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-tillage (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 conservation 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."

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But plowing is not correct. Hence, the main premise being untenable, we may rightly question the validity of every popularly accepted theory concerned with the production of any crop, when land has been plowed in preparation for its growth." Although Faulkner was considered a "fanatic" by the academic community of his time, today there is wide acceptance of conservation tillage systems throughout the world.

With the advent of preemergent herbicides in the 1940s, production of agronomic crops such as field corn and soybeans began a slow but steady movement toward incomplete, reduced, or minimum tillage – only tilling the soil enough to facilitate plant establishment and subsequent plant growth. Conservation tillage is defined as "any tillage sequence, the object of which is to minimize or reduce loss of soil and water; operationally, it is a tillage or tillage and planting combination which leaves a 30% or greater cover of crop residue on the surface" (Soil Science Society of America, 1987). No tillage is the extreme form of conservation tillage where the soil is left undisturbed before planting. Planting is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disc openers, in-row chisels, or roto tillers (Hebblethwaite, 1997). The term no tillage is in reality a misnomer since some tillage or soil loosening occurs from the coulters and the soil-opening devices of the planter (Phillips and Phillips, 1984).

Adoption of conservation tillage systems for vegetables

Compared to field corn and soybean, 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 inconsis-

tency 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 agronomic 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

Fig. 1. Two-row subsurface tiller-transplanter (SST-T) equipped with fertilizer applicators and drip layers.

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.

establish vegetable crops in high-residue, NT systems (Morse et al., 1993; Morse, 1999). One of the most successful units is the Subsurface Tiller-Transplanter (SST-T) manufactured by B&B No-Till (Laurel Fork, VA). The SST-T is a two-component system, combining subsurface soil loosening and transplanting to alleviate soil compaction and effectively set transplants in one operation (Figs. 1-4). The SST-T has a unique subsurface tiller (SST) aligned in front of the double-disk shoe of the NT transplanter. Both component function are accomplished with minimum disturbance of surface residues and surface soil (Morse et al., 1993).

Available NT transplanter such as the SST-T are equipped for precision placement of 1) liquid starter fertilizer-pesticide solutions around the root system of the transplant, 2) liquid or granular fertilizers underneath the transplant, 3) granular fertilizers surface applied in bands on both or either side of the transplant row, and 4) drip tubing at selected depths below the crop residues and in close proximity of the crop row.

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 light-weight modified version of the Ro-Till (Wilhoit et al., 1990) to till a narrow strip [8 to 12 inches (20 to 30 cm) wide] 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.

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

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

Fig. 4. Mature no-till cabbage in a typical hillslope field near Laurel Fork, Va.

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; Ismail 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 (HR/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 HR/NT production systems. Growers should use a year-round systems approach in HR/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 HR/NT systems. The remainder of this paper will focus on the latter: yield-enhancing practices specific for HR/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 active glyphosate exuded from roots of the treated cover crop to the roots of the transplanted crops. Often two or more sprays are

Table 1. Feasibility^z of achieving successful production of vegetable crops, using no-till^y production systems.

Vegetable crop		Planting method	
Botanical name	Common name	Direct seeded	Transplanted
<i>Zea mays</i> L.	Sweet corn	High	NA
<i>Phaseolus</i> sp.	Snap bean, lima bean	High	NA
<i>Brassica</i> sp.	Cabbage, broccoli, cauliflower, collard	Low	High
<i>Cucurbita</i> sp.	Pumpkin, summer squash, winter squash, gourds	High	High
<i>Cucumis</i> sp.	Muskmelon, honeydew melon, cucumber	High	High
<i>Citrullus lanatus</i> Thumb.	Watermelon	High	High
<i>Capsicum annuum</i> L.	Bell pepper, cayenne pepper	Low	High
<i>Lycopersicon esculentum</i> Mill.	Tomato	Low	High
<i>Solanum tuberosum</i> L.	Potato ^x	Moderate	NA
<i>Ipomoea batatas</i> L.	Sweetpotato	NA	Moderate

^zFeasibility based on past and current observations in research plots and grower fields. In many cases, grower experience has been limited to small-scale [<25 acres (11 ha)] fields. Feasibility ratings: high = broad-scale success achieved by both researchers and growers; moderate = experience limited mainly to small-scale research plots; low = not currently recommended because of insufficient research and/or grower experiences; NA = not applicable because planting method is not commonly practiced.

^yNo-till includes strip-till systems.

^xFor potato, whole seed tubers or cut seed tuber pieces are planted.

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.), fox-tail millet (*Setaria italica* L.), buckwheat (*Fagopyrum sagittatum* Grib.), 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-

ute the finely cut residues over the soil surface.

Rolling can effectively kill many cereal grain crops and some legumes. Cover crop kill is often less complete when rolled than when mowed. However, the NT transplanters function better and cover crop persistence and weed suppression are better in rolled than in mowed plots (Morse, 1995).

When rolled effectively, dense stands of mature annual cover crops are laid prostrate uniformly over the ground and remain lodged. Complete kill takes from a few days to several weeks, and in some cases partial greening may remain throughout the growing season of the transplanted crop. With most crops, however, any interspecific competition between the transplanted crop and the living cover is not a serious yield-limiting factor and is more than compensated by the many growth-promoting benefits of rolled, heavy crop residue mulch. Planting the transplanted crops in multiple rows often helps considerably to minimize greening of the follow cover crops and thus reduces interspecific competition effects.

Many types of equipment have been used to roll mature annual cover crops, including

- 1) **DISENGAGED FLAIL MOWER.** When disengaged and pulled over the ground, the roller gauge wheel of the flail mower can effectively flatten mature crop residues (Morse, 1995).
- 2) **GRAIN DRILLS.** Modified grain drills equipped with coulters and cast-iron press wheels spaced 5 inches (13 cm) apart have been effectively used to roll some cover crops (Dabney et al., 1991).

- 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-CRIMP 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 blade plow (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 HR/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 adequate kill 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 transplanters and inconsistent stand 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, coulter, 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 aggressive weed-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 redisturbing 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.

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