. Project Summary

Cover cropping replenishes soil organic matter and is a vital practice in sustainable organic production of annual vegetables and row crops. Winter annual cover crops like cereal rye and hairy vetch are widely used and have been managed successfully by mowing or rolling for no till planting of warm season vegetable crops. However, their life cycle is less compatible with production schedules for early spring vegetables. Our project explored the use of non-winter hardy cover crops to generate an *in situ* mulch of winterkilled cover crop residues for no-till planting of early spring vegetables, including brassicas, lettuce, spinach, pea and onion.

July plantings of summer cover crops including sorghum-sudangrass, pearl millet, forage soybean and sunnhemp generated up to 4 tons/ac aboveground biomass before frost. Cowpea and lablab bean yielded less biomass, yet provided significant weed suppression. Foxtail, Japanese and proso millets failed to yield substantial biomass when planted after the summer solstice, possibly reflecting a seasonal daylength response. August plantings of cool season crops including oat, bell bean, field pea, purple vetch and radish gave lower yields (~2 tons/ac), and sometimes failed because of hot dry weather after planting. High biomass summer cover crops accumulated more than 100 lb N per acre, but tissue N concentration was usually too low for much of this N to be released to the following crop.

Generally, winterkilled cover crops residues no longer covered the ground completely by the following March, and significant early spring weed growth was observed at this time in most treatments. Notably, lablab bean and radish residues decomposed quickly, yet fewer winter weeds grew after these cover crops, leaving considerable bare soil area by March. The possibility role of allelopathy in these cover crops merits further investigation.

Yield responses of vegetables to no-till planting after winterkilled cover crops (NT), compared to planting after residues were tilled in 4-6 inches deep (CT) varied widely. Responses of transplanted brassicas to NT varied from a 50% yield reduction to a 32% increase. Direct-seeded spinach emerged better in NT but subsequently showed lower mortality and faster growth in tilled treatments. NT slightly depressed yields of transplanted lettuce, had little effect on yield of onion grown from sets, and elicited a 55% increase in the yield of English shell peas in one trial. The NT treatment entailed significantly more labor for vegetable planting and weed control, sometimes retarded early growth of vegetable crops, and appeared to increase the incidence of seedling diseases (damping off) and/or slug damage in some trials.

Shallow incorporation (2 inches) of winter killed residues (ST) showed promise as a strategy for managing winterkilled cover crops for early spring vegetables, combining reduced soil disturbance with good yields and weed control. Lettuce, cabbage and broccoli performed equally well in ST and CT, whereas spinach and onions did better in ST than CT.

Spinach gave good yields after radish cover crops, much lower yields after cool season grain + legume bicultures, and was a crop failure after summer cover crops. Lettuce yields were higher after cool season grass + legume cover crops than after either summer cover crops or radishes. Cabbage yielded better after cool season grass + legume covers or pearl millet + sunnhemp than after other summer cover crops.

Outreach activities included farm field days for producers and for Extension and NRCS personnel and other agricultural professionals, presentations at winter conferences, and information sheets. Two trials have been planted at our main site to further evaluate possible allelopathy of radish and lablab bean, cover crop-vegetable compatibility and ST and NT residue management for early spring vegetable production.

2. Introduction

Cover crops can prevent soil erosion, protect and improve soil structure, add organic matter, increase nutrient availability, and harbor beneficial insects, and thus play an essential role in sustainable annual cropping systems [23]. Cover crops suppress weeds by direct competition, and sometimes by *allelopathy*, in which natural substances given off by the cover crop or its decaying residues suppress weed emergence and early growth. However, some of these benefits may be lost in the common practice of tilling the cover crop into the soil, allowing it to break down for several weeks, then tilling again to prepare a seedbed for the cash crop. Tillage can degrade soil structure and organic matter, and may stimulate weed seed germination. The waiting period after cover crop incorporation leaves the soil vulnerable to wind and water erosion, crusting and nutrient leaching. Since the early 1970s, an increasing number of conventional farmers have adopted no-till systems for killing mature winter annual cover crops and planting cash crops without delay. Although these systems normally entail the use of a burndown herbicide to kill the cover crop, they can confer several advantages:

reduced soil disturbance, giving better soil structure;
longer cover crop growing period, yielding greater organic inputs to the soil;
no bare soil period between cover and cash crops, preventing erosion;
reduced germination of annual weed seeds; and
suppression of weed growth by cover crop residues.

Organic farmers who do not use synthetic herbicides have struggled for decades to manage weeds effectively in annual vegetable and row crop without degrading the soil through repeated tillage and cultivation. Over the past 25 years, innovative growers and researchers have sought to adapt the no-till approach for organic production by killing the cover crop mechanically. Winter rye, hairy vetch, crimson clover and some other winter annual cover crops can be killed by mowing, undercutting, or roll-crimping after they reach the full bloom stage. Tomatoes, squash and other warm season vegetables have performed well when planted no-till into mechanically killed cover crops in late spring, sometimes outyielding crops grown in conventionally tilled or plastic mulched systems [1, 6, 10].

One challenge for smaller scale growers working with limited resources is the capital outlay required for a flail mower, roller-crimper or undercutter for managing the cover crop, and no-till vegetable planters. In response to these challenges, our project team is working to develop affordable equipment and simple techniques to adapt these systems for small-scale farms and market gardens. Dr. Ron Morse at Virginia Tech is developing low-cost no-till planting aids (NTPA) to prepare crop rows for planting. The NTPA consists of a heavy coulter to slice through cover crop residues, followed by a shank to loosen a narrow (2-3 inch) swath of soil to a depth of 5 to 8 inches, and optionally, a wavy coulter to create a finer tilth. Vegetable transplants or large seeds can then be planted manually or with standard equipment.

Success with summer vegetables planted no-till into mowed or rolled winter cover crops has stimulated interest in developing similar systems for vegetable crops planted at other times of the year. For example, some warm-season cover crops like forage soybean and foxtail millet can be planted after the spring frost date and mow-killed before planting late snap beans or cucumbers, or fall greens and brassicas. Others, such as cowpea and sorghum-sudangrass hybrid, tend to regrow after mowing.

Vegetable crops planted in early spring (March-April) require a different cover cropping strategy in our region (hardiness zones 6a-8a), since the winter annual cover crops make most of their growth after this point, and cannot be mow-killed before they reach full bloom in May. In our region, tender summer annuals like sorghum-sudangrass and soybean planted in July can achieve substantial biomass by the first frost, leaving an *in situ* mulch that suppresses winter weed growth, prevents erosion and adds organic matter. Similarly, semi-hardy cool-season annuals like spring oats, field peas or radish can be planted in August and grown until killed by the first hard freezes (10-20 F). If the mulch is persistent enough to provide adequate weed control into the spring season, it may allow for successful no-till or strip-till planting of early crops such as lettuce, spinach, brassicas, peas and onions [8].

Winter-killed cover crop mulches offer several advantages that could make no-till systems more accessible to small growers:

The mowing, rolling or undercutting operation is not needed.

Tender annual cover crops that are difficult to kill mechanically are reliably killed by frost.

Cover crop allelopathy will likely dissipate over winter so that it will not inhibit the following cash crops.

Winterkilled residues may be easier to manage for no-till planting than freshly cut or rolled cover crop residues that are tough and/or succulent.

Possible disadvantages include:

The mulch can slow soil warming and drying, thus delaying vegetable crop establishment.

Weed control may not be as good with the weathered, brittle mulch.

Some cover crops may not be completely winterkilled in a milder-than-normal winter.

In other field trials, mature cover crops that contain about 3 tons of above-ground biomass (dry matter) per acre have suppressed weed growth for the first 4 to 6 weeks after the cover crop is mowed or rolled. The critical weed-free period for vigorous vegetable crops like tomato, potato and squash is generally the first 5 weeks after planting; thus no-till planting into a good cover crop mulch can substantially reduce weed control costs. Since winterkilled cover crop residues undergo several months of weathering before the spring vegetable is planted, a higher biomass may be required to give adequate weed control.

The cover crop must also be *compatible* with the following vegetable crops. Its residues must not interfere with crop establishment by keeping the soil too cool or wet, by tying up soil nitrogen (N), by releasing allelochemicals that hinder crop growth, or by harboring organisms harmful to the crop. Ideally, the cover crop mulch would enhance vegetable growth by improving soil quality or by providing a favorable chemical or microbiological environment. These factors play significant roles in observed “rotation effects”, which can be quite species specific. [16,22]

In the event that the winter-killed cover crop mulch does not provide sufficient weed control or otherwise interferes with no-till spring vegetable production, other reduced-tillage options exist. These include shallow tillage to break up residues and knock out emerging weeds, and strip tillage that leaves mulch in place between crop rows.

Studies were conducted at six locations between July 2004 and July 2006 to evaluate various winter-killed cover crops for no-till and reduced tillage spring vegetable production.

3. Statement of Project Objectives

The original objectives, as stated in the project proposal were:

Objective 1: to demonstrate no-till organic production of early spring vegetables from three plant families (brassica, chenopod, allium) in winter-killed cover crop residues, using equipment and technology that is affordable and scale-appropriate for the small, limited-resource farm.

Objective 2: to compare biomass and N accumulation, date of frost-kill, growth stage at time of frost-kill, spring weed suppression, and spring soil nitrate-N levels for several non-winter-hardy cover crops planted in late summer.

Objective 3: to evaluate compatibility of each cover crop with brassica, chenopod and allium vegetable crops grown in their residues the following spring.

Objective 4: to communicate project concepts and findings to the farming community in the southeastern United States, and engage growers in evaluating, adapting and implementing organic no-till production systems for spring vegetables on their farms.

Our original plan was to begin the project in July 2004 and complete it in early summer of 2005. Problems with low biomass production in some cover crops and inadequate weed suppression by cover crop residues, combined with a delay in disbursement of project funds, led to a decision to limit spring vegetable plantings to small, unreplicated trials at two sites. As a result, Objectives 1, 3 and 4 could not be completed, and data collected for Objective 2 provided a preliminary evaluation of cover crops that merited follow-up trials. Availability of matching funds through a multi-year USDA Cooperative State Research, Education and Extension Service (CSREES) Organic Transitions grant allowed the research team to complete a preliminary evaluation of a wide range of cover crops, and to design and conduct a second series of trials in 2005-06. Based on results from 2004-05, the most promising cover crops were selected for re-testing, and Objectives 1 and 4 were modified as follows.

Objective 1: to evaluate and compare no-till, shallow-till and deep-till management of winterkilled cover crop residues for small-scale production of early spring vegetables from several plant families.

Objective 4: to communicate project concepts and findings to the farming community in the southeastern United States, and provide practical information on high biomass cover cropping and reduced tillage systems for early spring vegetable production.

4. Materials and Methods

Field trials were conducted at the Kentland Agricultural Research Farm of Virginia Polytechnic Institute and State University near Blacksburg, VA, on four working farms in Virginia using organic production practices, and at the homestead garden of the project coordinator. Site information, including soil conditions and trial planting dates, is summarized in Table 1.

Cover crops were evaluated in plots, each consisting of a 20-ft length of two adjacent raised beds or grow-zones separated by a traffic alley. Plots were 12 ft wide (beds spaced 6 ft center to center) at Site 1, and 9 to 10 ft wide at the other sites, depending on tractor wheel spacing. This permitted side-by-side evaluation of till versus no-till residue management. Because of space constraints at Site 6, plots were only one bed wide in some experiments, and no-till cover crop treatments were compared with a tilled, non-cover cropped control.

Kentland Farm (Site 1) was our main study site, at which replicated experiments were conducted and subjected to standard statistical analyses [21]. Cover crop treatments were arranged in a randomized complete block, with 3 replicates except where otherwise stated. Because of logistical constraints, tillage treatments were not randomized, but were applied to one continuous bed through the experimental field, so that each cover crop plot was divided into tilled and untilled halves. Data from the two halves of each plot were then treated as a paired comparison, and tillage effects were evaluated by a paired sample t-test. Because this does not constitute true replication, these results must be considered preliminary, and verified by further experiments in which tillage treatments are randomized and replicated.

In summer 2004, a variety of annual cover crops from two distinct groups were evaluated: warm season annuals sown in July or early August and grown until killed by the first frost in October (summer cover crops), and cool-season species hardy to 15-20 F sown in August and grown until killed by the first hard freezes of winter (fall cover crops). Legume seeds were inoculated with the appropriate *Rhizobium* species for symbiotic nitrogen (N) fixation, and cover crops were planted in rows 6 inches apart, using a manually operated Earthway* precision garden seeder. In most cases, cover crops were evaluated in biculture combinations of a grass with a legume or radish, sown either in alternating rows, or alternating bands of two rows grass, two rows legume. Cover crop species, seed sources, planting depths and rates, and cover crop abbreviations used throughout this report are shown in Table 2.

Three replications were conducted at Site 1. In Trial 1-04, FM+CP, JM+CP, PM+SH, JM+SB, SS+SB and SS+LB were planted July 16. Trial 2-04, also planted July 16, included SS, SH, LB and all three biculture combinations replicated 4 times. On August 7 trial 3-04 was planted, and included SO+LV, SO+PV, SO+BB, BO+PV, SO+BioP, and BO+MagP. At other sites, nonreplicated trials of cover crop treatments chosen in consultation with the participating farmer were planted on dates shown in Table 1.

After cover crop growth became curtailed by falling temperatures, aboveground biomass was evaluated by collecting all plant material (cover crop and any weeds) within a rectangular quadrat centered over two cover crop rows (one grass and one legume), and measuring 1.0 ft by 2.7 ft (2.7 sq ft = 0.25 sq. meter). Material was dried to constant weight in a crop dryer, and weighed. For selected treatments, dried material was ground and submitted to Cumberland Valley Analytical Services in Maugansville, MD for total N analysis. With the exception of Trial 2-04 at Site 1, summer cover crops were mowed or rolled after frost kill or after head emergence in SS and PM. Fall cover crops, which were finer and softer in texture, were allowed to fall naturally over winter.

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* Mention of a product brand or trademark does not imply endorsement by project personnel or Virginia Association for Biological Farming of that product over others designed for the same purpose.

Table 1. Study sites, soil conditions, and cover crop planting dates.

Site and Farmer	Location & Region	Soil Properties[z]: Texture	%OM	pH	P	K	Water cap. g/100gDW
1 Kentland Farm, Virginia Tech	Prices Fork, VA (Appalachian)	Loam (32-43-25)	2.0	6.2	H	H	22
2 Dayspring Farm, Charlie Maloney	Cologne, VA (Tidewater)	Sandy loam (80-8-12)	1.7	6.0	H	H	12
3 Farm of Anthony Flaccavento	Abingdon, VA (Appalachian)	Clay loam (33-37-30)	5.8	6.8	VH	VH	
4 Farm of Warren LaForce	Dungannon, VA (Appalachian)	Loam (38-37-25)	1.0	7.3	VH	M	
5 Waterbear Organic Farm, Richard Ursomarso	Floyd, VA (Appalachian)	Loam (44-30-26)	4.2	6.9	VH	VH	
6 Homestead garden of Mark Schonbeck	Floyd, VA (Appalachian)	Loam (42-40-18)	3.0	6.3	L	H	37

Site	Cover Crop Planting Dates: 2004 Summer	2004 Fall	2005 Summer	2005 Fall
1 Kentland Farm	July 16	Aug 7	July 11	Aug 5
2 Dayspring Farm	July 5	Aug 30	July 3	Aug 4
3 Flaccavento farm	Aug 11	Aug 11	-[y]	-
4 LaForce farm	July 21	-	-	-
5 Waterbear Organic Farm	-	Aug 19	July 12	-
6 Homestead garden	July 14 & 18	Aug 16 & 27	July 18	-

[z] Texture class, and (% sand-silt-clay); OM = Soil organic matter by Walkley Black extraction; P and K by Mehlich 3; L = low, M = medium, H = high (optimum), VH = very high. Water capacity = approximate field capacity, measured 24-48 hours after a heavy soaking rain.
[y] not planted at this site-year.

Table 2. Cover crops, planting rates and depths, and seed sources

Summer Cover Crops	Abbre-viation	Planting depth, in	Seed plate[z]	Rate, lb/ac[y]	Seed Source[x]
Sorghum-sudangrass, *Sorghhum bicolor X S. b. sudanense*	SS	0.5-0.75	22 or 5	75 or 15	AB
Pearl millet, grazing hybrid, *Pennisetum glaucum*	PM	0.5	5	20	AB, AL
Foxtail millet, *Setaria italica*	FM	0.5	5	22	SSt
Japanese millet *Echinocloa crus-galli var. frumentacea*	JM	0.5	5	9	AB
Proso millet, *Panicum miliaceum*, cv. 'Dove'	DPrM	0.5	5	17	AB
Forage soybean, *Glycine max*, *cv.* 'Tyrone'	SB	1	22	60	AB
Cowpea, *Vigna unguiculata*, *cv.* 'Iron-Clay'	CP	0.75-1	22	65	AB
Sunnhemp, *Crotolaria juncea* cv. 'Tropic Sun'	SH	0.75	22[w]	40	PV, MS
Lablab bean, *Lablab purpureus*	LB	1.25	4	40	AB, TS
Buckwheat, *Fagopyrum esculentum*	BW	0.75	22	~40	SSF

Fall Cover Crops	Abbre-viation	Planting depth, in	Seed plate[z]	Rate, lb/ac[y]	Seed Source[x]
Spring oats, *Avena sativa*	SO	1	22	40	SSF
Black oats, *Avena strigosa*	BO	0.75-1	22	30	PS
Spring barley, *Hordeum vulgare*	SBar	1	22	55	SSF
Bell bean, *Vicia faba*	BB	1	14 or 22	115 or 55	PVF
Purple vetch, *Vicia atropurpurea*	PV	0.75	22	70	PVF
Lana Vetch, *Vicia dasycarpa*	LV	0.75	22	60	PVF
Field Pea, *Pisum sativum ssp. arvense*					
cv. 'Biomaster"	BioP	1	14	90	PVF
cv. 'Magnus'	MagP	1	14	90	PVF
Radish, *Raphanus sativus,* daikon	DR	0.5	5	10	PVF
oilseed	OR	0.5	5	11	PVF
fodder, *cv.* 'Colonel'	FR	0.5	5	11	

[z] For Earthway precision garden seeder.
[y] Based on rows 12 inches apart, as in a biculture planting on alternate rows. Rates are doubled for 6 inch row spacing, as in a solid monoculture seeding.
[x] AB = Adams Briscoe (www.abseed.com); AL = Albert Lea Seed (www.alseed.com); PL = Plantation Seed (800-543-4164); PVF = Peaceful Valley Farm Supply (www.growingorganic.com); SSF = Seven Springs Farm (www.7springsfarm.com); TS = Turner Seed; MS = Mississippi State University.
[w] Seed diluted 1:1 with white rice to obtain desired seeding rate.

In early spring of 2005, cover crop residues were evaluated at Sites 1, 2, 5 and 6 for ground coverage and weed suppression. Two 6-ft long line transects were laid out within each plot, and a total of 25 points at 0.5 ft intervals were observed and recorded as mulch (covered with dead residues), weed (live foliage, mostly weeds, occasionally cover crop regrowth), or bare soil.

Vegetables were grown no till (NT) *vs.* conventional till (CT; cover crop residues rototilled into top 4-6 inches of soil just prior to vegetable planting) after winterkilled cover crops at Sites 2, 5 and 6. Except where otherwise stated, plots were divided lengthwise into CT and NT half plots, each containing one bed or grow zone.

At Site 2, brassica crops were planted after FM+CP, FM+SB, JM+CP, JM+SB, PM+SB, PM+LB, SS+SH, SS+LB and SS+SB. On March 23, 2005, one 20-ft row each of 'Grand Prize' cabbage and 'Arcadia' broccoli was transplanted manually in each half plot, except that cover crops that included PM or SS left such coarse, stiff residues that manual planting in the NT half-plots was deemed impractical by the participating farmer. Tomatoes were successfully transplanted into these plots in May, when the residues had decomposed and become softer. All vegetable transplants received a starter organic 5-5-3 (N-P_2O_5-K_2O) fertilizer to provide ca. 50 lb N/ac. A supplemental trial was conducted in a field in which FM + CP had been planted May 12, 2004, mowed July 5 to prevent seed set by pigweed present in the cover crop, and rolled August 15. Mowing killed the FM but CP regrew vigorously until frost. Two adjacent 175-ft beds, one CT and one NT, were planted to broccoli on March 24, 2005.

On April 27-28, weeds were assessed (biomass and cover) and pulled manually, and broccoli plant diameter was measured to evaluate crop vigor at midgrowth. Broccoli main heads were harvested and weighed at maturity between May 19 and June 2, and cabbage was harvested and weighed between June 7 and June 13. Yields were calculated on a per-head and per-acre basis.

At Site 5, three broccoli hybrids – 'Pacman,' 'Gypsy,' and 'Arcadia' – were planted NT and CT into winterkilled SO+BB and SO+BioP on April 5, 2005. Crop rows in the NT treatment were prepared with a No-Till Planting Aid (NTPA) a few days prior to transplanting the broccoli starts. Equal numbers of each hybrid were planted in CT and NT treatments. The crop received 900 lb/ac organic 5-5-3 (45 lb N/ac) at planting, and 150 lb/ac Chilean nitrate[1] (20 lb N/ac) sidedressed on May 19. Broccoli was harvested between June 2 and June 21.

At Site 6, two vegetable plantings were done after winterkilled cover crops. In the first, single-bed plots of SS+SB, SS+CP and SS alone were scythed, organic 5-5-3 fertilizer was applied to planting rows to deliver 40 lb N per acre, and 'German Red' hardneck garlic was planted on October 25. Cloves were set 5 inches apart and 2 inches deep in a triple row in each bed. A tilled control treatment without cover crop was established in an adjacent block of four beds immediately after a harvest of sweet potato. Organic 5-5-3 fertilizer (40 lb N per acre) was applied to three control beds and the fourth was left unfertilized. Immediately after garlic planting, control beds were mulched with old hay at *ca.* 5 tons per acre (3-inch layer). On April 11, 2005, weeds were pulled manually, and on May 17, half of each of the no-till cover cropped plots was mulched with old hay at *ca.* 5 tons per acre. Garlic was harvested on July 14-15, cured for one month, cleaned, graded and weighed.

In the second trial, 'Snow Crown' F1 cauliflower, 'Early Jersey Wakefield' cabbage, 'Savoy' kale, and 'Prize Choy' bok choy were planted CT and NT on April 22-25, 2005 after FM+CP, SS+LB and PM+SB. Plants received organic 5-5-3 starter fertilizer at *ca.* 1,400 lb/ac (70 lb N/ac). All plots were hoed and mulched with *ca.* 4 tons per acre of old hay on May 16. Slugs were controlled with Sluggo[2], a low-toxicity slug bait based on iron phosphate. Kale was cut twice weekly between June 1 and July 28. Other brassicas were harvested as heads matured: Bok choy on May 23-June 12, cauliflower on June 19-26, and cabbage July 9-23.

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[1] Chilean nitrate or sodium nitrate is a restricted material in certified organic production. Its use is restricted to no more than 20% of the crop's total nitrogen requirement.
[2] Sluggo is listed by the Organic Materials Review Institute as acceptable for use in organic production.

In summer 2005, the most promising summer cover crops were evaluated further at Sites 1, 2 and 5, including PM, SS, SB, LB, and SH. Fall cover crops of SO, BO or SBar with BB, BioP and three radish cultivars were planted in August at Sites 1 and 2. Except where otherwise stated, the legume or radish was planted in four or five rows in the "grow zone" (top of beds where vegetable crops were subsequently planted), with the grass on shoulders and sides of beds, and traffic alleys. At Site 1, where beds were spaced 6 ft apart center to center, a single row of the grass was planted in the center, between future vegetable rows (Figure 1). At Site 6, a pure stand of PM was sown in July on preformed raised beds.

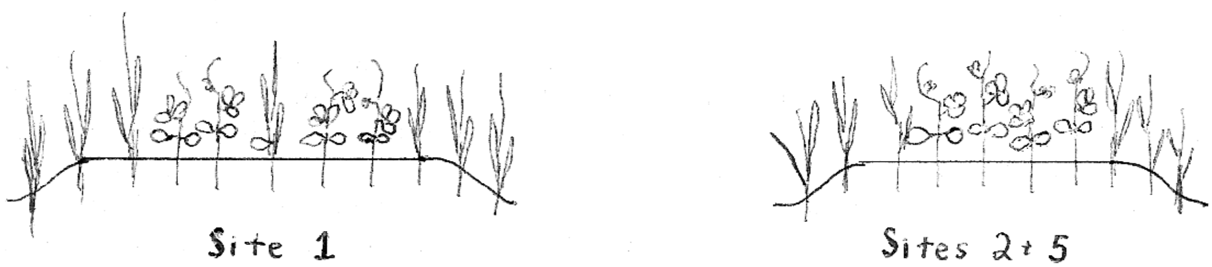

Figure 1. Zone planting of cover crops at Sites 1, 2 and 5.

At Site 1, the experimental field, measuring 440 ft long by 24 ft (four beds) wide, was divided into three separate trials (Figure 2). Trial 1-05 included SS+SB, SS+SH, SS+LB, PM+SB, PM+SH, PM+LB, and a control treatment of SS+SB planted in alternate rows (not "zone planted" as shown in Figure 1). Trial 2-05 included several fall grain + legume combinations: SO+BB, SO+BioP, BO+BB and SBar+BB. Trial 3-05 compared three radish varieties (DR, OR and FR) in the grow zone, with a mixture of SO and BO in alleys.

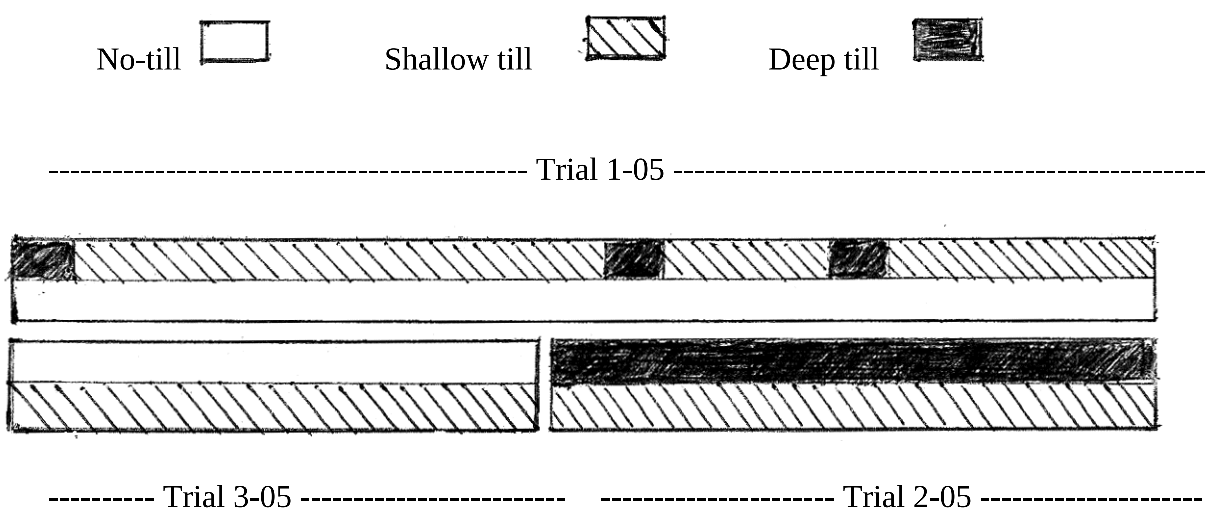

Figure 2. Arrangement of three trials at Site 1 in 2005, showing tillage treatments.

Cover crop biomass and N were measured on September 13 (Trial 1-05) or October 26 (Trials 2-05 and 3-05) as described above. Summer cover crops were rolled with a roller-crimper on September 19 to curb formation of mature seed by the cover crops.

On March 10-13, 2006, coverage by cover crop residues and weeds was assessed as described earlier, except that four 6-ft line transects were taken for each plot to obtain 50 observations. On March 27, soil samples were collected from selected treatments to measure available N. For each plot, eight cores were taken 0-6 inches deep, mixed thoroughly, air-dried and sent to A&L Eastern Laboratories in Richmond, VA for NO_3-N analysis. On March 29, cover crop residues and weeds were collected from a 2.7 sq ft quadrat in each plot in Trials 1-05 and 3-05 to measure residue and weed dry weight and total N.

Tillage treatments (shown in Figure 2) were imposed on March 29, and consisted of shallow tillage (ST, rototiller set to a depth of *ca.* 2 inches), conventional deep tillage (CT, rototilled to 4-6 inches) or no till (NT). Tillage treatments for Trials 1-05 and 3-05 were NT and ST, except that the tilled half of the "control SS+SB" plots in Trial 1-05 were deep-tilled (CT). Because of poor residue cover and higher weed pressure in Trial 2-05, tillage treatments were ST and CT.

On March 29, two planting rows spaced 18 in apart and running lengthwise through each bed were prepared with a two-row No Till Planting Aid (NTPA) set to create two 2-in. wide "slots" of prepared soil loosened to a depth of 6 to 8 in for NT. The NTPA was run shallowly (2 in.) through CT and ST plots to mark rows. On March 30-31, half of one row in each plot (10 ft) was manually planted with 'Stuttgarter' onion sets (3 per ft = 30 per plot). The remaining 10 ft of that row was worked lightly with a hand cultivator to create a finer seedbed, and planted with 'Tyee' F1 spinach at a depth of 0.5 in using the Earthway seeder with a #5 plate. For the radish trial, one-half (10 ft) of the second row was planted with 'Early Frosty' English shell peas at a depth of 1 in, using the #14 plate. Stand counts were taken for spinach, onions and peas in Trials 1-05 and 3-05 on May 24.

'Adrianna' butterhead lettuce and 'Fargo' F1 cabbage starts were produced in an organic starting mix in a greenhouse at Virginia Tech. Seeds were sown in early March, and starts were transplanted into the plots on April 19-20. Eight cabbage plants were set out 1.25 ft apart to occupy 10 ft of row in the summer and fall grain + legume trials. Cabbage was not planted after radish to avoid buildup of soilborne diseases and pests of Brassica family crops. Ten lettuce starts were set out 1 ft apart to occupy the remaining half row in each plot in all trials. Each start was watered with one cup of a transplant solution consisting of a 57:1 aqueous dilution of fish emulsion (4-1-1) that was further amended with approximately one part seaweed powder (1-0-2) to 1,000 parts solution. This provided approximately 5 lb N per acre.

On May 10-12, lettuce, cabbage and onions were sidedressed with a 3:1 mixture of feather meal (12% N) and Chilean nitrate (16% N) at 2.5 oz per 10 row-ft for lettuce (= 30 lb N/ac) and 5.1 oz/10 row-ft for cabbage and onion (= 60 lb N/ac). Spinach and peas were not sidedressed, as spinach was already approaching harvest maturity, while peas were inoculated just before planting with symbiotic N-fixing *Rhizobium.* Drip irrigation lines were installed on May 15 and water was applied as needed.

Weeds were managed to minimize competition against the test crops. Tilled treatments were hoed once on April 28-29, and hand weeded once on May 15 (Trial 1-05) or May 25 (Trials 2-05 and 3-05). No till treatments were hand weeded once on April 24-29 and again on May 23-25.

Vegetable crops were harvested and weighed as they matured. Whole spinach plants were cut on four dates between May 16 and June 9. On the first three harvests, plants that had reached a diameter of 10 in or more were cut to ensure harvest before bolting; on the final date any plant with leaf blades at least 2 in long were cut. Lettuce was harvested on June 5, and peas were picked at the fresh shelling stage on five dates between June 13 and June 28. Cabbage was cut on June 28-29, with the exception of a few later maturing plants, which were harvested on July 3. Onions were not harvested because of a widespread outbreak of neck rot.

At Site 2, summer cover crops were zone-planted on July 3, and scythed and left as mulch on September 7. Because of heavy weed pressure in spring 2006, no-till was not attempted. Plots of SS+LB and SS+SB were deep-tilled (CT) in February 2006. On March 20, PM+SB and PM+SH plots were divided into ST and CT treatments. An adjacent CT "control" plot that was not cover cropped, and had grown arugula and mustard in late fall of 2005, was also tilled at this time.

Vegetable crops were planted March 21-23. For each treatment, one 20-ft row of 'Stuttgarter' onion sets at 3/ft (= 60 per plot), one 20-ft row of 'Space' F1 spinach, and a 20-ft staggered double row of 'Arcadia' broccoli starts (20 plants/plot) were planted. Rows in the adjacent control plot were 45 ft long, and yields were calculated accordingly. All plots were manually weeded on May 6. Broccoli main heads were harvested and weighed between May 18 and June 1, and onions were harvested on July 19, cured for a month, graded and weighed. The spinach crop failed and was not harvested.

At Site 5, bicultures of PM+SH, PM+LB, PM+SB, DPrM+SB and SS+SB were rolled on September 28 by drawing a tractor mounted rototiller with the power off along the bed three times to flatten the crops. In spring 2006, one bed running through all five treatments was rototilled 4-6 in deep (CT), while the other was left NT and prepared with the NTPA. Broccoli starts were transplanted May 5, the crop was hand weeded as necessary, and broccoli was harvested on four dates between June 26 and July 6.

At Site 6, the PM was allowed to grow and die in place. Immediately before planting onion sets, the millet was manually removed from the beds, and aged cow manure was applied at *ca* 5 tons/ac (NPK analysis not determined). The following treatments were applied to separate beds:

'Stuttgarter' onion sets planted March 12 after working the soil lightly (2 in) with hand tools (ST), millet residues replaced as mulch.

'Stuttgarter' onion sets planted NT on March 12, millet residues replaced as mulch.

Yellow onion sets (variety not stated) planted April 2, soil worked lightly (ST), millet residue replaced.

Yellow onion sets planted April 2 in an adjacent tilled bed that had not grown millet (CT no cover), and mulched with hay in May.

All plots were hand weeded as required. Onions were harvested July 21-25, cured for about one month, graded and weighed.

5. Project Results

2004 Cover Crops

At Site 1, Trial 1-04 became heavily infested with volunteer oats from a previous crop that had been allowed to set seed, and the trial was terminated by flail mowing on Sept. 13, 59 days after planting (DAP). Biomass of the *intended* grass component (i.e. excluding volunteer oats) was higher for treatments that included pearl millet (PM) or sorghum-sudangrass hybrid (SS) (1.6-2.3 tons/acre) than for treatments with foxtail millet (FM) or Japanese millet (JM) (~0.4 ton/acre). Differences in legume biomass among soybean (SB), cowpea (CP), sunnhemp (SH) and lablab bean (LB), and differences in total biomass (crops + weeds), were not significant (data not shown).

In Trial 2-04, bicultures of SS+SH, SS+LB and SH+LB had significantly higher biomass than LB alone, with SS and SH monocultures intermediate (Table 3). At most sites, cover crops that included SS, PM, SB or SH generally produced over 3 tons/acre, with weeds comprising less than 10% of total biomass. Exceptions included Site 3, where the later planting date (Aug. 11) undoubtedly limited cover crop biomass accumulation; SS+SB at Site 4, where weed pressure was unusually intense; and the SS+SB and SS+LB treatments at Site 6. At this site, slow establishment of LB in the SS+LB plot allowed giant foxtail to accumulate significant biomass, and self-seeding from a previous buckwheat (BW) crop in the SS+SB plot resulted in a dense stand of volunteer BW that markedly suppressed the growth of both SS and SB.

Table 3. Summer cover crop biomass, N concentration and N content at five sites in 2004.

	-- Site 1, Trial 2-04 --			------ Site 2 ------			Site 3	Site 4	------ Site 6 ------		
Treat-ment	dry wt, t/ac	%N	N, lb/ac	dry wt, t/ac	%N	N, lb/ac	dry wt, t/ac	dry wt, t/ac	dry wt, t/ac	%N	N, lb/ac
FM				1.4	1.16	33					
SS	3.2 ab[z]	0.87	53	6.2	0.90	112					
SH	3.6 ab	1.18[y]	84								
LB	1.8 b	2.03	72								
FM+CP				1.9[x]	2.25	86		1.7[w]	2.1	2.24	94
FM+SB				4.4[x]	2.55	225					
FM+SH								3.1			
JM+CP				1.5[x]	2.29	68	1.3[x]		2.2	2.36	103
JM+SB				3.8[x]	2.75	211	1.7[xw]				
PM+SB				4.2	1.33	111		3.3	3.0	2.06	122
PM+SH								3.5			
PM+LB				3.4	1.29	88					
SS+CP							2.6		3.3		
SS+SB				4.4	1.20	99	2.6	3.3[w]	1.7[v]		
SS+SH	4.6 a			4.8	1.50	144					
SS+LB	4.9 a			3.2	1.33	84			3.2[u]	1.50	95
SH+LB	3.0 a										

[z] Dry weight means within this column that do not have letters in common are significantly different ($p<0.05$) according to Duncan's Multiple Range Test.
[y] Sunnhemp had lost most of its leaves by the time of sampling at this site (Nov. 15); thus N and possibly biomass may be underestimated.
[x] Legume component dominant, comprising more than 90% of the cover crop biomass.
[w] Weeds comprised 10-25% of total biomass.
[v] Volunteer buckwheat (*Fagopyrum esculentum*) comprised 67% of total biomass.
[u] Weeds, primarily giant foxtail (*Setaria faberi*), comprised 30% of total biomass.

FM and JM grew poorly from July plantings, and were strongly outcompeted by CP or SB, resulting in nearly pure stands of the legume at Sites 2 and 3. LB and CP produced much less biomass than SB or SH, but CP produced dense, dark green foliage with rapid canopy closure (within 35-40 DAP) that effectively suppressed weeds.

Most summer cover crops began reproductive development before frost kill, and some showed potential for self-seeding. SS and PM heads emerged as early as 55-60 DAP (Sites 1 and 2) or as late as 70 DAP (Sites 4 and 6). If allowed to grow uninterrupted until frost, July-planted SS could set mature seed. At Site 1, developing SS seeds reached the milk stage by the end of September (86 DAP) and the grower clipped and removed seed heads to prevent self-seeding. Very few mature seeds were observed on PM heads. FM heads emerged about 55-60 DAP and seed development began at 70 DAP, but we have not seen problems with volunteer FM even where the crop was allowed to reach full maturity with dry, firm seed. JM headed and formed seed very rapidly, with seeds reaching the dough stage (probably viable) by 55-60 DAP. However, poor JM growth and strong competition from the companion legumes limited seed production, and no self-seeding was observed in the following season.

'Tyrone' forage soybean began flowering at 55-65 DAP, with pod filling observed at 73-86 DAP. At Site 2, soybeans were allowed to grow until frost (~100 DAP), and self-seeding caused a moderate weed problem in spring broccoli the following season. Iron-Clay cowpea showed sporadic flowering and pod set after 70 DAP at Sites 2 and 4, and formed so few mature seeds that self-seeding was negligible. LB remained vegetative until frost, while SH flowered after 70 DAP, but did not form mature seed by frost.

Nitrogen (N) levels were higher in legume than grass cover crops, as expected. Bicultures contained 70-140 lb N/acre, except 200+ lb N/ac for FM+SB and JM+SB at Site 2, in which the legume comprised over 90% of total biomass. Foliar N concentrations for bicultures that included SS or PM ranged between 1.2-1.5% except for PM+SB at Site 6, whereas bicultures with FM or JM exceeded 2% N, reflecting the higher legume content in these treatments.

In early spring of 2005, winterkilled residues of summer cover crops planted in July 2004 no longer covered the ground completely. In March, residues of CP or SB grown with FM or JM covered only 35-65% of the soil surface, and winter weed cover ranged from 8-45%. Residues of SS or PM with any of the legumes covered 50-85% of the soil surface when the cover crops were mowed or rolled in fall or late winter, but only 35-45% in Trial 2-04, in which the crops were left standing. Some weed growth (5-35% cover) was observed, except for PM+SB at Sites 2 and 6, and SS+SH at Site 2. In trial 2-04 at Site 1, LB alone left sparse residues, and significantly more bare soil (62%) than all other treatments (21-37%), yet weed cover tended to be lower in LB (10%) than in other treatments (24-36%). Thin but virtually weed-free residues of winterkilled LB were observed in several other cover crop trials at this site in 2005 and 2006.

Fall cover crops generally yielded lower biomass than summer cover crops, with the best yield on the highly fertile soil at Site 5 (Table 4). At Site 1, biomass was significantly higher in black oats + 'Magnus' field pea (BO+MagP) than other treatments. At Site 2, hot dry conditions in September 2004 severely hindered cover crop establishment and growth (biomass data not collected). By the end of September, only daikon radish (DR) achieved substantial ground cover (70-100%), while combinations of spring oats (SO) or BO with lana vetch (LV), purple vetch (PV), bell bean (BB), 'Biomaster' field pea (BioP) and MagP had only 15-50% ground cover.

SO planted in early August reached the early heading stage by 70-75 DAP, and showed some potential to set mature seed before winterkill in milder years or climates. BO headed about two weeks later than SO, and DR remained vegetative. BB and BioP flowered as soon as 55 DAP,

Table 4. Fall cover crop biomass in 2004, and percent cover by cover crop residues and weeds in March 2005 at three sites.

	Site 1				Site 2		Site 5			Site 6		
	dry wt,	% cover			% cover		dry wt,	% cover		dry wt,	% cover	
Treatment	t/ac	residue	weed	bare	resid.	weed	t/ac	resid.	weed	t/ac	resid.	weed
SO+LV	1.8 b[z]	65 b	24	11 b								
SO+PV	1.7 b	71 ab	23	7 b	10	68				1.0	44	18
BO+PV	1.9 b	64 b	28	8 b	12	84						
SO+BB	2.0 b	64 b	7	29 a	12	55	2.8	36	35	1.4	36	28
SO+BioP	2.1 b	83 a	8	9 b	4	76	3.6	45	36	1.1	50	14
SO+MagP					20	68				1.1	76	12
BO+MagP	2.8 a	83 a	11	7 b								
BO+BW					4	88				0.8	16	44
DR trts[y]					28	24				1.1	20	12

[z] Means within the same column without letters in common are significantly different ($p<0.05$) according to Duncan's Multiple Range Test.
[y] Mean for DR alone, DR+BO and DR+BW at Site 2; DR+SO at Site 6.

while MagP, PV and LV were later. None of the legumes set viable seeds before winterkill. Buckwheat (BW), which we added in a few treatments to establish early ground cover and weed suppression, flowered at 25-30 DAP and set some seed by 45 DAP.

Some weeds grew through residues of all fall cover crops by early spring of 2005 (Table 4). At Site 1, residue coverage was better for bicultures containing field peas than those containing BB, PV or LV (Table 4). SO+BB had significantly more bare soil than other treatments, and tended to have less weed cover than the vetch treatments. Residue cover and winter weed suppression were generally poor at other sites, owing to low biomass at Sites 2 and 6, and deer grazing on the legumes and the oat seedheads at Site 5. DR residues decayed quickly over winter, and DR plots tended to have more bare soil and less weed cover than other treatments.

Spring 2005 Vegetable Yields

At Site 2, brassica crop growth and yield showed little difference among cover crop treatments (data not shown), but showed distinct responses to tillage treatment. Where weed pressure was high, broccoli plants grown NT after CP or SB were considerably smaller at midgrowth (late April) than broccoli grown CT after any of the cover crops tested (Table 5). At this time, weed biomass (including volunteer soybeans) was about 1,100 lb/acre for NT, compared to just 120 lb/acre for CT. Weeds were pulled manually and the time required for weeding was equivalent to about 120 hr/ac for NT and 45 hr/ac for CT. Broccoli head weight and yield were also lower in NT than CT. In contrast, cabbage head weight was slightly higher and plant mortality slightly lower in NT than CT, resulting in higher total yields in NT.

In a second trial where weed pressure was considerably lower, broccoli plant diameter at the midgrowth was slightly less for NT than for CT, but final crop yields showed the opposite trend (Table 5). Weed biomass in late April was just 180 lb/ac in NT and 100 lb/ac in CT. Weeds were removed by manual pulling for NT (85 hr/ac) and by hoeing for CT (60 hr/ac).

Table 5. Weed cover and brassica plant diameter, head weight and yield in CT and NT treatments after winterkilled cover crops in spring 2005 at Site 2.

	--- March 23 ---		------- April 27-28 -------					
Cover crops & planting date	% weed cover	Tillage	% weed cover	broccoli plant diam, in	broccoli yield: oz/head	broccoli yield: lb/ac	cabbage yield: oz/head	cabbage yield: lb/ac
CP or SB[z]	26	CT	24	18.5	9.0	5,660	26.1	15,100
(July 5, 2004)		NT	78	13.2	5.8	2,830	29.3	20,000
SS or PM+leg.[y]	4	CT	19	18.1	9.0	4,500	26.7	15,200
(July 5, 2004)								
CP[x], May 12	9	CT	32	17.9	11.0	5,510		
(May 12, 2004)		NT	38	16.2	11.8	6,760		

z CP or SB planted with FM or JM; legume became dominant.
y SS planted with LB, SB or SH; PM planted with SB or LB.
x CP planted with FM; only CP regrew after mowing.

At Site 5, broccoli grown after O+BB or O+BioP gave similar yields for NT (3,100 lb/ac) and CT (3,300 lb/ac). Because grazing by deer had severely reduced cover crop residue cover and thus allowed early spring weed growth, the grower manually removed weeds at time of planting. Weed biomass at the end of broccoli harvest was similar for NT (850 lb/ac) and CT (750 lb/ac). Soil NO_3-N concentrations measured June 15 were low (3 ppm for CT and 5 ppm for NT), and the grower attributed low broccoli yields to limited N availability.

At Site 6, kale, bok choy and cauliflower yielded more in CT than NT (Table 6), while cabbage yielded slightly more in NT because some plant mortality occurred in CT. Pre-plant weed pressure was light except in FM+CP.

Table 6. Spring brassica yields at Site 6 after winterkilled cover crops.

Cover Crop	March 18 % weed cover	Tillage	oz/plant Kale	------------- oz /head ------------ Bok Choy	Cauliflower	Cabbage
FM+CP	28	CT	20.3	-[z]	12.5	19.7
		NT	15.7	-	11.4	18.4
SS+LB	8	CT	22.4	21.1	15.4	20.0
		NT	13.3	20.0	5.6	16.3
PM+SB	0	CT	18.1	18.2	12.8	16.0
		NT	15.2	16.0	9.9	16.6
			------------------- lb/acre	-------------------	-------------------	-------------------
Mean across cover crops:		CT	29,100	24,100	8,800	9,400
		NT	24,000	22,100	5,900	11,200

z Not grown in this treatment.

Garlic planted NT into frost killed cover crops had lower marketable yields than garlic planted in tilled beds after sweet potato harvest (Table 7). The SS+SB treatment, which was dominated by volunteer BW, showed the greatest reductions in yield, head size and percent marketable heads, followed by SS alone, with SS+CP showing only slight reductions. On May 17, the garlic crop showed no visible treatment-related differences in vigor, but by June 17, NT garlic was noticeably less vigorous than CT, especially in SS+SB (BW) and SS, where plants showed signs of premature senescence. Soil NO_3-N was tested on the latter date for three plots, and low values were found. However, the trend was the reverse of the yield trend (Table 7). Furthermore, crop yield was not depressed in the unfertilized CT plot, where slightly smaller head size was compensated by higher percent marketable heads.

The NT treatment required manual weeding on April 11, while the mulched CT beds were nearly clean and required no hand weeding. Weeding the NT plots entailed about 2.5 hours of labor, equivalent to about 285 hours/ac. Supplemental mulch applied to half of each NT plot on May 17 had little effect on garlic yield (data not shown).

Table 7. Yield and yield components of garlic planted no-till into winterkilled cover crop residues or into tilled soil after sweet potato harvest at Site 6.

Cover Crop	Tillage	June 17 soil NO_3-N	% marketable heads[z]	head weight, oz/head	Marketable yield, lb/ac
SS+SB[y]	NT	10	76	1.33	4,920
SS	NT		78	1.49	5,570
SS+CP	NT	5	86	1.71	7,090
(Sweet potato)[x]	CT	2	83	1.98	8,500
(Sweet potato)	CT[w]		95	1.60	8,880

z 100% X (number of marketable heads / number of cloves planted)
y Volunteer buckwheat comprised 67% of cover crop biomass.
x Garlic planted shortly after sweet potato harvest.
w Unfertilized bed.

<u>2005 Cover Crops</u>

All summer cover crops generated at least 3 tons/acre aboveground biomass within 63-66 DAP, and differences among cover crop treatments at Site 1 were not significant (Table 8). PM grew especially vigorously at Sites 2 and 5, and dominated the companion legumes, especially SB and LB. Weed biomass was negligible, with the exceptions of SS+SB and SS+LB at Site 2, which became infested with pigweed (*Amaranthus* sp.) and morningglories *(Ipomoea* spp.).

Most cover crops accumulated 100-170 lb N/ac, but generally had N concentrations of 1.7% or less, indicating that this N would not become available to the subsequent crop. Exceptions include PM+SB at Site 1, SS+SB and 'Dove' proso millet (DPrM) +SB at Site 5, in which the legume comprised over 50% of total biomass, and SS+LB at Site 2 in which succulent weeds comprised 27% of total biomass. At Site 1, PM+SB, PM+SH and SS+SH had significantly higher N concentration and total N content than SS+LB, with other treatments intermediate.

PM heads emerged and began shedding pollen (anthesis) at all four sites by the time of biomass measurement (63-66 DAP). A few nearly-mature seeds were observed on PM heads at Site 2, but no self-seeding occurred here or at Site 6, where the crop was allowed to stand until frost-kill (>90 DAP). SS reached anthesis at Site 2, and early head emergence at Site 5 by 63-66 DAP, but remained in the boot stage (head not yet emerged from leaf sheaths at top of stalk) at Sites 1 and 6. At this time, soybeans were setting pods at Sites 2 and 5, and flowering at Site 1, whereas LB and SH remained vegetative at all sites.

Growth of PM and SH was effectively terminated by rolling at Sites 1 and 5, whereas SS stems recurved upward after rolling, and made some additional growth until frost. SB and LB stayed down after rolling, but remained green and continued to grow as prostrate vines. At Site

Table 8. Summer cover crop biomass, N concentration and total N content in 2005, and residue and weed cover in spring 2006 at four sites.

Treat-ment	biomass tons/ac	composition, % grass	legume	weed	%N	lbN/ac	March 2006 % cover: residue	weed	bare
Site 1									
SS+SB	4.0	71	25	4	1.29 bc[z]	103 ab	77 ab	19 cd	4 c
SS+SB*[y]	4.2	77	21	2	1.26 bc	101 ab	85 a	11 d	4 c
SS+SH	4.0	52	47	1	1.42 b	113 ab	70 bc	26 bc	4 c
SS+LB	3.3	74	22	4	0.88 c	58 c	78 ab	11 d	11 b
PM+SB	3.3	46	50	4	1.87 a	122 a	53 d	37 b	10 b
PM+SH	4.1	45	47	7	1.49 ab	122 a	48 d	51 a	1 c
PM+LB	3.4	72	25	3	1.21 bc	83 bc	62 cd	17 cd	21 a
Site 2									
SS+SB	4.0	72	13	15	1.72	138	-[x]	-	-
SS+LB	3.8	68	5	27	2.04	153	-	-	-
PM+SB	4.8	92	7	1	1.32	126	42	58	0
PM+SH	4.1	62	37	1	1.58	131	50	50	0
Site 5									
SS+SB	3.9	43	55	2	2.18	171	72	4	24
DPrM+SB	3.2	18	79	2	2.33	150	58	2	40
PM+SB	5.5	89	11	0	1.49	165	72	10	18
PM+LB	6.8	94	6	0	1.63	223	72	12	16
PM+SH	4.5	73	26	1	1.39	126	74	20	6
Site 6									
PM	4.0	98		2	1.63	130	~85	~1	~14

[z] For Site 1, means within a column without letters in common are significantly ($p<0.05$) different according to Duncan's Multiple Range Test.
[y] SS and SB planted in alternate rows rather than zone planted.
[x] Treatments tilled in February; residue and weed cover data not taken.

1, LB grew especially vigorously after rolling removed the shading effect of the companion PM or SS. At Site 2, SS regrew to a height of 3 ft after scything, whereas other crops did not regrow. Additional biomass and N in this regrowth was not measured, but may have been significant; thus figures in Table 8 for treatments that include SS, SB or LB may be underestimates.

In March 2006, residues of summer cover crops covered 42-85% of the soil surface, while weed cover varied from 1% after PM at Site 6 to 37-58% after PM+SB and PM+SH at Sites 1 and 2 (Table 8). These treatments had higher residue cover and less weed growth at Site 5, where PM biomass was unusually high.

At Site 1, SS+legume treatments, in which the grass continued to grow after rolling, had significantly greater mulch cover and generally less weed cover than the corresponding PM+legume treatments, in which PM died after rolling. LB+grass treatments had more bare ground and tended toward less weed cover than corresponding SB or SH treatments.

At the end of March, cover crop residues retained 43-68% of biomass observed the preceding September, but lower N concentrations in the winterkilled residues resulted in total N content of just 20-52 lb/a, or 30-40% of cover crop N content at 63-66 DAP (Table 9). At Site 1, PM+SB

Table 9. Residue and weed dry weight and N, and soil NO_3-N in spring 2006 at two sites.

Treat-ment	Residue dry wt., tons/ac	% of cover crop biomass	Weed biomass lb/ac	%N[z]	N content, lb/ac: residue	weed	total	Soil NO_3-N (ppm)	Total N recovered[y] lb/ac	%
Site 1										
SS+SB	2.7 a[x]	68 a	235 b	0.74	41	6	47	7 a	60	58
SS+SB*[w]	2.7 a	65 ab	57 b	0.64	34	1	36	6 a	49	49
SS+SH	2.6 a	67 a	238 b	0.87	46	6	52	5 ab	61	54
SS+LB	2.2 ab	66 a	64 b	0.47	20	1	22	5 ab	31	53
PM+SB	1.6 b	49 b	707 a	1.16	37	17	54	2 b	59	48
PM+SH	2.6 a	64 ab	951 a	0.90	47	23	70	2 b	73	60
PM+LB	2.1 ab	61 ab	216 b	0.70	29	5	34	6 a	47	57
Site 2										
PM+SB	2.6	54	1,127	0.99	52	20	72	6	78	56
PM+SH	1.8	43	840	0.82	29	15	44	17	61	40
SS+SB[v]								9		
SS+LB[v]								2		
Control[v]								2		

[z] Based on one pooled sample per treatment. Weed %N was 2.47% at Site 1, and 1.79% at Site 2.
[y] Residue N + weed N + soil NO_3-N (lb/ac = 2Xppm for 0-6 in sample depth); given as total lb/ac and as percent of cover crop N measured at 63-66 DAP.
[x] For Site 1, means within a column without letters in common are significantly ($p<0.05$) different according to Duncan's Multiple Range Test.
[w] SS and SB planted in alternate rows rather than zone planted.
[v] Residue samples not collected. Control is adjacent bed in which no cover was grown.

residue weight was lower relative to cover crop biomass in September than for other treatments. Weed biomass was significantly greater in PM+SB or PM+SH than in other cover crops at Site 1, and similarly high weed biomass was found in these two treatments at Site 2. Common chickweed *(Stellaria media)* and deadnettle *(Lamium* sp.) were observed growing vigorously in these treatments even where residue cover was relatively thick. Soil NO_3-N measurements at the 0-6 in depth was consistently low at Site 1, and low to medium at Site 2. NO_3-N was 9 ppm after PM at Site 6, and 10-18 ppm in the five treatments at Site 5 (data not shown). Residue N + weed N + soil NO_3-N accounted for 40-60% of the N content of cover crops at 63-66 DAP (Table 9).

Cool season grass + legume cover crops again generated less than 3 tons/acre biomass at Site 1, and did not leave sufficient surface residue to prevent substantial weed growth by March 26 (Table 10). A fall drought interfered with cover crop establishment and growth, and weeds comprised roughly 10-20% of total biomass (visual estimate). Vigor of BO was further compromised by low viability and vigor of the seed, which was one year out of date. N concentration was considerably lower in SBar+BB than in other treatments, while N content was higher in SO+BioP than BO+BB. Spring residue cover was significantly higher for SO+BB or SO+BioP than for SBar+BB or BO+BB, but weed suppression was inadequate for no-till vegetable planting in all treatments.

SBar had reached the dough stage of seed development (probably viable seed) by October 18 (74 DAP), yet no self-seeding problems were observed the next spring. SO was heading at this time, and both BB and BioP were in full bloom, while BO heads had not yet emerged; none of these cover crops set mature seed before winterkill.

Table 10. Fall grain +legume cover crop biomass, N concentration and total N at Site 1. Biomass and N measured Oct. 2005; residue and weed cover measured March 2006.

Treatment	Biomass, tons/ac	%N	lbN/ac	March 13 % cover: residue	weed	bare
SBar+BB	2.6	1.37 b[z]	71 ab	27 b	37	36
SO+BB	2.1	1.95 a	84 ab	44 a	25	31
BO+BB	1.7	1.89 a	64 b	19 b	61	20
SO+BioP	2.7	1.96 a	107 a	55 a	25	20

z Means within a column without letters in common are significantly ($p<0.05$) different according to Duncan's Multiple Range Test.

Radish + oat cover crops also yielded less than 3 tons/acre at Site 1 (Table 11). Many FR and a few DR and OR bolted by Oct. 18 (74 DAP) and flowered a week later, but no self-seeding was observed in 2006. A few DR and OR survived over winter but their regrowth in spring 2006 was not vigorous enough to cause a serious weed problem. Residues, mostly from SO and BO, covered only about half the ground area mostly along edges of beds, leaving most of the soil in grow zones exposed. However, weed cover was substantially less than in fall grain+legume cover crops. Cover crop residues had about half of the dry matter content of the live cover crops in October, and their N concentrations were only slightly lower than the live covers. Residue N + weed N + soil NO_3-N accounted for 70-83% of cover crop N measured in October.

Table 11. Cover crop biomass, N concentration and total N on October 18, 2005, residue and weed cover, biomass and N in March 2006, in three varieties of radish grown with oats.

Treatment	Biomass, lb/ac	%N	lb N/ac	March 13 % cover: residue	weed	bare
DR+O[z]	1.9	1.93	75	47	2	51
FR+O	2.8	1.66	94	45	8	47
OR+O	2.1	1.76	72	52	5	43

	March 29									
Treatment	residue, lb/ac	% of biomass	weeds, lb/ac	residue %N[y]	lb N/ac residue	lb N/ac weed	lb N/ac total	Soil NO_3-N, ppm	Total N recovered,[x] lb/ac	Total N recovered,[x] %
DR+O	0.9	45	41	1.84	31	1	32	15	62	83
FR+O	1.6	56	117	1.50	47	3	50	8	66	70
OR+O	1.0	48	110	1.67	33	3	36	-[w]		

[z] Mixture of SO and BO on sides of beds and alleys, radish in grow zones.
[y] Based on one pooled sample per treatment. Weed %N was 2.47%.
[x] Residue N + weed N + soil NO_3-N (lb/ac = 2Xppm for 0-6 in sample depth); given as total lb/ac and as percent of cover crop N measured at 74 DAP.
[w] Not measured for this treatment.

Spring 2006 Vegetable Yields

Spinach planted after winterkilled radish + oat cover crops (Trial 3-05) yielded over twice as much as after fall grain + legume combinations (Trial 2-05), and largely failed when planted after summer cover crops (Trial 1-05) (Table 12). In trial 3-05, stand counts on April 24 (24 DAP) were significantly higher in NT than ST. However, plants reached harvest size a full week later and were significantly lighter in NT than ST, and yields for the two treatments were similar. Yield was significantly higher for the DR and OR treatments than for FR.

In trial 2-05, stand counts at harvest and yield in ST were nearly double those for CT, and plants matured an average of three days earlier in ST. In trial 1-05, yields were very poor regardless of tillage, though initial stands were substantially better in NT than tilled treatments. Some plant mortality between 24 DAP and harvest was observed. Losses resulted mostly from damping-off and slug damage, and were greater in NT than CT or ST.

The lettuce crop was rendered unmarketable by numerous small slugs damaging outer leaves and the bases of heads. Slugs seemed most numerous in NT, but significant damage occurred in all treatments. A “usable yield” (acceptable by local food banks) was determined after removing badly damaged outer leaves. No significant yield differences among cover crop treatments were noted *within* any of the three trials, but head size and yield were somewhat higher after fall grain + legume cover crops than after either radish + oat or summer cover crops (Table 13, page 24). In trial 1-05, head size and yield were significantly lower in NT than ST, while tillage effects were not significant in the other two trials. A few plants were lost to a head rot diagnosed by Virginia Tech Plant Disease Clinic as “drop” *(Sclerotinia sclerotiorum)* and to a stunting and yellowing syndrome for which no pathogens were identified. Plant mortality varied 1–9%, with no significant differences among cover crops or tillage treatments.

Table 12. Spinach stand counts at 24 DAP and at harvest, mean plant size, yield and average date of harvest in three trials at Site 1.

Trial	Tillage	Plants/10 ft row 24 DAP	Plants/10 ft row harvest	Plant wt., oz/plant	Yield, lb/ac	Average date of harvest
1-05 (summer cover crops)	CT	6	2	0.85	280	-[z]
	ST	6	3	0.63	380	-
	NT	23	6	0.46	520	-
Significance[y]		**	*	ns	ns	
2-05 (fall grain + legume)	CT	-[z]	7	0.73	1,050	May 29
	ST	-	13	0.78	2,010	May 26
Significance[y]			**	ns	**	*
3-05 (fall radish + oat)	ST	25	23	1.12	4,710	May 25
	NT	41	32	0.72	4,250	June 1
Significance[y]		**	**	*	ns	**
Trial 3-05 by cover crop (averaged across tillage treatments):						
DR		34	30	1.01	5,260 a[x]	May 27
FR		30	25	0.80	3,580 b	May 30
OR		34	28	0.95	4,600 a	May 28

[z] Data not taken.
[y] Comparison of ST vs NT (Trials 1-05 and 3-05) or CT vs ST (Trial 2) by paired sample t-test. ns = not significant; * = p<0.05; ** = p<0.01.
[x] means without letters in common are significantly different according to Duncan's Multiple Range Test.

Cabbage head weight and yield were substantially lower for NT than tilled treatments in the summer cover crops (Trial 1-05, Table 14, page 24). Yields and head weights were generally higher after the fall grain + legume cover crops (Trial 2-05), with no significant differences between ST and CT. Cabbage yielded significantly more after PM+SH than after PM+SB and any of the SS treatments, with PM+LB intermediate.

In trial 3-05, English shell peas yielded 50% more in NT than ST (Table 15, page 25), with no significant differences among radish cover crop treatments (data not shown). Most of the yield difference resulted from higher stand counts in NT, though plants also appeared more vigorous and flowered slightly earlier in NT than ST.

Table 13. Lettuce head weight and yield in three trials at Site 1 in 2006.

Trial	Tillage	Head wt, oz	Yield, lb/ac	% plant mortality
1-05 (summer cover crops)	CT	5.1	4,380	7
	ST	6.0	5,280	3
	NT	4.6	4,200	1
Significance[z]		*	*	ns
2-05 (fall grain + legume)	CT	7.8	6,940	3
	ST	7.3	6,070	9
Significance[z]		ns	ns	ns
3-05 (fall radish + oat)	ST	5.8	5,020	6
	NT	5.5	4,850	3
Significance[z]		ns	ns	ns

[z] Comparison of ST vs NT (Trials 1-05 and 3-05) or CT vs ST (Trial 2) by paired sample t-test. ns = not significant; * = p<0.05

Table 14. Cabbage head weight and yield after different cover crops and tillage treatments in two trials at Site 1 in 2006.

Trial	Tillage	Head wt, oz	Yield, lb/ac
1-05 (summer cover crops)	CT	27.0	19,600
	ST	27.3	19,700
	NT	20.2	14,500
Significance[z]		**	**
2-05 (fall grain + legume)	CT	34.7	25,000
	ST	31.2	22,500
Significance[z]		ns	ns
Trial 1-05 by cover crop (averaged across tillage treatments)			
SS+SB		22.1 b	15,800 b[y]
SS+SH		23.2 b	16,800 b
SS+LB		18.6 b	13,500 b
PM+SB		19.4 b	14,100 b
PM+SH		32.6 a	23,800 a
PM+LB		28.2 ab	19,900 ab

[z] Comparison of ST vs NT (Trial 1-05) or CT vs ST (Trial 2) by paired sample t-test. ns = not significant; * = p<0.05; ** = p<0.01.
[y] means without letters in common are significantly different according to Duncan's Multiple Range Test.

Table 15. Stand counts at 24 DAP and yields of English shell peas grown after fall radish cover crops (Trial 3-05) at Site 1 in 2006.

Tillage	Plants/10 ft row	--------Yield --------	
		oz/plant	lb/ac
ST	21	2.7	4,860
NT	27	3.1	7,530
Significance [z]	*	ns	**

[z] Comparison of ST vs NT by paired sample t-test.
ns = not significant; * = $p<0.05$; ** = $p<0.01$.

Stand counts in Trials 1-05 and 3-05 at 24 DAP showed that an average of 95% of onion sets had established viable plants in NT, compared to 86% in ST and 79% in CT. By May 12 (42 DAP), onions appeared a little more vigorous in NT and ST than in CT (data not shown). Onion bulbs developed well in all cover crop and tillage treatments, many reaching 3-4 in diameter by mid July. However, a severe outbreak of neck rot (pathogen not identified) rendered most of the crop unmarketable, and no yield data were collected.

CT and ST plots were hoed once and hand weeded once, whereas NT, in which residues made hoeing impractical, was hand weeded twice. Labor was 70 hours/ac for ST and 140 hours/ac for NT in Trial 1-05, and 50 hours/ac for ST and 190 hours/ac for NT in trial 3-05.

Broccoli yields and head weights were low at Sites 2 and 5, probably as a result of a spring drought in 2006. At Site 2, yields were similar after summer cover crops were managed ST or CT (Table 16), whereas in the control (no cover crop) CT plot, cabbage root maggots attacked and killed the broccoli crop shortly after transplanting. This plot had been in arugula and mustard (same plant family as broccoli) during the winter immediately before broccoli planting. Residues of these crops likely harbored the pest. At Site 5, broccoli yields were higher in CT than NT. No cover crop related differences in yield or head size were observed.

Table 16. Head weight and yield of broccoli grown after summer cover crops at two sites in 2006.

Site	Tillage & cover crops	heads per plot [z]	-------- Yield -------	
			oz/head	lb/ac
Site 2	CT – PM+SB, PM+SH	19.5	4.9	2,600
	ST – PM+SB, PM+SH	16.0	6.2	2,700
	CT – SS+SB, SS+LB	18.0	6.0	2,900
	CT, no cover	----- crop failure ----------------------		
Site 5	CT, all [y]		4.2	4,500
	NT		2.9	3,200

[z] 20 plants were grown in each plot
[y] Data for SS+SB, DPrM+SB, PM+SB, PM+SH and PM+LB averaged for each tillage treatment.

Dry weather in spring also restricted onion yields at Site 1, but the crop had lower mortality, higher average bulb weight and higher yields in ST than CT (Table 17). The control (no cover) had the largest bulbs but also the highest mortality. The grower observed better soil moisture retention and lower weed pressure in ST compared to CT.

At Site 6, onions grown in PM mulch gave fairly good yields despite some losses to neck rot and bottom rot (pathogens not identified), with little difference between NT and ST. In an adjacent CT plot in which no cover crop had been grown and the onions were mulched with hay, a higher percentage of sets yielded marketable onions, but average bulb weight was substantially lower. Notably, the PM plots produced the best onion crop in 9 years of gardening at this site, and only required one light hand weeding to remove a few perennial weeds emerging through the mulch from rootstocks in the soil. In past years, onions have been plagued by heavy populations of galinsoga *(Galinsoga spp.)* and other summer annual weeds despite hay mulch application, requiring repeated hand weeding and yielding poor crops of small (2 oz) bulbs.

Table 17. Bulb size and yield of onions from sets in different cover crop and tillage treatments at two sites in 2006.

Site and Onion variety	Cover crops	Tillage	% of sets yielding sound onions	oz/bulb	Yield, lb/ac
Site 2					
Stuttgarter	PM+SB, PM+SH	CT	59	1.2	4,000
		ST	81	2.0	8,800
	SS+SB, SS+LB	CT[z]	50	1.5	4,000
	None	CT	34	2.8	3,900
Site 6					
Stuttgarter	PM	ST[y]	67	4.3	14,200
		NT	69	4.3	14.500
Yellow, VNS	PM	ST[y]	49	5.3	12,700
	None	CT[x]	80	2.6	10,300

[z] Tilled in February, about one month before planting
[y] PM cleared from bed, bed tilled lightly and planted, PM replaced as mulch.
[x] Bed mulched with old hay in May

6. Discussion and Conclusions

Our project did not fully achieve viable organic no-till production of early spring vegetables in the residues of winterkilled cover crops; however it did demonstrate that integrating these cover crops into vegetable rotations can greatly enhance organic matter input to the soil, and may allow reduced tillage in early spring seedbed preparation. Project successes included:

Production of 3 to 5 tons aboveground cover crop biomass containing 100-200 lb N per acre within 65 days after planting summer cover crops in July.

- Demonstration of a shallow tillage (2 in) treatment for incorporating winterkilled cover crop residues that reduces disruption of the soil profile while giving adequate weed control and vegetable yields comparable or superior to deeper (4-6 in) tillage.
- Higher yields in no till than shallow till in shell peas grown after radish cover crops.
- Fair yields and excellent weed control in onions grown after winterkilled pearl millet at one site where onion yields have been historically poor due to heavy weed pressure.
- Evidence for possible allelopathic activity of some winterkilled cover crops against winter and early spring weeds, apparently without adverse impacts on spring vegetables.

Several problems for no-till spring vegetable production were encountered, including:

- Insufficient residue cover, even in high-biomass summer annual cover crops.
- Low biomass in fall cover crops, especially when hot dry conditions followed planting.
- Significant early spring weed growth through residues of most of the cover crops tested.
- Increased labor requirements for planting and weed control in the no-till system.
- Increased incidence of slugs and damping-off, slower crop establishment, and lower marketable yields for some vegetables in the no-till treatment.

<u>Cover crops</u>

Perhaps the most valuable outcome of this project is the information gathered on the performance of various cover crops in the southeastern United States, including some underutilized species with excellent potential. A synopsis of our findings follows.

Sorghum-sudangrass hybrid (SS), already used regularly by some growers in our region, can produce tremendous biomass and is known for suppressing weeds through competition and allelopathy [15]. It regrows vigorously after mowing or rolling until killed by frost, and may require mowing at about 70 DAP to prevent self-seeding. It requires fertile soil with ample N, and can give poor, weedy stands on lower-fertility soils. The strong, stout stems of a good SS stand may reach a height of 9 ft and provide support for vining legumes like lablab bean (LB). Mowing SS back to a height of 12-18 inches at least several weeks before frost can stimulate additional root growth and magnify the crop's ability to loosen hardpan and suppress weeds [12]. Whereas SS cannot be mow-killed for no-till *fall* vegetable production, it appears well suited as a winterkilled cover crop ahead of early spring vegetables.

Pearl millet (PM) is not widely used in our region, yet it shows tremendous potential as a late summer cover crop. It emerges and grows well on limited moisture, consistently reaches 6-9 ft and 4 tons/ac within 65 DAP, and is somewhat more tolerant to lower soil fertility than SS. Heads emerge around 60 DAP, but we later learned that the varieties used in our trials are male-sterile hybrids bred for grazing, which can be allowed to stand until frost without risk of self-seeding. PM regrows vigorously if mowed before heading but is readily killed by mowing or rolling after heading. Rolling PM+legume bicultures at this stage can release the legume from shading by the tall PM to allow additional legume growth and N fixation. We have seen vigorous early spring weed growth through thick mats of PM + soybean (SB) rolled the previous September, which suggests that any allelopathic effects of PM residues are weak or short lived. Allowing PM to grow until frost gave excellent weed control at one site, and this strategy merits further evaluation. PM seeds are available by mail order, and the low seeding rates (10-20 lb/ac) could make mail order economically viable for many growers.

Foxtail millet (FM), *Japanese millet* (JM) and *'Dove' proso millet* (DPrM) all grow poorly from July plantings, giving thin stands only 1-3 ft tall by 65 DAP, and often succumbing to competition from weeds and/or the companion legume. All three perform well when planted before the summer solstice, reaching heights of 3-5 ft and biomass of 3-5 tons/acre in 60 days. FM in full head (about 60 DAP) is very easy to kill by mowing or rolling, and has become our "workhorse" summer grass for no-till *fall* vegetables. FM seeds are locally available at farm supply stores in Virginia, and quite inexpensive, especially since seeding rates of 10-20 lb/ac are sufficient. We have never seen self-seeding problems with FM, and speculate that its seeds decay over winter. JM sets mature seeds by 60 DAP and regrows after mowing and thus appears unsuitable for organic no-till systems. DPrM can be mow-killed, but its biomass production and weed suppression appears less consistent than other millets.

Buckwheat (BW) has a short life cycle (30 days to flower, 45-60 days to mature seed), and does not produce sufficient biomass for no-till before it must be terminated to prevent self-seeding. Its nectar-rich flowers provide food for beneficial insects, and its rapid early canopy closure and allelopathic activity [7] make BW a valuable summer cover crop for weed control during short fallow periods. Market gardeners in our region sometimes grow two generations by letting the first planting set seed before mowing or incorporating the crop. BW could be grown between rows of oats, peas or bell beans planted near the end of summer; the BW would hold back early-sprouting weeds, then die at first frost to make room for the semihardy crops. Further trials of this strategy may be warranted.

Cowpea (CP) grows well when planted anytime after the soil is thoroughly warm (65-70 F), and up to the end of July. It regrows readily after mowing or rolling, and suffers far less damage by Japanese beetle (JB), Mexican bean beetle (MBB) or deer than SB. Whereas CP produces less biomass and N than other summer legumes, its rapid emergence, early canopy closure, and dense, dark green foliage provide summer weed suppression similar to BW. CP establishes easily even on limited soil moisture, thrives in hot summer weather, and tolerates partial shade from tall SS or PM in bicultures. It has little cold tolerance, giving poor stands when planted at the spring frost date when the soil is still fairly cool and moist. The 'Iron-Clay' variety used in our trials (actually a combination of two late-maturing strains) flowers sporadically, sets few pods and continues vegetative growth until killed by the first hint of frost. Many other varieties of CP are grown throughout the Southeast, including shell pea varieties like southern peas, crowder peas, or blackeye peas. Some farmers, including project participant Charlie Maloney, plant these varieties of CP for multiple purposes: weed suppression, beneficial insect habitat, organic matter and N, as well as a marketable harvest.

Forage soybean (SB) produces more biomass from July plantings than CP – up to 4 tons/ac containing up to 200 lb N/ac. It is a little more cold tolerant, and may grow a couple of weeks further into the fall than CP. However, SB is less drought tolerant, especially during emergence and establishment, and is very susceptible to damage by MBB, JB and deer. SB continues active growth after rolling, but can be killed by mowing to a short (2-3 in) stubble height. Late maturing forage varieties, such as 'Tyrone' are recommended, as grain or edamame types produce much less vegetative biomass and mature earlier. Whereas soybean seeds are considered short-lived (1 year) and susceptible to deterioration by weathering, 'Tyrone' grown uninterrupted from early July until frost self-seeded and caused a moderate weed problem in the following year's vegetable crops in two of our trials. When pest pressure is not excessive, and the crop is managed to prevent seed set, late-maturing forage soybeans are well suited as the legume component of winterkilled cover crops. Soybean seeds are usually available through local farm supply stores, but since soybean varietal maturity is linked to seasonal daylength patterns, varieties obtained from a lower latitude than one's own will mature later and yield more biomass.

Sunnhemp (SH) is a tropical legume that combines N fixing capacity with the stemmy, persistent residues of millets and SS. Tissue N concentration is lower in SH than other legumes, and the crop is fairly susceptible to Japanese beetle. SH does very well alone or in biculture with SS or PM, and we have seen weed-free stands of PM+SH in fields with heavy weed pressure that infested SS+SB and SS+LB. It is readily killed by rolling after 65-70 DAP, but this is not necessary in our region, where July planted sunnhemp will not set seed before frost. SH seeds are quite expensive and not widely available; thus it remains an experimental crop at this time.

Lablab bean (LB) is a viny tropical legume that produces much less biomass from a July planting than SH or SB, especially in the cooler Appalachian region. LB can become weed-infested while growing unless it is sown at high rates (100 lb/ac) to guarantee early canopy closure. This may not be practical for most growers, as seeds are expensive and not widely available. However, LB merits further evaluation, as its winterkilled residues seem to suppress weeds even though the residues themselves become quite sparse by March, suggesting possible allelopathic activity. This crop has been rated tops for weed suppression in a study comparing 14 different tropical legumes in Nigeria [3]. Regardless of the mechanism of suppression, the nearly clean seedbed left when a good stand of LB is winterkilled may facilitate early spring vegetable production with minimum tillage.

Spring oat (SO) planted in August can produce sufficient mulch to protect the soil over winter, slowing weed growth and promoting good tilth by early spring. Normally, SO will winterkill in hardiness zones 7b or colder, though some producers have reported some spring regrowth after a mild winter. SO requires ample moisture and mild temperatures to establish and grow well, and hot dry weather during the first 4-6 weeks after planting can result in thin, weedy stands with low biomass. August-planted SO may set mature seed if winter freezes arrive later than normal; timely mowing can prevent this. SO may be more suited to spring planting, alone or with legumes like field peas, bell beans or vetch, ahead of midsummer vegetable plantings.

Black oat (BO) is widely used as a cover crop for no-till soybean production in Brazil, but its use in the US remains experimental and the seeds are not yet commercially available. Its high biomass production, later maturity than SO, freeze-susceptibility (~20 F), and reported allelopathic activity against weeds [24], make it a good candidate for a winterkilled cover crop in our region. Further trials with higher quality seed are warranted.

Spring barley (SBar) appears more drought tolerant than SO or BO, but it sets mature seed within 75 DAP. Biomass production may be limited by early maturity and the need to mow to prevent self-seeding. Whereas barley self-seeding did not occur in our study (in which spring tillage may have killed germinating barley seeds), significant problems with volunteer barley have occurred in other trials at Site 1. SBar may be better suited as a short season cover crop in early spring ahead of summer vegetables.

Bell bean (BB), *purple vetch* (PV), *and 'Magnus' and 'Biomaster' field peas* (MagP and BioP) are cool season semihardy legumes that have shown excellent biomass and N fixation in mild California winters [14], and they reliably winterkill at about 20 F. *Lana vetch* (LV) proved more winterhardy than expected in our trials, surviving freezes as hard as -4 F. Overwintered LV grows faster and flowers about a month earlier in spring than does hairy vetch, the most widely used winter annual legume cover crop in the upper South. As with SO, hot dry weather can hinder establishment and growth of any of these legumes planted in August; they perform better when planted in early spring in our region. These semihardy annual legumes are not available locally, and mail-ordering from California may not be economically feasible due to high seeding rates (50-120 lb/ac).

Radish cover crops, including *daikon radish* (DR) and *'Colonel' fodder radish* (FR), show great potential as winterkilled cover crops for some spring vegetables. Judging from appearance, *oil radish* (OR) appears identical or very similar to DR. Whereas radish biomass production is similar to that of SO and semihardy annual legumes, FR and DR emerge and cover the ground much faster, and tolerate warm dry fall weather better. Whereas radish residues decompose rapidly, few weeds grow in their wake, leaving a nearly clean seedbed for early spring vegetable production. Radishes may suppress weeds through release of allelochemicals called isothiocyanates, as has been shown for other brassica cover crops [5]. In our trials, radish cover crops did not seem to hinder the growth of peas or lettuce, and apparently enhanced spinach production. One drawback is that a radish cover crop cannot be grown less than three years before or after another brassica (vegetable or cover crop) because of the high risk of clubroot and buildup of other diseases and pests of this plant family.

Cover crop contributions to soil organic matter and soil nitrogen

In organic production systems, soil fertility and crop nutrition are based on the continual breakdown and replenishment of the soil's active organic matter by the web of microorganisms and other biota in the soil. The soil life must receive a sufficient quantity, quality and diversity of organic inputs (food) each year to maintain favorable soil organic matter (SOM) and plant-available nutrient levels, and high soil quality and productivity. Insufficient organic inputs and frequent or intensive tillage, which accelerates organic matter breakdown, are two major factors in soil degradation. Organic production systems have effectively addressed the first concern, but the second is a challenge since organic growers rely on tillage and cultivation in lieu of herbicides for weed management. Our project aimed to address both concerns in relation to early spring vegetable production, through the use of high biomass winterkilled cover crops managed through no-till or minimum-till.

Cover crops play a vital role in this equation by adding organic carbon (C) and nitrogen (N), and making soil phosphorus (P), potassium (K) and other essential nutrients more available by bringing them into the active organic matter cycle [8, 9, 23]. Two requirements for successful cover crop based reduced-tillage vegetable production are that the cover crops provide sufficient food (biomass) to the soil life and that they promote timely release of nutrients, especially N, to the vegetable crops. In a typical agricultural soil, the soil life might decompose 1,200-4,000 lb/ac of the soil's organic matter each season, most of it from the active fraction. [2, 9]. The warmer the climate, the sandier the soil and the more it is tilled, the faster organic matter is consumed. When soil organisms feed on *fresh* organic matter such as cover crop residues, about 20% of the original mass remains as active SOM at the end of one year, the rest being respired as carbon dioxide. Thus organic inputs of 3-10 tons/ac may be needed to maintain active and total SOM levels and soil life. Meanwhile, annual crops add roughly 0.5 tons organic matter below ground as roots + root deposition (root exudates, sloughed fine roots, etc.) [2, 25]; thus some summer cover crops in our study provided 4.5-7.5 tons/ac of "food" for the soil life. Thus, when managed no-till or by reduced tillage, winterkilled cover crops could provide most or all of the input required to maintain SOM levels. The semihardy fall cover crops may add only 1-4 tons/ac, which is still a substantial improvement over bare winter fallow.

A critical factor for organic growers, especially with regard to heavy-feeding early spring vegetables like brassicas, lettuce and spinach, is plant-available (soluble) soil N. Organic residues with N concentrations above 2% tend to release soluble N as they decompose in the soil (mineralization), while residues with less than 1.5% take up existing soluble N, which can lead to a temporary N deficiency for the crop [2]. Residues between 1.5% and 2.0% are "balanced food" for soil life and have little immediate impact on soil soluble N; they also tend to promote the greatest buildup of soil microbial biomass and active SOM.

We grew mostly cover crop bicultures, because earlier studies have shown that they can yield higher biomass, greater weed suppression and sometimes more favorable soil N dynamics than either the grass alone (which can tie up N), or the legume alone (which can release N so quickly that leaching losses occur) [2, 19]. Many of our cover crops contained 100 lb N/ac or more, but their N concentrations fell mostly within or below the "neutral" range cited above. Thus residues are unlikely to have made any *direct* contribution toward the N requirement of spring vegetables. Bicultures in which SB dominated (Site 2 in 2004 and Site 5 in 2005) had well over 2% N, and a significant fraction of their 150-200+ lb N/ac might have been mineralized. However, it is not known how much of this N became available for plant growth in the spring, and how much was lost to leaching or denitrification during winter.

In biologically active soils with good SOM levels, the soil life can release 100-200 lb N/ac-year from the active organic matter, potentially meeting the N requirements of most vegetable crops. However, the rate of N release is closely correlated with soil temperature, and is generally well matched to the N needs of summer vegetables like tomato and squash. In contrast, early spring vegetables require a *large amount* of N in a *relatively short period*, and much of it while the soil is still too cool to support rapid microbial N mineralization. Soil NO_3-N levels of about 25 ppm are considered optimal for heavy feeding crops [9], and soil NO_3-N values in March 2006 fell below this level, averaging only 5 ppm at Site 1, 9 ppm at Sites 2 and 6, and 13 ppm at Site 5. Thus early vegetables would be expected to require supplemental N, and in most of our trials they were given organic starter and/or sidedress fertilizer to provide at least 50 lb N/ac. In other trials at Site 1, spring broccoli has shown yield responses to organic fertilizer N up to 100 lb/ac [18]; thus low vegetable yields in some of our trials may indicate that crop N requirements have not been fully met.

With the exception of radish + oat cover crop, winterkilled residues had substantially lower N concentrations than the living cover crop, and the sum of residue N + weed N + soil NO_3-N in March 2006 accounted for roughly half of the cover crop N as measured the previous fall (Tables 9 and 11). The other half must have become incorporated into active SOM and soil life, and/or lost to leaching, volatilization or denitrification. N losses occur mostly when soil soluble N levels are high, or when N-rich organic residues are added to the soil. Some N losses may have occurred in soybean-dominated bicultures with N levels above 2%, while in other treatments with lower N concentrations, the "missing" N was more likely incorporated into the soil's organic N pool. Whereas this N is not directly available to the next crop, it does contribute to the soil's long term fertility and ability to mineralize N.

Because N mineralized from freeze-killed cover crops might be leached over winter, alternate-row grass + legume biculture plantings may be more ecologically and economically sustainable for winterkilled cover crops than an N-rich legume or radish monoculture over the entire bed or even within the "grow zone." The possibility that N is lost from zone-planted, winterkilled legume or radish cover crops should be investigated further. Zone planting may contribute more effectively to vegetable crop N nutrition when the cover crops are mechanically killed shortly before planting late spring, summer or fall vegetables that can utilize N as it is mineralized.

Vegetable crop and weed responses to cover crop residues

One objective of this project was to evaluate the compatibility of different winterkilled cover crops with early spring vegetables planted into the residues. Plant to plant interactions include allelopathy (effects mediated by plant-synthesized chemical substances) and microbially mediated rotation effects (rhizosphere or endophytic microbiota of one plant species assisting or hindering another plant species), as well as direct competition for space, light, nutrients and water. These relationships can be highly species-specific [16, 22] and this was reflected in our findings.

Generally, cover crop species had less impact on vegetable yield than tillage treatment, with some notable exceptions. Spinach failed after summer cover crops, gave low yields after fall grain + legume covers, and threefold higher yields after radish + oat covers (Table 12). Stand counts taken after emergence and at harvest showed the same trend: radish >> fall grain + legume > summer covers. Whereas this is not a statistical (replicated) comparison, the dramatic differences between three trials planted side-by-side on the same date merit further investigation. Spinach also failed when direct-sown after summer annual cover crops at Site 2. The isothiocyanate allelochemicals given off by brassicas can kill or inhibit pathogenic soil fungi as well as weed seeds [5]; thus it is possible that the radish residues reduced or eliminated certain soil fungi that attacked germinating spinach seeds in the other trials.

At Site 1, lettuce gave higher yields after fall grain + legume covers (Trial 2-05) than after either summer cover crops (Trial 1-05) or radish + oat (Trial 3-05) (Table 13). Cabbage did better after fall grain + legume than after most of the summer covers, notably those that included SS (Table 14). Cabbage was not planted in the radish trial for crop rotation reasons. Germinating lettuce seed is highly sensitive to allelopathic effects [15, 16, 17], and lettuce transplants have been adversely affected by a *fresh* SS mulch [11].

The low yield and early senescence of garlic after (BW)+SS+SB and SS at Site 6 resembled N limitation, but this was not confirmed by trends in soil NO_3-N measured when symptoms first occurred (Table 7). Weed competition was minimized through hand weeding; thus allelochemical or microbiological effects related to the cover crop residues may be involved. Allelopathic effects of sorghum and sorghum-sudangrass against both weeds and vegetable crops are well documented [11, 15], and allelochemicals active against test plants from several plant families have been isolated from buckwheat [7].

In most cover crop treatments, any ground area not well covered by winterkilled residues tended to become occupied by weeds by the time of spring vegetable planting. At Sites 1 and 2 in 2006, common chickweed *(Stellaria media)* and deadnettle *(Lamium* sp.) seemed to thrive in SS+SB and SS+SH even where these residues were still relatively thick. In contrast, LB, radishes and to a lesser degree BB retarded winter and early spring weed growth, leaving a greater proportion of bare soil as their residues decayed over winter. Rigorous laboratory and field procedures would be required to verify allelopathic plant-to-plant effects [16,17]. However, the observed weed suppression, combined with favorable response of spinach to radish and absence of significant suppression of other vegetables by either radish or lablab bean, make these two cover crops high priority for further field evaluation for early spring vegetable production.

Whereas summer cover crop yielded almost twice the biomass obtained from fall cover crops, the amount of winter residue coverage and weed growth in March were roughly similar for both groups. Summer cover crops died at the first frost in October (or were killed by rolling or mowing in September), while fall cover crops grew until the first hard freezes in December.

Thus residues of fall cover crops underwent a shorter weathering period before spring vegetable plantings, and were likely in a less advanced stage of decomposition than the summer crops. Whereas neither category consistently gave sufficient weed control to make no-till practical for spring vegetables, all cover crops retarded winter weed growth sufficiently for minimum- or shallow-till systems. Most cover crops also yielded sufficient residues to prevent soil erosion over winter, with the possible exceptions of radish and lablab bean. Growing these fast-decomposing crops in biculture with a grass may be needed to obtain sufficient soil protection.

Tillage effects on early spring vegetables: practical considerations for producers

Yields of vegetables planted in early spring after winterkilled cover crops showed highly varied responses to tillage that do not point to a simple conclusion. Brassica vegetable yields were 18-50% lower in no-till than in tilled treatments in five comparisons (one broccoli trial at Site 2, kale and cauliflower at Site 6 in 2005, cabbage at Site 1 and broccoli at Site 5 in 2006); 19-32% higher in three comparisons (a second broccoli trial at Site 2, and cabbage at Sites 2 and 6 in 2005); and little affected in two others (broccoli at Site 5, kale and bok choy at Site 6). Five other vegetable crops, each evaluated in just one or two trials, also showed varied responses to no-till: a substantial yield loss in garlic planted into summer cover crops in October (about the time the latter were frost-killed), a small decrease for spring planted lettuce and spinach, little effect on spring planted onions, and a 55% *increase* in spring shell peas after radish cover crops. Clearly, a complex of factors are involved that require further study. At a practical level, our results suggest that the effects of no-till residue management on early spring vegetables are unpredictable, and that farmers should experiment on a small scale with these systems before implementing them for production.

The effects of tillage include accelerated soil warming, drying, and release of plant-available N, faster decomposition of organic residues, and destruction of weeds, all of which would be expected to favor the establishment of early spring vegetables, especially heavy N feeders such as brassicas, spinach, onion and lettuce. However, tillage also accelerates breakdown of SOM, and does some damage to soil structure, soil life and moisture holding capacity. Some of our findings might be understood in light of these considerations. On the sandy loam at Site 2, broccoli plants initially grew faster in the CT treatment (residues incorporated by rotary tillage to 4-6 inch depth) than in NT, likely reflecting the faster soil warming and N release in the former. Broccoli yields were severely depressed in NT in one trial with heavy weed pressure, but slightly *enhanced* in NT in a second trial with much lower weed pressure (Table 5). Apparently, in the absence of intense weed competition, soil conditions in NT became quite favorable to broccoli later in the spring, allowing the crop to catch up with the CT planting by the time of harvest. At this site, summer vegetables have also given better yields in NT (winter cover crops mowed or rolled) than CT (winter covers incorporated). The grower speculates that tillage can promote an excessively rapid release of soluble N on this sandy soil, resulting in leaching losses and less N available to the crop later in its growth cycle.

Surprisingly, NT cabbage outyielded CT cabbage at this site in the presence of heavy weed pressure that severely hurt NT broccoli yields (Table 5), and NT cabbage also did well at Site 6 in a trial that showed yield depression in other NT brassicas (Table 6). Cabbage matured later than the other brassicas, and may have been more able to utilize soil N mineralized in the late spring and early summer as soil temperatures increased.

Spinach showed a complex response to tillage at Site 1 in 2006. Smaller-seeded, direct-sown vegetables such as spinach are usually not recommended for no-till planting after cover crops because of their greater susceptibility to allelopathy and need for a fine seedbed [12, 15, 16, 17]. We were aware that the risk of crop failures in NT was higher with this crop than transplanted brassicas and lettuce, onion sets or large-seeded peas. Yet spinach emerged better in NT than tilled treatments. Subsequently those plants that did emerge in the tilled treatments grew larger and matured faster. Apparently, soil conditions in NT, possibly better structure and aeration, favored emergence, though post-emergence mortality was higher in NT. Subsequently, faster soil warming and/or N mineralization likely promoted better plant growth in tilled treatments.

The soil at this site is in the early stages of transition from conventional to organic production, and is still fairly low in organic matter for a loam in the Appalachian region. This soil readily becomes muddy and sealed-over from heavy rains, which could hinder emergence or promote pre-emergence damping off. We estimated the soil's field capacity by sampling one day after a substantial (~1 inch) rain had left it somewhat muddy and compacted, and found 22 g H_2O/100 g dry wt. In contrast, the soil at Site 6, also a loam but under organic management for 20 years, contained 37 g H_2O/100 g dry weight after a similar rain, yet remained soft, crumbly and well aerated. Spinach emerged well at this site from a lightly tilled seedbed.

Observed spinach yields for till *vs* NT in these trials must be interpreted with caution. We used the 10-inch plant diameter criterion in the belief that plants would bolt and become ummarketable if allowed to grow larger. However, a short row left unharvested in a buffer zone between trials grew at least two weeks longer and became several times larger without bolting, indicating that our method grossly underestimated potential marketable yields for this spinach hybrid. Had we delayed harvest until full maturity, yields from the faster growing plants in ST plots might have greatly exceeded NT yields.

English shell peas showed the most dramatic positive response to NT versus tillage (Table 15). Peas are good N fixers and thus much less dependent on soil-mineralized N. Their large seeds are more tolerant to allelochemicals than smaller crop seeds [16, 17] and germinate well at low temperatures [14]. Thus this crop is less prone than other early season vegetables to the potentially adverse effects of no-till management of winterkilled cover crop residues. Further trials are needed to determine whether this crop will consistently perform well in NT.

In 2005, we tested a shallow tillage treatment (ST, rototilling to a depth of 2 inches) against both CT and NT. Lettuce, cabbage and broccoli performed equally well in ST and CT, whereas spinach and onions from sets yielded substantially more in ST than CT. The yield difference in spinach at Site 1 was clearly related to better emergence in ST, possibly because this treatment had less impact on soil structure than CT.

Shallow tillage removes smaller weeds and aids soil warming without causing as much disruption to the soil profile or soil life as deeper tillage. Winterkilled cover crop residues that have partially inhibited winter weed growth are much more amenable to shallow tillage than either the heavier winter weed growth associated with winter fallow or a winter cover crop that begins rapid growth in March. Very shallow tillage (as little as 1 inch) may be practical and effective after radish or lablab bean has been grown and winterkilled in the grow zones, as these leave sparse residues yet effectively suppress winter weeds. Compared to the common practice of winter fallowing those beds to be planted in early spring vegetables, winterkilled high-biomass cover crops managed with shallow tillage offer tremendous advantages, including replenishment of soil organic matter, reduced wintertime soil erosion, less disruption of soil structure, and partial weed suppression.

Another tactic, not evaluated in our trials but worthy of investigation, is strip tillage, in which residues are cleared from a 6-12 in wide swath centered on each vegetable row, and a seedbed prepared within that swath. Soil warming, N mineralization and within-row weed control are probably better in this system than in NT, yet soil structure disruption and soil surface exposure are less than for CT or ST.

Other Practical Considerations for the Small Farm

Implementing organic no-till or reduced tillage systems for cover crop management and vegetable planting can be difficult for small farms working with limited resources. Winterkilled residues are easier to manage than live cover crops, yet certain equipment is needed to facilitate no-till vegetable planting through residues, and possibly to roll down the residues themselves. Roller-crimpers specially designed for rolling cover crops are not yet widely available. However, many farms have implements that can be used to roll the cover crop, such as a cultipacker, or a flail mower run across the field with the power off (the weight of the mower head flattens cover crops effectively). Two of our cooperators – Richard Ursomarso and Charlie Maloney – have found that their tractor-mounted rototillers, again with the power off, do a fair job, although two or three passes are necessary to achieve sufficient flattening.

Project consultant Ron Morse developed a subsurface tiller-transplanter (SST-T) for planting vegetable starts through heavy cover crop residues [13, 20], which is a major capital investment. More recently, he developed no-till planting aids (NTPA) that have performed well in both fresh and winterkilled residues, and can be constructed for less than $1,000 per row [12]. A major objective of rolling is to orient cover crop residues parallel to the direction of travel, which greatly facilitates operation of either the SST-T or the NTPA, and is *essential* for fresh (non-winterkilled) residues. Fortunately, both the rototiller and the flail mower (operated with power off) are fairly effective in orienting residues.

Another practical consideration in evaluating organic no-till systems is labor. Planting vegetables through residues requires more time and care than planting into tilled soil, especially when planting is done manually. We timed broccoli planting in one trial at Site 2, and estimated labor for manual transplanting at 280 person-hours/ac for NT versus 160 person-hours/ac for CT. In four trials (two at Site 1 and two at Site 2), weed management labor was estimated at an average of 135 person-hours/ac for NT compared to 55 person-hours/ac for CT or ST. Assuming farm labor is paid a living wage of $10/hour, the increased time required for weed control might entail an additional cost of $800/ac. If planting is done manually, no-till could add some $2,000/ac in labor expenses. These added costs would need to be compensated through crop yield increases in NT, and/or through a substantial long-term enhancement in productivity related to improved soil quality.

Conclusions and Recommendations:

1. Based on practical implications of the findings of this project, we recommend the following for organic production of early spring vegetable crops:

- grow summer or fall cover crops that will winterkill, leaving residues that will build soil organic matter, prevent erosion, enhance soil structure and suppress winter weeds;
- manage residues through shallow tillage, strip tillage, or other reduced-tillage just before planting vegetables; and
- optionally, experiment with no-till residue management and vegetable planting on a small scale, especially for peas and onions which responded favorably to no-till in our trials.

2. Some tender summer annuals, especially sorghum-sudangrass, pearl millet, forage soybean and sunnhemp, can develop high biomass (3-5 tons/ac) when planted in July. August-planted oats and semihardy annual legumes produce less biomass, and are susceptible to failure during fall droughts, but have the advantage of occupying less of the growing season for cover crop production.

3. Forage radish, daikon radish and lablab bean leave sparse residues yet suppress winter weeds effectively, and may thus be particularly effective in facilitating seedbed preparation for early spring vegetables with minimal tillage. However, they may not provide adequate erosion control on sloping land unless grown in biculture with oat or another cool season grass.

4. Several notable phenomena observed in our study merit further investigation, including:
- possible allelopathic weed suppression by radish, lablab bean and perhaps bell bean;
- the remarkably better performance of spinach sown after radish + oat than spinach sown after grass+legume cover crop bicultures;
- successful production of nearly weed-free onions after winterkilled pearl millet at a site that has historically experienced severe weed pressure and low yield in onions;

Two replicated cover crop trials have been planted at Site 1 to evaluate all of these phenomena, and to continue testing of ST and NT residue management systems. Some funds remaining in the matching grants can help to cover the labor and materials to conduct these trials. The project leader is considering application for an additional OFRF grant to secure additional funding for this study.

7. Outreach

This project is part of a larger program in organic vegetable production research and outreach, including cover cropping, no-till and minimum till production, and farmscaping for insect pest management. Dr. Ron Morse, Professor Emeritus of Horticulture at Virginia Tech is the overall program leader, and the author of this report is a major participant. As part of this program, field days open to farmers and the general public have been conducted at Kentland Agricultural Research Farm in 2004 and 2005, and at Dayspring Farm (Site 2) in 2005. Presentations were given in winter 2003-04, 2004-05 and 2005-06 at the Virginia Biological Farming Conference, and/or the Southern Sustainable Agricultural Working Group (SSAWG) Annual Conference. Each of these presentations, attended by 40-60 people, covered various aspects of organic no-till/ minimum till vegetable production, including but not limited to early spring vegetable production after winterkilled cover crops. A series of information sheets on cover cropping and no-till systems has been written and periodically updated, based on our research findings.

A SARE Professional Development Program funded training in sustainable agriculture for Extension agents, Natural Resources Conservation Service personnel, and other agricultural consultants and educators in Virginia and North Carolina during the 2006 season. About 40 trainees participated. An initial 3-day intensive training was held at Kentland Farm on June 6-8; on-farm field days were held in late June at Vineyard Nursery in Middleburg, VA and at the North Carolina Agriculture and Technology State University experimental farm in Greensboro, NC; and a follow-up training at Kentland Farm took place September 13-14. Additional field days were held on September 26 at North Carolina State University's Center for Environmental Farming Systems in Goldsboro, NC, and on September 27 at Dayspring Farm. Trainees have organized into five regional teams, each of which is now making plans to hold one or more training sessions for farmers in their respective regions in 2007.

The program has assisted two participating farmers, Richard Ursomarso (Site 5) and Charlie Maloney (Site 2), in acquiring No Till Planting Aids (NTPA) to enable them to implement no-till and minimum-till cover crop management in their organic vegetable production.

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