Development of Strip Tillage on Sprinkler Irrigated Sugarbeet

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. Treatments were compared to conventional grower practices in fifty-six 15 m by 25 m (48 ft by 80 ft) side-by-side plots. Both treatments were flat planted with no ridges or beds. All tillage and fertilization was done in the fall after removal of a malt barley crop. Thirty centimeter (12 inch) wide strips were tilled directly into the straw residues about 20 cm (8 inches) 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 of the future seed placement. Beets were planted about 2.5 cm (1 in.) deep on 60 cm (24 in.) 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 tiller required about 25 tractor horsepower per row, but substantial fuel savings were realized with this system by greatly reducing the number of tractor equipment field passes. 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 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. Strip tillage was performed in the fall on clay soils in eastern Montana where it was expected to result in better seedbed conditions than spring strip tillage; whereas lighter, sandy soils would probably perform as well when strip tilled in the spring, which could be combined with planting into a single pass operation. 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. Banding fertilizer is highly recommended to increase fertilizer use efficiencies and reduce input costs. RTK-GPS guided steering is also recommended for strip tilling and planting when the planter is not mounted on the strip tiller.

Key Words: Conservation tillage, zone till, inter-till, soil erosion, crop residue, minimum till.

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Robert G. Evans, W. Bart Stevens and William M. Iversen[1]
USDA-ARS, Northern Plains Agricultural Research Laboratory
Agricultural Systems Research Unit
Sidney, Montana 59270

INTRODUCTION[2]

Strip tillage (sometimes called zone tillage, row clearing or inter-till) is widely used in rainfed areas in the Midwest U.S.A. 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 the escalating high price of diesel fuel.

By some manufacturers' definitions, strip tillage is a method that tills a relatively narrow 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.]) covering 25% to 50% of the surface area. Zone tillage, on the other hand, often refers to technologies that till similar strips, but are deeper than 7.5 cm. In this paper, we are using strip tillage as a general term even though we are tilling in the 20 cm (8 in.) deep range because of term's wider usage among growers and researchers when referring to all of these technologies.

It is estimated that there are currently more than twenty 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 spherical or conical disks in various configurations to loosen the soil and prepare the seedbed. Many also use some type of shank or ripper 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 sort 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 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

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[1] Member, ASABE. Supervisory Agricultural Engineer, Robert.Evans@ars.usda.gov , Research Agronomist, Bart.Stevens@ars.usda.gov , and Physical Scientist, Bill.Iversen@ars.usda.gov , respectively. USDA, Agricultural Research Service, Northern Plains Agricultural Research Laboratory, Sidney, MT 59270.

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like sugarbeet where good seed-soil contact is critical and even nearby 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 techniques and equipment that minimize the problems of several types of conventional strip till equipment on a small seeded crop like sugarbeet.

The overall goal of this research was to develop and test a strip till system that was suitable for small seeded crops after small grains. The primary hypothesis of this research is 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:

1. To develop and evaluate a prototype strip tiller and banded fertilizer application system suitable for small seeded crops such as sugarbeet after small grains.
2. To develop a set of experiments to compare conventional tillage and strip till under sprinkler irrigation on yields and quality of both sugarbeet and malting barley (*Hordeum vulgare L.*).
3. To develop a cultural system for two year sugarbeet rotations based on strip tillage in high levels of small grain residue, and that relies on a grower's existing equipment as much as possible.

While not reported in this manuscript, this multidisciplinary, irrigated cropping systems research project is also comparing soil properties, nitrogen/carbon cycling, N-fertility placement and amounts, incidence of foliar diseases, soil compaction and conservation of soil moisture between strip till and conventional tillage treatments.

PREVIOUS STRIP TILLAGE RESEARCH ON SUGARBEET

There has been strong interest in conservation tillage techniques, mostly looking at some type of strip till, for sugarbeet for many years (i.e., Simmons and Dotzenko, 1975; Fornstrom and Boehnke, 1976; Glenn and Dotzenko, 1978; Sojka et al., 1980; Halvorson and Hartman, 1980, 1984, 1988; Giles et al., 1982; Deibert 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 below, although its potential has been widely recognized.

Pervious strip till work on sugarbeet at Sidney, Montana used multiple-row, narrow rototiller type devices to make 18 cm (7-inch) strips in the grain stubble on heavy clay soils to obtain the necessary type of seedbed (Halvorson and Hartman, 1984, 1988). The following discussion in this section reviews some of this research, but other research done around the same time used similar equipment and had similar results.

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 planted. In the early 80s there was very little overhead irrigation in the lower Yellowstone Valley region, so the researchers developed a system that could be used with furrow irrigation.

The challenge of creating a sufficient furrow to irrigate the beets the following year was addressed by creating a raised bed before the grain was planted and not disturbing it prior to strip tilling. There was also no 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 typically irrigated, which now required a siphon tube in every row instead of the simpler and more common practice of a few holes cut into an earthen ditch between border dikes. In addition, the rotary tillers could not handle large amounts of crop residue and the straw could also create problems with blocking irrigation furrows both of which required removal of as much straw as practical.

Practically, it was fairly difficult not to deform the beds during the harvest of the small grain crop and the subsequent baling and removal of the straw. If the soil was very dry, the beds stood up to the traffic relatively well, but if the soil was somewhat moist a combine with a full hopper could flatten the bed tops to the furrow level. The cut straw was also baled and removed, which was time consuming because traffic had to be restricted to the direction of travel parallel to the beds, and the tires used on the balers and loader tractors didn't always fit the predetermined row spacing. Problems created by the deformation of the bed-furrow structure weren't usually apparent until the following year when the beets were planted. If the beds were compacted by field operations prior to the strip tillage, the tiller tines would not adequately till the area where the beets were to be planted so stand establishment could be compromised. A commercially-built row crop cultivator for high surface residue conditions was not available to the researchers, so the rototiller strip tiller was also used in the furrows between the planted strips for the first cultivation. It was hoped that the tiller would chop and incorporate the residue sufficiently to allow the use of a conventional row crop cultivator for the following cultivations. Hoods over the tiller tines were supposed to contain the tilled soil, but low spots in the beds caused by the previous year's traffic would often cause the beets to be covered with soil creating some problems with young sugarbeet seedlings. Deformed furrows would also cause some irrigation uniformity problems and localized flooding between adjacent furrows. Weed escapes on the shoulder of the deformed beds were common. The second cultivation could be tedious due to small dams or plugs caused by floating, loose straw residue.

Fertilizer was broadcast in the fall for these early strip till trials. Thus, only the fertilizer that was in the path of the 18 cm (7 inch) tilled strip was incorporated. 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 a moist clay loam soil with the 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 most likely be exacerbated in the spring causing delayed planting. In addition, spring tillage would negate many of the soil mellowing benefits in the seedbed due to freeze-thaw cycles during the winter on heavier soils.

This system also presented some other practical problems if the crop had to be irrigated to facilitate seed germination in the spring. For example, in 1981, a frost on May 8th killed the sugarbeet in all plots (Halvorson and Hartman, 1984). The beets were reseeded on May 12th but had to be sprinkler irrigated using handlines to achieve good germination. Most commercial growers in the area would not have had the option to use sprinklers. 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.

Growers were also discouraged by the high equipment maintenance and low field speeds inherent in rotary tillers, poor weed control, and frustration with residue buildup when cultivating. In addition, the difficulty experienced when harvesting sugarbeet in muddy conditions on clay soils was enhanced by the straw residue that was still present at harvest time in significant although not highly visible quantities. Consequently, if an appreciable amount of precipitation was received during harvest, instead of just the usual muddy field condition difficulties, the straw would bind with the mud and cling to the cleaning rolls on the harvester until they built up to a diameter large enough to rub against each other and activate the slip clutches. The mud and straw could also form balls in the linked chain. This did not happen with conventional tillage under the same moisture conditions and most growers preferred to stay with older tried and trusted methods, thus abandoning strip tillage until it could be refined.

Despite these perceived and 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 advantages in reducing production input costs and wind erosion with minimal yield impacts. Strip till has become especially attractive to growers using Roundup Ready® sugarbeet plantings.

CONVENTIONAL SUGARBEET ROTATIONS

Sugarbeet in the lower Yellowstone Valley region are typically grown in a two 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 (1 to 2 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 may be more practical than bedding if wind erosion can be controlled by residues or other means. In addition, the high prices of diesel fuel are making the conventional land preparation system unsustainable in the Lower Yellowstone Valley region where 2008 production costs are estimated to be about $2,200 per hectare ($900/ac) for sugarbeet due to the high fertilizer, chemical and fuel costs.

Tillage for sugarbeet is typically done in the fall following common grower practice in the area because the time window to complete all spring operations is quite compressed due to high probability for rain and cold soils. In addition, this also allows any clods in the clay soils on the well tilled fields time to breakdown by freeze-thaw cycles during the late fall and winter.

In addition, there is an increasing amount of sugarbeet production under self-propelled center pivot irrigation due to reduced labor availability and other considerations, and it was expected the strip tillage techniques should work well under sprinkler irrigation. Flat planting sugarbeet was included in this study because it reduces the number of equipment passes compared to the raised bed systems, which is not needed under sprinklers; however, strip tillage should also be possible under furrow irrigation (a topic of future research and some growers are already doing this). Flat planting with standing stubble combined with the tilled strips should provide the same or increased benefits of wind erosion control and improved soil water levels at the surface as the commonly used bedding system.

The recent addition of an elevator facility by Busch Agricultural Resources, Inc. has made six-row malting barley the primary irrigated spring grain, replacing spring wheat in many local farming enterprises. Surface irrigation techniques are the most common methods of water application. The small grains are typically grown in surface irrigated borders whereas the sugarbeet are typically furrow irrigated.

CURRENT STRIP TILLAGE RESEARCH ON SUGARBEET

Although there has been no single great breakthrough, several advances in herbicides, irrigation technologies, tillage and planting equipment, and the success of strip tillage for large seeded crops have given rise to the idea that many of the difficulties faced by earlier attempts with sugarbeet could be overcome, and the potential benefits made it worth another look. To our knowledge, there are currently (in 2008) four locations, using various equipment types and having different objectives, where strip tillage of sugarbeet is being investigated: North Dakota State University, Fargo, ND; University of Nebraska, Scottsbluff, NE; USDA-ARS, Kimberly, ID; and USDA-ARS, Sidney, MT. Researchers in three of these locations are working on single soil types in their areas whereas the work in Sidney, MT is being done on both clay loam and sandy loam soils. There is also some limited research on strip tillage being done by sugar companies in Idaho and Alberta, Canada.

We believe that it would be advantageous to have a strip tillage machine that would also shank in banded fertilizer (reduce fertilizer losses) and incorporate the residue in the strip while providing a firm seedbed. The remaining standing stubble would also protect the crop seedlings from damage due to wind-blown soil particles. An important consideration was that reducing machinery passes from between five and seven down to one would provide substantial fuel savings. It was expected that there should 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 development of strip tillage systems would make irrigated sugarbeet rotations eligible for USDA conservation programs such as CSP, as well as an acceptable practice for required NRCS farm conservation plans.

Strip Till Equipment

A review of literature on available equipment and some site visits in 2003 to observe some in the field failed to find a strip tiller that the authors believed would provide an adequate seedbed for small seeded crops after small grains. Thus, the Sidney-based research used a custom-built, six-row strip tiller (Schlagel Mfg., Torrington, WY) with a 60 cm (24 inch) row spacing that leaves alternating strips of tilled and untilled small grain residue.

The custom-built machine tilled a 30 cm (12 inch) strip and left a 30 cm (12 inch) strip of standing stubble rows in between each tilled row. The strip tiller 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 x 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 inches). Hydraulically-activated, adjustable row markers with 30 cm (12 inch) convex notched coulter wheels were added.

The strip till machine (Figure 1) was designed so that it doesn't bury any straw in a layer, but mixes it with the soil within each strip. Each row assembly was individually attached to the main tool bars and designed to operate independently. Each row assembly unit had a single 50 cm (20 inch) straight coulter centered in front to cut through residue. An adjustable semi-parabolic ripper shank was located directly behind the straight coulters to lift and break up the soil (about 20 cm [8 inch] depth).

The ripper shank is followed by two 43 cm (17 inch) straight fluted coulters that were angled about 15º from front to back (widest in front) to cut the sides of the strip, mix the residue into the soil, and help squeeze the soil to close the ripper slot and eliminate voids. This was followed by two side-by-side, rolling 38 cm (15 inch) diameter by 10 cm (4 inch) wide "crows-foot" packer wheels in each row that was used to repack the tilled strip to form the seed bed. These packer wheels carry all the weight of each tiller assembly, about 240 kg (600 lbs) of down force on each strip during the packing operation. This helps ensure the firm seed bed required for sugarbeet seed and breaks up some of the larger clods.

Several minor modifications have been made to this machine and the planter as the research progressed over the next 5 years, mostly with respect to trash handling and guidance. For example, both the strip tiller and the John Deere 1700 MaxEmergePlus (John Deere, Moline, IL) machine were equipped with toothed-wheel row cleaners (Dawn Equipment Company, Sycamore, IL). In spring 2008, less aggressive row cleaners with a swept back tooth profile (Dawn Equipment Company, Sycamore, IL) were installed on the planter.

Mechanical Guidance. A simple mechanical guidance system was added to the strip tiller in 2005 to facilitate spring planting operations. The strip tiller was originally equipped with two bull-tongue chisels Two single 50 cm (20 inch) fluted straight vertical coulters were mounted on the front bar of the strip till machine to slice the residue and till narrow grooves 123 cm (48 in.) apart (same spacing as the front tires on the tractor used for spring planting). Next a bull-tongue chisel cut a shallow (e.g., 8 cm [3.5 inch]), narrow furrow that was followed by 33 cm (13 in.) furrowing wheels (Miller's Fabrication, Lovell WY) that formed a small v-shaped ditch that could be used to guide mono-rib tires on the planting tractor in the spring. The bull-tongue and furrowing wheel was later replaced with rolling 50 cm (20 in.) cone-wheels which left a firmer, more distinct guidance groove. The straight fluted coulters were removed in the clay soils if the ground was found to be too wet, but leaving the chisel. The lack of the coulter ahead of the chisel would often result in plugging, so the chisel would be removed as well. In softer soils it was discovered that the machine was heavy enough to press the cone wheels into the soil several inches. The same type and size cone wheels were also placed on the planter to match the mono-rib tire spacing. This was done to keep the planter from drafting out of the center of the tilled strip and fertilizer band due to slack in the three-point hitch system. This has worked well the following spring 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 purchased and used in the fall of 2007 for the 2008 crop year; however, the mechanical guidance furrows and cone wheels were still required to keep the planter on the row (eliminate drafting by the planter).

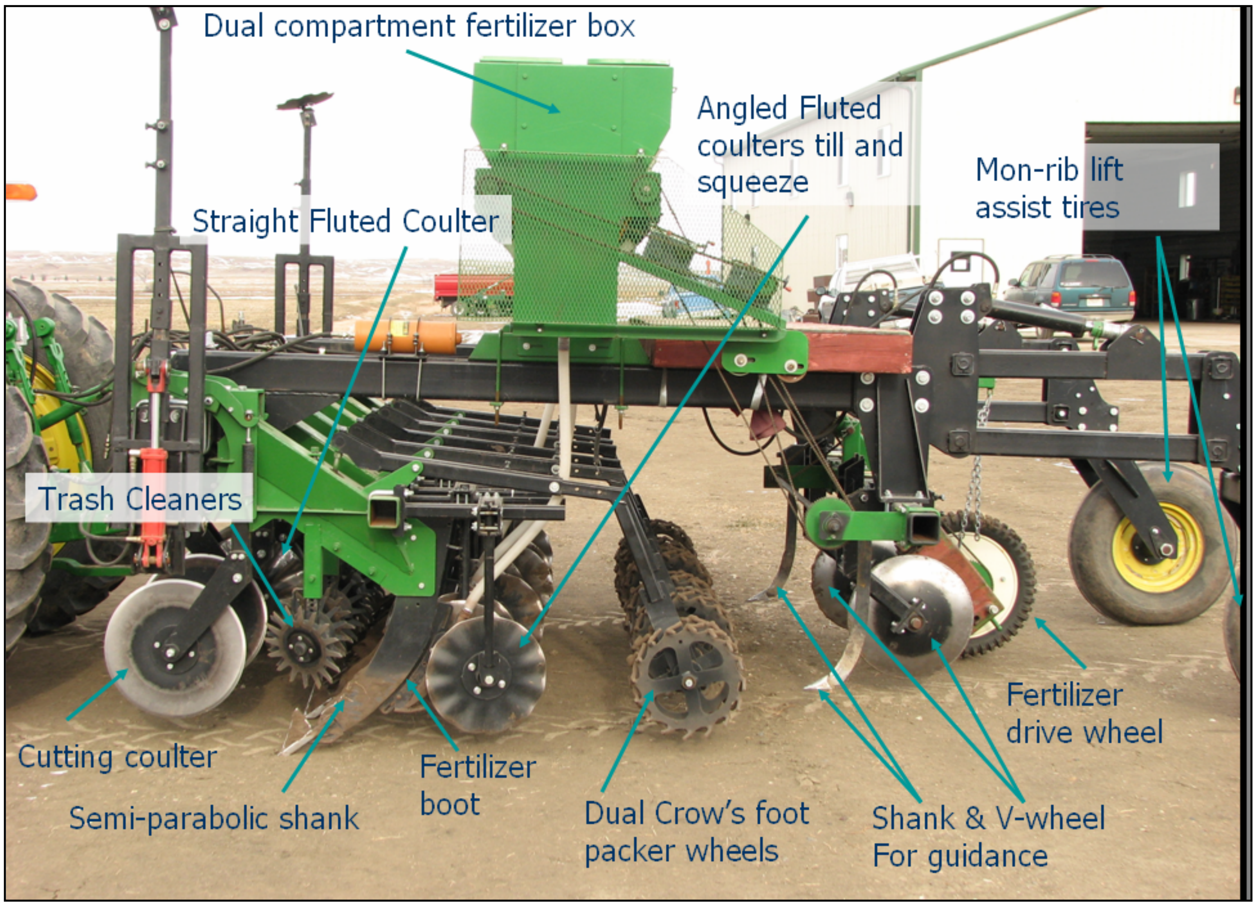

Figure 1. Custom-built strip tiller showing the progression of coulters, rippers and packer wheels.

Fertilizer Application System. This machine was set up for dry fertilizer but it is also equipped to apply liquid fertilizers. All the dry fertilizer was placed in a band during the same operation. A fertilizer tube and a "shoe" is located on the back of each ripper shank to deposit dry fertilizer about 7.5 cm (3 inches) directly below where the seed would be placed, although some fertilizer also dribbles to the bottom of the tilled zone. The depth of fertilizer application can be changed by moving the fertilizer shoe up or down on the ripper shank.

A divided, gravity feed fertilizer box was added to the strip tiller in 2003 to enable one-pass operation. Application rates are controlled by two ground driven a Model Y1 Zero-Max Adjustable speed drives (Zero-Max, Plymouth, MN; http://www.zero-max.com/products/drives/drivesmain.asp), which are infinitely adjustable over their operational range. Amazone metering cups (Amazone Farm Machinery Ltd., Brandon, Manitoba, Canada R7A 6N2) are used to meter fertilizer into the tubes. These cups can be used for either seed or fertilizer, and calibration and spot testing showed them to be accurate and repeatable.

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

Experimental Design

Research including strip tillage of sugarbeet into barley stubble was conducted at two sites on two different soil types. These include: 1) the Montana State University (MSU) Eastern Agricultural Research Center (EARC) farm (4 ha [10 ac]) near Sidney, MT (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 for the irrigated projects are approximately 15 m x 25m (50 ft x 80 ft). Non-sampled plot border/buffer areas are 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 are fertilized and planted at the same times with the same equipment. Sugarbeet is planted in 60 cm (24 inch) rows and malting barley in 20 cm (8 inch) rows. Because all the plot area at both locations was sprinkler irrigated and furrows were not needed, all the plots were flat-planted and ridges were not used even for conventional till. There were no special soil preparations other than the zone tillage operation to accommodate the strip tilled beets.

Both the EARC and Nesson Valley locations utilized an off-the-shelf programmable logic controller (PLC) and GPS system interfaced with a custom-built, site-specific irrigation system on a self-propelled linear move sprinkler system (Evans and Iversen, 2005; Kim et al, 2008). Both self-propelled linear move irrigation systems use a buried wire alignment system (with the antennas located in the middle of the machine) that guides the system through the plot area. Nominal operating pressure is about 250 kPa (35 psi) and maximum ground speed is 2.1 m min^{-1} (7 ft min^{-1}) at the100% setting for both machines.

The EARC research is examining the interaction between irrigation method and tillage on two-year sugarbeet-malt barley crop rotations. The experiment was designed as two complete rotations plus the establishment year (5 years total) starting with the 2004 growing season. The soil is a relatively heavy Savage clay loam (fine, smectitic, frigid Vertic Argiustolls) with sand content of 209 g kg^{-1}, silt 463 g kg^{-1}, and clay 328 g kg^{-1}.The water table is relatively shallow (e.g., 1.2 m [4 ft]) and may contribute to crop water needs during the season. The entire EARC 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,

The EARC field is laid out in 14 strips in the direction of travel. Each 15-m wide plot is irrigated by a self-propelled linear move sprinkler irrigation system 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; and Bordovsky and Lascano, 2003) with pressure regulators on flexible drops spaced every 1.2 m (4 ft) that apply water (bubbler) about 0.2 m (8 inch) above the soil surface between every other crop row without wetting the canopy. Fifty-six plots are arranged in an unbalanced, randomized stripped block design with four replications. Half of the plots are irrigated with MESA and the others with LEPA each year. Water is applied to meet the calculated ET_a of each crop strip (backed up with soil moisture readings) using data from a nearby weather station. Equivalent depths of water are applied for both irrigation methods. Each 15 m (50 ft) strip is planted either to sugarbeet or malting barley, which alternates from year to year.

Starting in 2003, tillage for both EARC treatments was done after barley harvest (August-early September) to prepare for the following season. Conventional tillage operations were performed after broadcasting the fertilizer. The sequence of operations in all years for the conventional treatments consisted of tilling the soil with a ripper (Case IH, Racine, WI) to a depth of about 23 cm (9 inches), 2 passes with a rolling mulcher (Brillion Inc., Brillion, WI), and 2 passes with a leveler (Eversman, Denver, CO). The following spring, a single pass was made with an S-tine cultivator equipped with rolling baskets (Kongskilde Mfg., Soro, Denmark) prior to planting.

Tillage was not a treatment on the NDSU Nesson Valley (Nesson) project and is therefore not comparable to the EARC project, but is included for general interest. This 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. This project is 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 - 30 cm depth ranged from 640 to 674, 176 to 184, and 150 to 166 g kg^{-1}, respectively. Soil bulk density at 0 - 30 cm depth ranged from 1.51 to 1.66 Mg m^{-3}. The water table is deep (e.g., 30 m [100 ft]) and does not contribute to crop water use. These plots utilized the same planting, tillage and cultivation equipment used at the EARC site.

Land preparation for the Nesson project started in fall 2004 and the first irrigated crops planted in 2005. Strip till on sugarbeet started in fall 2005 for the 2006 season because there was no small grain stubble present on the site in the fall of 2004. There were three crop sequences with two irrigation frequencies and six replications in a stripped-randomized complete block design (72 plots, each 15 m × 60 m) with all components of each sequence present every year. These results are not strictly comparable to the EARC study because all sugarbeet at the Nesson site were strip tilled (not a treatment) following barley, whereas the conventionally tilled sugarbeet followed potatoes.

The Nesson site has 19 15-m (50 ft) wide strips along the length of the machine set up for site-specific irrigation although only 18 strips are used for this research. 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 inch) above the ground on flexible drops. There are two crop sequences with two irrigation frequencies and six replications in a stripped-randomized complete block design with all components of each sequence present every year resulting in 72 plots. Irrigation frequency is varied based on either 30 mm or 60 mm cumulative ET_c 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 80% application efficiency.

Table 1 presents the total rainfall and irrigation amounts for 2004, 2005, 2006, 2007 and 2008 growing seasons for Sidney and Nesson Valley research sites. All tillage and fertilizer applications are done in the fall at Sidney (heavy soils). At the sandy Nesson site, strip tillage was done in the fall and fertilizers are shanked into the soil, whereas conventional tillage and fertilization was done in the spring because of wind erosion concerns. Nitrogen fertility is supplemented as needed through the sprinkler irrigation system during the season based on petiole analyses, especially on the sandy soils. 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.

Sugarbeet (cv. ACH 927 large bare, American Crystal Co., Eden Prairie, MN) were planted at 135,000 seeds ha^{-1} (55,000 seeds ac^{-1}) at a 60 cm (24 inch) row spacing to a depth of about 2.5 cm (1 inch). In 2008, the Nesson plots were planted to a Roundup Ready® variety (Beta RR 86RR44) because of a change in research design to a new project (still using strip till and conventional till, however) 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, IA), and in 2005-2008, the planting was done with a John Deere 1700 MaxEmergePlus planter.

Certified malt barley (cv. Tradition, Busch Agricultural Resources, Inc., West Fargo, ND) was seeded at 90 kg ha^{-1} (80 lbs ac^{-1}) at about 19 cm (7.5 inch) row spacings to a depth of about 3.8 cm (1.5 inches) using a small grain drill (Kirschmann Mfg Co, Bismarck ND). All barley plots were planted on the same date using the same equipment. Over the course of this research, malting barley yields have ranged from about 4000 kg ha^{-1} (75 bu ac^{-1}) to 6450 kg ha^{-1} (120 bu ac^{-1}). A straw and chaff spreader was used on the combine and no residue was removed from any of the plots.

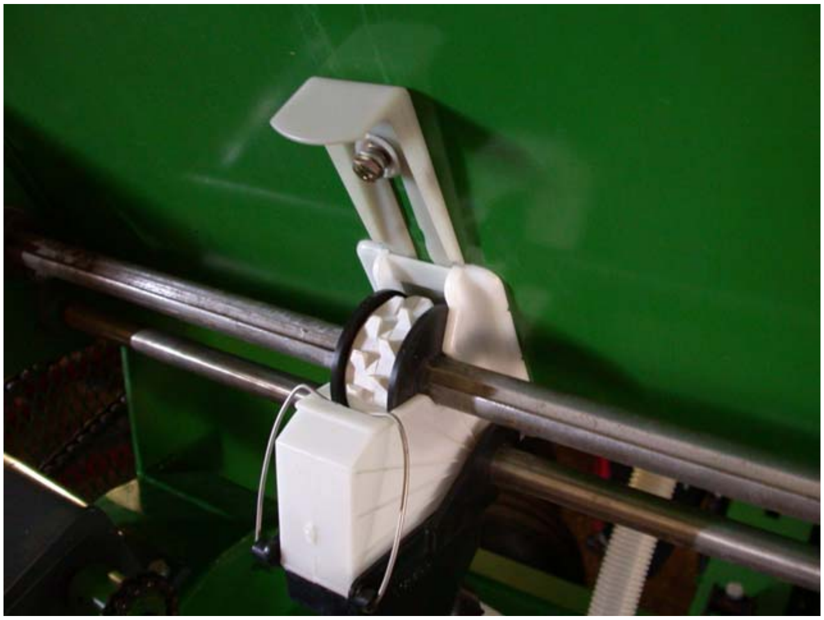

Figure 3. Photograph of the adjustable Amazone metering cup arrangement on the fertilizer box.

Fertilization. Most strip tillage in the Midwest is done in the spring with banded liquid fertilizers, whereas fall tillage and banding dry fertilizers were used in this study. Dry fertilizers are used by almost all growers in the area, and were used in this study to have the same type of fertilizers in both treatments. All fertilizer for the conventionally tilled plots were broadcast 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), most of the fertilizer appeared to end up in the bottom of the ripper slot, about 8 inches (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 ac^{-1}), resulting in N application rates varying from 108 to 146 kg N ha^{-1} (97 to 130 lbs ac^{-1}) at Sidney and from to 135 kg N ha^{-1} (120 lb ac^{-1}) at Nesson Valley. Phosphorus was applied each year at a rate of 56 kg P_2O_5 ha^{-1} (50 lbs P_2O_5 ac^{-1}) at Sidney and 168 kg P_2O_5 ha^{-1} (150 lbs P_2O_5 ac^{-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.) guideline of 185 kg N ha^{-1} (165 lbs ac^{-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. For barley, N fertilizer was applied so that the sum of fertilizer and plant-available soil nitrate-N was equal to 0.025 kg N per kg (1.2 lb N per bushel) of expected yield, resulting in N application rates ranging from 86 to 108 kg N ha^{-1} (77 to 96 lb ac^{-1}) at Sidney and from 101 to 115 kg N ha^{-1} (90 to 103 lb ac^{-1}) at Nesson Valley. Potassium (KCl) was added as indicated by fall soil test results to maintain adequate levels for sugarbeet production (>200 ppm soil test). All plots of each crop were fertilized and planted at the same times with the same equipment, respectively.

Both strip till and conventional till were cultivated twice during the season, once at about the 6 leaf stage and a second time just prior to full canopy development. A high trash cultivator (H&S, Stephen, MN) with rolling disk shields 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 inches) high. A straw and chaff spreader on the combine evenly distributed the residue over the 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 “trash” than would normally be encountered because most growers in the area bale the straw and remove it from the field. This was the most difficult condition, and it is assumed that if strip tillage is successful under these conditions, it should certainly work for those who remove the straw.

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. Research at the Nesson site started in 2005

Year	Location	Rainfall		Irrigation		Total water applied	
		mm	inches	mm	inches	mm	inches
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

RESULTS AND DISCUSSION

The strip tillage system was designed to eliminate unnecessary tillage operations by accomplishing the same objectives in one pass as conventional operations, but with substantial savings in time and fuel. No beds or ridges were created in the barley or the sugarbeets.

This research experience has shown that operation of the strip tiller 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 seemed to work well). Narrow strips or shallower tillage would likely reduce tractor horsepower requirements. Figure 2 shows the tiller 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). The malt barley crops in all years yielded in the range of 5400-6400 kg ha^{-1} (100-120 bushel ac^{-1}), and exceeded all the malting requirements for acceptance. Sugarbeet were all early harvested in late September so that tonnage and sucrose content are slightly lower that what most growers would experience with a later harvest date.

Observations have shown that beets planted in strip till situations have emerged 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. 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-induces moisture loss as well as greater, more uniform capture of snowfall. The opposite result was observed at Sidney in 2006 when plant population at the initial count was 50% less for strip tillage than for conventional tillage; however, the cause of this observation was also a difference in soil moisture at the time of planting. The spring of 2006 was unusually wet. Both conventional and strip till plots were planted the same day. 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. This conditions caused some seedlings in the strip tilled plots 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 is more favorable. Early plant population measurements at Nesson in 2008 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. As a result, plant population at the time of the final count was only about 50% of the target population for both tillage systems.

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).

Year	Initial Count				Final Count			
	DAP	CT	ST	*P*>|*t*|	DAP	CT	ST	*P*>|*t*|
		-- plants/acre --				-- plants/acre --		
Sidney								
2004	15	1452	4538	*0.014*	50	40384	42290	*0.563*
2005	28	16456	17424	*0.688*	56	40959	43560	*0.160*
2006	14	22188	11707	*0.001*	30	35393	22551	*<0.001*
2007	10	17243	13643	*0.102*	26	38811	38418	*0.714*
2008	20	17243	22824	*0.056*	53	42516	41768	*0.039*
Nesson								
2006	15	30265	28528	*0.173*	38	31899	33457	*0.417*
2007	16	7305	30810	*<0.001*	29	38660	45012	*<0.001*
2008	21	30220	24321	*0.055*	46	21841	21326	*0.844*

Strip till has also been observed that the strip till method results in more uniform and deeper snow catch, thus retaining more moisture than the conventional method. This additional soil water is likely the cause of the more uniform and earlier germination.

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). The only year with a significant difference in sugarbeet yield and sucrose yield per hectare for Sidney was 2005 and that difference was due an early season wind storm that heavily damaged the conventional plots while the strip tilled plots were not affected. Basically, these data show that there are 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.

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

Year	**Beet Yield - m. ton ha^{-1} (tons ac^{-1})**		**Percent Sucrose**		**Sucrose - kg ha^{-1} (lbs ac^{-1})**	
	CT	**ST**	**CT**	**ST**	**CT**	**ST**
2004	52.0 (23.2)	51.4 (22.9)	19.8	20.1	10,360 (9,225)	10,342 (9,208)
2005	51.8 (23.1)	62.6 (27.9)	19.9	19.9	10,124 (9,014)	12,094 (10,768)
2006	63.4 (28.3)	71.2 (31.8)	17.7	17.4	11,315 (10,078	12,448 (11,085)
2007	57.8 (25.8)	61.1 (27.3)	19.8	19.7	11,540 (10,280)	12,000 (10,685)
2008	52.5 (23.4)	54.7 (24.4)	18.7	18.7	9,649 (8,780)	10.037 (9,133)
Average	55.5 (24.8)	60.2 (27.5)	19.2	19.2	10,413 (9,475)	11,184 (10,176)

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

Year	Beet Yield - m. ton ha^{-1} (tons ac^{-1})		Percent Sucrose		Sucrose - kg ha^{-1} (lbs ac^{-1})	
	CT	**ST**	**CT**	**ST**	**CT**	**ST**
2006	59.0 (26.3)	59.0 (26.3)	17.2	17.4	10,196 (9,079)	10,264 (9,140)
2007	61.2 (27.3)	60.1 (26.8)	18.4	18.1	11,305 (10,067)	10,902 (9,708)
2008*	70.4 (31.4)	69.9 (31.2)	17.0	17.2	11,726 (10,668)	11,792 (10,728)
Average	63.5 (28.3)	63.0 (28.1)	17.5	17.6	11,076 (9,938)	10,986 (9,859)

***Sugarbeets in 2008 were a Roundup Ready® variety.**

The generally slightly higher sucrose yield per hectare of strip till that was observed in this work compared to conventional tillage was also found in other strip tillage research (Sojka et al, 1980; Halverson and Hartman, 1980, 1984). There were no statistical differences in percent sucrose, but sugarbeet yields were often slightly higher in the strip till. It is speculated that this is related to earlier nitrogen fertilizer uptake in the strip till resulting in the higher sugar content because those beets ran out of soil nitrogen earlier. Research was initiated in 2006 to test this hypothesis.

The percent sucrose was significantly lower for both tillage treatments in 2006 than in other years, and the strip till was slightly lower than the conventional. The low sucrose levels were common in the area and were likely due to the cooler than normal summer that caused the sugarbeet to still 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.

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 replanting was not required, but it delayed them sufficiently such that there were significant yield differences in the fall (this is clearly shown in Table 2 above).

The average number of sugarbeet per 3.3 m (10 ft) of row over the four years at Sidney was 15.15 and 14.8 for conventional and strip till, respectively. The corresponding average weights per sugarbeet were 0.69 (1.53 lbs) and 0.80 (1.76 lbs) 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 kg (1.75 lbs) and 0.81 kg (1.76 lbs) per sugarbeet for the conventional and strip till treatments, respectively.

CONCLUSIONS, RECOMMENDATIONS AND OBSERVATIONS

The three objectives of the research, which were stated above, were successfully met. 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 savings in fuel and time. 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. This technology should also provide substantial savings in fuel and time for local growers.

One of the central tenets of this research is that strip tillage is not just a minimum tillage technique. It affects the tractor, planting, cultivation and harvesting equipment. It must be an integral part of an entire cultural system that minimizes equipment passes through the field while saving fuel and time. Fertilization amounts, timing and placement may have to be altered. Use of strip tillers in sugarbeet rotations after small grains will require some changes to planting and cultivation equipment and practices to handle the 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 rollers. It should be noted that the strip tillage treatment doesn't require any more tillage than the conventional tillage following sugarbeet harvest before the succeeding barley crop.

High level guidance of the strip tiller and subsequent operations is especially critical if each operation is done separately. Mechanical or hydraulically assisted RTK-GPS guidance is highly recommended for both the tiller and the planter 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 high level guidance systems are probably not necessary.,

Fertilizer use patterns 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 extensive tillage than with reduced tillage. 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 are of minimal consequence to system productivity. Further work is needed to determine if banding nitrogen fertilizer under the strip tillage system affects the optimum fertilizer application rate as compared to conventional practices, but this research suggests that current fertilizer recommendations are adequate for strip till systems.

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 inches) 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, row cleaners or "trash whippers" are recommended for the strip tiller to avoid plugging. Plugging usually occurred between the two fluted coulters 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, row cleaners are recommended for the planter as well because some residue will be moved back onto the tilled strips by wind.

Strip tillage is not a method that enhances weed control. Prior to Roundup Ready® sugarbeet**, w**eed 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 must continue to cultivate using a cultivator that can handle high amounts of residue.

Almost all sugarbeet growers in the Lower Yellowstone region do most of their tillage and fertilizer applications in fall to save time during the short tillage-planting window in the spring, but can result in wind erosion problems. 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 but greatly reduces the wind erosion problem.

Snow catch across a field also appears to be much more uniformly distributed under fall strip tillage compared to conventional fall tillage. Measured surface soil moisture (top 15 cm) is higher in strip tilled plots and more uniform compared to adjacent conventional till plots. This may save an irrigation to get the beets germinated. We believe that this is because there are very few or no snow drifts within the field and fewer, smaller snow drifts at the field edges. Emergence data shows that sugarbeet in a dry spring get an earlier start with strip till. In addition, even though the average soil moisture may be 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. A straw and 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 residue.

Heavy soils must be worked at a medium moisture level in the fall to get a good seedbed under strip till. If it is worked too wet the shank merely cuts a slot, and if it's too dry the clods don't break down. Completing the strip till operation in the fall allows the strips to settle and collect moisture for better seed germination. The window of opportunity for tillage in the spring in this northern area is very short, though on a sandy soil the required conditions may be able to be met. Spring tillage would result in very little straw decomposition prior to planting which would probably make 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 or "trash-whippers" 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 inches) or more behind the point of seed drop may have difficulty in consistently placing the seed at the required shallow depths because of the undulations of the strip tilled seed bed.

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

To date, this research has been conducted only on sprinkler irrigated sugarbeet. 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. 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 a 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 2009 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 grain harvesting, it would be desirable to strip till at an angle to the direction of travel by the combine harvester. 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 get re-filled and re-compacted, and the seed may be placed on top of the ground or in the bottom of the void in these situations. This may be one reason that ur strip till stands aren't consistently higher than CT. Thus, other future research will look at ways to improve the operation of the strip tiller in breaking up heavy soils, and ways to decrease the large HP requirements so that growers can utilize existing tractors as much as possible.

Fertilizer recommendations currently used for sugarbeet were developed for furrow irrigation with full tillage. It may be necessary to re-evaluate these recommendations in terms of strip tillage and sprinkler irrigation. Self propelled sprinkler irrigation (e.g., center pivots and linear moves) also offer flexibility for split applications of nitrogen applied through the irrigation system.

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