No-till Vegetable Production—Its Time is Now

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SUMMARY. Advantages of no-till (NT) production systems are acknowledged throughout the world. During the 1990s, production of NT vegetable crops has increased for both direct seeded and transplanted crops. Increased interest in reduced-tillage systems among research workers and vegetable growers is attributed to: 1) development and commercialization of NT transplanters and seeders, 2) advancements in the technology and practice of producing and managing high-residue cover crop mulches, and 3) improvements and acceptance of integrated weed management techniques. Results from research experiments and grower’s fields over the years has shown that success with NT transplanted crops is highly dependent on achieving key production objectives, including: 1) production of dense, uniformly distributed cover crops; 2) skillful management of cover crops before transplanting, leaving a heavy, uniformly distributed killed mulch cover over the soil surface; 3) establishment of transplants into cover crops with minimum disturbance of surface residues and surface soil; and 4) adoption of year-round weed control strategies.

Benefits of conservation tillage in general and no-till (NT) systems in particular are well documented for many agronomic crops such as field corn (Zea mays L.), soybean [Glycine max (L.) Merr.], and cotton (Gossypium hirsutum L.) (Carter, 1994; Crosson, 1981; Griffith et al., 1986; Lal et al., 1990). Adoption of conversation tillage systems is increasing in North and South America to the extent that it now constitutes the normal or conventional method of crop production for field corn and soybean in some areas (Hebblethwaite, 1997).

Evolution of conservation in the United States

A major change in tillage practices has required a long transition period because the change involved development and adaptation of new types of equipment and methodology as well as different ways of perceiving the soil ecosystem (Brussard and Ferrera-Cerrato, 1997). In the early 1900s, moldboard plowing, excessive secondary tillage operations, and multiple cultivations led to serious erosion problems which led to serious flooding and dust storms (Phillips and Phillips, 1984). In 1943, Edward Faulkner boldly challenged the validity and wisdom of using the moldboard plow (Faulkner, 1947). Faulkner asserted: “The truth is that no one has ever advanced a scientific reason for plowing. The entire body of reasoning about the management of the soil has been based upon the axiomatic assumption of the correctness of plowing.”
The adoption of conservation tillage systems for vegetables has been slow due to several factors. However, with the increased acceptance of no-till production systems by both the research community and vegetable growers, adoption of conservation tillage systems for vegetables is still in its infancy stage. Before the 1990s, reluctance to adopt NT techniques for vegetable crops was fueled by several factors.

**Inadequate Equipment.** Until recently, there were no commercially available NT transplanters and seeders. Any attempt to establish NT vegetables relied on using conventional seeders and transplanters that were not built to handle untilled, high-residue soils.

**Poor, Uneven Stands.** Inconsistency in obtaining desired plant stands and uniform crop growth has been commonplace in NT vegetable research plots and farm fields. Much of this inconsistency can be attributed to use of inappropriate planting equipment and excessive weed growth because of ineffective herbicides (Lanini et al., 1989; Standifer and Best, 1985). Also, when direct seeding into rough, residue-covered soil, small seeded crops such as lettuce (Lactuca sativa L. var. capitata L.), and broccoli (Brassica oleracea L. var. italica Plenck) present greater obstacles to germination than large seeded crops, because shallow seeding is required and allelopathic interference is more severe (Putnam, 1986).

**Loss of Precocity.** Earliness or precocity is often extremely important in the marketing and profitability of many vegetable crops. Organic mulches insulate the soil and generally slow early plant growth and delay crop maturity, resulting in loss of precocity (Dutton, 1957; Horton, et al., 1994).

**Weed Control Problems.** Weedy fields have been a major deterrent to adoption of NT vegetable crops, especially when growers failed to achieve uniformly distributed, high-residue mulched fields. Historically, there have been relatively few labeled herbicides available for production of most vegetable crops, compared to a wide selection for agricultural crops (Standifer and Best, 1985). Therefore, reliance on cultivation to control post-emergence weeds has been a standard practice for production of many vegetable crops. During transition from conventional to NT systems, weedy fields have often occurred because most vegetable growers do not have high-residue cultivators.

Increase in NT vegetable crops in the 1990s

Even though crop specific data are not available, interest in and production of conservation tillage vegetable crops have increased during the 1990s (Table 1). Although still practiced on a limited scale, there has been considerable increase in adoption of NT for vegetable crops during the past 6 to 8 years (Conservation Technology Information Center, 1997). Recent events and circumstances have contributed to greater acceptance of NT production systems by both the research community and vegetable growers.

**Availability of Planting Equipment.** For >40 years, conventional transplanters have been modified to function in untilled fields (Morrison et al., 1973; Rutledge and Dutton, 1999; Worsham, 1985). These NT transplanters have been used mainly by research workers and are not commercially available. In all cases, these NT transplanters have not given consistent results in less-than-optimal conditions. In compacted and/or dry soils, reduced plant survival and uneven early plant growth have often occurred, because, without an upfront in-row soil loosening device, proper soil depth placement and subsequent root-soil contact have been difficult to achieve.

NT transplanters and seeders are now commercially available that have been successfully used in many states to...
In the 1980s, strip-till systems for vegetable crops were explored by North Carolina and Virginia researchers in the attempt to rectify the soil compaction and the resulting poor plant survival associated with the existing NT transplanters. Two-pass, strip-till systems were developed using a Bushhog Ro-till machine (Bushhog, Selma, Al.) (Hoyt, 1985; Morse, 1989) or a lightweight modified version of the Ro-Till (Wilhoit et al., 1990) followed by a subsequent operation using a conventional transplanter for plant establishment. The row-till machines effectively loosened in-row soils, resulting in excellent survival, growth, and yield of the vegetables tested; however, this more expensive two-pass system did not find favor with the farmers. In the relatively wide-tilled strip, the soil was exposed and weed seeds were brought to the surface, resulting in decreased soil and water conservation and increased weed problems, compared with NT systems.

In many states, successful NT direct seeding of vegetable crops has been achieved either 1) by using NT seeders built for agronomic crops, in which appropriate seed plates were used for vegetable crops; and/or 2) by mounting coulters, trash cleaners and other standard NT devices ahead of precision vegetable seeders that enabled seeding and stand establishment in untilled or reduced-tilled soils. With the possible exception of pumpkin (Cucurbita pepo L.), in most instances low-residue crop management has been used with direct seeded vegetable crops. Research is needed to evaluate NT direct-seeded systems for vegetable crops grown in rotation with well established and properly managed high-residue cover crops.

Fig. 2. Row of no-till pumpkins 3 weeks after transplanting; transplants were established, fertilizer was applied, and drip tubing was installed with minor disturbance of surface soil and in situ surface mulch.

use of high-residue cover crops and effective residue management techniques. Historically both NT researchers and farmers were reluctant to invest the requisite expense, time, and risk to produce and manage high-residue cover crops for production of agronomic crops. However, stimulated by the desire for reduced nonchemical weed suppression and improved produce quality, high-residue NT systems for soybeans (Reeves et al., 1997) and transplanted vegetable crops (Morse, 1995) have been developed in which proper growth and management of cover crop residues has been preeminent for success. Associated development of equipment capable of planting into high residues has allowed successful production of soybean and other vegetable crops, in which appropriate seed plates were used for vegetable crops; and/or 2) by mounting coulters, trash cleaners and other standard NT devices ahead of precision vegetable seeders that enabled seeding and stand establishment in untilled or reduced-tilled soils. With the possible exception of pumpkin (Cucurbita pepo L.), in most instances low-residue crop management has been used with direct seeded vegetable crops. Research is needed to evaluate NT direct-seeded systems for vegetable crops grown in rotation with well established and properly managed high-residue cover crops.

Fig. 3 (cover photo). Three-row subsurface tiller–transplanter (SST–T) setting cabbage transplants on Linford Belcher’s farm in Laurel Fork, Va.


**Vegetables.** Indeed, high-residue farming on untilled soil is the most cost- and time-efficient approach for the soil scientist, in situ production and the perspective of both the farmer and Jones, 1996; Ismail et al., 1994). From turn increases soil quality (Doran and soil organic matter content, which in many vegetable crops in high-residue, well-managed NT systems.

**LABELING EFFECTIVE HERBICIDES FOR VEGETABLES.** Many researchers and farmers have shown that the combination of producing and maintaining uniformly distributed, high-residue covers and timely use of both preemergence and postemergence herbicides can provide equal or even better weed control than that achieved in conventionally tilled systems (Abdul-Baki et al., 1997; Hackett, 1998; Morse, 1995). Improvements in the formulation and labeling of glyphosate (N,N'-bis(phosphonomethyl)glycine) and other herbicides (Hackett, 1998) for vegetables have enabled growers to successfully control weeds in NT vegetable production systems.

**NT Transplanted Vegetables in the 1990s—Keys to Success**

Reducing or minimizing tillage (particularly inversion of the soil, using the moldboard plow, disk, etc.) increases soil organic matter content, which in turn increases soil quality (Doran and Jones, 1996; Smail et al., 1994). From the perspective of both the farmer and the soil scientist, in situ production and retention of high levels of crop residues (high-residue farming) on untilled soil (NT) is the most cost- and time-effective way of increasing soil organic matter (Crovetto, 1996). Indeed, high-residue/NT (H R/NT) farming systems can play a major role in achieving a sustainable agriculture worldwide (Lal et al., 1990).

High-residue covers can interfere with seed germination and seedling growth, reducing the chance of achieving adequate plant stands with direct-seeded crops. Conversely, proper establishment of large, vigorous transplants minimizes crop interference and dramatically increases the chance of plant survival in high-residue covers. In addition, using transplants favors rapid canopy closure and weed suppression, reducing the need for chemical weed control (Morse, 1995).

High, profitable yields are achievable using H R/NT production systems. Growers should use a year-round systems approach in H R/NT farming. Success depends on 1) selecting the most sustainable or appropriate crops, cultivars, soils, and microclimatic conditions and 2) identifying and applying yield-enhancing practices inherent or specific for H R/NT systems. The remainder of this paper will focus on the latter: yield-enhancing practices specific for H R/NT systems. In the sections that follow, four production strategies (objectives) are briefly presented, emphasizing proper use of available equipment and associated technology.

**Objective I: Produce a Dense, Uniformly Distributed Cover Crop Before Transplanting**

Sparse, unevenly distributed crop residues is a major cause of poor results in NT transplanted crops. In contrast, establishing a dense, uniformly distributed cover crop before transplanting provides the greatest chance for success. Benefits from heavy, evenly distributed residues include weed suppression, reducing or eliminating the need for preemergence herbicides; greater conservation of soil and water; and greater trafficability resulting in improved flexibility in timing field operations.

With NT production systems, investing in cover crop residues before transplanting is like establishing a savings account: you receive the input (deposit) back plus interest later. Every effort and expense to establish a relatively weed-free, dense cover crop will be rewarded later in the form of improved crop yields and quality. Recommended cultural practices include selecting the most adaptive and compatible cover crops, obtaining a uniform dense stand by drilling high seed rates at close between-row spacing and providing adequate growth inputs (water and nutrients) and growing time to maximize cover crop biomass.

**Objective II: Kill Cover Crops Before Transplanting, Leaving a Heavy, Uniformly Distributed Mulch Cover Over the Soil Surface**

Weeds reduce crop yields predominantly by interspecific (weed–crop) competition for water, nutrients and light. To minimize interspecific competition, the cover crop must be killed and subsequently managed in such a manner that the in situ mulch effectively covers and shades the soil surface but does not excessively shade or deleteriously affect growth of the transplanted crops. Either chemical and/or mechanical methods can be used to kill and retain a dense uniformly distributed mulch (Dabney et al., 1991; Morse, 1995).

**Chemical Methods.** Contact herbicides such as glyphosate and paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) are needed to desiccate perennial and immature annual weed and cover crop species. Desiccation should be done 2 to 5 weeks before transplanting to ensure complete vegetative kill. Glyphosate should be applied at least 4 weeks before transplanting to avoid any potential stunting of the transplanted crops from root-to-root transfer of actively glyphosate exuded from roots of the treated cover crop to the roots of the transplanted crops. Often two or more sprays are...
required to completely desiccate all vegetation.

**MECHANICAL METHODS.** Many species of mature annual grass and legume cover crops can be effectively killed using mechanical methods (Morse, 1995). To be successful, however, mechanical treatments must occur after the annual species have developed beyond their vegetative stage and ideally after flowering. When attempting to kill mixtures of annual species (cover crops and/or weeds) mechanically, all species should be mature and incapable of regrowth following mechanical treatments. Mechanically killing cover crops has two distinct advantages over using contact herbicides: 1) negative environmental impacts of herbicides are reduced; and 2) cover crops can be killed immediately before planting, which maximizes the growth potential and maturation of the residues. Since a relatively high percentage of transplanted crops are irrigated, potential soil moisture depletion problems arising from drought before planting are negated.

Flail mowing and rolling have been used effectively to kill black oat (Avena strigosa Schreb.), cereal rye (Secale cereale L.), wheat (Triticum aestivum L.), foxtail millet (Setaria italica L.), buckwheat (Fagopyrum sagittatum Grilb.), crimson clover (Trifolium incarnatum L.), and soybean (Morse, 1995; Reeves et al., 1997). Flail mowing effectively kills most mature annual cover crops and distributes a uniform layer of organic mulch over the soil surface. Rotary mowers are not recommended because they tend to windrow the chopped residues. Flail mowers contain many small double-edged knives affixed to a parallel rotor that uniformly distrib-

<table>
<thead>
<tr>
<th>Vegetable crop</th>
<th>Botanical name</th>
<th>Common name</th>
<th>Direct seeded</th>
<th>Transplanted</th>
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</thead>
<tbody>
<tr>
<td>Z. mays L.</td>
<td>Sweet corn</td>
<td></td>
<td>H high</td>
<td>N A</td>
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<tr>
<td>Phaseolus sp.</td>
<td>Snap bean, lima bean</td>
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<td>H high</td>
<td>N A</td>
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<tr>
<td>Brassica sp.</td>
<td>Cabbage, broccoli, cauliﬂower, collard</td>
<td>Low</td>
<td>High</td>
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<tr>
<td>Cucurbita sp.</td>
<td>Pumpkin, summer squash, winter squash, gourds</td>
<td>H high</td>
<td>High</td>
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<tr>
<td>Cucumis sp.</td>
<td>Musk melon, honeydew melon, cucumber</td>
<td>H high</td>
<td>High</td>
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<tr>
<td>Citrullus lanatus Thumb.</td>
<td>Watermelon</td>
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<tr>
<td>Capsicum annuum L.</td>
<td>Bell pepper, cayenne pepper</td>
<td>Low</td>
<td>High</td>
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<tr>
<td>Lycopersicon esculentum Mill.</td>
<td>Tomato</td>
<td>Low</td>
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<td>Solanum tuberosum L.</td>
<td>Potato</td>
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<td>Ipomoea batatas L.</td>
<td>Sweet potato</td>
<td>N A</td>
<td>M moderate</td>
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Table 1. Feasibility of achieving successful production of vegetable crops, using no-till production systems.

Other mechanical killing methods include: 1) mechanical killing of cover crops has two advantages over the use of herbicides: reduced environmental impacts and the ability to kill cover crops immediately before planting; 2) cover crops can be killed immediately before planting, which can maximize the growth potential and maturation of the residues; 3) turf or construction rollers, commercially available water-filled rollers used for compacting and rolling turf and roadways could be used to roll crop residues (Hoffman et al., 1993); 4) roller-crimper drum, water-filled drum rollers modified with horizontal welded blunt steel blades or metal strips have been used in Brazil and other locations to roll-crimp cover crops, thus facilitating killing yet leaving plant stems intact (Reeves et al., 1997); 5) undercutter-roller, a modified bladeplow (V-plow sweep) has been used as an undercutter, designed to sever the cover crop roots, followed by a rolling harrow which rolls the residues flat over the ground. This undercutter-roller functions well on raised beds under dry, nonrocky conditions (Creamer et al., 1995); 6) rolling stalk chopper, when properly adjusted or modified, stalk choppers can effectively roll and evenly distribute high-residue cover crops (Hackett, 1998). Rolling appears to have considerable merit for mechanically killing cover crops. Ongoing crop residue management research and field testing in several states (Virginia, North Carolina, Pennsylvania, Alabama, Maryland, and California) should help clarify the relative advantages and specific uses of different rolling methods for mechanically killing cover crops in H/R/NT vegetable production systems.

**CHEMICAL AND MECHANICAL METHODS.** The SST–T functions best in upright-standing (intact) residues, regardless of the height of the cover crops. In
contrast, in some situations the SST–T functions poorly in lodged desiccated residues or coarsely chopped, unevenly distributed residues such as derived from rotary mowers (Morse et al., 1993). Although the benefits of high residues are many, shading and survival of newly germinated or transplanted crops can be problems in dense, tall-standing residues.

In some situations where contact herbicides are required to achieve an adequatekill of tall-standing cover crops, mowing or rolling may be used to flatten the desiccated residues and minimize shading of the transplanted crop (Morse, 1995). For example, contact herbicides combined with or without preemergent herbicides can be used to desiccate tall-standing, dense residues, followed by mowing or rolling before transplanting or mowing (with mower blades held above the established transplants) after transplanting.

Recently, several cover crops have been effectively killed by first rolling tall-standing covers followed by applying paraquat. This method looks very promising since rolling orients and flattens upright-standing residues in one direction, which improves transplanting effectiveness with the SST–T (R.D. Morse, unpublished data).

Objective III: Establish transplants into cover crops with minimum disturbance of surface residues and surface soil

Lack of reliable NT transplants and inconsistent establishment have been major factors limiting the adoption of NT systems for transplanted crops. Generally, low yields occur when NT is practiced in poorly drained, compacted soils. In NT systems, when a device (chisel plow, coulters, rototiller, undercutter, etc.) is used to loosen or fracture a strip of in-row soil before transplanting, both stand establishment and subsequent plant growth are improved, approaching or even surpassing that achieved in tilled soils. With the recent development of the SST–T, no tillage with in-row soil loosening and transplanting are combined in one pass across the field (Morse et al., 1993).

Objective IV: Practice year-round weed control

The old adage “an ounce of prevention is worth a pound of cure” is particularly valid in HR/NT farming.

Weed control can be achieved in two ways—directly using both chemical and mechanical means and indirectly by using cultural practices that promote rapid plant growth and canopy closure. Preemergence and postemergence herbicides can be applied and, in conjunction with physical and allelopathic effects associated with high-residue covers, often provide adequate weed control. However, the best direct method is to lower weed and seed populations before transplanting (i.e., apply aggressiveweed-control measures before and/or during production of the cover crop).

Of critical importance, NT fields should not have a serious perennial weed problem such as nutsedge (Cyperus L.), quackgrass (Agropyron repens (L.) Beauv.), johnsongrass (Sorghum halepense (L.) Pers) or morningglory (Ipomoea L.). Weedy fields should be cleaned up before seeding the cover crop; and/or, if necessary, herbicides should be used in conjunction with production of the cover to minimize weed population before transplanting. Appropriate use and timing of pretransplant herbicides to achieve a “stale seedbed” (reduced weed seed population) and a dense weed-free cover crop are generally more environmentally friendly and less expensive than typical uses of herbicides.

The term stale seedbed (more appropriately stale transplant bed) refers to techniques allowing weed seeds in the soil surface to germinate and be killed without redispersing the soil other than the seeding operation. Following the NT field before seeding the cover crop and eradicating emerged weeds, either by mowing or with herbicides, followed by NT drilling cover crops is an excellent way to obtaining both a stale seedbed and a weed-free cover crop before transplanting.

Using cultural practices that promote rapid plant growth and canopy closure will result in improved weed suppression and higher crop yields. Recommended cultural practices include: 1) using large, vigorous transplants; 2) arranging plants in multiple rows; and 3) precision placing and timing of fertilizer and irrigation water.

Literature cited


Horton, R., G.J. Kluitenberg, and K.L. Bristow. 1994. Surface crop residue effects to techniques allowing weed seeds in the soil surface to germinate and be killed without redispersing the soil other than the seeding operation. Following the NT field before seeding the cover crop and eradicating emerged weeds, either by mowing or with herbicides, followed by NT drilling cover crops is an excellent way to obtaining both a stale seedbed and a weed-free cover crop before transplanting.

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