Development of Strip Tillage on Sprinkler Irrigated Sugarbeet

R. G. Evans, W. B. Stevens, W. M. Iversen

Abstract. *A project to evaluate new technologies for strip tillage of small seeded crops was initiated in fall 2003 near Sidney, Montana, for sprinkler irrigated sugarbeet (*Beta vulgaris *L.) to be grown in 2004. Strip till treatments were compared to conventional grower tillage practices in fifty-six 15- × 25-m (48- × 80-ft) side-by-side plots. Both treatments were flat planted with no ridges or beds. All strip tillage and fertilization was done in the fall after removal of a malt barley crop. Conventional tillage was done in the fall at the Sidney site and in the spring at the Nesson site. Thirty-centimeter (12-in.) wide strips were tilled directly into the straw residues about 20 cm (8 in.) deep using straight and paired fluted coulters and a modified parabolic ripping shank followed by a crows-foot packer wheel. Toothed-wheel row cleaners were installed in front of the straight coulter to move loose residue to the side to avoid plugging. At the same time, dry fertilizer was shanked (banded) about 8 to 13 cm (3 to 5 in.) below the anticipated seed placement location. Sugarbeet were planted about 2.5 cm (1 in.) deep with 60-cm (24-in.) spacing between rows in the spring. Toothed-wheel row cleaners were also placed in front of each row on the planter to move any residue displaced by winter storms. Operation of the strip tillage machine required about 25 tractor horsepower per row, but substantial fuel savings were realized with this system by reducing the number of tractor equipment field passes by up to 75%. In 2004, 2006, 2007, and 2008 there were no significant differences in yields or sugar production between the two tillage treatments; however, in 2005 the strip tilled plots produced about 17% greater yields (tonnage and gross sugar). This benefit in 2005 was primarily due to the standing straw stubble in the strip tilled plots that protected sugarbeet seedlings from blowing soil during a spring wind storm that severely damaged seedlings in the conventionally tilled plots where there was no surface crop residue. It was concluded that strip tillage must be considered as part of a larger cropping system that affects timing and equipment choices for planting, cultivation, spraying, and harvesting as well as tillage and other cultural practices. Based on these results, it is generally recommended that strip tillage should be performed in the fall on clay soils in eastern Montana where it has been shown to result in better seedbed conditions than spring strip tillage. Whereas lighter, sandy soils would probably produce equally well when strip tilled in the spring, which could then be combined with planting into a single pass tillage, fertilizing, and planting operation. Banding fertilizer is highly recommended under strip till to increase fertilizer use efficiencies and reduce input costs. RTK-GPS guided steering in combination with some type of mechanical steering assistance on the implements are also recommended for both strip tilling, planting, and cultivation (if needed).*

Keywords. *Conservation tillage, Zone till, Inter-till, Soil erosion, Crop residue, Minimum till.*

Sugarbeet in the lower Yellowstone Valley region are typically grown in a 2-year rotation alternating with spring grains. Normally, a sugarbeet grower in the "MonDak" area of eastern Montana and western North Dakota (as well as many other sugarbeet producing areas) will make five or more passes across a field for fertilizer applications: disking, plowing or ripping, leveling (one to two times), mulching, and hilling; most of which is done in the fall preceding the sugarbeet crop. These fuel-intensive operations are often the same for sprinkler- as well as furrow-irrigated fields, but some such as the leveling are not really necessary for sprinklers unless the field had been moldboard plowed, but are done to prepare a smooth seedbed following the aggressive tillage and to fill in center-pivot tower tire tracks. In addition, the hilling or bedding operation is often required to meet a farmer's USDA-NRCS farm conservation plan on highly wind-erodible soils (based on the effects from traditional, multi-pass tillage practices). Flat planting sugarbeet after a small grain crop is more practical than bedding if wind erosion can be controlled by crop residues or other means. In addition, the highly volatile prices of diesel fuel are making the conventional land preparation system economically unsustainable in the Lower Yellowstone Valley region where 2008 production costs were estimated to be about $2,200/ha ($900/acre) for sugarbeet due to the high fertilizer, chemical, and fuel expenses, which was approximately equal to total income.

The American Society of Agricultural and Biological Engineers (ASABE) defines conservation tillage as any

Submitted for review in April 2009 as manuscript number SW 7981; approved for publication by the Soil & Water Division of ASABE in September 2009.

Mention of a trademark, vendor, or proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products that may also be suitable. This type of information is solely provided to assist the reader in better understanding the scope of the research and its results.

The authors are **Robert G. Evans, ASABE Member Engineer,** Supervisory Research Agricultural Engineer, **W. Bart Stevens,** Research Agronomist, and **William M. Iversen,** Physical Scientist, USDA-ARS, Northern Plains Agricultural Research Laboratory, Agricultural Systems Research Unit, Sidney, Montana. **Corresponding author:** Robert G. Evans, USDA-ARS, Northern Plains Agricultural Research Laboratory, Agricultural Systems Research Unit, Sidney, MT59270; phone: 406-433-9496; fax: 406-433-5038; e-mail: Robert.Evans@ars.usda.gov.

tillage or seeding equipment that maintains a minimum of 30% of residue cover on the soil surface. ASABE further defines strip tillage as a conservation tillage technique where crops are grown in narrow tilled strips in previously undisturbed soil regardless of tillage depth, no more than one third of the surface residue is disturbed and crop residues are maintained on the soil surface year around (*ASABE Standards*, EP 291.3., 2009).

Strip tillage (sometimes called zone tillage, row clearing, or inter-till) is widely used in rainfed areas in the Midwest United States on large seeded crops like corn (*Zea mays* L.), soybeans [*Glycine max* (L.) Merr.], and cotton (*Gossypium* species) (e.g., Smith et al., 2002; Al-Kaisi and Licht, 2004; Niehues et al., 2004; Janssen et al., 2005; Janovicek et al., 2006). However, development of strip tillage for small seeded crops like sugarbeet (*Beta vulgaris* L.) has been slow, but that is rapidly changing with the advent of Roundup Ready® sugarbeet cultivars and current low-profit margins for sugarbeet growers.

By some manufacturers' definitions, strip tillage is a method that tills a strip [e.g., 20 to 30 cm (8 to 12 in.) wide] into existing crop residues at a relatively shallow depth [e.g., ≤7.5 cm (3 in.)] disturbing 25% to 50% of the surface area. Often, these machines are designed to primarily move the surface residue to the side of the strip in preparation for direct seeding using shallow tillage techniques. Zone tillage, on the other hand, often refers to technologies that till similar strips, but are deeper than 7.5 cm (3 in.). Following these definitions, there are distinct differences in intent and equipment. Although in this study, the strip tillage machine tilled to a depth of approximately 20 cm (8 in), we refer to this practice as ”strip tillage” because of the wider use of this term among growers and researcher when referring to all of these related technologies rather than by the more appropriate and accurate term of zone tillage.

It is estimated that there are currently more than 20 different manufacturers of ”strip till” equipment, and most of these have been developed for corn and soybean culture. There is wide variety in how the strips are tilled, shaped, and packed, as well as tillage depths. Most of the currently available strip till machines use different conical, fluted, or flat disks or coulters in various configurations to loosen the soil and prepare the seedbed. Many also use some type of shank or ripper in combination with disks to help loosen the soil and to apply liquid or dry fertilizer either to the side or below the seed bed. Many machines have some type of packer wheels or rolling baskets to re-firm the tilled soil, break up large clods, and do some minor surface shaping of the strip. Several of the disk- or coulter-based till systems tend to place soil over the residue with limited mixing of the residue and others may not adequately repack the strip to create a firm seedbed. Others do not have good methods for re-closing the ripper slot to minimize voids in the seedbed. Several are unable to be used at row spacing of less than 76 cm (30 in.). However, most of the available equipment does produce a reasonable seedbed for corn, soybeans, cotton, and other larger-seeded crops; however, a major concern is that many of these machines generally don't make a firm enough bed for small seeded crops like sugarbeet where good seed-soil contact is more critical and even relatively small air pockets must be avoided near the seed. Furthermore, seedlings of tap rooted crops like sugarbeet often have difficulty penetrating buried residue layers and hard pans. Thus, there was a need to develop and evaluate techniques and types of strip till equipment in a production system including small seeded crops, such as sugarbeet.

The overall goal of this research was to develop and test a strip till system that was suitable for small seeded crops following small grains. The primary hypothesis of this research was that strip tillage after spring grain under sprinkler irrigation will produce sugarbeet yields and quality at least equal to conventional tillage practices while saving fuel and time, and reducing potential wind erosion of soils. The specific objectives were:

- To develop and evaluate a prototype strip tillage machine and banded fertilizer application system suitable for small seeded crops such as sugarbeet after small grains.
- To compare conventional tillage and strip till under sprinkler irrigation on yields and quality of sugarbeet.
- To evaluate two-year sugarbeet rotations utilizing strip tillage systems into heavy small grain residue, which maximizes use of grower's existing equipment.

In addition to the data presented here, this multidisciplinary, irrigated cropping systems project also compared soil properties, nitrogen/carbon cycling, N-fertility placement and application rate, foliar disease incidence, soil compaction, and soil moisture content between strip till and conventional tillage treatments.

Previous Strip Tillage Research on Sugarbeet

There has been strong interest in conservation tillage techniques, primarily looking at some type of strip till, for sugarbeet production for many years (i.e., Simmons and Dotzenko, 1975; Fornstrom and Boehnke, 1976; Glenn and Dotzenko, 1978; Halvorson et al., 1978; Sojka et al., 1980; Halvorson and Hartman, 1980, 1984, 1988; Deibert et al., 1982; Giles et al., 1982; Miller and Dexter, 1982; Adams, 1988; Smith et al., 2002). However, relatively little work has been done on strip tillage of sugarbeet over the last 20 to 25 years for both practical and technical reasons that will be explored later, although its potential has been widely recognized.

Previous strip till work on sugarbeet at Sidney, Montana, employed multiple-row, narrow rototiller-type devices to make 18-cm (7-in.) strips in the grain stubble on heavy clay soils to obtain an adequate seedbed (Halvorson et al., 1978; Halvorson and Hartman, 1984, 1988). While relatively successful, this work was not generally adopted by growers for a number of reasons. The system required plowing, mulching, leveling, and bedding of the field prior to the planting of the small grain crop in the year before the sugarbeet crop was grown because most fields were furrow irrigated at that time in the Lower Yellowstone Valley region.

At that time, the challenge of creating a sufficient furrow to irrigate the beets the following year was addressed by creating a raised bed immediately after the grain was planted but before it had germinated. This process resulted in some of the seed being too shallow and some too deep, and if it rained after planting and the bedding operation was delayed, the sprouted seed that was disturbed could be killed. Ideally the beds would maintain their shape until the strip tilling operation, though if the soil was moist when the grain was harvested some beds were deformed by the heavy equipment. There was also a need to obliterate border dikes which were no longer needed to irrigate the grain if the furrows were in place prior to strip till. This necessitated a change in how small grains were managed and irrigated, requiring a siphon tube in every row instead of the simpler and more common practice of a few holes cut into an earthen ditch between widely spaced border dikes. In addition, rotary tillers could not handle the heavy crop residue and straw could also create problems with blocking irrigation furrows, both of which required removal of as much straw as practical after the grain harvest.

Fertilizer was broadcast applied in the fall for these early strip till trials. Thus, only the fertilizer that was in the 18-cm (7-in.) tilled strip was incorporated in the tillage operation. In order to minimize the loss of nutrients from the fertilizer (ammonium nitrate and monoammonium phosphate) left on the soil surface, the researchers delayed the application until late fall when air and soil temperatures were lower. (However, ammonium nitrate is no longer generally available, and highly volatile urea nitrogen fertilizer is not recommended for unincorporated broadcast applications.) If it rained before the strip tillage operation was completed, it was impossible to strip till the moist clay loam soil with the standing straw residues because the tiller hoods would quickly become clogged. It could take up to two weeks for the soil to dry out so the operation could be completed. On a farm scale operation, this could put the grower in a situation where the strip tillage would not be completed before the soil froze. The wet soil problem would likely be more severe in the spring, causing delayed planting. In addition, spring tillage would not allow soil "mellowing" benefits in the seedbed due to freeze-thaw cycles during the winter on heavier soils, resulting in a rougher, cloddy seedbed.

These systems also presented some other practical problems if the crop had to be irrigated to facilitate seed germination in the spring. Furrow irrigation was not practical in this case because the grain stubble in the furrows restricted water flow so that the water tended to overflow the furrows and run down the soft tilled strips where the sugarbeet seed was planted, washing out the seeds.

Despite these demonstrated shortcomings, the promise of reduced wind erosion without a reduction in yields encouraged two area sugarbeet growers to further experiment with strip tillage. They made some changes to the system, most notably eliminating the extensive tillage before planting the small grain crop and attempting to band fertilizer. However, by the mid-1990s these efforts were largely abandoned in the Lower Yellowstone Valley. Nevertheless, high grower interest in strip tillage for sugarbeet from Montana, North Dakota, Minnesota, Colorado, Idaho, and Canada has continued because of the large potential economic advantages in reducing production input costs and wind erosion with minimal yield impacts. Strip till has become especially attractive to growers planting Roundup Ready® sugarbeet varieties.

Although there has been no single great breakthrough, several advances in herbicides, irrigation technologies, tillage and planting equipment as well as more general availability of larger horsepower tractors have revived interest in strip tillage. In addition, successes of strip tillage for large seeded crops have shown that many of the difficulties faced by earlier attempts with sugarbeet could be overcome, and the sizable potential economic benefits made it worth another look.

We believed that development of a strip tillage machine that would band-apply fertilizer (reduce fertilizer losses) and incorporate the residue in the strip while providing a firm seedbed would greatly promote the use of strip tillage among sugarbeet growers with small grain crops in their rotations. The non-tilled standing grain stubble would also protect the crop seedlings from damage due to wind-blown soil particles. Reducing machinery passes from as many as seven down to just one would provide substantial fuel, time, and equipment maintenance savings. It was expected that there would also be some water conservation benefits in more uniform trapping of snow and reduced soil evaporation where residue protects the soil surface. Furthermore, it was hoped that the research and evaluation data of strip tillage systems would make irrigated sugarbeet rotations eligible for USDA programs such as Conservation Security Program, as well as become an acceptable practice for required USDA National Resource Conservation Service farm conservation plans, which has happened in many areas.

Materials and Methods

Strip Till Equipment

A review of manufacturer's literature on available strip till equipment and some site visits were made in 2003 to observe some commercially available strip tillage machines in the field. However, the search failed to find a strip tillage machine that the authors believed would provide an adequate seedbed for small seeded crops after small grains for the MonDak soils, climate, and irrigation systems while at the same time allowing for fertilizer rate and placement flexibility. Thus, the Sidney, Montana based research program contracted for the fabrication of a six-row strip tillage machine (Schlagel Mfg., Torrington, Wy. and FabroEnterprises Limited, Swift Current, SK Canada.) with a 60-cm (24-in.) row spacing and a fertilizer box in an attempt to implement various machine modifications to optimize the preparation of an adequate soil environment for small-seeded crops.

The custom-built machine tilled a 30-cm (12-in.) strip and left a 30-cm (12-in.) strip of standing stubble rows in between each tilled row. The strip tillage machine was attached to the tractor's 3-point hitch, and because of the additional weight of the added dry fertilizer box, two free swiveling 7.50 × 16 mono-rib tires were placed in the back on hydraulically adjustable support assemblies. The mono-rib tires were placed on the same spacing as the tractor tires [e.g., 2.44 m (96 in.)]. Hydraulically-activated, adjustable row markers with 30-cm (12-in.) convex notched coulter wheels were also added.

The strip till machine (fig. 1) was designed so that it did not bury straw in a layer which could be a barrier to root penetration, but rather mixed the residue with the soil within each strip. Each row assembly was individually attached to a single straight-line tool bar and designed to operate independently. Each row assembly unit had a single 50 cm (20 in.) straight, flat coulter centered in front to cut through residue. An adjustable semi-parabolic ripper shank was located directly behind the straight coulter to lift and break up the soil [about 20 cm (8 in.) depth].

The ripper shank was closely followed by two 43-cm (17-in.) straight fluted coulters angled approximately 15° from front to back (widest in front) to cut and define strip edges, mix the residue into the soil, and squeeze the tilled soil to help close the ripper slot and eliminate large voids. This was followed by two rolling 38-cm (15-in.) diameter by 10-cm (4-in.) wide "crows-foot" packer wheels in each row that repacked the tilled strip to firm the seed bed. These packer wheels carried all the weight of each tiller assembly, about 240 kg (600 lb) of down force, on each strip during the packing operation. This helped ensure the firm seed bed required for good seed-soil contact and breaks up some of the larger clods. Machine speed during strip tillage operations was in the range of 6.4 to 8 kph (4 to 5 mph).

In the fall of 2006, 33-cm (13-in.) taper tooth Yetter Residue Managers (Model 2967, Colchester, Ill.) were installed to remove as much surface residue as possible and to reduce potential residue clogging problems around the parabolic shank. Project personnel fabricated the mounts to attach these on the strip tillage machine in front of the parabolic shank and behind the lead coulter. These mounts were later replaced with Yetter pin-adjust mounts. These Yetter units were swapped back and forth between the planter and strip till machine until the spring of 2008 when the planter residue managers were replaced with a less aggressive version.

Mechanical Guidance

The research strip tillage machine was originally equipped with two bull-tongue chisels located behind the tractor wheels about 8 cm (3.5 in) deep. These were followed by the mono-rib support tires on the strip tiller to make slots for the monorib tires on the planting tractor to assist guidance the following spring. However, the residue tended to bunch up in front of the chisels and quickly plugged between the row units. This arrangement had been employed successfully by the manufacturer at 76-cm (30-in.) row spacing; however, at 61 cm (24 in.) there wasn't enough clearance for the residue to flow between the chisel and row units. A simple modification was added to the strip tillage machine in 2005 to prevent residue buildup. Two single 50-cm (20-in.) fluted straight vertical coulters were mounted on the front bar of the strip till machine to slice the residue and form narrow grooves 123 cm (48 in.) apart (same spacing as the front tires on the tractor used for spring planting). Next, the bull-tongue chisels were followed by 33-cm (13-in.) diameter furrowing wheels (Miller's Fabrication, Lovell, Wy.) that formed a small, wider v-shaped ditch that could be used to guide mono-rib tires on the planting tractor in the spring. The straight-fluted coulters were removed in the clay soils if the ground was found to be too wet, but leaving the bull tongue chisels. The absence of the coulter ahead of the chisel would often resulted in plugging, so the chisel would be removed as well. While this was an improvement, the bull-tongue chisels and furrowing wheels were both replaced in 2006 with rolling 50-cm (20-in.) cone-wheels (H & S Manufacturing, Inc, Stephen, Minn.) which left a firmer, more distinct guidance groove. In softer soils it was discovered that the machine was heavy enough to press the cone wheels into the soil several centimeters. The same type and size cone wheels were also placed on the planter to match the grooves made by the strip tillage machine. This was done to keep the planter from drafting out of the center of the tilled strip and fertilizer band due to inherent slack in the three-point hitch system. This arrangement worked well to keep the planter centered in the tilled strip and ensure that the seed was in the right proximity to the previously banded fertilizer. An RTK-GPS auto-steer system was installed on the tractor and used in the fall of 2007 for the 2008 crop year; however, it was found that the mechanical guidance furrows and cone wheels were still required to keep the planter on the row (eliminate drafting by the planter).

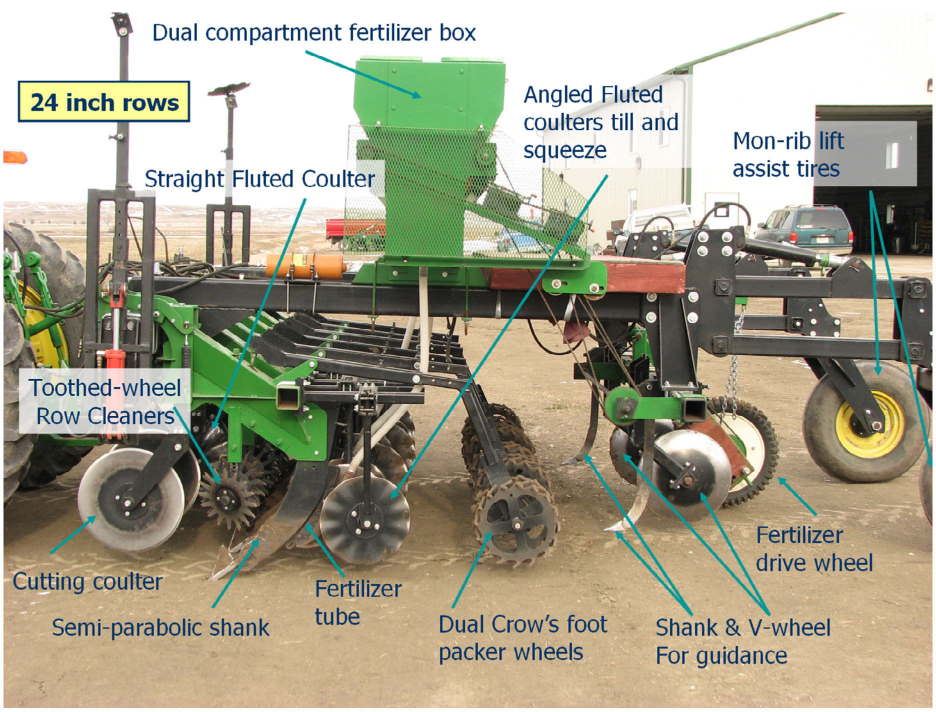

Figure 1. Custom-built strip tillage machine showing the progression of coulters, rippers, and packer wheels.

Fertilizer Application System

The strip till machine was originally set up with a dry fertilizer application system but it was also equipped to apply liquid fertilizers. All the dry fertilizer was placed in a band during the same operation. A fertilizer tube was attached to a triangular piece of flat iron acting as a defector plate or "shoe" located on the back of each parabolic shank to deposit dry fertilizer about 7.5 cm (3 in.) directly below or slightly to the side of where the seed would be placed, although some fertilizer also dribbled into the slot from the parabolic shank down to the bottom of the tilled zone. The depth of fertilizer application could be changed by moving the fertilizer tube and shoe up or down on the ripper shank.

A custom-built divided, gravity-fed fertilizer box (FabroEnterprises Limited, Swift Current, SK Canada.) was mounted on the strip tillage machine in 2003 to enable one-pass tillage and fertilizer operation. Application rates were controlled by two ground driven Model Y1 Zero-Max Adjustable speed drives (Zero-Max, Plymouth, Minn.; www.zero-max.com/products/drives/drivesmain.asp, which were infinitely adjustable over their operational range. Metering cups (Amazone Farm Machinery Ltd., Brandon, Manitoba, Canada) were used to meter fertilizer into the tubes. These metering cups could be used for either seed or fertilizer, and calibration and spot testing showed them to be accurate and repeatable.

Conventional Tillage Operations

Conventional tillage operations were performed in the fall after broadcasting the fertilizer, and consisted of tilling the soil with a ripper (Case IH, Racine, Wis.) to a depth of about 23 cm (9 in.), 2 passes with a rolling mulcher (Brillion Inc., Brillion, WI), and 2 passes with a leveler (Eversman, Denver, Colo.). The following spring, a single pass was made with an S-tine cultivator equipped with rolling baskets (Kongskilde Mfg., Soro, Denmark) prior to planting.

Experimental Design

Research including strip tillage of sugarbeet into barley stubble was conducted at two sites on two different soil types. These included: 1) the Montana State University (MSU) Eastern Agricultural Research Center (Sidney) farm [4 ha (10 acre)] near Sidney, Montana (47.73N, 104.15W); and, 2) the North Dakota State University (NDSU) *"Mon-Dak Irrigation Research and Development Project Farm"* (Nesson) in the Nesson Valley (16 ha) in North Dakota (48.09N, 103.06W, about 120 km ENE of Sidney). Plot sizes at both locations were approximately 15 × 25m (50 × 80 ft). Non-sampled plot border/buffer areas were at least 3 m (10 ft) into the plot to eliminate edge and sprinkler overlap effects. As much as possible, all plots at each site were fertilized and planted at the same times with the same equipment. Sugarbeet was planted in 60-cm (24-in.) rows and malting barley in 20-cm (8-in.) rows. Because both site locations were sprinkler irrigated and furrows were not needed, both strip tilled and conventionally tilled treatments were flat-planted. There were no other special soil preparations for the strip tillage operation. All plots at both locations were irrigated with self-propelled linear move sprinkler irrigation systems (Valmont Industries, Inc., Valley, Nebr.).

Figure 2. Picture of the strip tillage machine in operation with the direction of travel to the left.

Irrigation applications at both sites were scheduled on calculated ETa of each crop strip using data from nearby automated weather stations, and supported by weekly neutron probe soil water measurements to a depth of 120 cm (4 ft). The same sprinkler irrigation custom control systems were installed at both locations (Evans et al., 2006).

All tillage and fertilizer applications were done in the fall at Sidney (heavy soils) for both the strip till and conventional plots. At the sandy Nesson site, strip tillage and fertilization were accomplished at the same time in the fall, whereas conventional tillage and fertilization were in the spring because of wind erosion concerns.

The Sidney research site was laid out in 14 strips of plots parallel to the direction of travel by the linear move irrigation system. Each 15- × 24-m (50- × 80-ft) plot was planted either to sugarbeet or malting barley, which alternated from year to year. Every plot was irrigated with either mid-elevation spray application (MESA, the most common method in region) heads with pressure regulators on flexible drops about 1 m (3.5 ft) from the canopy every 3 m (10 ft) apart, or low energy precision application (LEPA) heads (Lyle and Bordovsky, 1981, 1983, 1995; Bordovsky et al., 1992; Bordovsky and Lyle, 1996; Bordovsky and Lascano, 2003) with pressure regulators on flexible drops spaced every 1.2 m (4 ft) that applied water about 0.2 m (8 in.) above the soil surface between every other crop row without wetting the canopy. Half of the plots were irrigated with MESA and the others with LEPA each year. Equivalent volumes of water were applied for both irrigation methods to each crop.

The Sidney soil was classified as a relatively heavy Savage clay loam (fine, smectitic, frigid Vertic Argiustolls) with 21% sand, 46% silt, and 33% clay. The water table was relatively shallow [e.g., 1.2 m (4 ft)] and may contribute to crop water needs during the season. The entire Sidney plot area was planted to sugarbeet in 2002 and malt barley in 2003. The linear move sprinkler irrigation system was installed in the spring of 2003.

Research at the Sidney site examined the interaction between irrigation method and tillage on a two-year sugarbeet-malt barley crop rotation. The experiment was designed as two complete rotations plus the establishment year (5 years total) starting with the 2004 growing season. The Sidney research site had 56 15- × 24-m (50- × 80-ft) long plots arranged in an unbalanced, randomized stripped block design with four replications.

Starting in 2003, tillage for both Sidney treatments was done after barley harvest (August-early September) to prepare for the following season. The barley plots were usually lightly irrigated [about 40-60 mm (1.5-2 in)] after harvest to rewet the soils for improved tillage as well as to germinate volunteer barley and weeds. The plots were strip tilled two to three weeks later.

The Nesson project was on Lihen sandy loam soils (sandy, mixed, frigid Entic Haplustoll) consisting of very deep, well-or somewhat excessively-drained soil. The amount of sand, silt, and clay in the soil at 0- to 30-cm depth ranged from 64.0% to 67.4%, 17.6% to 18.4%, and 15.0% to 16.6%, respectively. Soil bulk density at 0- to 30-cm depth ranged from 1.51 to 1.66 Mg m^{-3}. The water table was deep [e.g., 30 m (100 ft)] and did not contribute to crop water use. These plots utilized the same planting, tillage and cultivation equipment used at the Sidney site. The linear move irrigation system was installed in spring 2005.

The Nesson site was converted from dryland hay production to irrigation and extensive land preparation was initiated in 2004 to prepare the area for irrigation. The first irrigated crops were planted in 2005 but no data are reported because tillage and crop sequence treatments were not expected to have any effect until 2006. Strip till treatments on sugarbeet were not started unit the fall 2005 for the 2006 season. The irrigation control software and hardware allowed the strip till sugarbeet to be irrigated and fertilized at rates independent of the rates applied to the conventionally tilled sugarbeet. This flexibility allowed the researchers to compensate for the small differences in soil moisture and nitrogen between plots and between treatments, if necessary.

The Nesson research study was designed to complete two full rotation cycles of a three-year rotation of sugarbeet, malting barley and potatoes evaluating irrigation frequency and crop rotations under a linear move sprinkler system using MESA spray heads. There were two crop sequences with two irrigation frequencies and six replications in a stripped-randomized complete strip block design with all three components of each sequence present every year resulting in 72 plots.

The Nesson research site was laid out in eighteen strips of plots parallel to the direction of travel by the linear move irrigation system. Each set of plots was irrigated by MESA sprinkler heads (with pressure regulators) spaced every 1.5 m (5 ft) about 1.1 m (42 in.) above the ground on flexible drops. Irrigation frequency is varied based on either 30- or 60-mm cumulative ETc replacement as calculated by the North Dakota (NDAWN) weather network for the Nesson location. Application depths were correspondingly adjusted for each crop using an assumed 85% application efficiency. Soil water levels are monitored continuously with various automated sensors in selected plots, in addition to weekly neutron probe readings at one location in every plot to a depth of 120 cm (4 ft).

Tillage was not a treatment on the Nesson project and was therefore not directly comparable to the Sidney project. In addition, all sugarbeet at the Nesson site were strip tilled following barley, whereas the conventionally tilled sugarbeet followed potatoes. However, the two studies provide significant insight and detailed information on the same tillage and planting system interactions on two soil types in two different rotations which are common to the region.

Sugarbeet (cv. ACH 927 large bare, American Crystal Co., Eden Prairie, Minn.) were planted at both sites at 135,000 seeds ha^{-1} (55,000 seeds $acre^{-1}$) at a 60-cm (24-in.) row spacing to a depth of about 2.5 cm (1 in.). In 2008, the Nesson plots were planted to a Roundup Ready® variety (Beta RR 86RR44). All sugarbeet plots at each site were planted on the same date using the same equipment. In 2004 planting was done with a Heath unit planter (Arts-Way Mfg. Co., Armstrong, Iowa), and from 2005 through 2008, the planting was done with a John Deere 1700 MaxEmergePlus planter.

Because strip tillage was done in the fall, and there were problems with wind blowing loose straw onto the tilled strips, Yetter Residue Managers (Colchester, Ill.) were installed on the planter in April of 2006. However, these devices were quite depth sensitive and difficult to adjust. In 2008, they were replaced on the planter with Dawn TrashWheel2® row cleaners (Dawn Equipment Co, Sycamore, Ill.). The Dawn row cleaners featured a 32-cm (12.75-in.) diameter wheel with a swept tooth design with more open area between the teeth that removed residue with minimal soil disturbance. These were mounted on Dawn screw adjust mount assemblies (Part no. 1140-1/-2). However, the Yetter Residue Managers were still used on the strip till machine.

Both strip till and conventional till were cultivated between the plant rows twice during the season for weed control, once at about the 6-leaf stage and a second time just prior to full canopy development. A single shank cultivator (H&S, Stephen, Minn.) with rolling disk shields designed for high residue conditions was used to keep residue and soil off the sugarbeet seedlings only during the first cultivation.

After combine harvesting, the standing stubble was 15 to 20 cm (6 to 8 in.) high. A straw and chaff spreader on the combine evenly distributed the residue over the entire area. All barley straw and residues were left in the field so there was a mix of standing and flat residue. The net result was that these plots had much higher levels of residue or “trash” than would normally be encountered because most growers in the area bale the straw and remove it from the field. The high residue conditions were probably the most difficult scenario, and it was assumed that if strip tillage was successful under these more challenging conditions, it should probably also work for those who remove most of the loose straw.

Figure 3. Photograph of the adjustable Amazone metering cup arrangement on the fertilizer box.

Fertilization

Dry fertilizers are currently used by almost all growers in the area, and banding dry fertilizer was therefore used in this study for strip tillage treatments. All fertilizer for the conventionally tilled plots were broadcast and incorporated whereas, as part of the one-pass process, all the strip tilled fertilizer was shanked into the soil in narrow bands and the soil packed to minimize nitrogen volatilization losses as well as reduce nitrogen tie up by residues. In 2003 (for the 2004 crop year), physical observations showed that most of the fertilizer appeared to end up in the bottom of the ripper slot, about 8 in. (20 cm) deep. The fertilizer tube and placement shoe on the ripper shank were modified in 2004, and the fertilizer was placed about 7.5 cm (3 in.) below the soil surface although probably about half still ended up near the bottom of the ripper slot for the 2005-2007 seasons.

Nitrogen and P fertilizers (as urea and monoammonium phosphate, respectively), were based on the soil test results and crop requirement. For sugarbeet, enough N fertilizer was applied so that the sum of fertilizer and plant-available soil nitrate-N was 185 kg N ha^{-1} (165 lb $acre^{-1}$), resulting in N application rates varying from 108 to 146 kg N ha^{-1} (97 to 130 lb $acre^{-1}$) at Sidney and from 102 to 135 kg N ha^{-1} (91 to 120 lb $acre^{-1}$) at Nesson Valley. Phosphorus was applied each year at a rate of 56 kg P_2O_5 ha^{-1} (50 lb P_2O_5 $acre^{-1}$) at Sidney and 168 kg P_2O_5 ha^{-1} (150 lb P_2O_5 $acre^{-1}$) at Nesson Valley. The higher amount was applied at the latter location to build up the available P from an initial level of 5.6 mg kg^{-1} bicarbonate-extractable P. Nitrogen application rates were based on sugar company (Sidney Sugars, Inc., Sidney, MT) guideline of 185 kg N ha^{-1} (165 lb $acre^{-1}$) minus the 100% residual in the top 60 cm (2 ft) and 80% of the residuals in the bottom 60 cm (2 ft) of the soil profile. P application rates were based on recommendations published by Montana State University for furrow irrigated sugarbeet. Potassium (as KCl) was added as indicated by fall soil test results to maintain adequate levels for sugarbeet production (>200 ppm soil test). Petiole samples were taken in early June for nitrogen management and periodically thereafter to generally track sugarbeet nitrogen status in all treatments.

Results and Discussion

This research experience has shown that operation of the strip tillage machine for the 30 cm (12 in.) width and 20 cm (8 in.) depth requires about 25 tractor horsepower (HP) per row so tractor size is important (front wheel assist or tracked tractors worked well). Narrow strips or shallower tillage would likely reduce tractor horsepower requirements. Figure 2 shows the tillage machine in operation.

No significant yield differences for either the sugarbeet or barley were observed between the LEPA and MESA irrigation treatments in the four years of this study (2004, 2005, 2006, and 2007). Sugarbeet were all early-harvested in late September so that tonnage and sucrose content are slightly lower than what most growers would experience with a later harvest date.

Rainfall during the growing season ranged from 125 to 229 mm (4.91 to 9.02 in.) at Sidney and from 196 to 309 mm (7.72 to 12.17 in.) at Nesson Valley with 2005 being the wettest and 2006 the driest at both locations table 1. Irrigation amounts also varied with year and were determined based on precipitation and predicted ET. Application amounts at the Nesson site (sandy soils) tended to be higher because of the lower soil water holding capacities and generally greater wind runs for the location.

Observations have shown that sugarbeet planted in strip till situations have emerged a few days earlier under dry spring conditions than the conventional beets, but the conventionally tilled beets tended to quickly catch up. Table 2 summarizes the plant stand data for the two sites two to four weeks after planting. Initial counts were the first time (typically in early May) plant population were evaluated during the growing season, and the final counts were the last time (typically early June) plant population was evaluated before an inter-row cultivation was performed. The stand count for strip tilled beets was greater than for the conventional beets ($P<0.10$) in 2004 and 2008 at Sidney and in 2007 at Nesson (table 2).

In all three cases, weather conditions were dry during the emergence period and pre-emergence irrigation was required to ensure satisfactory germination. The greater number of seedlings germinated with strip tillage at the time of the initial count suggests that there was more soil moisture present than with the conventional tillage treatment. This coincides with qualitative observations of soil moisture at the time of planting and is likely the result of less tillage-induced moisture loss as well as greater, more uniform capture of snowfall and reduced evaporation. The opposite result was observed at Sidney in 2006 when plant population at the initial count was 50% less for strip tillage than for

Table 1. Rainfall and irrigation amounts during the growing season for the sprinkler irrigated strip till research plots for 2004, 2005, 2006, 2007, and 2008.[a]

		Rainfall		Irrigation		Total Water Applied	
Year	Location	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)
2004	Sidney	172	6.76	232	9.14	404	15.90
2005	Nesson	309	12.17	307	12.10	616	24.27
	Sidney	229	9.02	194	7.62	423	16.64
2006	Nesson	196	7.72	462	18.20	658	25.92
	Sidney	125	4.91	212	8.36	337	13.27
2007	Nesson	224	8.83	536	21.10	760	29.93
	Sidney	227	8.94	315	12.41	542	21.35
2008	Nesson	172	8.31	460	18.1	655	25.77
	Sidney	142	5.58	288	11.33	430	16.91

[a] Research at the Nesson site started in 2005.

conventional tillage; however, the cause of this observation was also a difference in soil moisture at the time of planting.

Though 2006 growing season precipitation was the lowest of the five study years, April rainfall in that year was 3 in. greater than average resulting in unusually wet soil conditions at planting for the clayey Sidney soil. Both conventional and strip till plots were planted the same day at the Sidney site. While the soil moisture level was favorable under conventional tillage, it was excessively wet under strip tillage, resulting in smeared walls of the seed-row and poor seed-to-soil contact. These conditions caused some seedlings in the strip tilled treatments to desiccate following germination as indicated by the significantly lower plant population at the final count (table 2). This is a situation that can be avoided in production by delaying planting into strip tillage fields until the soil moisture conditions are more favorable. Excessive spring moisture did not cause the same effect at the sandy Nesson Valley site, where the final stand count was not affected by tillage system (table 2).

Early plant population measurements at Nesson in 2008 (table 2) also showed a slightly higher plant population with conventional than with strip tillage, but observations suggest this was due to differences in seedling survival rather than variable emergence. Both army cutworm (*Euxoa auxiliaris*) feeding and wind-blown soil caused seedling mortality in 2008 regardless of tillage system. Cutworm damage was likely greater in strip till plots where surface residue favored cutworm activity while wind damage was likely greater in conventional plots where there was no residue to protect seedlings from blowing soil. The strip tilled plots trapped some of the blowing soil from adjacent plots, burying some seedlings. As a result, plant population at the time of the final count was only about 50% of the target population for both tillage systems. Some of these effects could also be due to the preceding crop differences at the Nesson site, and possibly some higher levels of residual insecticides (not measured) from the potato plots.

Tables 3 and 4 present summaries of the strip till and conventional till yield and quality averaged across all plots for the sugarbeet plots at Sidney (five years) and in the Nesson Valley (three years). Sugarbeet yield and gross sucrose yield per hectare were not affected by tillage systems at either site. Basically, these data show that there were no significant differences in either yield or quality between the conventional and strip till sugarbeet in terms of production; however, the reduced equipment trips with strip till should greatly lower input costs for fuel. There were no statistical differences in percent gross sucrose at either location. Over the course of this research, malting barley yields have ranged from about 4000 to 6450 kg ha^{-1} (75 to 120 bu $acre^{-1}$).

The percent sucrose was lower for both tillage treatments in 2006 at Sidney than in other years. At Nesson Valley, percent sucrose was also lower than in 2007, but was not different than in 2008. The low sucrose levels observed in 2006 were common in the area and were likely due to the cooler than normal summer that caused the sugarbeet to still

Table 2. Average stand count results for the two sites comparing conventionally tilled (CT) and strip tilled (ST) plots based on days after planting (DAP).

	Initial Count[a]				Final Count			
Year	DAP	CT (plants/acre)	ST (plants/acre)		DAP	CT (plants/acre)	ST (plants/acre)	
Sidney								
2004	15	1452	4538	*	50	40384	42290	ns
2005	28	16456	17424	ns	56	40959	43560	ns
2006	14	22188	11707	***	30	35393	22551	***
2007	10	17243	13643	ns	26	38811	38418	ns
2008	20	17243	22824	+	53	42516	41768	*
Nesson								
2006	15	30265	28528	ns	38	31899	33457	ns
2007	16	7305	30810	***	29	38660	45012	***
2008	21	30220	24321	+	46	21841	21326	Ns

[a] Statistical significance of the difference between two means is indicated as follows: ***, $P \leq 0.001$; **, $P \leq 0.01$; *, $P \leq 0.05$; +, $P \leq 0.1$; ns, $P > 0.1$.

Table 3. Average yield and quality summary for sprinkler irrigated, fall tilled conventional (CT) and fall strip till (ST) sugarbeet at the Sidney site over five years on clay loam soils, 2004-2008.

	Sugarbeet Yields, metric tonnes ha^{-1} (tons $acre^{-1}$)[a]		Percent Sucrose		Gross Sucrose, kg ha^{-1} (lb $acre^{-1}$)	
Year	CT	ST	CT	ST	CT	ST
2004	52.0 (23.2) d	51.4 (22.9) d	19.8 ab	20.1 a	10,360 (9,225) abcd	10,342 (9,208) bcd
2005	56.2 (25.1) cd	62.6 (27.9) bc	19.4 bc	19.9 ab	11,048 (9,864) abcd	12,094 (10,768) a
2006	63.4 (28.3) ab	71.2 (31.8) a	17.7 e	17.4 e	11,315 (10,078) abc	12,448 (11,085) a
2007	57.8 (25.8) bcd	61.1 (27.3) bc	19.8 ab	19.7 b	11,540 (10,280) abc	12,000 (10,685) ab
2008	52.5 (23.4) cd	54.7 (24.4) cd	18.7 d	18.7 cd	9,649 (8,780) d	10,037 (9,133) cd
Average	56.4 (25.2)	60.2 (27.5)	19.1	19.2	10,782 (9,645)	11,184 (10,176)

[a] Means of a given variable may be compared across years and tillage systems. Means followed by the same letter are not significantly different ($P \leq 0.05$).

Table 4. Average yield and quality summary for sprinkler irrigated spring tilled conventional (CT) and fall strip tilled (ST) sugarbeet at the Nesson Valley site over three years on sandy loam soils, 2006-2008.

	Sugarbeet Yields, metric tonnes ha^{-1} (tons $acre^{-1}$)		Percent Sucrose		Gross Sucrose, kg ha^{-1} (lb $acre^{-1}$)	
Year	CT	ST	CT	ST	CT	ST
2006	59.0 (26.3) b	59.0 (26.3) b	17.2 b	17.4 b	10,196 (9,079) b	10,264 (9,140) b
2007	61.2 (27.3) b	60.1 (26.8) b	18.4 a	18.1 a	11,305 (10,067) a	10,902 (9,708) a
2008[a]	70.4 (31.4) a	69.9 (31.2) a	17.0 b	17.2 b	11,726 (10,668) a	11,792 (10,728) a
Average	63.5 (28.3)	63.0 (28.1)	17.5	17.6	11,076 (9,938)	10,986 (9,859)

[a] Sugarbeets in 2008 at the Nesson site were a Roundup Ready® variety.
Means of a given variable may be compared across years and tillage systems. Means followed by the same letter are not significantly different ($P \le 0.05$).

have excess soil nitrogen available late in the season for both tillage treatments, and the strip tilled sugarbeet appeared to be growing more vigorously later in the 2006 season than the conventional sugarbeet.

Petiole nitrogen levels and available soil nitrogen were both observed to be lower with strip tillage than with conventional tillage in some years, but this effect was not consistent over the duration of the study. Even when lower nitrogen uptake was observed, root yield was not affected, suggesting that differences in fertilizer availability and uptake were not extensive enough to affect crop productivity.

The effectiveness of strip tillage in preventing wind erosion was demonstrated in the spring of 2005. There were four sets of sugarbeet plots side by side, each set containing one plot of conventional tillage and one planted in strip till. The beets were planted in mid-April and were in the 4-leaf stage in mid-May when a high wind event occurred. The blowing soil severely damaged the leaves on the young beets in all the conventional tillage plots, whereas the young beets in all strip tilled plots had no visible damage. The beets in the strip tilled plots were apparently protected from the blowing soil particles by the strips of standing stubble between rows, even in side-by-side conventional and strip till plots. Fortunately, cool weather conditions after the wind storm allowed most of the conventional beets to re-grow so there was no significant difference in plant stand (table 2), but it delayed them sufficiently to result in significant yield differences in the fall (table 3).

The average number of sugarbeet per 3.3 m (10 ft) of row at harvest over the four years at Sidney was 15.2 and 14.8 for conventional and strip till, respectively. Sugarbeet smaller than 6 cm (2.25 in.) were not included because they were considered to be unharvestable. The corresponding average weights per sugarbeet at harvest were 0.69 kg (1.53 lb) and 0.80 kg (1.76 lb) for the same tillage treatments, respectively. For the two years at the Nesson Valley, the averages were 14.3 and 14.0 sugarbeet per 3.3 m (10 ft) of row, and 0.8 and 0.81 kg (1.75 and 1.76 lb) per sugarbeet for the conventional and strip till treatments, respectively.

Visual observations of snow catch across a field indicated that snow depth was much more uniformly distributed under fall strip tillage compared to conventional fall tillage. Initial measured surface region soil moisture data using neutron probes at the 25-cm (9-in.) depths at the 3- to 4-leaf stage were typically about 1% higher in strip tilled plots and more uniform compared to adjacent conventional till plots, but were not statistically significant (data not presented). We believe that the higher uniformity was because there were very few or no snow drifts observed during the winter months within the field and fewer, smaller snow drifts at the plot edges. Emergence data (not presented) also showed that sugarbeet in a dry spring get an earlier start with strip till by three to four days. In addition, even though the average soil moisture may be slightly higher, cultural operations can potentially begin a few days earlier in the strip till because the grower does not have to wait for the relatively small areas which had the heavier snow drifts to dry out, as is often the case under conventional tillage practices.

Conclusions, Recommendations, and Observations

Five years of results have shown that strip tillage will produce yields comparable to conventionally tilled sugarbeet in the Lower Yellowstone River Valley. These experiments have shown that strip till yields were at least equal to conventionally tilled beets, but with many fewer passes of equipment and considerable cost savings in fuel and time. This is a positive result in favor of strip tillage, especially now that use of Roundup Ready® sugarbeet are becoming common. In addition, the presence of standing small grain residue before each sugarbeet crop potentially makes strip tillage a viable way to reduce the risk of crop damage due to soil erosion by wind in the spring.

One of the central tenets of this research is that strip tillage is not just a minimum tillage technique. Strip tillage necessitates new considerations for tractors, planting, cultivation, and harvesting equipment used for sugarbeet production. It must be an integral part of an entire cultural system that minimizes equipment passes through the field. The straw and chaff must be evenly distributed. Use of strip tillage machine in sugarbeet rotations after small grains will require some changes to planting and cultivation equipment and practices to handle high residue levels. Herbicide and other pest control programs may also have to be modified to be effective in high residue conditions. Beet harvesters may require some adjustments in very heavy soils if residue and mud build up on cleaning rolls. It should be noted that the strip tillage treatment did not require any more tillage than the conventionally tilled treatment following sugarbeet harvest before the succeeding barley crop.

High level guidance of the strip tillage machine, planters, cultivators and any other subsequent machine operations is especially critical. Mechanical or hydraulically assisted RTK-GPS guidance is highly recommended for both the tiller and the planter in addition to guidance furrows to ensure accurate placement of both fertilizer and seed within the strip. However, if strip till, fertilizing, and planting are being done in one operation in the spring, the higher level guidance systems may not be as necessary.

Fertilizer recommendations currently used for sugarbeet were developed for furrow irrigation with full, conventional tillage practices. Nitrogen fertilizer use patterns (data not presented) appear to be somewhat different under strip till than under conventional tillage due to a combination of the effects of nitrogen placement (i.e., banding vs. broadcast) and mineralization of crop residues and soil organic nitrogen, which tends to be more rapid with full-width tillage than with reduced tillage. It may be necessary to re-evaluate these N recommendations in terms of strip tillage and sprinkler irrigation as well as for the new, high yielding Roundup Ready® varieties. Fertilization rates, timing, and depth placement may also have to be altered from past practices because of earlier availability in strip till, which may require supplemental applications to avoid running out of nitrogen fertilizer too early. Self propelled sprinkler irrigation (e.g., center pivots and linear moves) also offer flexibility for split applications of nitrogen applied through the irrigation system. However, this research suggests that current fertilizer recommendations are generally adequate for strip till systems based on the comparable yields.

Maintaining standing stubble is desired for wind erosion control and to trap snow in the winter. Standing stubble probably should be at least 15 cm (6 in.) or higher and needs to be sustained until the beets are sufficiently large to withstand spring wind storms. Due to non-uniform residue deposition by the combine and wind, toothed-wheel row cleaners (sometimes called "trash whippers") or other residue clearing devices are recommended for both the strip tillage machine and planter to avoid plugging. Plugging usually occurred between the two fluted coulters on the strip tillage machine because the two units are relatively close together and the shanks fluff the soil up in front of the coulters between the shank and coulter, or between adjacent shanks. If planting is done as a separate operation, toothed-wheel row cleaners are recommended for the planter as well because some residue may be moved back onto the tilled strips by wind. A straw and a chaff spreader on the combine is highly recommended to ensure uniform residue cover and avoid wet spots in the spring as well as to avoid plugging of tillage and planting equipment by piles of crop residue.

Prior to Roundup Ready® sugarbeet**,** weed control programs couldn't rely solely on herbicides to keep the fields clean. Control of weeds impacted by wheel traffic seems to be especially difficult for herbicides. Growers who utilize strip till on non-Roundup Ready® sugarbeet varieties must continue to cultivate using a cultivator that can handle high amounts of residue.

Almost all sugarbeet growers in the Lower Yellowstone River Valley region do most of their tillage and fertilizer applications in the fall to save time during the short tillage-planting window in the spring, but this can result in wind erosion problems under conventional practices. Fall tillage also starts the decomposition of residue earlier and the freeze-thaw cycles break down clods and "mellow" the soil, especially on heavier clay soils. Strip tillage in the fall offers the same advantages and also greatly reduces soil loss due to wind erosion.

Heavy soils must be worked at an intermediate moisture level in the fall to get a good seedbed under strip till. If it is tilled while too wet, the shank merely cuts a slot, and if it's too dry, large clods don't break down. Completing the strip till operation in the fall allows the strips to settle and collect moisture for earlier, more uniform seed germination. The window of opportunity for tillage in the spring in this northern area is very short, although not part of this research, it appears that the required seed bed conditions are possible on strip till of sandy soils. Spring tillage would result in very little straw decomposition prior to planting which could make for a poorer seed bed.

Strip till also requires a planter for high residue conditions such as the John Deere MaxEmergePlus with toothed-wheel row cleaners on the front to lightly clear off loose surface residues that may blow into the tilled area over the winter to avoid any "hair pinning" of straw that might create undesirable air spaces near the sugarbeet seeds. It was determined that the planter's seeding depth gauge wheels should be very close to the point of seed drop. Planter designs which control the seeding depth by use of a packer wheel 20 cm (8 in.) or more behind the point of seed drop may have difficulty in consistently placing the seed at the required shallow depths because of the surface undulations of the strip tilled seed bed. In situations where the strips are slightly mounded, the gauge wheels on the planter will tend to ride along the higher edge of the strip, which tends to make seeding depths too shallow.

This research used a dry fertilizer box mounted on the strip tillage machine, which adds considerable weight to the machine, yet holds only a relatively small amount of fertilizer. Practical use of dry fertilizers on a field scale would probably require modifications to the strip tillage machine for a suitable air delivery system from a trailing cart. Adding the capability to apply liquid fertilizers from a trailing tank or tractor-mounted systems would be fairly straightforward and should also work well.

To date, this research has been conducted only on sprinkler irrigated sugarbeet in the Yellowstone River Valley. Strip tillage techniques should also work on furrow irrigated fields with sufficient slope (e.g., 0.3% or greater), especially if the cut straw is removed from the field following small grain harvest while leaving the standing stubble, and further research is planned to address this issue. Other irrigation parameters such as length of run and soil type would also impact the success of furrow irrigation. The retarding effect of the residue on irrigation water velocity could prove to be an erosion benefit in fields with an excessive amount of slope where the water in the furrows tends to cut deep trenches. A project is planned for the 2010 growing season to look at strip tillage of furrow irrigated sugarbeet on grower fields.

Because of wheel compaction due to combine and truck traffic during small grain harvest, it would be desirable to strip till at an angle to the direction of travel by the combine harvester, if possible. Otherwise, tillage in the already compacted wheel rows may still have large clods and potentially result in a poor seedbed. When the larger clods are heaved out of the row area by the shank they leave a void that doesn't always get re-filled and re-compacted, and the seed may be placed either on top of the ground or in the bottom of the void in these situations. This may be one reason that final strip till stands aren't consistently higher than CT. Thus, other future research will look at ways to improve the operation of the strip tillage machine in breaking up heavy soils, and ways to decrease the large horsepower requirements so that growers can utilize existing tractors and equipment as much as possible.

References

Adams, L. 1988. Wyoming studies look at beets under reduced tillage. *Sugarbeet Grower* March(2): 20-21.

Al-Kaisi, M., and M. A. Licht. 2004. Effect of strip tillage on corn nitrogen uptake and residual soil nitrate accumulation compared with no tillage and chisel plow. *Agron. J.* 96(3): 1164-1171.

ASABE Standards. 2009. EP 291.3: Terminology and definitions for soil tillage and soil-tool relationships. St Joseph, Mich.: ASABE.

Bordovsky, J. P., and R. J. Lascano. 2003. Variable rate irrigation using low energy precision application (LEPA). In *2003 Electronic Proc. of the Beltwide Cotton Conf.* Nashville, Tenn.: National Cotton Council, Memphis, TN.

Bordovsky, J. P., and W. M. Lyle. 1996. LEPA irrigation of grain sorghum with varying water supplies. *Trans. ASAE* 39(6): 2033-2038.

Bordovsky, J. P., W. M. Lyle, R. J. Lascano, and D. R. Upchurch. 1992. Cotton irrigation management with LEPA systems. *Trans. ASAE* 35(3): 879-884.

Deibert, E. J., J. G. Giles, J. Enz, and D. Lizotte. 1982. Reduced tillage sugarbeet production. In 1981 Sugarbeet Research and Extension Reports. North Dakota State University and University of Minnesota. 12: 123-127.

Evans, R. G. W. B. Stevens and W. M. Iversen, 2006. Development of site-specific irrigation research under linear move systems. In *Proc. 26th Annual Intl. Irrigation Show.* Phoenix, Ariz.: Irrigation Association, Falls Church, VA. Available on CDROM.

Fornstrom, K. J., and R. D. Boehnke. 1976. A growing mulch tillage system to reduce wind erosion losses of sugarbeet. *J. American Soc. of Sugarbeet Tech.* 19(1): 65-73.

Giles, J. F., E. J. Deibert, L. Smith, J. B. Fitts, and J. Enz. 1982. Sugarbeet production with reduced primary tillage. In 1981 Sugarbeet Research and Extension Reports. North Dakota State University and University of Minnesota. 12: 116-122.

Glenn, D. M., and A. D. Dotzenko. 1978. Minimum vs. conventional tillage in commercial sugarbeet production. *Agron. J.* 70(2): 341-344.

Halvorson, A. D., and G. P. Hartman. 1980. Response of several sugarbeet cultivars to N fertilization: Yield and crown tissue production. *Agron. J.* 72(4): 665-669.

Halvorson, A. D., and G. P. Hartman. 1984. Reduced seedbed tillage effects on irrigated sugarbeet yield and quality. *Agron. J.* 76(4): 603-606.

Halvorson, A. D., and G. P. Hartman. 1988. Nitrogen needs of sugarbeet produced with reduced-tillage systems. *Agron. J.* 80(5): 719-722.

Halvorson, A. D., G. P. Hartman, D. F. Cole, V. A. Haby, and D. E. Baldridge. 1978. Effect of N fertilization on sugarbeet crown tissue production and processing quality. *Agron. J.* 70(5): 876-880.

Janovicek, K. J., W. Deen, and T. J. Vyn, 2006. Soybean response to zone tillage, twin-row planting and row spacing. *Agron. J.* 98(3): 800-807.

Janssen, K. A., W. B. Gordon, and R. A. Lamond. 2005. Strip tillage and no tillage fertilization systems evaluated for eastern Kansas rain-fed corn. *North Central Extension-Industry Soil Fertility Conf.*, Vol. 21. Brookings, S.D.: Potash & Phosphate Institute.

Lyle, W. M., and J. P. Bordovsky. 1981. Low energy precision application (LEPA) irrigation system. *Trans. ASAE* 24(5): 1241-1245.

Lyle, W. M., and J. P. Bordovsky. 1983. LEPA irrigation system evaluation. *Trans. ASAE* 26(3): 776-781.

Lyle, W. M., and J. P. Bordovsky. 1995. LEPA corn irrigation with limited water supplies. *Trans. ASAE* 38(2): 455-462.

Miller, S. D., and A. G. Dexter. 1982. No-till crop production in the Red River Valley. *N.D. Farm Res.* 40(2): 3-5.

Niehues, B. J., R. E. Lamond, C. B. Godsey, and C. J. Olsen. 2004. Starter nitrogen fertilizer management for continuous no-till corn production. *Agron. J.* 96(5): 1412-1418.

Simmons, S. R., and A. D. Dotzenko. 1975. Evaluation of conservation tillage effectiveness on sugarbeet fields in northeastern Colorado. *J. American Soc. Sugarbeet Tech.* 18(4): 307-311.

Smith, J. A., R. G. Wilson, G. D. Binford, and C. D. Yonts. 2002. Tillage systems for improved emergence and yield of sugarbeet. *Applied Eng. in Agric.* 18(6): 667-672.

Sojka, R. E., E. J. Deiibert, F. B. Arnold, and E. Enz. 1980. Sugarbeet production under reduced tillage: Prospects and problems. *N.D. Farm Res.* 38(2): 14-18.