EVOLUTION OF CONSERVATION TILLAGE SYSTEMS FOR TRANSPLANTED CROPS -- POTENTIAL ROLE OF THE SUBSURFACE TILLER TRANSPLANTER (SST-T)

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EVOLUTION OF CONSERVATION TILLAGE SYSTEMS IN THE UNITED STATES

Conservation Tillage Versus Conventional Tillage - The Farmer's Dilemma

In the early 1900s, moldboard plowing, excessive secondary tillage operations, and multiple cultivations led to serious erosion problems and the "much-talked-about" flooding and dust storms (Phillips and Phillips, 1984).1n 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. 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, the wide acceptance of conservation tillage systems today throughout the world is a fitting testament to the "self-sufficiency of the soil" ("sustainability") he so avidly proclaimed.

With the advent of pre-emergent herbicides in the 1940s, agriculture 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 a form or extension of minimum tillage. Conceptually, 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" (SSSA, 1987). No-tillage (NT) is the extreme form of conservation tillage where the soil is left undisturbed prior to planting. Planting is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disc openers, in-row chisels, or roto tillers (CTIC, 1992). The term "no-tillage" is in reality a misnomer since some tillage or soil loosening occurs from the coulter and the soil-opening devices of the planter (Phillips and Phillips, 1984). Therefore, the fact that some tillage occurs in NT systems leads to the central question or focus in this article--"how much soil loosening or tillage is necessary to reduce the compaction of an undisturbed soil to a level that will not deleteriously affect crop establishment and yield potential?" The answer to this question depends on a) the severity of the existing soil compaction, b) the crop species being grown, and c) the extent to which the advantages of using NT systems offset or counter-balance soil compaction and other disadvantages in the particular abiotic and micro-climatic conditions in question.

Role of Soil Physical Properties

The relative importance of soil compaction and poor drainage in reducing crop establishment and yield potential varies with the length of growing season and the extent to which the advantages of no-tillage are expressed during the growing season. Poor plant stands generally result in reduced crop yield, unless the particular crop grown has a strong indeterminate growth pattern and the length of the growing season is long enough to allow for crop yield-compensating effects to occur (Morse, 1990).

Even when plant stands are not affected in NT systems, crop yield potential may be reduced because of poor soil drainage (Griffith and Mannering, 1985). In general, as soil drainage decreases, the need for tillage increases. Thus, with easily compacted impermeable soils, crop yield potential is often reduced under NT systems (Griffith and Mannering, 1985). Poor drainage is most common on clayey soils (Webber et al., 1987) and/or soils with natural or man-made impermeable soil layers or "pans." This yield disadvantage associated with NT on poorly drained soils occurs most often in early plantings. Lower soil temperatures and excess wetness early in the growing season are common on poorly drained soils, and both problems are

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accentuated when crop residues are left on the surface and the soil is not loosened by tillage.

Poor drainage does not reduce yields under all conditions. In areas with long growing seasons, late spring or summer plantings on poorly drained soils under droughty conditions may result in favorable or even improved yields with NT (Griffrth et al., 1986).

Unfortunately, there is little information on long-term (many years or decades) advantages of using NT systems. However, using NT may result in lower rates of erosion and, over many years, can maintain or even increase soil productivity, crop yields, and grower profits (Crosson, 1981; Hargrove, 1990).

In-Row Tillage-A Sustainable Compromise

Compared with CT or even mulch tillage (CTIC, 1992), reducing tillage to only a narrow in-row area (strip tillage and ridge tillage) appears to be an excellent choice on compacted, erosive soils. The relative advantages of each conservation tillage system vary or interact with the degree to which soil moisture and other growth factors are limiting (Morse, 1993). Based on previous research with transplanted cabbage (Love, 1986; Morse, 1989), in-row tillage appears to be the best overall system under either ample or deficit soil moisture. The combination of in-row tillage for improved planting efficiency and soil condition and maintaining between-row surface cover for moisture and soil conservation make in-row tillage an excellent compromise between NT and CT.

EVOLUTlON OF NO-TILLAGE PLANTERS

Agronomic Crop

The first plow was a forked stick, pulled through the soil by the wife and steered by the husband. Fortunately, the wife's role has changed toddy; however, the role of the plow is not much different - only the depth of plowing and level of remaining surface residues have changed (Hayes, 1985). Until the early 1900s, the plow left field surfaces very rough with some remaining unburied residues. With advances in the industrial revolution came more powerful tractors and moldboard plows that more completely buried crop residues, leaving the soil surface exposed to wind and water erosion (Hayes, 1985). This movement to clear-tillage resulted in the serious flooding and the dust storms of the 1930s, which led to the establishment of the Soil Erosion Service in 1933 and its successor, the Soil Conservation Service in 1935. In the 1940s, Faulkner (1947) and other progressive thinkers (Sears, 1935; Scarseth, 1961) focused on the erosion hazards from using the moldboard plow. These scientists advocated less plowing and greater use of plant residues.

Acceptance of no-tillage as a viable production system and manufacturing of NT planters were practically nonexistent until the 1960s and 1970s. Prior to this period, farmers interested in NT planters were forced to modify existing equipment (Phillips and Phillips, 1984). The performance of these make-shift planters was inconsistent at best, frequently resulting in poor plant stands and low crop yields. Today conservation tillage of agronomic crops is widely accepted, and the modern NT seeders function well in undisturbed soils and chemically killed residues. Under most conditions, these NT seeders effectively prepare a mini in-row seedbed and precision-place seeds at desired depths in the soil (Hayes, 1945; Gebhardt and Fornstrom, 1985). Excellent progress is also made in developing more sustainable NT systems for corn *(Zea mays* L.) in which heavy stands of mechanically killed, cereal-legume cover crops are used to partially or even totally replace conventional inorganic herbicides and nitrogen fertilizers (Ess et al., 1992a and b; Vaughan et al., 1992).

Tobacco and Vegetables

Direct seeding of tobacco and vegetable crops using NT systems is not a commercial practice in the United States, except for a relatively small acreage of sweet corn and snap beans (CTIC, 1992). Although small-seeded species, such as broccoli, have been successfully seeded in NT systems (Schertz et al., 1986; Young, 1989), lack of precision vegetable seeders and effective registered herbicides have virtually inhibited adoption of commercial NT production systems for these crops (Standifer and Best, 1985; Putnum, 1986; Lanini, 1989). Setting vegetable and tobacco transplants in undisturbed soils have been tested for over 20 years (Moschler et al., 1971; Morrison et al., 1973; Knave1 et al., 1977; Worsham, 1985). Yield results have been inconsistent for basically the same reasons as discussed for NT production of direct-seeded agronomic crops in the 1940s and 1950s.

No-Tillage Transplanters

To meet farmer expectations and perform satisfactorily under a wide array of soil and plant-residue conditions, NT transplanters must fulfill the following basic requirements: a) be constructed heavy enough and strong enough to efficiently set plants in adverse conditions such as compacted, hard (dry), moist, or rocky soils; h) have a high clearance design and the capacity to set plants in heavy residues with minimal disturbance of surface soil and surface residues, thereby maximizing soil and water conservation and improving weed control; c) till or loosen a narrow band of soil and displace small rocks to ensure proper functioning of the transplanter shoe and placement of the transplants--the volume of loosened soil should measure 5 to 10 cm wide and 15 to 25 cm deep, depending on the species grown and soil amendments applied; d) firm the loosened soil around the transplant to ensure the necessary root-soil contact for optimum survival and growth of the plants; and e) have the capacity to precision-place requisite pesticides and fertilizers to ensure survival and rapid growth of the plants.

Currently, there are no commercially available NT transplanters that will even remotely approach the five requirements listed above (Standifer and Best, 1985; Shelby et al., 1988). Some of the major manufacturers of conventional transplanters in the United States and Europe offer up-front coulter attachments installed on their normal conventional transplanters. Under light-residue and moist, friable soil conditions, these "no-till" transplanters will function properly and plant yields are good (Wilhoit et al., 1990). However, this exacting requirement for soil moisture and soil tilth limits the usefulness of these transplanters. Furthermore, when used in excessively wet soils, the coulter and shoe of the transplanters merely part or slice open the soil without loosening or crumbling it. The root-soil contact of transplants set in these soil "wedges" or "slices" is poor, resulting in reduced plant survival and slow plant growth. In the drier, more normal conditions characteristic of hilly, well-drained soils ideal for NT systems, the efiectiveness of the existing NT transplanters has been unreliable and has slowed adoption of this technology. Under dry conditions, these transplanters are virtually nonfunctional. The shoe cannot effectively penetrate the soil, resulting in frequent mechanical breakdowns and resetting of plants.

The evolution of NT transplanters has taken a similar path, as with the NT seeders. In the late 1960s and 1970s, various researchers used locally modified conventional transplanters to set tobacco (Morrison et al., 1973; Chappell and Link, 1977; Worsham, 1985) and vegetable (Knavel et al., 1977; Knavel and Herron, 1981) transplants in undisturbed soils. The changes made consisted of three main modifications: a) attaching a coulter ahead of the standard machine to cut the surface mulch and roots of the killed sod to a depth adequate for transplanting; b) replacing the conventional shoe-type furrow opener with a double-disc opener to part the surface residues and more adequately protect the shoe; and c) adding additional weights on the press wheels and/or behind the planter to ensure adequate planting depth. Survival, growth, and yield of the tobacco and vegetables set with these early NT models were inconsistent because of erratic weed and insect control (Worsham, 1985) and poor root-soil contact (Knavel and Herron, 1981). The later problems (poor root-soil contact) can be serious in early-spring plantings (cold, wet soils) and compacted, less friable soils, principally because these transplanters do not till or loosen a narrow strip of in-row soil (Zartman et al., 1975; Knavel and Herron, 1981).

In attempts to rectify the soil compaction problems associated with the earlier NT planters, North Carolina and Virginia researchers in the 1980s experimented with two major changes. First, by replacing the double-disc shoe with a conventional shoe having a narrow cultivator-type nose or point welded in front, in-row soil was loosened and braught to the surface to facilitate improved root-soil contact by the firming action of the press wheels. This modification resulted in improved crop establishment; however, often the rigid-mounted, fragile shoe did not hold up well in dry, rocky, or compacted soils because the shoe was required to "plow" the unloosened soil. Second, a two-pass system was developed--using a Bushhog Ro-till machine (Hoyt, 1985; Morse, 1989) or a light-weight modified version of the Ro-Till (Wilhoit et al., 1990) to till a narrow strip (20 to 30 cm wide) in one operation, followed in a subsequent operation by using a conventional transplanter for plant establishment. The Ro-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.

The Subsurface Tiller Transplanter (SST-T)

A strong movement in the 1990s toward a more sustainable agriculture has stimulated the development of the Subsurface Tiller Transplanter (SST-T), which was released in late May 1992 (Fig. 1). The SST-T has an upright, high-clearance design with a double-disc shoe similar to that of the 1970s' models. However, in

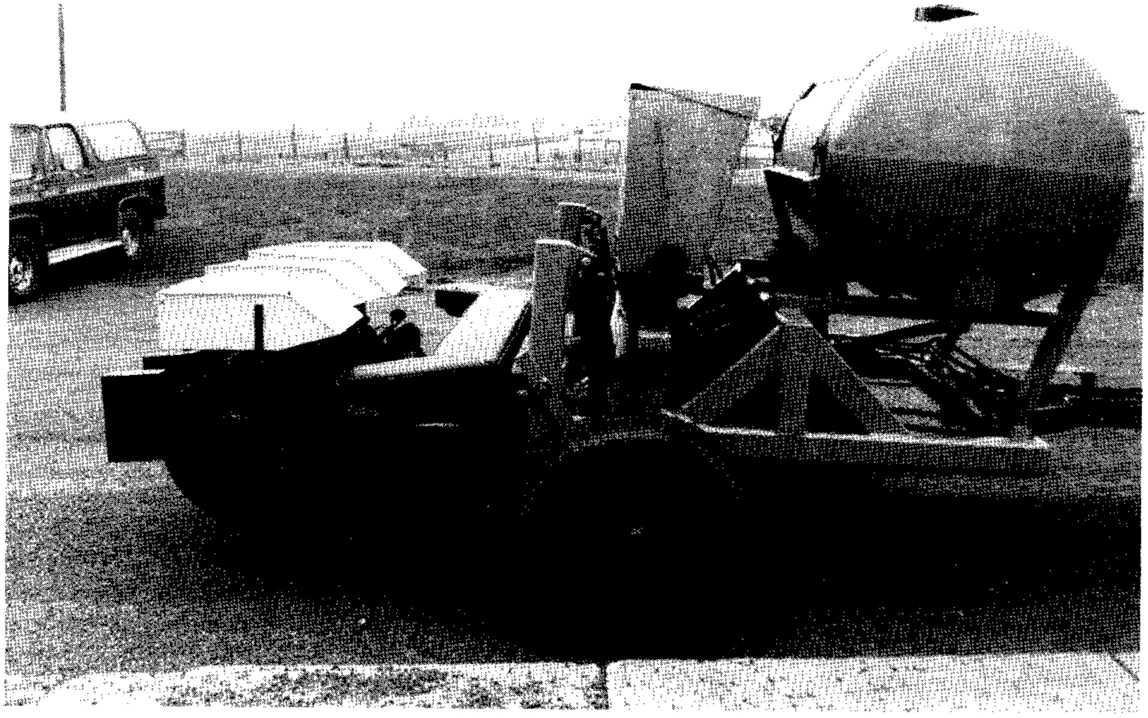

Fig. 1. The Subsurface Tiller Transplanter (SST-T). The SST-T has two main components -- the SST up-front that loosens a narrow strip with minimal disturbance of the surface soil or plant residue; and a conventional transplanter aligned behind the SST to set plants in the tilled strip. The transplanter shown in this photo is the Holland (Holland Transplanter Co.--Holland, MI) Model 1600 with a double-disc assembly added in front of the standard round-point shoe. The SST component also includes a hydraulic-driven Holland fertilizer attachment.

addition, the SST-T has a unique subsurface tiller (SST, patent pending) aligned in front of the double-disc shoe of the transplanter. The SST is composed of a DMP Tru-Tracker (Fig. 2) mounted on a 10 x 10-cm tool bar. The Tru-Tracker contains a 50-cm smooth, spring-loaded coulter and a ACRA-plant fertilizer knife with a winged point that is designed to loosen a narrow strip (5 to 10 cm wide).

The conceptual design and functioning of the SST-T is uniquely different from that of the earlier NT transplanters. With the NT models of the 1980s (NT80s), the cultivator-type shoe performs both the tilling and the planting functions. Under compacted, rocky conditions, the rigid-mounted shoe of the NT80s was easily bent or broken, which seriously reduced its usefulness for conservation tillage systems. In contrast, the spring-loaded Tru-Tracker component of the SST-T has heavy-duty construction and subsurface tills a narrow strip of soil ahead of the double disc shoe of the transplanter. The double-disc shoe moves through the residues and tilled strip with relatively little resistance and with minimal surface soil and surface residue disturbance. The SST-T is an efficient (less equipment breakdown) and effective (less resetting needed) transplanting system that, when used in heavy residues, maximizes soil and water conservation and early field reentry permitting planting, spraying, and harvesting operations to be done within a few hours following irrigation or rainfall.

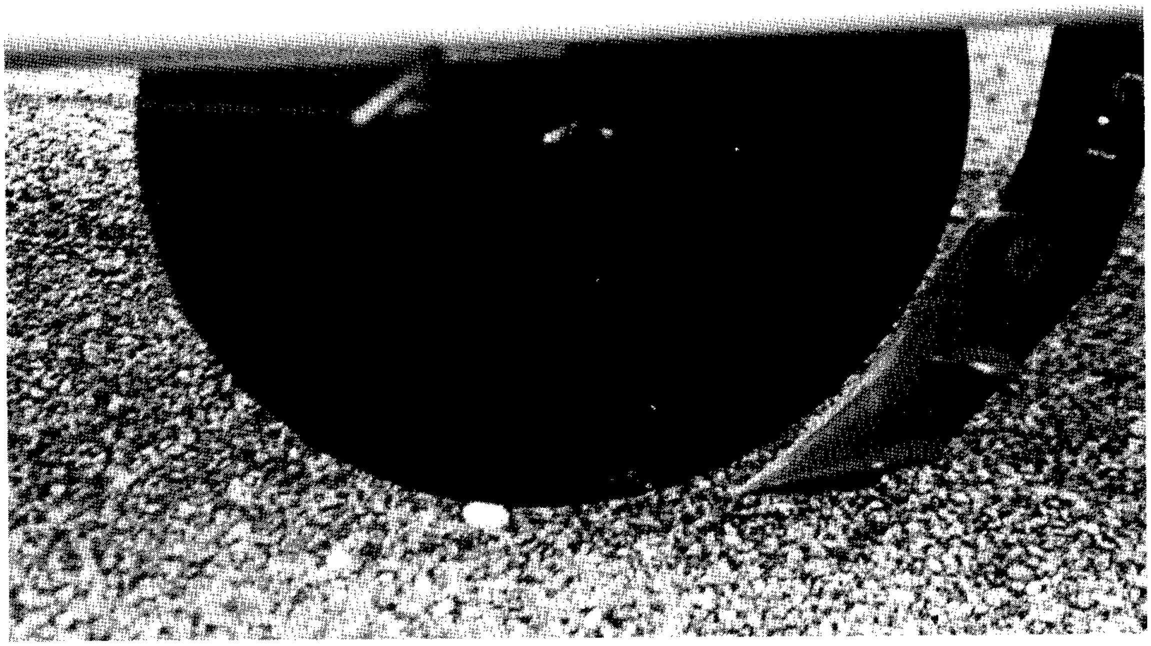

Fig. 2. A close-up of the bottom part of the soil loosening mechanism of the Subsurface Tiller (SST)--composed of a DMI (DMI, 1nc.--Goodfield, IL)Tru-Tracker and a ACRA-Plant (ACRA-Plant Sales, 1nc.--Garden City, KS) Knife with a winged point.

The single coulter and double-disc shoe of the NT models of the 1970s (NT70s) often do not loosen enough in-row soil for optimum root-soil contact, resulting in reduced plant survival and slow early growth of the improperly set transplants. Fluted or ripple coulters can loosen more in-row soil than the smooth coulters; however, they do not cut the residues as effectively as the smooth coulter and may cause hair pinning (pressing of the residues into the soil without cutting).

The SST-T is also equipped for precision placement of a) liquid starter fertilizer-pesticide solutions around the root system of the transplant, b) liquid fertilizer solutions underneath the transplant, and c) granular base fertilizers surface applied in two bands on either of the transplant rows. A combination of these treatments is expected to eventually give the most efficient use of soil amendments. In future experiments, the SST-T will be used to test various combinations of both inorganic and organic (natural) soil amendments for optimum growth of tobacco and vegetable crops.

CONCLUSION

Conservation tillage principles and practices have evolved over the past 50 years until they were widely accepted, and have a significant, annually increasing proportion of the acreage of corn, soybeans, cotton, sorghum, and cereal grains. Although NT systems for transplanted row crops are still relatively unknown and are predominantly in the experimental stages, there is considerable interest in using more sustainable production methods in areas where transplanted tobacco and'vegetable crops are grown on hillslopes and other erosive and droughty conditions.

Lack of reliable NT transplanters have been a major factor limiting the adoption of NT systems for transplanted row crops. A new transplanter, the Subsurface Tiller Transplanter (SST-T), was recently developed that incorporates the best components of previous models into an efficient one-pass planting system. The SST-T offers a viable compromise between conventional tillage (CT) and the previously tested NT transplanters of the past two decades (NT70s and NT80s). The SST-T has three major advantages over the previous models.

More efficient and effective planting. By loosening a narrow strip of in-row soil, the Tru-Tracker component of the SST improves both crop establishment and yield. Using the Tru-Tracker as the tillage instrument reduces damage to the shoe of the transplanter. In the NTSOs' models, the shoe itself is the tillage instrument and, therefore, it takes the brunt of the physical abuse in rocky and compacted soils. The Tru-Tracker works well in difficult soils, preparing a tilled strip for the shoe that follows.

Increased capacity to set plants in heavy residues, thereby. maximizing soil and water conservation. To effectively set plants in heavy residues, a high-clearance, double-disc shoe is superior to low-clearance, blunt- or round-point shoes. In some NT80s models, the side braces of the shoe catch the cover crop residues, resulting in residue clogging or build-up ahead of the shoe. With the SST-T one-pass system, the coulter and fertilizer knife of the Tru-Tracker part the residue with minimal disturbance and the double-disc shoe follows along in the tilled strip without residue build-up.

Reduced disturbance of surface residues and surface soil. thereby, improving weed control. To obtain good root-soil contact in an undisturbed soil, the in-row tillage mechanisms of the NT transplanter must adequately loosen the soil, and the press wheels must have the capacity to effectively close the narrow furrow and firm the soil around the roots. With too little soil loosening, setting and survival of plants may be impaired. Disturbing too much soil and plant residues may minimize the desired soil and water conservation and weed control benefits of NT farming. By modifying the location and the type of point on the transplanter shoe and the fertilizer knife of the Tru-Tracker, the amount and distribution of loosened soil can be altered. Although considerable progress has been made in this area, testing different subtiller and shoe designs will he continued to obtain the desired amount and distribution of loosened soil in different field situations.

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