Reviews

Conservation Tillage for Vegetable Production

G.D. Hoyt[1], D.W. Monks[2], and T.J. Monaco[2]

Additional index words. no-till, strip-till, minimum-till, cover crops, weed control

Summary. Conservation tillage is an effective sustainable production system for vegetables. No-till planters and transplanters and strip-till cultivation equipment are presently available for most vegetables. Lack of weed management tools (herbicides, cultivators, etc.) continues to be the cultural practice that limits adaptability of some vegetables to conservation tillage systems. Nitrogen management can be critical when grass winter cover crops are used as a surface residue. Advantages of using conservation tillage include soil and water conservation, improved soil chemical properties, reduction in irrigation requirements, reduced labor requirements, and greater nutrient recycling. However, disadvantages may include lower soil temperatures, which can affect maturity date; higher chemical input (desiccants and postemergence herbicides); potential pest carryover in residues; and enhancement of some diseases.

[1]*Department of Soil Science, North Carolina State University, Mountain Horticultural Crops Research & Extension Center, Fletcher, NC 28732-9628.*

[2]*Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695-7609.*

The use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service or Cooperative Extension Service, nor criticism of similar ones not mentioned. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement *solely to indicate this fact.*

Vegetable acreage in the United States constitutes a relatively small percentage of farmland compared with agronomic crops such as corn, soybeans, and small grains. Although acreage planted to vegetables is small, production is intensive, with most growers using conventional cultivation practices. Recent advances in farm equipment and herbicides have afforded producers of vegetables the opportunity to grow their crops under some form of conservation tillage (Coolman and Hoyt, 1993). Conservation tillage technology developed for agronomic crops is usually not directly applicable to vegetable production and must be modified. Such modifications require a strong management commitment and current knowledge of pesticides.

Benefits of conservation tillage practices have been discussed in previous publications dealing with agronomic crops (Blevins et al., 1977; Doran, 1987; Gallaher and Ferrer, 1987). A few of these apply to intensive culture of vegetable crops, including a decrease in time required to prepare fields for planting, a reduction in irrigation water required due to increased infiltration of rain and irrigation (Morse and Tessore, 1984), and an increase in organic residues from cover crops grown for soil improvement (Hoyt, 1992).

Undesirable consequences of conservation tillage for vegetables include lower soil temperatures in spring resulting from mulching and shading effects of cover crop residues (Hoyt and Konsler, 1988) and potential overwintering of pests in surface residues from previous crops. Reduced soil temperatures may slow the growth of some vegetable crops, possibly resulting in delayed maturity, thereby missing potentially lucrative early market prices. Reduced soil temperatures may not affect adversely cool-season vegetables such as cole crops, potatoes, and leafy greens, but may reduce early growth of warm-season crops such as tomatoes, sweet corn, snap beans, and squash planted in early spring (Bellinder et al., 1987; McKeown et al., 1988; Petersen et al., 1986). Growth of tomatoes and other vegetables during the late spring and summer have not been affected by the changes in soil temperatures produced by residues in conservation tillage systems (Drost and Price, 1991b; Morse and Seward, 1986; Morse et al., 1982; Shelby et al., 1988; Wilhoit et al., 1990).

Problems with pests can be minimized by fall tillage of crop debris and then seeding the field with a grass or legume cover crop (Phatak et al., 1991). This will reduce pest carryover and provide sufficient residue for soil erosion control.

Equipment

Vegetable production using conservation tillage techniques requires seeding and transplanting equipment appropriate for planting in an undisturbed cover crop (no-till) or in a tilled strip in the cover crop (strip-tillage). Different soil preparation equipment is required for strip-tillage than is used for conventional tillage.

Large-seeded vegetable crops such as sweet corn, snap beans, and squash may be planted in the undisturbed cover crop using no-till field corn or soybean planters (Knavel et al., 1985; Mascianica et al., 1986; Mullins et al., 1988). No-till planters should be fitted with a coulter (to cut through residue) and double disk openers to ensure proper placement and coverage of seed. No-till planters with seed plates can be used for some vegetables by carefully matching plates to seed size. Plateless no-till planters can accommodate a wider range of vegetable crops. Conservation tillage planters for small-seeded vegetables such as cole crops, carrots, onions, or radishes are

Strip-tillage equipment cultivation a narrow band of soil in killed hairy vetch residue before tomato transplanting.

being developed (Morse et al., 1987). Use of gel seeding for better seed placement and improved emergence and survival has been investigated (Drost and Price, 1991a, Pill, 1991).

Seedbeds prepared through strip-tillage can be planted with equipment used with conventional tillage. Equipment used for transplanting tomatoes, peppers, and cole crops by conventional methods are suitable for planting these same crops in strip-tillage culture. In addition, conventional transplanters have been modified to plant bare-root or containerized transplants in undisturbed soil (Morrison et al., 1973a, 1973b; Morse and Seward, 1986; Wood and Worsham, 1986). A shank and a cutting coulter in front of the transplanter opens a slit in the soil for the transplant. A heavier-than-normal pack wheel presses the soil around the roots.

Special equipment has been designed to prepare a seedbed for strip-tillage culture of direct-seeded or transplanted vegetables. A rotary power-driven tiller, with all but the two middle tines removed, will produce a well-prepared seedbed 8 to 12 inches wide to the depth of the tines (Loy et al., 1987; McKeown et al., 1988; Petersen et al., 1985). This technique is inefficient in that it has a high energy requirement and is relatively slow, making it impractical for commercial growers. More-efficient implements are available that can prepare an 8- to 16-inch-wide strip, subsoil, and travel at acceptable rates of speed (>1 acre / h per row) (Mullins et al., 1988). These implements use a front-cutting coulter, a subsoiler, a set of two tilling coulters on each side of the subsoiler, and a rolling basket to break clods (Hoyt, 1987; Morse et al., 1987). This equipment prepares the soil and can incorporate fertilizers as well as pesticides. Additionally, the equipment can be modified to fumigate the tilled strip prior to planting (Estes et al., 1985).

No-till planting equipment can be used for large-seeded vegetable crops.

Land preparation and cover crop establishment

Insect and disease buildup is associated with continuous annual cropping of the same or related crops and when crop residue is allowed to remain on the soil surface until the following growing season. As with conventional tillage, crop rotation and destruction of previous crop debris are very important in managing diseases and insects. Soil tillage associated with establishing fall cover crops will incorporate crop residues and provide an opportunity to add non-mobile fertilizer materials such as lime, phosphate, and possibly potash. Cover crops provide protection against water and wind erosion, and generate beneficial organic residue for the following year (Hoyt and Hargrove, 1986). The choice of cover crops depends on the vegetable crop to be grown and the cropping season. Grass (small grains) cover crops offer good protection against soil erosion by water or wind and ample plant residue for early plantings of cool-season vegetables such as potatoes, cabbage, or broccoli (Ditsch and Alley, 1991; Hoyt, 1984). Grass cover crops can remove excess soil water in the spring, but may be detrimental if dry soil conditions exist. Legumes can develop abundant biomass and provide significant amounts of nitrogen (N) through symbiotic N-fixation for warm-season vegetables such as tomatoes, sweet corn, snap beans, and squash (Hoyt, 1989; Knavel and Herron, 1986; Skarphol et al., 1987) and fall-planted cole crops (Morse and Seward, 1986).

No-till and strip-till implements can be used in grass or legume cover crops. With no-till, the vegetable crop can be planted at the time of cover crop desiccation, thus allowing for

Conventional transplanting equipment can be used in strip-tillage.

maximum cover crop development (and N accruement with legumes) and germination of weed seeds before application of the herbicide. With strip-tillage, the cover crop should be killed at least 1 to 2 weeks prior to soil preparation. This interval will allow initiation of the breakdown of cover crop roots and reduce the tendency for clod formation.

Weed management

Weed interference (competition) studies have not been conducted with vegetable crops in conservation tillage systems. However, several studies have determined the critical weed-free period for specific weeds in vegetable crops in conventional systems. Information generated from weed interference studies in beets (Hewson and Roberts, 1973; Vengris and Stacewicz-Sapuncakis, 1971), broccoli (Bitterlich and Upadhyaya,1990), cabbage (Bellinder et al., 1989; Lawson, 1972; Roberts et al., 1976; Weaver, 1984), carrots (Fiveland, 1974), cucumber (Friesen, 1978; Labrada et al., 1983; Lanini and Strange, 1991; Weaver, 1984), field beans (Dawson, 1964; Glasgow et al., 1976), lettuce (Lanini and Strange, 1991; Roberts et al., 1977), lima beans (Glaze and Mullinix, 1984), muskmelon (Nerson, 1989), onions (Williams et al., 1973), pepper (Lanini and Strange, 1991; Meadt and Monaco, 1979), potato (Ivany, 1986; Rioux et al., 1979; Saghir and Markoullis, 1974; Sonmez and Karaca, 1975; Thakral et al., 1989; Vitolo and Ilnicki, 1985), snap beans (Frank, 1990; Neary and Majek, 1990; Vengris and Stacewicz-Sapuncakis, 1971; Williams et al., 1973), sweet corn (Williams et al., 1973), sweetpotato (Kasasian and Seeyave, 1969; Levett, 1992; Talatala et al., 1977), and tomatoes (Friesen, 1978; Gworgwor, 1990; Kasasian and Seeyave, 1969; Monaco et al., 1981; Rajagopal and Sankaran, 1980; Weaver, 1984; Weaver and Tan, 1987) provides useful insights into when weed control or suppression is necessary to prevent yield and quality reductions from weeds.

Although management tools for insect and disease control are not affected greatly by production system (conservation or conventional tillage), management tools (cultivation, pre-

Strip-till fresh-market tomato production using hairy vetch (top) and cabbage using wheat residue (bottom).

Tomato production using a no-till transplanter in rye residue.

plant herbicide application, etc.) for weed control are limited in a conservation tillage system. However, an effective weed management program is essential in the development of conservation tillage systems for vegetable crops. Several requirements must be met to achieve an effective weed management program in conservation tillage systems.

An effective herbicide for desiccation of live vegetation (cover crop, previous crop, or weeds) prior to planting is necessary to establish a growth advantage of the crop over weeds. The herbicide must provide complete shoot kill and prevent regrowth of the previous crop or weeds. It should be capable of controlling all emerged plant species present, but should have no residual activity on the crop being planted. Finally, it must be registered for the crop being grown. Paraquat (Gramoxone Extra) or glyphosate (Roundup and other trade names) fit the criteria very well, and at least one of them is registered to control emerged weeds prior to planting in every vegetable crop (Monks and Monaco, 1993; Standifer and Beste, 1985). Both herbicides control most annual weeds; however, glyphosate is more effective for the control of perennial weeds than is paraquat. Paraquat must remain on plant foliage for ≈30 min after application to be effective, whereas glyphosate requires at least 6 h to prevent wash-off by rain or irrigation.

Strip-tillage produces loose cultivated soil in the row area.

An effective preemergence herbicide program is required to control weeds that germinate after crop planting. The preemergence herbicide(s) should provide selective control and must be registered for the crop to be grown. Preplant soil-incorporated herbicides cannot be used in strictly no-till systems, but can be used in the tilled strip in a strip-tillage system (Wilcut et al., 1990). More rainfall generally is needed to activate preemergence herbicides in conservation tillage plantings. Because some of the herbicide is intercepted by the cover crop mulch, more rainfall or overhead irrigation is needed to move the herbicide into the soil in comparison with herbicides applied in conventional tillage systems. Although not as many herbicides are registered for preemergence weed control in vegetable crops as in field crops, effective choices are available for crops such as beans, cabbage, potatoes, sweet corn, and tomatoes.

In conservation tillage systems, effective weed control after crop emergence almost always is required in early season to prevent the negative effects of weeds on yield and quality of vegetable crops. Preemergence herbicides do not provide complete control of every weed species present throughout the growing season in either conventional and conservation tillage systems. Therefore, cultivation and / or use of a postemergence herbicide are required. Cultivation is impossible in most conservation tillage systems. However, early cultivation of the tilled strip in a strip-tillage system is possible during the first 2 to 3 weeks following crop emergence or transplanting.

Lack of effective postemergence herbicides can be a limiting factor in conservation tillage systems. Effective postemergence herbicides for control of annual grasses and broadleaf weeds are essential for a successful conservation tillage system. Vegetable crops that have postemergence herbicides registered and / or have been successfully produced in a conservation tillage system are asparagus, beans, beets, cabbage, carrots, onions (dry bulb), peas, Irish potatoes, spinach, popcorn, sweet corn, and tomatoes. Major vegetable crops that lack postemergence herbicides for control of broadleaf weeds include broccoli, cauliflower, cucurbits (cucumber, watermelon, muskmelon, squash, and pumpkin), pepper, greens, okra, and sweetpotato. Production of these vegetable crops using conservation tillage will not be successful unless hand-weeding is practiced throughout the growing season or until effective postemergence herbicides are developed for these crops.

Fertilizer recommendations

Fertilizer rates and application methods must be adjusted when conservation tillage is used. A proper soil fertility program should be started in the fall when a grass or legume cover crop is being established. Soil should be tested for each field or each soil type within the field to determine the correct amount and type of fertilizer for the following spring or summer vegetable crop. Prior to seeding the cover crop, the recommended lime, phosphorus, and potassium materials are applied (if fall leaching is not a problem), and the field tilled (if tillage is required) to incorporate the fertilizer materials and any crop and / or weed residue. Nitrogen and any other fertilizer materials that were not applied in the fall should be applied at vegetable planting the next year. Fertilizer is applied most effectively in a band to the side and slightly below the seed or transplant. Fluted coulters are required to cut through the residue and open a furrow for the fertilizer.

Most fertility changes recommended for no-till agronomic crops also are applicable to conservation-tilled vegetables. Specific adjustments include the following:

1) Nitrogen application rate should be increased based on density and type of cover crop and soil type used and for the inefficiency of placing fertilizer N on the surface. Grass cover crops tie up soil N in the spring, and grass residues have a slow rate of decomposition during the summer (Doss et al., 1981; Hoyt, 1993; Knavel and Herron, 1981; Knavel and Herron, 1985; Knavel et al., 1977). Fertilizer N can be reduced if a legume cover crop is used (Hoyt, 1991; Knavel, 1986; Morse and Seward, 1986; Skarphol et al., 1987);

2) Nitrogen, phosphorus, and potassium fertilizer materials should be band-applied rather than broadcast whenever possible to achieve greater efficiency (Robbins and Voss, 1991);

3) Starter fertilizer can be placed in transplant water to enhance initial root growth of the transplants; in seeded crops, starter material can be placed beside and below the seed;

4) Urea fertilizer materials should be incorporated or at least side-banded to reduce N loss.

Vegetable crops for conservation tillage

Vegetable crops easily adapted to a conservation tillage system are those that can be produced with planting equipment and pesticides similar to those used in producing conservation-tilled agronomic crops. Large-seeded or transplanted vegetable crops perform successfully with conservation tillage. Small-seeded crops, such as lettuce, usually have a slow early growth rate, causing them to be extremely susceptible to competition by faster growing weeds. Germination of small-seeded crops often is inhibited by allelopathic chemicals produced by decaying cover crops. Popcorn (Knavel et al., 1985), sweet corn (Beste, 1973; Beste, 1974), snap beans (Bellinder et al., 1987; Tompkins et al, 1976), lima beans, and peas have been produced successfully in a conservation tillage system. Transplanted crops such as tomato (Beste, 1973; Monaco et al., 1986; Shelby et al., 1988), cabbage, and sweetpotato can be planted with modified no-till equipment or by planting with conventional equipment into a field that has been strip-tilled. Effective preemergence and postemergence herbicides are registered for these crops, and yields have been excellent under these conservation tillage systems.

Literature Cited

Bellinder, R.R., H.P. Wilson, and T.E. Hines. 1987. Comparative studies of conventional and no-tillage systems for snap bean production. HortScience 22(1):159.

Bellinder, R.R., D. Wilcox-Lee, A. Senesac, and D.T. Warholic. 1989. Response of early-maturing cabbage (*Brassica oleracea* var. *capitata*) to metolachlor. Weed Technol. 3:463–466.

Beste, C.E. 1973. Evaluation of herbicides in no-till planted cucumbers, tomatoes, and lima beans. Proc. Northeast Weed Sci. Soc. 27:231–239.

Beste, C.E. 1974. Evaluation of no-tillage vegetables in a rye cover-crop mulch. Weed Sci. Soc. Amer. Abstr. 14:250.

Bitterlich, I. and M.K. Upadhyaya. 1990. Lambsquarters interference with direct seeded broccoli. Can. J. Plant Sci. 70:1215–1221.

Blevins, R.L., G.W. Thomas, and P.L. Cornelius. 1977. Influence of tillage and nitrogen fertilization on certain soil properties after 5 years of continuous corn. Agron. J. 69:383–386.

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

Dawson, J.H. 1964. Competition between irrigated field beans and annual weeds. Weed Sci. 12:206–208.

Ditsch, D.C. and M.M. Alley. 1991. Non-leguminous cover crop management for residual N recovery and subsequent crop yields. J. Fert. Issues 8(1):6–13.

Doran, J.W. 1987. Microbial biomass and mineralizable nitrogen distributions in no-tillage and plowed soils. Biol. Fert. Soils 5:68–75.

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. 106(1): 95–97.

Drost, D.T. and H.C. Price. 1991a. Stand establishment of fluid-drilled tomato in rye and wheat tillage systems. HortScience 26(12):1475–1478.

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

Estes, E.A., W.A. Skroch, T.R. Konsler, P.B. Shoemaker, and K.A. Sorensen. 1985. Net economic values of eight soil management practices used in stake tomato production. J. Amer. Soc. Hort. Sci. 110 (6):812–816.

Fiveland, T.J. 1974. The competition between swedes or carrots and annual weeds. Norwegian Plant Protection Inst., Dept. of Herbology. Rpt. 114:2–15.

Frank, J.R. 1990. Influence of horsenettle (*Solanum carolinese*) on snapbean (*Phaseolus vulgaris*). Weed Sci. 38:220–223.

Friesen, C.H. 1978. Weed interference in pickling cucumbers (*Cucumis sativus*). Weed Sci. 26(6):626–628.

Gallaher, R.N. and M.B. Ferrer. 1987. Effect of no-tillage vs. conventional tillage on soil organic matter and nitrogen contents. Commun. Soil Sci. Plant Anal. 18(9):1061–1076.

Glasgow, J.L., J.W. Dicks, and D.R. Hodgson. 1976. Competition by, and chemical control of, natural weed populations in spring-sown field beans (*Vicia faba*). Ann. Applied Biol. 84:259–269.

Glaze, N.C and B.G. Mullinix. 1984. Competitive effects of sicklepod on lima beans. Weed Sci. 32:1–3.

Gworgwor, N.A. 1990. Growth and yield of irrigated tomato (*Lycopersicon esculentum* Mill.) as affected by weed association. J. Agron. & Crop Sci. 165:301–305.

Hewson, R.T. and H.A. Roberts. 1973. Effects of weed competition for different periods on the growth and yield of red beet. J. Hort. Sci. 48:281–292.

Hoyt, G.D. 1984. The effect of cover crops on strip-till vegetable and tobacco production. Soil Sci. Soc. North Carolina Proc. 27:10–20.

Hoyt, G.D. 1987. Conservation tillage for burley tobacco. 1987 Burley Tobacco Information. N.C. Agr. Ext. Publ. AG 376. p. 22–24.

Hoyt, G.D. 1989. Predicting nutrients from winter cover crops for no-till management, p. 70–72. In: I.D. Teare (ed.). Proc. 1989 Southern Conservation Tillage Conf. Spec. Bul. 89-1. Univ. of Florida.

Hoyt, G.D. 1991. Conservation tillage for burley tobacco: Selecting a surface residue. 1991 Burley Tobacco Information. N.C. Agr. Ext. Publ. AG 376. p. 31–34.

Hoyt, G.D. 1992. Effect of cover crop and N rate on soil N and yield of no-till sweet corn and strip-till tomato. HortScience 27(6):663. (Abstr.)

Hoyt, G.D. 1993. Conservation tillage for burley tobacco: Nitrogen recommendations. 1993 Burley Tobacco Information. N.C. Coop. Ext. Publ. AG 376. p. 36–38.

Hoyt, G.D. and W.L. Hargrove. 1986. Legume cover crops for improving crop and soil management in the southern U.S. HortScience 21(3):397–402.

Hoyt, G.D. and T.R. Konsler. 1988. Soil water and temperature regimes under tillage and cover crop management for vegetable culture. Proc. 11th Intl. Conf., ISTRO. Edinburgh, Scotland. p. 697–702.

Ivany, J.A. 1986. Quackgrass competition effect on potato yield. Can. J. Plant Sci. 66:185–187.

Kasasian, L. and J. Seeyave. 1969. Critical periods for weed competition. PANS 15(2):208–212.

Knavel, D.E. 1986. Effects of previous tillage system and nitrogen rates on yield and nitrogen concentration and recovery by turnip. HortScience 21(6):1337–1338.

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.W. Herron. 1985. Effect of sudan grass on yield and elemental content of cabbage. HortScience. 20(4): 680–681.

Knavel, D.E. and J.W. 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., J.W. Herron, and G.M. White. 1985. No-till popcorn performs as well as conventionally grown popcorn. HortScience 20(1):136–137.

Labrada, R., E. Paredes, and R. Muniz. 1983. Weed competition in a cucumber crop. Trop. Pest Mgmt. 29(1):52–55.

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

Lawson, H.M. 1972. Weed competition in transplanted spring cabbage. Weed Res. 12:254–267.

Levett, M.P. 1992. Effects of various hand-weeding programmes on yield and components of yield of sweet potato (*Ipomoea batatas*) grown in the tropical lowlands of Papua, New Guinea. J. Agr. Sci. 118:63–70.

Loy, S.J.W., L.C. Peirce, G.O. Estes, and O.S. Wells. 1987. Productivity in a strip tillage vegetable production system. HortScience 22(3):415–417.

Mascianica, M.P., H.P. Wilson, R.F. Walden, T.E. Hines, and R.R. Bellinder. 1986. No-tillage snap bean growth in wheat stubble of varied height. J. Amer. Soc. Hort. Sci. 111(6):853–857.

McKeown, A.W., R.F. Cerkauskas, and J.W. Potter. 1988. Influence of strip tillage on yield, diseases, and nematodes of tomatoes. J. Amer. Soc. Hort. Sci. 113(3):328–331.

Meadt, R.D. and T.J. Monaco. 1979. Prickly sida and cocklebur interference in transplanted peppers. Proc. South. Weed Sci. Soc. 32:140.

Monaco, T.J., A.S. Grayson, and D.C. Sanders. 1981. Influence of four common weed species on growth, yield, and quality of direct seeded tomatoes (*Lycopersicon esculentum*) Weed Sci. 29:394–397.

Monaco, T.J., G.D. Hoyt, and A.D. Worsham. 1986. Evaluation of no-tillage techniques for staked tomatoes. Proc. South. Weed Sci. Soc. 39:174.

Monks, D.W. and T.J. Monaco. 1993. 1993 Weed control recommendations in small fruits and vegetables. Dept. of Horticultural Science, North Carolina State Univ. p. 1–100.

Morrison, J.E., Jr., D.C. Milbocker, W.O. Atkinson, and J.H. Smiley. 1973a. Transplanter modification and survival of transplants under no-tillage conditions. HortScience 8:483–485.

Morrison, J.E., Jr., J.H. Smiley, W.O. Atkinson, and D.C. Milbocker. 1973b. A no-tillage transplanter. Tobacco Sci. 17:44–46.

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

Morse, R.D. and C.M. Tessore. 1984. Efficient water use: conservation of soil moisture with no-tillage. The Vegetable Growers News. 39(1):2, 4.

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

Morse, R.D., D. Vaughan, L. Schertz, and A. Borowski. 1987. Strip tillage for production of direct-seeded broccoli. The Vegetable Growers News. 41(4):3–4.

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

Neary, P.E. and B.A. Majek. 1990. Common cocklebur (*Xanthium strumarium*) interference in snap beans (*Phaseolus vulgaris*). Weed Technol. 4:743–748.

Nerson, H. 1989. Weed competition in muskmelon and its effects on yield and quality. Crop Protect. 8:439–443.

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.

Petersen, K.L., H.J. Mack, and R.H. Cuenca. 1985. Effect of tillage on the crop-water production function of sweet corn in western Oregon. HortScience 20(5):901–903.

Phatak, S.C., R.L. Bugg, D.R. Sumner, J.D. Gay, K.E. Brunson, and R.B. Chalfant. 1991. Cover crop effects on weeds, diseases, and insects of vegetables, p. 153–154. In: W.L. Hargrove (ed.). Cover crops for clean water. Soil and Water Cons. Soc., Ankeny, Iowa.

Pill, W.G. 1991. Advances in fluid drilling. HortTechnology 1(1): 59–65.

Rajagopal, A. and S. Sankaran. 1980. Crop–weed competition in tomato. Madrasagric. J. 67(1):1–8.

Rioux, R., J.E. Comeau, and H. Genereux. 1979. Effect of cultural practices and herbicides on weed population and competition in potatoes. Can. J. Plant Sci. 59:367–374.

Robbins, G.R. and R.D. Voss. 1991. Phosphorus and potassium stratification in conservation tillage systems. J. Soil & Water Cons. 46:298–300.

Roberts, H.A., W. Bond, and R.T. Hewson. 1976. Weed competition in drilled summer cabbage. Ann. Applied Biol. 84:91–95.

Roberts, H.A., R.T. Hewson, and M.E. Ricketts. 1977. Weed competition in drilled summer lettuce. Hort. Res. 17:39–45.

Saghir, A.R. and G. Markoullis. 1974. Effects of weed competition and herbicides on yield and quality of potatoes. Proc. 12th British Weed Control Conf. 2:533–539.

Shelby, Jr., P.P., 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.

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.

Sonmerz, S. and I. Karaca. 1975. Competition between annual weeds and potatoes and weed control. Turkish Phytopathol. 4(1):35–43.

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. Monogr. 2.

Talatala, R., A.M. Mariscal, and A.C. Secreto. 1977. Critical periods for weed control in sweet potatoes. Philipp. J. Weed Sci. 5:1–6.

Thakral, K.K., M.L. Pandita, S.C. Khurana, and G. Kalloo. 1989. Effect of weed removal on growth and yield of potato. Weed Res. 29:33–38.

Tompkins, F.D., B.L. Bledsoe, and C.A. Mullins. 1976. Minimum tillage snap beans. Tenn. Farm and Home Sci. Prog. Rpt. 98: 18–20.

Vengris, J. and M. Stacewicz-Sapuncakis. 1971. Common puslane competition in table beets and snapbean. Weed Sci. 19(1):4–6.

Vitolo, D.B and R.D. Illnicki. 1985. Grass competition in white potatoes. Weed Sci. Soc. Amer. Abstr. 25:78.

Weaver, S.E. 1984. Critical period of weed competition in three vegetable crops in relation to management practices. Weed Res. 24:317–325.

Weaver, S.E. and C.S. Tan. 1987. Critical period of weed interference in field-seeded tomatoes and its relation to water stress and shading. Can. J. Plant Sci. 67:575–583.

Wilcut, J.W., G.R. Wehtje, and T.V. Hicks. 1990. Evaluation of herbicide systems in minimum- and conventional-tillage peanuts (*Arachis hypogaea*). Weed Sci. 38:243–248.

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

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

Wood, S.D. and A.D. Worsham. 1986. Reducing soil erosion in tobacco fields with no-tillage transplanting. J. Soil and Water Cons. 41:193-196.