No-Till, No-Herbicide Systems for Production of Transplanted Broccoli

Ronald Dean Morse
Virginia Polytechnic Institute & State University

Introduction

Weed control has been a severe problem in no-till (NT) vegetable systems because cultivation and plastic mulches are normally not used in untilled (NT) soils. Since chemical weed control in vegetables is often ineffective or environmentally unfriendly, integrated weed management (IWM) systems are generally required. In IWM, all aspects of crop production are considered to both reduce the effect of weed interference on crop yield and minimize impacts of crop production on the environment (Swanton and Weise, 1991). Weed management methods are commonly divided into four overlapping categories: cultural, biological, mechanical, and chemical (Forcella and Burnside, 1994). Combinations of two or more of these methods, especially when considering sustainable weed management, are applications of IWM.

As vegetable and tobacco production moves toward more sustainable systems, cultural weed control methods should play a major role, and in many cases should predominate in IWM systems. Cultural weed control exploits the ecological principles of plant competition in which the first plants to occupy an area or space have a competitive advantage over those that follow (Wicks et al., 1994). Thus, effective cultural weed control practices are those that favor growth of the planted crop over germination and growth of intruding species (weeds). Cultural weed control practices can be conveniently divided into two strategies: (a) those that enhance rapid growth and canopy closure of the planted crop, and (b) those that inhibit or delay germination, emergence and growth of weeds.

The extent to which cultural practices can predominate in IWM systems is highly dependent upon the vegetable species grown and crop establishment method used. Transplanting a fast-growing cole crop such as broccoli in narrow multiple-row beds using large, vigorous transplants results in rapid canopy closure in the bed area, minimizing or even eliminating the need for herbicides (Infante and Morse, 1995).

No-till production systems using dense, evenly distributed, persistent cover crop residues minimize the need for herbicides and optimize the conservation of soil and water (Morse, 1993). Achieving dense, uniform (before and after transplanting) persistent crop residues necessitates (a) proper establishment of recommended cover crops; (b) providing adequate growth inputs (water, nutrients and edaphic factors) and growing time to maximize cover crop biomass and quality (low weed levels and maturation of the cover crop tissues); and (c) effective establishment of the transplanted crop into the heavy killed mulch with minimal disturbance of surface residues and surface soil. Mechanical killing the cover crops has two distinct advantages over using contact herbicides: (a) because herbicides are not used, negative environmental impacts are reduced; and (b) cover crops can be killed just before planting, which maximizes the growth potential and maturation of the residues. Dense, mature plant residues persist longer throughout the growing season, which increases weed suppression and conservation of soil and water (Hoffman et al., 1993). Since a relatively high percentage of high-value transplanted crops are irrigated, potential soil moisture depletion problems from drought prior to planting are negated. Flail mowing and rolling can effectively kill mature cereal rye *(Secale cereale* L.), hairy vetch *(Vicia villosa* Roth), mixtures of hairy vetch and rye, crimson clover *(Trifolium incarnatum* L.), and wheat *(Tnticum* ***aestivum*** L.) (Dabney and Griffeth, 1987; Dabney et al., 1991; Hoffman et al., 1993).

Using the Subsurface Tiller Transplanter (SST-T) (Morse et al., 1993) to effectively set vegetable and tobacco transplants in mechanically-killed, heavy residues enhances the potential of reducing or even eliminating the use of chemical herbicides for production of transplanted row crops. Both cultural-method strategies are favorably affected in the SST-T/NT, heavy-residues system. Improved stands and rapid canopy closure (Morse, 1995) and persistence of uniform, dense residue ground cover intensify the competitive advantages of the transplanted crops over weed growth.

The objectives of this study were (a) to assess the effectiveness of flail mowing and rolling annual cover crops on weed suppression and persistence of killed cover crop residues, and (b) to determine the cover-crop and weed-management effects on yield of NT broccoli.

Materials and Methods

Field experiments were conducted in the fall of 1994 at the Virginia Polytechnic Institute and State University Kentland Agriculture Research Farm, Blacksburg. The soil was a Hayter loam (fine-loamy, mixed, mesic, Ultic Hapludaf), with a pH of 6.4. The experimental design was a split-split plot with four replications. Main plots (20 x40 ft) were cover crops:

Ronald D. Morse, Associate Professor, Department of Horticulture, 306C Saunders Hall, Virginia Polytechnic Institute & State University, Blacksburg, VA 24061-0327 (Phone: 703-231-6724; Fax: 703-231-3083).

soybeans (S), buckwheat (B), and foxtail millet (FM). Subplots (10 x 40 ft) were chemical weed control: herbicide (H) applied on August 19 and control (no herbicide). Sub-subplots (5 x 40 ft) were cover crop residue management methods: flail mowing (F) and rolling (R), done on August 23.

On May 31, 1994, soybeans *(Glycine max* L.), buckwheat *(Fagopyrumsaggitatum* Grlib.), and foxtail millet *(Setariaitalica S L.)* were drilled in rows 7 inches apart at a rate of 75, 120, and 45 lb/acre, respectively.

On June 23, 1994, granular fertilizer was surface broadcast with (in lb/acre) 50N-22P-42K in buckwheat and foxtail millet plots and with ON-22P-42K in soybean plots. All plots were irrigated with a solid-set, overhead-sprinklersystem during times of prolonged soil-moisture deficits.

Herbicide plots (H/F and H/R) were sprayed on August 19 with a tank mixture of l,l'-dimethy1-4-4'-bipyridiniumion (paraquat) at 0.5 lb ai/A and 2-chloro-l-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl)benzene (oxyfluorofen) at 0.5 lb ai/A.

Designated plots were flail mowed (F and H/F) or rolled (R and H/R) just prior to transplanting broccoli on August 23. Flail mowing was done with a reverse-rotor Alamo-Mott (74 inches wide, weight 850 pounds). Rolling was accomplished by pulling the disengaged Alamo-Mott flail mower across the plot. Only one pass was used for both flail mowing and rolling.

At transplanting and again on October 25, cover crop dry weight was determined by taking 5.4-ft² samples from each plot and drying them at 158 °F for 2 weeks. Cover crop persistence was determined by calculating the percentage of cover crop remaining on October 25 [(DW remaining x lOO)/DW at transplanting].

Bareroot 'Emperor' broccoli *(Brassica oleracea* L. var. italica) transplants were set on August 23 with the Subsurface Tiller-Transplanter (SST-T) (Morse et al., 1993). Granular fertilizer was surface banded at planting 3 inches from both sides of each row with (lb/acre) 85N-36P-141K-2B, using the SST-T. All plots were sidedressed by hand with NH_4NO_3 at 50 lb N/acre on September 8 and again on September 30.

To ensure a complete stand, transplants that did not survive were replaced by hand. Sprinkler irrigation was used at all sites throughout the growing season to minimize soil stress. Pesticides were applied at planting and at regular intervals thereafter, according to the Virginia Commercial Vegetable Production Recommendations (Virginia, 1994). One twin row (16,200 plants/acre) was planted in each sub-subplot. Rows were spaced 18 inches apart and 42 inches between twin rows (5 feet center to center); in-row spacing was 16 inches between plants. A total of six harvests were taken at weekly intervals, beginning October 13. Immediately after harvest, heads were cut to a length of 7.5 inches and fresh weights were recorded. Weed samples (5.4 ft²) were taken between the twin rows on October 25 and dried for 2 weeks at 158 °F. The Statistical Analysis System (SAS) was used to perform all statistical analysis procedures (Scholtzhauer and Littel, 1987). Duncan's multiple range test was used for mean separation. Percentage data for cover crop persistence were analyzed after arcsine transformation.

Results and Discussion

Cover Crop Growth and Persistence

At transplanting, above-ground biomass was 4.1, 2.5, and 3.6 tons/acre for soybeans, buckwheat, and foxtail millet, respectively. Stand establishment was excellent for all cover crops. Since no preemergent herbicides were used, weeds germinated and grew along with the cover crops. However, cover crops outgrew and eventually smothered most weeds, except redroot pigweed *(Amaranths retroflexus* L.), which survived somewhat in soybean plots (5 % of the total biomass was pigweed).

At broccoli transplanting (12 weeks from seeding the cover crops), buckwheat had flowered and developed viable seed, foxtail millet had flowered and set immature seed, and soybeans were in early flowering. All cover crops were effectively killed by mowing or by the paraquat/oxyfluorfen treatment. One week after rolling, cover crops and most weeds were killed and lying prostrate over the ground, except in the soybean plots. Most of the redroot pigweed and some of the soybean residues were still green after one week in the rolled soybean plots. Redroot pigweed plants were not totally flattened in some areas, requiring hand chopping to minimize shading of the broccoli transplants. Regrowth did not occur in the millet and buckwheat plots and soybean greening did not become a yield-limiting factor, probably because rapid canopy closure within the broccoli twin rows smothered soybean regrowth.

In IWM systems, weed growth only limits growth of the planted crop when competition for available resources occurs. In the soybean plots, moisture, nutrients, and light interception apparently were adequate and did not limit broccoli growth, even though the soybean and redroot pigweed plants were not totally killed. Yield-limiting levels of growth inputs did not occur in rolled soybean plots because recommended nutrients and water were maintained in the root zone of the broccoli plants by irrigation and nitrogen sidedressings and shading was prevented by using narrow, twin-row plant arrangement. Rolling for transplanted NT row crops appears to be a viable residue management and cultural weed control technique when practiced on mature, annual cover crop species that are not heavily contaminated with large annual or perennial weeds.

Although increasing cover crop persistence can improve weed suppression (Hoffman et al., 1993), there is little research data evaluating methods for increasing residue persistence. Data in this study illustrate three distinct factors that increase residue persistence (Table 1).

First, cover crop species was a major factor, with foxtail millet being nearly double that of soybeans or buckwheat. The high C/N ratio (Aref Abdul-Baki, unpublished data) of

Table 1. Main effects on cover crop persistence, 1994.

Treatment	Cover crop persistence (%)[z]			Significance
	Soybean	Buckwheat	Foxtail millet	
Cover crop	33b[z]	30b	52a	***
	Herbicide	No herbicide		
Chemical weed control	33	43	**	
	Rolling	Flail mowing		
Residue management	47	29	***	

[y]Percentage cover crop residues remaining on October 25, 1994 (9 weeks after transplanting).

[z]Mean separation among cover crops by Duncan's multiple range test at $P \leq 0.05$. NS, **, *** F-test nonsignificant at $P \leq 0.05$ or significant at $P \leq 0.01$ and 0.001, respectively. There were no interactions among treatments ($P \leq 0.05$).

foxtail millet compared to soybeans and buckwheat probably accounts for this persistence difference among species.

Second, rolling retarded mineralization of cover crop tissues (improved persistence), compared to flail mowing. Rolling tends to layer and thus expose less residue surface area in contact with the soil compared to flail mowing, which shreds residues into small pieces (Dabney et al., 1991). Also, rolling leaves the plant intact longer than mowing, resulting in continued metabolism and delayed cellular degradation.

Third, not killing the cover crops (no herbicides) prior to rolling or mowing delayed breakdown of residue tissues. Of utmost importance, there were no interactions among treatments—i.e., treatment effects were additive. The most persistent plots (66%) were unsprayed (no herbicide), rolled foxtail millet; while the least persistent (17%) was herbicide-treated, flail-mowed buckwheat.

Weed Biomass

Weed growth was probably not a yield-limiting factor in any treatment. Weed biomass was low, averaging 263 pounds per acre dry weight and did not differ among treatments (data not shown). The high level of weed suppression can be attributed to several factors.

First, dense, uniform surface residues present at planting were maintained relatively intact Over the research plots. In previous experiments at the Kentland Agriculture Research Farm, Infante and Morse (1995) showed that weed suppression was greater in NT plots than with conventional tillage (CT). The high-clearance design of the Subsurface Tiller-Transplanter (SST-T) used in this study enabled effective broccoli transplanting with minimal disturbance of surface soil and surface residues (Morse et al., 1993). The SST-T functioned better in the rolled cover crops than flail mowed. Intact residues, rolled or oriented in the same direction that the SST-T traveled, resulted in greater transplanting efficiency compared to mowed residues, which showed some hairpinning and clogging of residues behind the shank of the SST. Hairpinning and clogging conceivably could be serious problems in heavy, mowed residues, particularly in wet, spongy soils.

Second, transplanting into a "stale seedbed" resulted in less weed seed germination than planting into freshly-tilled CT fields (Standifer and Beste, 1985). The stale seedbed technique is a form of limited tillage normally applied to plow-disk systems in which a flush of new weed seedlings germinating after tillage is killed with chemicals prior to planting. In like manner, the soil surface underneath a cover crop becomes a stale seedbed and, if left undisturbed after planting, will normally have less viable weed seeds than if tilled prior to transplanting.

Third, narrow twin rows facilitate rapid canopy closure within the twin-row areas (Forcella and Burside, 1994). In this study, in-row weed biomass was virtually held to zero because shading smothered the germinated weed seedlings. Infante and Morse (1995) and Serage (1993) showed similar results, with weed biomass within broccoli twin rows held to approximately 10% of adjacent weed biomass between the twin rows.

Broccoli Yield

Broccoli yield was unaffected by experimental treatments (data not shown), averaging 7 tons/acre (636 boxes/acre). There were no differences in quality (head size, texture, color, etc.) among treatments. These results further show that, when properly established and maintained, NT production systems are a viable option for producing broccoli (Hoyt et al., 1994). The SST-T used in this study is equipped with an in-row soil loosening (IRSL) device aligned ahead of the transplanter, which often improves stand establishment and crop yield (Morse et al., 1993).

In a recent review of 10 years of data (Morse, 1995), yields of cabbage and broccoli in IRSL/NT plots were increased by an average of 8% and 9%, compared to conventional tillage (CT) and unloosened NT plots, respectively. Compared to NT, yield stability was also enhanced during this 10-year period (1984-1994). Yields in IRSL/NT plots were generally equal to or higher than yields in unloosened NT plots. Only in an exceptional dry year (1991) was yields in IRSL/NT plots less than unloosened NT.

Summary and Conclusions

Based on data in this paper and presented elsewhere (Infante and Morse, 1995; Serage, 1993), no-till broccoli can be successfully produced without using contact or preemergent herbicides. In these studies, various cultural weed-control methods were combined to minimize interspecific (weed-broccoli) competition. Each cultural method either promoted rapid broccoli growth and/or reduced germination and growth of weeds.

(A). Heavy (dense, thick layer), uniformly distributed surface residues of soybean, buckwheat and foxtail millet were obtained prior to transplanting broccoli and maintained after transplanting. Rolling effectively killed mature annual cover crops, which persisted longer than mowed residues (Hoffman et al., 1993). Obtaining and maintaining (persistence) uniformly distributed, heavy surface residues is paramount for no-herbicide weed control, especially when the weed-seed population and soil environment are optimum for weed growth. Selecting rapid-growing, allelopathic cover crop species or mixtures of species for specific weed problems and using high-clearance, effective NT transplanters such as the SST-T (Morse et al., 1993) will help establish and maintain uniform, dense cover.

(B). Reduced weed-seed populations (stale seedbed) and relatively weed-free cover crops were achieved prior to transplanting. To be successful, NT fields should be free of weeds as possible at transplanting to aid the planted crop to secure a competitive advantage over subsequent germination and growth of weeds (Wicks et al., 1994). If established early, this controlled plant dominance hierachy (transplanted crop established first which dominates later germinating weeds) is generally relatively easy to maintain. Proper establishment of a dense, uniform cover crop will generate a stale seedbed by smothering germinating weeds. If the stale seedbed is left undisturbed at transplanting, weed growth will be minimized. If necessary, contact and/or preemergent herbicides applied at low rates before or shortly after seeding cover crops could be used. Appropriate use and timing of early pretransplant herbicides to achieve a stale seedbed and a dense weed-free cover crop is generally an inexpensive, more environmentally friendly use of herbicides than if applied later in conjunction with production of the transplanted crop.

(C). Canopy closure within the twin-row area (2 feet) occurred in approximately 5 weeks and virtually eliminated inrow weed growth. In all treatment plots, the fast-growing broccoli canopy outgrew weeds germinating between the broccoli twin rows in untreated plots (F and R), resulting in no broccoli yield reductions, compared with herbicide-treated plots (H/F and H/R). Narrow-row spacing (more equidistant plant populations) is known to increase the ability of row crops *to* compete with weeds (Forcella and Burnside, **1994).** Thus, the need for herbicides can be reduced or even eliminated when large, vigorous transplants are effectively set in narrow twin rows in persistent, heavy-residue NT systems.

Literature Cited

Dabney, S.M., and J.L. Griffeth. 1987. Efficiency of burndown herbicides on winter legume cover crops, p, 122-134. In J.F. Power (ed). Legume cover crops in conservation tillage production systems. Soil Cons. Soc. Amer., Ankeny, IA.

Dabney, S., M., N.W. Buehring, and D. B. Reginelli. 1991. Mechanical control of legume cover crops, p. 146-147. In W.L. Hargrove (ed). Cover crops for clean water. Soil and Water Cons. Soc., Ankeny, IA.

Forcella, F., and O.L. Burnside. 1994. Pest management—weeds, p. 157-197. In J.L. Hatfield, and D.L. Karlen (eds). Sustainable agriculture systems. Lewis Publ., Boca Raton, FL.

Hoffman, M.L., E.E. Reenier. and J. Cardina. 1993. Weed and corn *(Zea* Mays) responses to hairy vetch *(Viciavillosa)* cover crop. Weed Technol. 7:594-599.

Hoyt, G.D., D.W. Monks, and T.J. Monaco. 1994. Conservation tillage for vegetable production. HortTechnology 4(2):129-135.

Infante, M.L., and R.D. Morse. 1995. Integration of no-tillage and overseeded legume living mulches for transplanted broccoli production. HortScience (in press).

Morse, R.D. 1993. Components of sustainable production systems for vegetables—conserving soil moisture. HortTechnology 3(2):211-214.

Morse, R.D. 1995. In-row soil loosening improves plant survival and yield of no-till cabbage and broccoli. In K.J.Bradford and T.K.Hartz (eds). Proc. Fourth Nat. Symp. on Stand Establishment (April 23-26, 1993, Monterey, CA.

Morse, R.D., D.H. Vaughan, and L.W. Belcher. 1993. Evolution of conservation tillage systems for transplanted crops; potential role of the Subsurface Tiller Transplanter (SST-T), p. 145-151. *In* P.K. Bollich (ed). Proc. Southern Conservation Tillage Conference for Sustainable Agriculture, Monroe, LA.

Schlotzhauer, S.D., and R.C. Littell. 1987. SAS system for elementary statistical analysis. SAS Institute, Inc. Cary, ,NC.

Serage, T.I. 1993. Effects of overseeded legume living mulches and tillage on weed suppression and broccoli yield. MS Thesis, Virginia Polytech. Inst. and State Univ., Blacksburg, VA.

Standifer, L.C., and C.E. Beste. 1985. Weed control methods for vegetable production with limited tillage, p. 93-100. In A.F. Wiese *(ed).* Weed control in limited tillage systems. Weed Sci. Soc. Amer., Champaign, IL.

Swanton, C.J., and S.F. Weise. 1991. Integrated weed management: The rational and approach. Weed Technol. 5:657-663.

Virginia commercial vegetable production recommendations. 1994. VA Coop. Ext. Serv. Publ. 420-456.

Wicks, G.A., O.C. Burnside, and W.L. Felton. 1994. Weed control in conservation tillage systems, p. 211-244. In P.W. Unger (ed). Managing agricultural residues. Lewis Publ., Boca Raton, FL.