FALL AND SPRING BROCCOLI YIELDS AND WEED CONTROL UNDER NO-TILL AND CONVENTIONAL TILLAGE WITH OVERSEEDED LEGUME LIVING MULCHES

by

Michelle Louise Infante

Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Horticulture

APPROVED:

R. D. Morse, Chairman

C. R. O'Dell

H. E. White

November 21, 1994

Blacksburg, Virginia

FALL AND SPRING BROCCOLI YIELDS AND WEED CONTROL UNDER NO-TILL AND CONVENTIONAL TILLAGE WITH OVERSEEDED LEGUME LIVING MULCHES

by

Michelle Louise Infante

R. D. Morse, Chairman

Horticulture

(ABSTRACT)

Experiments were conducted with 'BigSur' broccoli (*Brassica oleracea* var. *italica* Plenck) at two sites in fall of 1993 and at two sites in the spring of 1994 on a Hayter loam in southwestern Virginia. Objectives were to determine the tillage main-plot (CT = conventional tillage, and NT = no-tillage) and weed-control subplot (C = no overseeding or preemergent herbicide; HB = oxyfluorfen; RC = red clover (*Trifolium pratense* L.); WC = Dutch white clover (*Trifolium repens* L.); and HV = hairy vetch (*Vicia villosa* Roth) effects on broccoli yield and weed suppression. At all sites, marketable broccoli yield was equal or higher in NT than CT and was unaffected by overseeded legume living mulches. Overseeded legumes suppressed weeds as well as the HB in three of the four sites. These data show that the NT systems used in these experiments can suppress weeds and produce high broccoli yields and that overseeded legume living mulches can be effectively established after transplanting to suppress weeds without reducing broccoli yield.

DEDICATION

I would like to dedicate this thesis to my Father, Mother, Rocco, Grandma Infante, Grandma Rinyu, Diana, and Tara for all of the years of love and support in everything I do.

ACKNOWLEDGEMENTS

I would like to thank my committee - Dr. Ronald Morse, Charlie O'Dell, and Dr. Harlan White for their guidance in preparing my thesis and for their belief in my abilities. I would also like to expresses my sincere appreciation for all of the help I received from the farm crew and from fellow graduate students. I am also grateful to Dr. Richard Harkess for his computer assistance and sincere friendship. A special thanks goes to Dr. Neil Vincent of Delaware Valley College for helping me to believe in myself and for convincing me to pursue a graduate degree. Lastly I would like to acknowledge Dr. John Barden, Donnie Sowers, and Tom Freeman for always putting a smile on my face.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Sustainable agriculture has gained new popularity due to concerns for the environment and the need for efficient agriculture systems. In conventional vegetable production systems, control of insects, diseases, and weeds is becoming more difficult because of an ineffective and a dwindling number of labelled pesticides. Research is needed to develop alternative pest control measures in order for growers to continue to produce a sufficient quantity and quality of produce, here in the United States and around the world.

Sustainable production methods not only work to control pests naturally while conserving and often improving agricultural lands. With prime farmland diminishing, growers must prepare for the future by using conservation tillage systems to preserve the land they have and to convert marginal soils into productive cropland. Reduced tillage methods have been utilized by agronomists for many years. Vegetable producers, however, have been reluctant to adopt conservation tillage because research and on-farm trials have not given consistent positive results (Wilhoit et al., 1990). To help vegetable growers meet the demanding changes that challenge the industry, research is needed to identify and resolve the factors limiting adoption of conservation tillage systems.

Reduced tillage greatly improves soil moisture conditions and helps plants to survive during dry periods. In many studies no-till soil moisture is higher than in conventional-tillage soil throughout the growing season (Knavel and Herron, 1981). Higher yields with no-till are often associated with greater availability and more efficient use of soil water (Doss et al., 1981). Increased soil moisture aids in crop growth, but can also benefit growth of weed species in the field. Weed control may be more difficult with no-till culture compared to conventional tillage (Mullins et al., 1980). Living mulches can be used to control weeds in no-till systems. There are many cover crop options and management decisions to make when using a living mulch to suppress weeds. It is particularly important, that the living mulch not compete with the main crop for water, nutrients, space, and sunlight (Nicholson and Wein, 1983; Lanini et al., 1989; Wiles et al., 1989; Grubinger and Minotti, 1990). Along with controlling weeds in a no-till system, living mulches can minimize erosion, decrease soil temperature, improve water infiltration rate, improve soil structure, favor microbial activity, and increase crop yield (Alobundu and Okigbo, 1983). The benefits of living mulches have similarities with benefits of no-till systems.

The purpose of this research was to determine the feasibility of producing broccoli in an irrigated no-till system, utilizing overseeded living mulches for weed control. Broccoli yield was used as an indicator of tillage and living-mulch results. Dry weights of weed biomass were taken to determine effectiveness of the living mulches. Tillage and living-mulch combinations were evaluated for synergistic effects.

LITERATURE REVIEW

Vegetable Crop Yields in No-Till (NT) vs Conventional Tillage (CT). Reported yields of vegetable crops under a NT system have been varied. Problems with NT vegetables need to be overcome before NT is a widely accepted practice for vegetable production. Seeding and transplanting vegetables directly into a killed cover crop may be mechanically difficult, possibly requiring alterations to machinery (Shelby et al., 1988; Wilhoit et al., 1990). When planting into a NT field, plant stand tends to be a major problem due to poor root-to-soil or seed-to-soil contact (Zartman et al., 1976; Knavel and Herron, 1981; DeGregorio and Ashley, 1986; Knavel and Herron, 1986; Love, 1986; Asoegwu, 1987; South, 1993). When vegetable plants such as tomato (Price and Baughan, 1987), pepper (Knavel et al., 1977), and cabbage (Knavel and Herron, 1981) are transplanted into a NT field initial growth is often delayed compared to transplant into a CT field (Van Wijk et al., 1959). Besides poor contact with soil, NT fields also have lower soil temperatures, especially under spring conditions (Petersen et al., 1986; Price and Baughan, 1987). The delay of initial growth may slow maturation of some crops and may also cause decreases in yield (Love and Morse, 1986; Price and Baughan, 1987; Sterrett et al., 1991). However, some researchers have found no delay in maturation with some crops when planting into a NT system (Knavel and Herron, 1981; Knavel 1989).

Equal or increased yields of some vegetable crops have been reported in NT systems compared to CT systems for crops such as cucumber, cabbage, squash, tomato, sweet corn, snap bean, carrot, and watermelon (Knavel et al., 1977; Orzolek and Carrol, 1978; Mullins et al., 1980; Morse et al., 1982; Morse and Seward, 1986; Mullins et al., 1988; Neilsen and Anderson, 1989). Higher yields of these crop in a NT system may be attributed to higher soil moisture throughout the growing season (Doss et al., 1981; Morse et al., 1982; and Asoegwu, 1987). Knavel and Herron (1981) and Love (1986) found that NT soil moisture was generally higher than that for CT soils throughout their studies. Decreased crop yields have been reported in NT systems for crops such as sweet corn (Petersen et al., 1986), egusi-melon and okra (Asoegwu, 1987), spring cabbage (Knavel and Herron, 1986), and tomato, pepper, and cucumber (Knavel et al., 1977). Lower yields could have been the result of poor plant stands and cooler soil temperatures. The production of agronomic crops using NT has been practiced for more than two decades (Drost and Price, 1991). More research is needed to evaluate the use of NT for vegetable crops in certain areas, in different seasons, and with different crop species before this practice will become widely accepted in olericuture (Simpson and Gumbs, 1985).

Weed Control with NT and CT. Weed control is a dilemma in all crop production practices. NT and CT both have their benefits and drawbacks in controlling weeds. Benefits of a NT system for weed control are related to the ability of cover crop residues to inhibit successful weed seed germination (Lal et al., 1991).

Researchers have reported variable degrees of weed control by cover crop residues (Echtenkamp and Moomaw, 1989; Janke and Peters, 1989; Weston, 1990). Residues from killed cover crops can provide good weed control for a short period of time, but additional weed control measures may be necessary for prolonged periods of weed control (Weston, 1990). Killing cover crops and additional control measures in a NT system usually mean more use of chemical herbicides with NT than with CT (Wallace and Bellinder, 1992). Another disadvantage of NT is an increase in perennial weed problems (Putnam, 1990). Weed control is generally more difficult in a NT system than in a CT system (Beste, 1973; Knavel et al., 1977; Mullins et al., 1988). Organic matter from residue can bind herbicides and can prevent them from penetrating to the soil surface.

Conventional-tillage practices also use herbicides for weed control, but unlike NT, it also uses mechanical means for weed control. Disadvantages of CT practices include soil compaction, reduced soil moisture, erosion, and redistribution of weed seed and vegetative parts (Asoegwu, 1987; Nelson et al., 1989; Wallace and Bellinder, 1992). Nelson et al. (1989) found that CT practices have little effect on kinds and numbers of annual weeds in cereal grains. Conventional-tillage practices also result in greater wind and water erosion.

Soil erosion and other environmental concerns have been major reasons for a shift toward sustainable practices like NT. Another reason is to gain greater efficiency in agricultural systems. With NT fewer trips are made across a field, which saves on fuel and reduces soil compaction. Timing and flexibility of cultural operations (planting, spraying, harvesting, etc.) are often greatly improved with NT, compared to CT (Knavel et al., 1977; Doss et al., 1981). However, moving machinery onto any tillage system under wet conditions will increase soil compaction. Cover crops combined with a judicious use of herbicides when needed, may suppress weeds effectively and reduce herbicide use in vegetables and other crops (Beste, 1973; Wallace and Bellinder, 1992).

Cover Crop Effects on Weed Control. Certain cover crops seem to selectively inhibit seed germination of weeds and appear to be a viable strategy for weed suppression in agroecosystems (Shilling, 1983; Barnes and Putnam, 1986; Putnam, 1990). Cover crop weed inhibition may be due to factors such as poor penetration of a residue by an emerging seedling, reduced availability of essential nutrients during residue decomposition, allelopathic effects of residues, and inhibitory effects of soil pathogens harbored by decomposing residues (Weston, 1990). Barnes and Putnam (1986) reported that a living cover of spring-planted winter rye (*Secale cereale* L.) reduced early season biomass of common lambsquarters by 98%, large crabgrass by 42%, common ragweed by 90%, and total weed biomass by 94% over controls where no rye was present. Allelopathy and competition for water, light, and nutrients may all contribute to these reductions. With a killed cover crop water competition is absent and, in fact, soil moisture is higher under the residue which may enhance germination. Even if germination occurs, there are other factors which inhibit growth of weed seedlings under cover crop residues (Wallace and Bellinder, 1992).

Reports of inhibition of weed seeds under a NT-cover crop situation may also suggest inhibition of crop seeds. Crop stand and vigor may be reduced by water soluble allelochemicals released from decomposing cover crop residues (Wallace and Bellinder, 1992). DeAlmeida (1985) reported that water extracts of several winter cover crops reduced germination and growth of crops such as cotton, rice, beans, and corn. Under simulated conditions in the greenhouse, Barnes and Putnam (1986) found that rye residues reduced emergence of lettuce and proso millet seeds. Lal et al. (1991) reported that corn and soybean production in killed-rye cover crops sometimes results in yield losses. However, in NT field studies Beste, (1973), observed no stand reduction or crop injury to cucumber, tomato, or lima bean. Further studies are needed to determine which cover crops will provide prolonged weed suppression while minimizing interference with establishment and growth of row crops (Weston, 1990).

Yield Results with Living Mulches. Living mulches are established before the main crop is planted or are interseeded/overseeded at the same time or after the main crop is planted (Regnier and Janke, 1990). Both methods can have beneficial effects in a row crop situation as long as competition with the row crop for water, nutrients, and light does not occur (Graham and Crabtree, 1987; Lal et al., 1991). Some researchers have reported higher yields of vegetables when grown in a living mulch situation (Graham and Crabtree, 1987; Foulds et al., 1991; Mangan et al., 1991; Costello and Altieri, 1994). The reported use of living mulches in vegetable crop production is minimal compared to reports of use in agronomic crops.

The overseeding of legumes into small grains in early spring as the ground is thawing has been a standard practice of farmers for several decades as a low cost, efficient way of establishing a sod rotation (Palada et al., 1983). Overseeding legumes has helped to maintain soil fertility and has provided excellent ground cover for erosion control and weed inhibition (Akobundo, 1980; Palada et al., 1983; Costello and Altieri, 1994). Yields of agronomic crops have varied when grown with overseeded or preestablished living mulches. Dyke and Barnard (1976) reported lower yields of cereals because of competition with the legumes. A living mulch system is risky without irrigation due to competition for water between the living mulch and the crop (Neilsen and Anderson, 1989; Grubinger and Minotti, 1990). Other reports have shown increased yields in crops like corn, soybean, wheat, and other grains when grown in a legume living mulch situation (Stewart et al., 1980; Akobundu and Oligbo, 1983; Elkins et al., 1983; Palada et al., 1983; Cook and King, 1991). Legumes used as a living mulch can produce excellent grain yields with a considerable reduction in applied N fertilizer (Elkins et al., 1983). More research is needed to evaluate the use of living mulches in vegetable production.

Competitive Effects of Living Mulches for Weed Control:

Preestablished LM. To avoid crop yield reduction, growth of the living mulch must be suppressed. However the living mulch must have the ability to control weed growth (Loughran and Hartwig, 1987). Preestablished living mulches may be killed-off by herbicides, mowed, or left undisturbed before the crop is planted. Most often the living mulch is suppressed before the crop is planted to avoid competition (Lanini et al., 1989; Wiles et al., 1989; Grubinger and Minotti, 1990). If the living mulch is unsuppressed it may become too vigorous and reduce yields (Nicholson and Wien, 1983). Preestablished living mulch systems are time and labor intensive which may explain why farmers have not readily adopted this technique (Schonbeck, 1988). However, choosing a living mulch with a low-growing, dense growth habit can provide effective weed suppression without competing with the row crop for resources (Vrabel et al., 1980; Nicholson and Wien, 1983; Altieri et al., 1985, Hynes and Hartwig, 1985; Enache and Ilnicki, 1986). Living mulch ground covers which provide the best growth habit to control weeds with limited competition to the row crop include white clover (Vrabel et al., 1980), crown vetch (Hynes and Hartwig, 1985), subterranean clover (Lal et al., 1991), crimson clover and hairy vetch (Foulds et al., 1991) and turfgrasses (Nichloson and Wien, 1983).

Overseeded LM. Overseeding has shown increasing promise in weed control due to less intense management and less competition with the crop plant than preestablished LM.. Vrabel et al. (1980) were most successful in suppressing weeds and obtaining high yields of sweet corn when the legumes and sweet corn were planted at the same time.

Overseeded legume living mulches have an advantage over selective herbicides in that they competitively control all weeds (Evers, 1983). Research is needed to evaluate cover crops as living mulches and situations in which preestablished and overseeded living mulches will work best.

Other Aspects of Living Mulch Systems. Living mulches have other benefits in addition to weed control in a sustainable system. A living mulch ground cover can also help reduce some harmful insect infestations and may provide a stable environment for beneficial insects. Results of a study in the Salinas Valley, California showed that cabbage aphid infestations were lowered on broccoli grown in living mulch compared to clean culture, possibly because light reflectance patterns are less attractive to incoming aphids (Costello and Altieri, 1994). Another benefit of a living mulch is as a wind break for low-growing crops. The wind-break action reduces abrasion and particulate damage to the leaf cuticle and epidermis of plants. Mechanical damage to leaves may allow for disease infection to occur, as in the case of leaf scorch infection in strawberry (Newenhouse and Dana, 1989 and Putnam, 1990).

A living mulch system also has disadvantages. Heavy plant cover with high humidity provides an excellent environment for buildup of insects and diseases (Palada et al., 1983). Yield decreases and maturity delays in a living mulch system are other potential disadvantages and are most often attributed to competition for nutrients or water (Graham and Crabtree, 1987). Living mulch species need to be evaluated further before they are widely accepted in horticultural crop production.

Crop Canopy Closure Effects on Weed Control. Crop plants are able to compete well with weeds after they are established and are able to shade the soil surface within the row (Stoller and Myers, 1989). Weed control practices may be more effective when crops are planted at closer than standard row spacings. Weed suppression occurs sooner with narrow row spacing than with wider spacing (Williams et al., 1973; Teasdale and Frank, 1982; Tollenaar et al., 1994). Selecting high-yielding crop cultivars or hybrids that are relatively competitive with weeds also constitutes a potentially viable means of enhancing integrated weed control (Staniforth, 1961; Lanini and strange, 1991; Tollenaar et al., 1994). If crops can reduce incident light by 50% or more, weeds will seldom become a problem (Sweet, 1974).

While canopy closure shades out weeds, it can also shade out living mulches. The amount of living mulch ground cover is subject to several factors including light transmission, soil moisture, and weed-crop competition. These factors limit growth and survival of living mulch species under crop canopies (Palada et al., 1983). With more attention paid to natural methods of weed control, herbicide usage can be decreased and more efficient sustainable methods can be adopted.

Nitrogen Aspects of Living Mulches and Tillage. Legume species can fix atmospheric nitrogen when symbiotic *Rhizobium* species infect roots and form nodules.

Nitrogen can be provided by exudates from effective nodules or by decomposition of legume residues. Due to the relatively low C/N ratios of legume residues, decomposition of a legume plant releases inorganic N into the soil system (Lal et al., 1991). The total quantity of N produced by a legume depends on both biomass and N concentration in the tissue. Based on tissue nitrogen content and dry matter production, clovers, alfalfa, and vetch can fix from 76 to 367 kg of N/ha, which is sufficient to meet most of the N requirement of field and vegetable crops (Palada et al., 1983). Legumes as a living mulch must be well established in order to provide N for the companion crop. White and Scott (1990) found that legume mulches did not appear to enhance N nutrition in the first year, but clovers did appear to contribute N to rye in the second year of growth.

No-till systems tend to need more N fertilization than do CT systems (Skarphol et al., 1987). More fertilizer N is often unavailable to plants under NT because of increased immobilization, denitrification, and leaching (Skarphol et al., 1987). CT systems may have more available N because tillage may influence biotic processes and soil physical properties to indirectly improve N nutrition of crops (Grubinger and Minotti, 1990). However, Knavel and Herron (1981) found no difference in N leaf content of spring broccoli planted in NT and CT. More studies need to be done to accurately assess N availability in sustainable systems.

LITERATURE CITED

Akobundu, I.O. 1980. Live mulch: a new approach to weed control and crop production in the tropics. Proc.1980 British Crop Protection Conf.-Weeds. 2:377-382.

Altieri, M.A., R.C. Wilson, and L.L. Schmidt. 1985. The effects of living mulches and weed cover on the dynamics of foliage-and-soil-arthropod communities in three crop systems. Crop Protection. 4:201-213.

Asoegwu, S.N. 1987. Comparison of tillage systems for the production of egusi-melon (*Colocynthus citrullus* L.) and okra (*Abelmoschus esculentus* L.) in eastern Nigeria. Crop Res. (Hort. Res.) 27:77-90.

Barnes, J.P. and A.R. Putnam. 1986. Evidence for allelopathy by residues and aqueous extracts of rye (*Secale cereale*). Weed Sci. 34:384-390.

Beste, C.E. 1973. Evaluation of herbicides in no-till planted cucumbers, tomatoes, and lima beans. Proc. Northeastern Weed Sci. Soc. 27:232-239.

Cook, M.G. and L.D. King. 1991. Crimson clover in a reduced-chemical-input croping system, p.176-177. In: W.L. Hargrove (ed.) Cover Crops for Clean Water. Soil and Water Conserv. Soc., Jackson, TN.

Costello, M.J. and M.A. Altieri. 1994. Living mulches suppress aphids in broccoli. California Agriculture. 48(4):24-28.

De Almeida, F.S. 1985. Effects of some winter crop mulches on soil weed infestation. Proc. Br. Weed Cont. Conf. 2:651-659.

DeGregorio, R.E. and R.A. Ashley. 1986. Screening living mulches/cover crops for no-till snap beans. Proc. N.E. Weed Sci. Soc. 40:87-91.

Doss, B.D., J.L. Turner, and C.E. Evans. 1981. Influence of tillage, nitrogen, and rye cover crop on growth and yield of tomatoes. J. Amer. Soc. Hort. Sci., Camb. 87:123-126.

Drost, D.T. and H.C. Price. 1991. Effect of tillage system and planting date on the growth and yield of transplanted tomato. HortScience 26(12):1478-1480.

Dyke, G.V. and A.J Barnard. 1976. Suppression of couch grass by Italian ryegrass and broad red clover undersown in barley and field beans. J. Agric. Sci., Camb. 87:123-126.

Echtencamp, G.W. and R.S. Moomaw. 1989. No-till corn production in a living mulch system. Weed Technol. 3:261-266.

Elkins, D., D. Frederking, R. Marashi, and B. McVay. 1993. Living mulch for no-till corn and soybeans Zea mays, Glycine max, erosion hazard. J. Soil Water Conserv. 38(5):431-433.

Enache, A.J. and R.D. Ilniki. 1986. Tillage and mulch systems study in field corn. New Jersey Agriculture Exp. Station Pub. No. J-15173-1-86:13-15.

Evers, G.W. 1983. Weed control on warm season perennial grass pastures with clovers. Crop Science. 23:171.

Foulds, C.M., K.A. Stewart, and R.A. Samson. 1991. On-farm evaluation of legume interseedings in broccoli, p.179-180. In: W.L. Hargrove (ed.). Cover crops for clean water. Soil and Water Conserv. Soc., Jackson, TN.

Graham, M.B. and G. Crabtree. 1987. Management of competition for water between cabbage (*Brassica oleracea*) and a perennial ryegrass (*Lolium perenne*) living mulch. Proc. West Soc. Weed Sci. 40:113-117.

Grubinger, V.P. and P.L. Minotti. 1990. Managing white clover living mulch for sweet corn production with partial rototilling. Amer. J. Alter. Agr. 5(1):4--12.

Hynes, E.M. and N.L. Hartwig. 1985. Crownvetch establishment following small grains and preceding winter wheat. Proc. N.E. Weed Sci. Soc. 39:34-38.

Janke, R. and S. Peters. 1989. Cover-crops, crop rotation, and weed control in sustainable croping systems. In Proc., Third Penn-Jersey Tillage Conf. Lehigh Univ., Bethlehem, PA.

Knavel, D.E., J. Ellis, and J. Morrison. 1977. The effects of tillage systems on the performance and elemental absorption by selected vegetable crops. J. Amer. Soc. Hort. Sci. 102(3):323-327.

Knavel, D.E., and J.W. Herron. 1981. Influence of tillage system, plant spacing, and nitrogen on head weight, yield, and nutrient concentration of spring cabbage. J. Amer. Soc. Hort. Sci. 106(5):540-545.

Knavel, D.E. and J.E. Herron. 1986. Response of vegetable crops to nitrogen rates in tillage systems with and without vetch and ryegrass. J. Amer. Soc. Hort. Sci. 111(4):502-507.

Knavel, D.E. 1989. Double-cropping fall cabbage by no-tillage and conventional tillage systems. Appl. Agr. Res. 4(4):270-274.

Lal, R., E. Regnier, D.J. Eckert, W.M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture, p. 1-11. In: W.L. Hargrove (ed.). Cover crops for clean water. Soil and Water Conserv. Soc., Jackson, TN.

Lanini, W.T. and M.E. Strange. 1991. Low-input management of weeds in vegetable fields. California Agr. 45(1):11-13.

Lanini, W.T., D.R. Pittenger, W.L. Graves, F. Munoz, and H.S. Agamalian. 1989. Subclovers as living mulches for managing weeds in vegetables. California Agr. 43(6):25-27.

Loughran, J.C. and Hartwig, N.L. 1987. Crownvetch as influenced by tillage in a corn-crownvetch living mulch system. Proc. Annu. Meet. Northeast Weed Sci. Soc. Beltsville, MD. 41:7-12.

Love, V.A. 1986. Conservation tillage methods for cabbage production. Masters Thesis, Virginia Polytech. Inst. and State Univ., Blacksburg, Virginia.

Mangan, F.X., S.J. Herbert, and G.L. Litchfield. 1991. Cover crop management systems for broccoli, p.178-179. In: W.L. Hargrove. Cover Crops for Clean Water. Soil and Water Conserv. Soc., Jackson, Tenn.

Morse, R.D. and D.L. Seward. 1986. No-tillage production of broccoli and cabbage. Applied Agr. Res. 1(2):96-99.

Morse, R.D., C.M. Tressore, W.E. Chappel, and C.R. O'Dell. 1982. Use of no-tillage for summer vegetable production. The Veg. Growers News 37(1):1.

Mullins, C.A., R.A. Straw, and D.L. Coffey. 1988. Production of snap beans as affected by tillage method and row spacing. J. Amer. Soc. Hort. Sci. 113(5):667-669.

Neilsen, J.C. and J.L. Anderson. 1989. Competitive effects of living mulch and no-till management systems on vegetable productivity. p 148-149. Res. Prog. Rep. West. Soc. Weed. Sci.

Nelson, J.E., B. Mullin, D. Wichman, and K. Schweitzer. 1989. Survey of weeds in conservation and conventionally tilled grain fields in Montana. Montana State Univ. Montana Ag. Ext. Station, Moccasin.

Newenhouse, A.C. and M.N. Dana. 1989. Grass living mulch for strawberries. J. Amer. Soc. Hort. Sci. 114(6):859-862.

Nicholson, A.G. and H.C. Wien. 1983. Screening turfgrasses and clovers for use as living mulches in sweet corn and cabbage. J. Amer. Soc. Hort. Sci. 108(6):1071-1076.

Orzolek, M.S. and R.B. Carroll. 1978. Yield and secondary root growth of carrots as influenced by tillage system, cultivation, and irrigation. J. Amer. Soc. Hort. Sci. 103(2):23.

Palada, M.C., S. Ganser, R. Hofstetter, B. Volak, and M. Culik. 1983. Association of interseeded legume cover crops and annual row crops in year-round cropping systems. p. 193-213. In: W. Lockeretz (ed.). Environmentally sound agriculture. Praeger, NY.

Petersen, K.L., H.J. Mack, and D.E. Booster. 1986. Effect of tillage on sweet corn development and yield. J. Amer. Soc. Hort. Sci. 111(1):39-42.

Price, H.C. and R.A. Baughn. 1987. Establishment of fresh market tomatoes in a no-till system. Acta Hort. 198:261-264.

Putnam, A.R. 1990. Vegetable weed control with minimal herbicide inputs. HortScience 25(2):155-159.

Regnier, E.E. and R.R. Janke. 1990. Evolving strategies for managing weeds, p. 174-202. In: C.A. Edwards, R. Lal, P. Madden, R.H. Miller, and G. House (eds). Sustainable agriculture systems. Soil and Water Conserv. Soc., Ankeny, IA.

Schonbeck, M.W. 1988. Cover cropping and green manuring on small farms in New England and New York: An informal survey. p 7-22. Res. Rpt. No. 10. New Alchemy Inst. East Falmouth, ME.

Shelby, P.P., Jr., D.L. Coffey, G.N. Rhodes, Jr., and L.S. Jeffery. 1988. Tomato production and weed control in no-tillage versus conventional tillage. J. Amer. Soc. Hort. Sci. 113(5):675-678.

Shilling, D.G. 1983. The suppression of certain weed species by rye (*Secale cereale* L.) mulch. Isolation, characterization, and identification of water-soluble phytotoxins from rye. Ph.D. Dissertation. N.C. State Univ., Raleigh.

Simpson, L.A. and F.A. Gumbs. 1985. A comparison of conventional tillage and no-till for cowpea (*Vigna unguiculata* L. Walp.) production. Trop. Agr. 62(3):248-251.

Skarphol, B.J., K.A. Corey, and J.J. Meisinger. 1987. Response of snap beans to tillage and cover crop combinations. J. Amer. Soc. Hort. Sci. 112(6):936-941.

South, L. 1993. No-till transplanter scales mounters. Amer. Veg. Grower 41(5):14-16.

Staniforth, D.W. 1961. Response of corn hybrids to yellow foxtail competition. Weeds. 9:132-136.

Sterrett, S.B., C.W. Coale, Jr., C.P. Savage, Jr. 1991. Comparison of management techniques for broccoli production using a systems approach. HortScience. 26(5):599-602.

Stewart, R.H., K.W. Lynch, and E.M. White. 1980. The effect of growing clover cultivars in association with barley cultivars upon grain yield of the barley crop in the year of sowing and the subsequent year. J. Agr. Sci., Camb. 95:715-720.

Stoller, E.W. and R.A. Myers. 1989. Effects of shading and soybean (*Glycine max* L.) interference on *Solanum ptycanthym* (Dun.) (eastern black nightshade) growth and development. Weed Res. 29:307-316.

Sweet, R.D., C.P. Yip, and J.B. Sieczka. 1974. Crop varieties: can they suppress weeds?. N.Y. Food and Life Sci. Quart. 7(3):3-5.

Teasdale, J.R. and J.R. Frank. 1983. Effect of row spacing on weed competition with snap beans. Weed Science 31:81-85.

Tollenaar, M., S.P. Nissanka, A. Aguilera, S.F. Weise, and C.J. Swanton. 1994. Effect of weed interference and soil nitrogen on four maize hybrids. Agron. J. 86:596-601.

Van Wijk, W.R., W.E. Larson, W.C. Burrows. 1959. Soil temperature and the early growth of corn from mulched and unmulched soil. Soil Sci. Soc. Amer. Proc. 23:428-434.

Vrabel, T.E., P.L. Minotti, and R.D. Sweet. 1980. Seeded legumes as living mulches in sweet corn. Proc. N.E. Weed Sci. Soc. 34:171-175.

Wallace, R.W. and R.R. Bellinder. 1992. Alternative tillage and herbicide options for successful weed control in vegetables. HortScience 27(7):745-749.

Weston, L.A. 1990. Cover crop and herbicide influence on row crop seedling establishment in no-till culture. Weed Sci. 38:166-171.

White, J.G. and T.W. Scott. 1991. Effects of perennial forage-legume living mulches on no-till winter wheat and rye. Field Crop Res. 28:135-148.

Wiles, L.J., R.D. William, G.D. Crabtree, and S.R. Radesevich. 1989. Analyzing competition between a living mulch and a vegetable crop in an interplanting system. J. Amer. Soc. Hort. Sci. 114(6):1029-1034.

Wilhoit, J.H., R.D. Morse, and D.H. Vaughn. 1990. Strip-tillage production of summer cabbage using high residue levels. Applied Agri. Res. 5(4):338-342.

Williams, C.F., G. Crabtree, H.J. Mack, and W.D. Laws. 1973. Effects of spacing on weed competition in sweet corn, snap beans, and onions. J. Amer. Soc. Hort. Sci. 98(6):526-529.

Zartman, R.E., R.E. Phillips, and W.O. Atkinson. 1976. Tillage and nitrogen influence on root densities and yield of burley tobacco. Tobacco Sci. 136:35-38.

MATERIALS AND METHODS

Field experiments were conducted at two sites (S1 and S2) in the fall of 1993 (FC) and at two sites (S1 and S2) in the spring of 1994 (SC) at the Virginia Tech Kentland Agricultural Research Farm in Blacksburg, Virginia. The soil at all sites was a Hayter loam (fine-loamy, mixed, mesic, Ultic Hapludaf), with a pH varying from 6.5 to 7.0. Soil tests showed that P, K, Ca, and Mg levels at all sites were very high, high, very high, and high, respectively. The experimental design was a split plot with four replications. Main plots (FC = 7.3m x 15.4m; SC = 30.5m x 3.7m) were tillage systems: no-till (NT) and conventional tillage (CT). Subplots (FC = 7.3m x 3.1m; SC = 6.1m x 3.7m) were weed control treatments: control (C--no legume mulch and no preemergent herbicide), herbicide (HB--one application of preemergent herbicide), red clover (RC--*Trifolium pratense* L.), Dutch white clover (WC--*Trifolium repens* L.), and hairy vetch (HV--*Vicia villosa* Roth.).

Tillage systems. On 7 June 1993, foxtail millet (*Setaria italica* L.) was drilled in FC/S1 at 34 $kg.ha^{-1}$ and soybean (*Glycine max* L.) was drilled in FC/S2 at 98 $kg.ha^{-1}$. On 11 November 1993, cereal rye (*Secale cereale* L.) was drilled in both SC/S1 and SC/S2 at 188 $kg.ha^{-1}$. The cover crops were desiccated 1 week prior to planting broccoli with N-(phosphonemethyl) glycine (glyphosate) at 3.4 kg a.i. ha^{-1}. Prior to transplanting, the desiccated cover crop residues were either flail mowed in FC sites or left intact in SC sites. Cover crop resides were left on the surface in NT plots and were incorporated using a rotovator leaving a clean surface in CT plots. For both NT and CT, HB subplots were sprayed with 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene (oxyfluorfen) at 5.6 kg a.i. ha^{-1} prior to transplanting broccoli. Above ground cover crop residues in dry weights were estimated to be 6.2, 2.8, 2.1, and 1.9 $Mg.ha^{-1}$ in FC/S1, FC/S2, SC/S1, and SC/S2, respectively. Dry weights were determined by taking 0.36 m^2 samples from each site and drying them at 70°C for 2 weeks.

Broccoli planting. Bareroot 'BigSur' broccoli (*Brassica oleracea* var. *italica* Plenck) transplants were produced adjacent to the research plots for the FC sites and by Sumner Farms in Tifton, Georgia for the SC sites. The transplants were set (FC/S2 = 5 August 1993; FC/S1 = 10 August 1993; SC/S1 and SC/S2 = 28 April 1994) with the Subsurface Tiller-Transplanter (SST-T) (Morse et al., 1993). Granular fertilizer was surfaced banded at planting 8 cm from both sides of each row in FC with (in $kg.ha^{-1}$) 112N-96P-278K-2.2B and in SC sites with 84N-72P-208K-1.7B, using the SST-T (Morse et al., 1993). At head initiation, $NaNO_3$ was sidedressed by hand at 56 kg N ha^{-1}. To ensure a complete stand, transplants that did not survive were replaced by hand. A solid set overhead sprinkler irrigation system was used at all sites throughout the growing season to minimize soil moisture stress. Pesticides were applied at planting and at regular intervals thereafter, according to the Virginia Commercial Vegetable Production Recommendations (Virginia, 1993). Double rows

(40,000 plants ha^{-1}) were planted in each subplot. Rows were spaced 46 cm apart and 76 cm between twin rows (122 cm center to center); in-row spacing was 41 cm between plants.

Legume overseeding. Two days after broccoli transplanting, 17 kg RC ha^{-1}, 11 kg WC ha^{-1}, and 50 kg HV ha^{-1} were surface broadcast by hand on the designated overseeding plots. The legume seeds were inoculated just before planting with the proper Rhizobium species and thoroughly mixed with 1200 g of finely-ground and sieved soybean meal to ensure even distribution when hand sowing.

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

Legume and weed biomass. Living mulch and weed samples (0.36 m^2) were taken between the twin rows (row middles) (BR) and inside the twin rows (IR) 7 weeks in FC sites and 8 weeks in SC sites after broccoli transplanting. Samples were separated for legume and weed portions and dried for 2 weeks at 70°C. The four most prevalent weed species were identified and recorded when samples were taken in the field.

Broccoli harvest. A total of four harvests were taken at weekly intervals for the FC sites, beginning 22 September 1993 in S2 and 26 September 1993 in S1. Three weekly harvests were taken for the SC sites, beginning 8 June 1994 in S1 and 13 June

1994 in S2. Sixteen heads were harvested from the FC sites and 20 heads from the SC sites. Immediately after harvest, heads were cut to a length of 19 cm and fresh weights were recorded.

Statistical analysis. The Statistical Analysis System (SAS) was used to perform all statistical analysis procedures (Scholtzhauer and Littell, 1987). Two-way analysis of variance (ANOVA) was used to determine significance (Norman and Streiner, 1994). Tukey's Honestly Significant Difference (HSD) was used for mean separation (Lentner and Bishop, 1993; Norman and Streiner, 1994).

RESULTS AND DISCUSSION

Legume and weed biomass. In FC/S2, both between-row and in-row HV living mulch (LM) biomass was higher than that of RC and WC (Tables 1 and 2). At all other sites, LM biomass did not differ among legume species. A LM species that has an erect, vigorous growth habit may compete with the row crop for water, nutrients, and light (Graham and Crabtree, 1987; Lal et al., 1991). White clover has a low-growing, dense growth habit, which is highly desirable for weed suppression when using a LM system (Nicholson and Wien, 1983).

Except in FC/S2, compared to the control, the LMs suppressed weeds as well as the HB treatment (Tables 1 and 2). There was no difference in weed suppression among the LM species in all sites. In-row legume, weed, and total (legume + weed) biomass was lower (by 60 to 99%) than corresponding between-row biomass in all sites. Reduced in-row biomass is probably the result of quick canopy closure with the broccoli (Stoller and Myers, 1988; Tollenaar et al., 1994).

Early plant growth. In both FC and SC sites, tillage and weed control method did not affect early growth of transplanted broccoli (Table 3). Researchers have showed that planting into NT systems may delay early plant growth, compared to planting into CT systems (Van Wijk et al., 1959; Knavel et al., 1977; Knavel et al., 1981; Price and Baughan, 1987). Similar growth in NT and CT may have occurred because adequate soil moisture was provided by irrigation throughout the growing season. Also, the rapid growth of the plants in the NT systems may have resulted from the effective in-row soil loosening and transplant root-soil contact achieved using the SST-T (Morse et al., 1993).

Leaf N content. Nitrogen content was not affected by tillage or weed control method in all sites (Table 4). Since the legume LM species were young, actively growing plants during broccoli growth and head development, they would not have provided N for the broccoli crop in that season (White and Scott, 1990). There were no differences in N content of broccoli leaves between the two sites in FC and SC (Table 4). However, broccoli leaves in FC sites had higher N contents than did leaves in SC sites. Rate of N uptake is temperature dependent, being depressed by cooler temperatures (Zsoldos, 1972; Clarkson and Warner, 1979). Therefore, cool springtime soil temperatures in SC possibly reduced N uptake, although leaf N contents in SC were in the sufficiency range (Jones et al., 1991). All plots were given similar amounts of N fertilizer at planting and again at sidedressing; however, differences between FC and SC sites in available soil N could have occurred because of differences in residual available N in the soil at planting and differences in rate of organic matter mineralization during the growing seasons.

Effects of tillage on broccoli yield. Broccoli yields with NT systems were equal to or higher than yields with CT in all sites (Table 5). Higher yields with NT can be attributed to greater weed suppression and less moisture stress in the NT plots

(Asoegwu, 1987; Doss et al., 1991; Morse et al., 1992). The greatest difference in tillage broccoli yields occurred under heavy weed pressure in FC/S2, where CT yields were 25% lower than NT.

Although not significant in all sites, weed suppression tended to be greater (weed biomass was lower) with NT than CT. This difference in weed suppression can be attributed to at least two factors. First, because planting with the SST-T minimized disturbance of both surface residues and surface soil (Morse et al., 1993), the "natural" stale-seedbed soil surface was maintained after planting, which probably resulted in the reduced weed seed germination (Ross and Lembi, 1985). The stale seedbed technique allows weed seed on the soil surface to germinate allowing for control of weed seedlings before the crop is planted. Second, the allelochemicals and smothering effects form the undisturbed, uniformly-distributed cover crop residues probably suppressed weed germination and seedling growth (Wallace and Bellinder, 1992). Although soil moisture was probably improved in the NT plots, which would have also favored weed growth, the combined stale-seedbed and allelopathic/smothering effects apparently more than compensated for the increased weed growth potential, resulting in greater weed suppression in NT plots. This was particularly evident in FC sites, where between-row biomass was reduced in NT by 68% in FC/S1 and 33% in FC/S2; and in-row biomass was reduced in NT plots by 52% in FC/S1 and 73% in FC/S2.

Soil moisture content is almost always higher in NT systems than in CT (Doss et al., 1981; Morse et al., 1982; Asoegwu, 1987). Even in irrigated crops such as in these studies, the soil moisture content in NT plots are normally maintained at a more favorable (more available) level than in CT plots. Although sprinkler-overhead irrigation was applied (weekly if no rainfall events occurred) in these studies to supplement rainfall during the growing season, both NT and CT plots were irrigated simultaneously and received the same amounts of water. Caution was taken to avoid runoff of irrigation water from the experimental sites. Water infiltration is generally improved in NT systems, compared to CT (Coolman and Hoyt, 1993); thus, in heavy rains and/or when excessive irrigation is applied, water runoff is often less in NT systems, particularly on hillslopes (Coolman and Hoyt, 1993).

Following each irrigation or heavy rain during these experiments, evaporation would have been less in the mulched NT plots, resulting in maintenance of the soil moisture content at a more available level (Tessore, 1982; Morse, 1993). The "limited irrigation" regime followed in these experiments is typical of that practiced by the vast majority of growers worldwide who use furrow or sprinkler-overhead irrigation systems (Hiller and Howell,1983). Only with automated trickle-irrigation systems can most growers afford to irrigate frequently enough to maintain the soil moisture content at ideal or optimum levels. Otherwise in most situations with furrow or overhead irrigation systems, growers irrigate less (and often considerably less) than needed, resulting in a fluctuating pattern of soil-moisture content in which intermittent periods of growth-limiting soil-moisture deficits occur throughout the growing season(Unger et al., 1988; Smittle et al., 1994). Thus, because of increased water infiltration and reduced soil-moisture evaporation in NT systems, crop yields and water-use efficiency, even in irrigated fields, are often improved in NT systems (Unger et al, 1988; Coolman and Hoyt, 1993).

Effects of overseeded LMs and weeds on broccoli yield. Growth of the overseeded LMs in all sites were neither detrimental nor beneficial to broccoli growth and yield (Table 5). In three sites (FC/S1, SC/S1, and SC/S2), weeds were relatively sparse and did not reduce yields, compared to the HB (oxyfluorfen-treated) plots. Apparently, in these sites the rapid and complete canopy closure within the broccoli twin rows was sufficient to suppress weed growth in both NT and CT plots (Harper, 1980; Regnier and Janke, 1991). In FC/S2, however, weed biomass was prolific (about 5 to 10 times that of the other sites), resulting in a 25% yield reduction, compared to HB plots. Overseeded LMs in FC/S2 had no effect on weed biomass or broccoli yield. Based on these data, overseeded legumes can decrease weed biomass without reducing broccoli yield when weed pressure is low; however, under heavy weed growth, broccoli yield can be reduced and overseeded LM will have little effect on reducing weed biomass. Apparently, the LM species in these studies could not compete well with the growth of the weed species, especially redroot pigweed (*Amaranthus retroflexus*), in FC/S2 and thus had no effect on broccoli yield.

Both biomass and growth habit (architecture) of the interfering species (weeds and/or LM) could have reduced broccoli growth and crop yield in FC/S2 (Harper, 1983). The rapid growth and eventual height of the in-row biomass, especially redroot pigweed, appeared to be a major factor which reduced broccoli yield in FC/S2. In an earlier experiment, conducted at the Virginia Tech Kentland Agriculture Research Farm, Serage (1993) showed that broccoli yield was only reduced in LM plots in which both between-row (3.1 $Mg.ha^{-1}$) and in-row (1.1 $Mg.ha^{-1}$) total biomass was relatively high; LM plots with high between-row (3.6 $Mg.ha^{-1}$) and low in-row (0.5 $Mg.ha^{-1}$) total biomass had no effect on broccoli yield. Data in FC/S1 (Table 1) showed similar results as Serage (1993)--the combination of high between-row (1.8 $Mg.ha^{-1}$) and low in-row (0.4 $Mg.ha^{-1}$) total biomass interference had no effect on broccoli yield. There was relatively little growth of redroot pigweed in FC/S1, indicating that either there were few seeds of redroot pigweed present and/or that germination and seedling growth were inhibited by the heavy foxtail millet residues (Putnam and Weston, 1986). In FC/S2, the combination of high between-row (5.8 $Mg.ha^{-1}$) and high in-row (1.6 $Mg.ha^{-1}$) total biomass reduced broccoli yield by 25%, compared to HB plots.

High levels of between-row biomass may not reduce crop yield if water and nutrients are not limiting and the between-row biomass (either LM or weeds) has a prostrate growth habit and thus does not tower above (shade) the main crop (Harper, 1983; Regnier and Janke, 1990; Serage, 1993; Costello and Altiere, 1994). In these studies, the rapid canopy closure of the broccoli twin-row system was able to sufficiently suppress all weeds and LMs, except for the redroot pigweed in FC/S2, to avoid yield-limiting competitive effects on broccoli yield. In the SC sites and FC/S1, redroot pigweed did not become a yield-limiting factor, possibly because it was suppressed more by allelochemicals from rye (Shilling , 1983) in SC/S1 and SC/S2 and foxtail millet (Putnam and Weston, 1986) in FC/S1 than from soybean in FC/S2. Also, the sparse flail-mowed soybean residues were rapidly decomposed in FC/S2, leaving a relatively bare surface in NT plots three weeks after planting. The soybean residues were completely incorporated by the rotovator in the CT plots, leaving a clean soil surface. In contrast, the dense flail-mowed foxtail millet residues were persistent, showing relatively slow decomposition during the broccoli growing season. The rotovator did not completely incorporate the chopped foxtail millet residues on the surface, which possibly resulted in some weed suppression from allelochemicals.

The data of these studies show that transplant establishment and crop yields of broccoli were equal or higher when using the SST-T/NT system than with CT. Rapid canopy closure within the broccoli twin rows suppressed weeds and resulted in no yield reduction in control (no herbicide) plots with both NT and CT when weed pressures were relatively low. Weed suppression, however, was best in NT systems and the combination of multiple-row plant arrangement and using dense, allelopathic plant residues in SST-T/NT systems appears to be very promising as we more toward a more sustainable agricultural. Overseeding legume living mulches suppressed weeds without reducing broccoli yields and in high-fertility-irrigated fields appears to be a potentially useful method of establishing an overwintering cover crop, reducing soil erosion, and maintaining or even improving soil productivity.

Table 1. Effects of tillage and weed control method on legume, weed, and total biomass in fall, 1993.[Z]

Weed control method (WCM)	Site 1[Y]			Site 2		
	NT	CT	WCM Mean	NT	CT	WCM Mean
			Between row living mulch ($kg \cdot ha^{-1}$)			
Red clover	656a	1657a	1157	463b[X]	151a	307
White clover	520a	1409a	964	484b	463a	473
Hairy vetch	430a	366b	398	1442a	538a	990
Tillage mean	535	1144		796	384	
Treatment effects						
Tillage (T)		*			*	
WCM		NS			*	
T x WCM		*			*	
			In-row living mulch ($kg \cdot ha^{-1}$)			
Red clover	220	183	202	22	32	27b
White clover	134	172	113	48	32	40b
Hairy vetch	285	94	228	290	376	333a
Tillage mean	213	149		120	147	
Treatment effects						
Tillage (T)		NS			NS	
WCM		NS			*	
T x WCM		NS			NS	

Weed control method (WCM)	Site 1[Y]			Site 2		
	NT	CT	WCM Mean	NT	CT	WCM Mean
			Between row weed biomass ($kg \cdot ha^{-1}$)			
Control	1097a	3152ab	2125	5423a	7424a	6423
Herbicide	452ab	818b	635	764b	850b	808
Red clover	183b	1237ab	710	3873a	5433a	4653
White clover	280b	850b	565	2926a	6090a	4508
Hairy vetch	441ab	1646ab	1044	4885a	7069a	5977
Tillage mean	491	1541		3594	5373	
Treatment effects						
Tillage (T)		*			NS	
WCM		*			*	
T x WCM		*			*	
			In-row weed biomass ($kg \cdot ha^{-1}$)			
Control	328	866	597	505b	2243a	1374
Herbicide	108	306	207	194b	145b	164
Red clover	92	221	156	366b	2839a	1602
White clover	183	210	196	221b	3447a	1834
Hairy vetch	151	199	175	1382a	1307ab	1345
Tillage mean	172	360		533	1996	
Treatment effects						
Tillage (T)		NS			*	
WCM		NS			*	
T x WCM		NS			*	

Weed control method (WCM)	Site 1[Y]			Site 2		
	NT	CT	WCM Mean	NT	CT	WCM Mean
			Between row total biomass ($kg \cdot ha^{-1}$)			
Control	1097a	3152a	2125	5423a	7424a	6423
Herbicide	452b	818b	635	764b	850b	808
Red clover	839a	2894a	1866	4336a	5584a	4960
White clover	800a	2259a	1529	3410a	6553a	4982
Hairy vetch	871a	2790a	1830	6327a	7607a	6967
Tillage mean	812	2383		4052	5604	
Treatment effects						
Tillage (T)		*			NS	
WCM		*			*	
T x WCM		*			*	
			In-row total biomass ($kg \cdot ha^{-1}$)			
Control	328	866	597	505b	2243a	1374
Herbicide	108	306	207	194b	145b	164
Red Clover	312	404	358	388b	2871a	1629
White Clover	317	382	349	269b	3479a	1874
Hairy Vetch	436	293	364	1672a	1683a	1678
Tillage mean	300	450		606	2084	
Treatment effects						
Tillage		NS			*	
WCM		NS			*	
T x WCM		NS			*	

[z] Weed species in order of decreasing visual frequency: site 1--*Mollugo verticillata* L.; *Lamuim amplexicaule* L.; *Galinsoga ciliata* Raf.; *Setaria italica* L.; site 2--*Amaranthus retroflexus* L.; *Mollugo vericillata* L.; *Oxalis stricta* L.; *Solanum ptycanthum* L.
[Y] NT = no-till; CT = conventional tillage
[X] Means separation within columns by Tukey's HSD at $P \leq 0.05$
NS,* = not significant, significant at $P \leq 0.05$

Table 2. Effects of tillage and weed control method on legume, weed, and total biomass in spring,1994.[Z]

Weed control method (WCM)	Site 1[Y] NT	CT	WCM Mean	Site 2 NT	CT	WCM Mean
			Between row living mulch (kg•ha^{-1})			
Red clover	834	511	673	726	963	845
White clover	328	487	407	646	597	621
Hairy vetch	543	608	575	1048	993	1020
Tillage mean	341	535		806	851	
Treatment effects						
Tillage (T)		NS			NS	
WCM		NS			NS	
T x WCM		NS			NS	
			In-row living mulch (kg•ha^{-1})			
Red clover	0	8	4	0	0	0
White clover	8	0	4	0	0	0
Hairy vetch	59	5	32	89	75	82
Tillage mean	22	4		29	25	
Treatment effects						
Tillage (T)		NS			NS	
WCM		NS			NS	
T x WCM		NS			NS	

Weed control method (WCM)	Site 1[Y] NT	Site 1 CT	Site 1 WCM Mean	Site 2 NT	Site 2 CT	Site 2 WCM Mean
			Between row weed biomass ($kg{\bullet}ha^{-1}$)			
Control	1022	1081	1052a[X]	635	1146	890a
Herbicide	363	223	293b	186	333	259b
Red clover	215	317	266b	449	304	376ab
White clover	180	212	196b	398	611	504ab
Hairy vetch	430	444	437b	234	565	399ab
Tillage mean	442	456		380	592	
Treatment effects						
Tillage (T)		NS			NS	
WCM		*			*	
T x WCM		NS			NS	
			In-row weed biomass ($kg{\bullet}ha^{-1}$)			
Control	164	151	157a	0	0	0
Herbicide	2	0	1b	0	0	0
Red clover	0	10	5b	0	0	0
White clover	0	0	0b	0	70	35
Hairy vetch	0	0	0b	40	78	59
Tillage mean	33	32		8	29	
Treatment effects						
Tillage (T)		NS			NS	
WCM		*			NS	
T x WCM		NS			NS	

Weed control method (WCM)	Site 1[Y] NT	CT	WCM Mean	Site 2 NT	CT	WCM Mean
			Between row total biomass ($kg\bullet ha^{-1}$)			
Control	1022	1081	1052a	635	1146	890ab
Herbicide	363	223	293b	186	333	259b
Red clover	1049	828	938a	1175	1267	1221a
White clover	508	699	603ab	1044	1208	1126a
Hairy vetch	973	1052	1013a	1282	1558	1420a
<u>Tillage mean</u>	628	812		864	1102	
Treatment effects						
Tillage (T)		NS			NS	
WCM		*			*	
T x WCM		NS			NS	
			In-row total biomass ($kg\bullet ha^{-1}$)			
Control	164	151	157a	0	0	0b
Herbicide	2	0	1b	0	0	0b
Red Clover	0	18	9b	0	0	0b
White Clover	8	0	4b	0	70	35b
Hairy Vetch	59	5	32b	129	153	141a
<u>Tillage mean</u>	47	35		26	45	
Treatment effects						
Tillage (T)		NS			NS	
WCM		*			*	
T x WCM		NS			NS	

[Z] Weed species in order of decreasing visual frequency: site 1--*Galinsoga ciliata* Raf.; *Amaranthus retroflexus* L.; *Lalium amplexicaule* L.; *Chenopodium album* L.; site 2--*Galinsoga ciliata* Raf.; *Amaranthus retroflexus* L.; *Chenopodium album* L.; *Lamium amplexicaule* L.

[Y] NT = no-till; CT = conventional tillage

[X] Means separation within columns by Tukey's HSD at $P \leq 0.05$

NS,* = not significant, significant at $P \leq 0.05$

Table 3. Effects of tillage and weed control method on early growth of broccoli (one month after planting).

Weed control method (WCM)	Site 1[z]			Site 2		
	NT	CT	WCM Mean	NT	CT	WCM Mean
			Fall plant height (cm)			
Control	24	24	24	25	27	26
Herbicide	23	22	23	27	26	27
Red clover	23	23	23	27	26	26
White clover	23	24	24	26	25	25
Hairy vetch	24	23	23	27	24	25
Tillage mean	23	23		26	25	
Treatment effects						
Tillage (T)		NS			NS	
WCM		NS			NS	
T x WCM		NS			NS	
			Spring plant height (cm)			
Control	15	16	16	13	13	13
Herbicide	16	16	16	14	13	13
Red Clover	16	15	16	14	14	14
White Clover	16	16	16	13	14	13
Hairy Vetch	14	15	15	14	14	14
Tillage mean	16	16		13	13	
Treatment effects						
Tillage (T)		NS			NS	
WCM		NS			NS	
T x WCM		NS			NS	

[z] NT = no-till; CT = conventional tillage
NS,* = not significant, significant at $P \leq 0.05$

Table 4. Effects of tillage and weed control method on nitrogen concentrations of broccoli leaves.[Z] Sufficiency range based on Jones et al., 1991.

Weed control method (WCM)	Site 1[Y] NT	Site 1 CT	Site 1 WCM Mean	Site 2 NT	Site 2 CT	Site 2 WCM Mean
		Fall leaf N(%) [sufficiency range: 3.2-5.5%]				
Control	6.1	6.3	6.2	5.0	4.9	5.0
Herbicide	6.4	6.2	6.3	5.3	5.2	5.2
Red clover	6.3	6.1	6.2	5.5	5.4	5.5
White clover	6.3	6.4	6.4	5.1	5.5	5.3
Hairy vetch	5.5	5.9	5.8	5.4	5.3	5.4
Tillage mean	6.1	6.2		5.2	5.3	
Treatment effects						
Tillage (T)		NS			NS	
WCM		NS			NS	
T x WCM		NS			NS	
		Spring leaf N(%) [sufficiency range: 3.2-5.5%]				
Control	3.6	3.4	3.5	3.7	4.1	3.9
Herbicide	3.7	3.8	3.8	3.7	3.9	3.8
Red clover	3.8	4.0	3.9	4.0	4.1	4.0
White clover	3.7	3.6	3.7	4.0	4.1	4.0
Hairy vetch	4.0	4.0	4.0	4.2	4.0	4.1
Tillage mean	3.8	3.8		3.9	4.0	
Treatment effects						
Tillage (T)		NS			NS	
WCM		NS			NS	
T x WCM		NS			NS	

[Z] Broccoli leaf samples were taken one month after planting
[Y] NT = no-till; CT = conventional tillage
NS,* = not significant, significant at $P \leq 0.05$

Table 5. Effects of tillage and weed control methods on marketable broccoli yield.

Weed Control	Site 1[Z]			Site 2		
Methods (WCM)	NT	CT	WCM Mean	NT	CT	WCM Mean
			Fall yield ($Mg{\bullet}ha^{-1}$)			
Control	16.9	15.4	16.2	13.8	11.4	12.6b[Y]
Herbicide	16.7	17.0	16.8	17.1	15.5	16.3a
Red clover	16.2	16.0	16.1	14.9	10.3	12.6b
White clover	18.2	14.2	16.2	17.4	10.1	13.7b
Hairy vetch	17.1	12.5	14.8	14.8	11.4	13.1b
Tillage mean	17.0	15.0		15.6	11.7	
Treatment effects						
Tillage (T)		NS			*	
WCM		NS			*	
T x WCM		NS			NS	
			Spring yield ($Mg{\bullet}ha^{-1}$)			
Control	9.3	8.6	8.9	9.7	8.4	9.1
Herbicide	9.9	8.2	9.1	8.4	8.1	8.3
Red clover	10.2	8.5	9.4	8.7	8.4	8.6
White clover	9.6	8.3	9.5	8.4	8.3	8.4
Hairy vetch	9.7	8.4	9.1	9.0	8.7	8.9
Tillage mean	9.7	8.4		8.8	8.4	
Treatment effects						
Tillage (T)		*			NS	
WCM		NS			NS	
T x WCM		NS			NS	

[Z] NT = no-till; CT = conventional tillage
[Y] Mean separation within columns by Tukey's HSD at $P \leq 0.05$
NS,* = not significant, significant at $P \leq 0.05$

LITERATURE CITED

Asoegwu, S.N. 1987. Comparison of tillage systems for the production of egusi-melon (*Colocynthus citrullus* L.) and okra (*Abelmoschus esculentus* L.) in eastern Nigeria. Crop Res. (Hort. Res.) 27:77-90.

Clarkson, D.T. and A.J. Warner. 1979. Relationships between root temperature and the transport of amonium and nitrate ions by Italian and perennial ryegrass (*Lolium multiflorum* and *Lolium perenne*). Plant Physol. 64(4):557-561.

Coolman, R.M. and G.D. Hoyt. 1993. The effects of reduced tillage on the soil environment. HortTech. 3(2):143-145.

Costello, M.J. and M.A. Altieri. 1994. Living mulches suppress aphids in broccoli. California Agriculture. 48(4):24-28.

Doss, B.D., J.L. Turner, and C.E. Evans. 1981. Influence of tillage, nitrogen, and rye cover crop on growth and yield of tomatoes. J. Amer. Soc. Hort. Sci., Camb. 87:123-126.

Graham, M.B. and G. Crabtree. 1987. Management of competition for water between cabbage (*Brassica oleracea*) and a perennial ryegrass (*Lolium perenne*) living mulch. Proc. West Soc. Weed Sci. 40:113-117.

Harper, F. 1983. Competition--inter-specific competition, p.198-229. In: F. Harper. Principles of arable crop production. Granada Publ. Limited, London.

Hillers, E.A. and T.A. Howell. 1983. Irrigation options to avoid critical stress: an overview, p. 479-497. In: H.M. Taylor, W.R. Jordan and T.R. Sinclair (eds.). Limitations to efficient water use in crop production. ASA, CSSA, and SSSA, Madison, WI.

Jones, J.B., B. Wolf, and H.A. Mills. 1991. Plant analysis handbook. Micro-Macro Publishing, Inc., Athens, GA.

Knavel, D.E., J. Ellis, and J. Morrison. 1977. The effects of tillage systems on the performance and elemental absorption by selected vegetable crops. J. Amer. Soc. Hort. Sci. 102(3):323-327.

Knavel, D.E., and J.W. Herron. 1981. Influence of tillage system, plant spacing, and nitrogen on head weight, yield, and nutrient concentration of spring cabbage. J. Amer. Soc. Hort. Sci. 106(5):540-545.

Lal, R., E. Regnier, D.J. Eckert, W.M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture, p. 1-11. In: W.L. Hargrove (ed.). Cover crops for clean water. Soil and Water Conserv. Soc., Jackson, TN.

Lentner, M. and T. Bishop. 1993. Experimental design and analysis. 2nd.Ed. Valley Book Company. Blacksburg, VA.

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

Morse, R.D. 1993. Evolution of conservation tillage systems for transplanted crops; potential role of the Subsurface Tiller Transplanter (SST-T), p. 145-151. In: P.K. Billich (ed.) Proc Southern Conservation Tillage Conference for Sustainable Agriculture, Monroe, L.A.

Morse, R.D., C.M. Tressore, W.E. Chappel, and C.R. O'Dell. 1982. Use of no-tillage for summer vegetable production. The Veg. Growers News 37(1):1.

Nicholson, A.G. and H.C. Wien. 1983. Screening turfgrasses and clovers for use as living mulches in sweet corn and cabbage. J. Amer. Soc. Hort. Sci. 108(6):1071-1076.

Norman, G.R. and D.L. Streiner. 1994. Biostatistics: The bare essentials. Mosby Year Book, Inc. St. Louis, MO.

Peterson, H.C. and G.A. Chesters. 1964. A reliable total nitrogen determination on plant tissue and accumulating nitrate nitrogen. Agron. J. 56:89-90.

Price, H.C. and R.A. Baughn. 1987. Establishment of fresh market tomatoes in a no-till system. Acta Hort. 198:261-264.

Putnam, A.R. and L.A. Weston. 1986. Adverse impacts of allelopathy in agricultural systems, p 43-45. In: A.R. Putnam and C.S. Tang (eds.) The science of allelopathy. Wiley and Sons, New York, NY.

Ross, M.A. and C.A. Lembi. 1985. p 29-31. Applied weed science. Macmillian Publishing Co., New York, NY.

Regnier, E.E. and R.R. Janke. 1990. Evolving strategies for managing weeds, p. 174-202. In: C.A. Edwards, R. Lal, P. Madden, R.H. Miller, and G. House (eds). Sustainable agriculture systems. Soil and Water Conserv. Soc., Ankeny, IA.

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, Viginia Polytech. Inst. and State Univ., Blacksburg, VA.

Shilling, D.G. 1983. The suppression of certain weed species by rye (*Secale cereale* L.) mulch. Isolation, characterization, and identification of water-soluble phytotoxins from rye. PhD Diss. N.C. State Univ., Raleigh.

Smittle, D.A., W.L. Dickens, and J.R. Stansell. 1994. Irrigation regimes affect cabbage water use and yield. J. Amer. Soc. Hort. Sci. 119:20-23.

Stoller, E.W. and R.A. Myers. 1989. Effects of shading and soybean (*Glycine max* L.) interference on *Solanum ptycanthym* (Dun.) (eastern black nightshade) growth and development. Weed Res. 29:307-316.

Tessore, C.M. 1982. Effect of tillage system and nitrogen rate on tomato yield. PhD Diss. Virginia Polytech. Inst. and State Univ., Blacksburg, VA.

Tollenaar, M., A.A Dibo, A. Aguilera, S.F. Weise, and C.J. Swanton. 1994. Effect of crop density on weed interference in maize. Agron. J. 86:591-595.

Unger, P.W., E.W. Langdale, and P.J. Papendick. 1988. Role of crop residues--improving water conservation and use, p 69-100. In: W.L. Hargrove (ed.) Cropping strategies for efficient use of water and nitrogen. ASA Spec. Publ. No. 51. ASA, CSSA, SSSA, Madison, WI.

Van Wijk, W.R., W.E. Larson, W.C. Burrows. 1959. Soil temperature and the early growth of corn from mulched and unmulched soil. Soil Sci. Soc. Amer. Proc. 23:428-434.

Virginia Commercial vegetable production recommendations 1993. VA Coop. Ext. Serv. Pub. 420-456.

Wallace, R.W. and R.R. Bellinder. 1992. Alternative tillage and herbicide options for successful weed control in vegetables. HortScience 27(7):745-749.

White, J.G. and T.W. Scott. 1991. Effects of perennial forage-legume living mulches on no-till winter wheat and rye. Field Crop Res. 28:135-148.

Zsoldos, F. 1972. Ion uptake by cold-injured rice roots. Plant-Soil 37(3):469-478.

APPENDIX

Table 6. Effect of multiple rows on yield in fall.

Row type (RT)	Site 1[z] NT	Site 1 CT	Site 1 RT Mean	Site 2 NT	Site 2 CT	Site 2 RT Mean
			Yield ($Mg \bullet ha^{-1}$)			
Double	17.04	15.04	16.04	15.60	11.75	13.67
Triple	16.95	15.86	16.41	14.19	11.86	13.03
Tillage mean	16.99	15.45		14.89	11.81	
Treatment effects						
Tillage (T)		NS			*	
RT		NS			NS	
T x RT		NS			NS	

[z] NT = no-till; CT = conventional tillage

NS,* = not significant, significant, 5% level

Table 7. Rhizobium inoculation of legume seed.[z]

Legume species	Rhizobium species
Red clover (*Trifolium pratense* L.)	*Rhizobium trifolii*
Dutch white clover (*Trifolium repens* L.)	*Rhizobium trifolii*
Hairy vetch (*Vicia villosa* Roth.)	*Rhizobium leguminosarium*

[z] Legume seeds were inoculated just prior to overseeding legumes into designated plots

VITA

Michelle Louise Infante was born on August 9, 1971 in Trenton, New Jersey. She attended Allentown High School in Allentown, New Jersey and received her diploma in 1989. In 1993 she received a B.S. in Horticulture from Delaware Valley College of Science and Agriculture in Doylestown, Pennsylvania and a M.S. in Horticulture from Virginia Tech in Blacksburg, Virginia in 1994.

Michelle L. Infante

Michelle Louise Infante