Strip Till Study on Sugar Beets

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• Status Report •

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Researchers at the USDA/ARS Northern Plains Agricultural Research Laboratory in Sidney, MT, including Bob Evans (agricultural engineer), Bill Iversen (physical scientist), and Bart Stevens (agronomist) as well as other scientists at the location initiated a four year strip till study in Fall 2003 for the 2004 season on sugar beets following small grains grown under sprinkler irrigation. They now have two years of data and some preliminary results are presented below.

Abstract

A four year strip tillage study on sprinkler irrigated sugarbeets was initiated in fall 2003 at Sidney, Montana. Treatments were compared to conventional grower practices in 50 ft by 80 ft (15 m X 25 m) side-by side plots with four replications in a 2-year barley sugarbeet rotation. Because they were sprinkler irrigated, both treatments were flat planted with no ridges or beds. All tillage and fertilizations was done in the fall after removal of a malt barley crop. Beets were planted on 24 inch (60 cm) rows in the spring. Twelve inch (30 cm) wide strips are tilled directly into the straw residues using straight and fluted disks and a modified ripping shank followed by a crows-foot packer wheel. Dry fertilizer is shanked in about 2 inches (5 cm) below and to the side of the future seed placement. Operation of the strip tiller requires about 25 tractor horsepower per row. Conventional tillage included broadcast dry fertilizer at the same rate as strip tilled, chisel plowing, leveling, and mulching. In 2004, there were no significant differences in yields or sugar production between the two set of treatments, however, in 2005 the strip tilled plots produced about 17% greater yields (tons and sugar), primarily to wind erosion protection provides by the standing straw stubble in the spring that severely damaged the conventionally tilled plots. Sugar content in the beets was consistently higher in the strip tilled plots.

Key Words: Strip till, zone tillage, sugarbeet, irrigation, soil erosion.

Introduction

Strip tillage (sometimes called zone tillage) is widely used in rainfed areas in the Midwest on large seeded crops like corn and soybeans (e.g., Janssen et al, 2005; Al-Kaisi and Licht, 2004). However, strip tillage for small seeded crops like sugar beets has not been nearly as successful, primarily due to poor seed to soil contact. Most strip tillage in the Midwest is done in the spring with liquid fertilizer if banded or dry if broadcast, whereas, in our new study, we are using fall tillage and banding dry fertilizers.

Many currently available strip till machines use a spherical or conical disk which places soil over the residue and does not pack the strip. However, this soil condition doesn't work well for small seeded crops like sugarbeets where good seed-soil contact is critical, as they generally don't make a firm enough bed and may also leave small air pockets.

Normally, a MonDak (eastern Montana-western North Dakota) grower makes five or more passes across a field for fertilizer applications, disking, plowing or ripping, leveling (1 to 2 times), mulching and hilling, all in the fall preceding the sugarbeet crop. These operations are often the same for sprinkler as well as furrow irrigated fields, but some such as leveling and hilling are not really necessary for irrigation under sprinklers, but are done to prepare a smooth seedbed following the aggressive tillage and to fill in the tire tracks. The hilling operation is often required to meet the farmer's USDA farm conservation plan on highly wind erodible soils. Flat planting after a small grain crop may be more practical if wind erosion can be controlled.

Although there has been no single great breakthrough, advances in herbicides, irrigation technologies, tillage and planting equipment led the current researchers to believe that many of the difficulties faced by earlier attempts could be overcome and the potential benefits made it worth another look. Furthermore, they believed that a strip tillage machine could be designed that would shank in banded fertilizer (reduce fertilizer losses) and incorporate the residue in the strip while providing a firm seedbed.

Flat planting was included because it would work well under sprinklers; however, it should also be possible under furrow irrigation. 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 bedding. The standing stubble will also protect the crop seedlings from wind blown soil particles, which bedding fails to do. Furthermore, it is hoped that strip tillage will make sugarbeet ground eligible for USDA conservation programs such as CSP.

This study was initiated because it seemed that strip tillage on flat plantings would be able to help growers reduce machinery passes (reduced labor and fuel costs) and control wind erosion. There should also be some water conservation benefits in more even trapping of snow and reduced soil evaporation where residue protects the soil surface. In addition, there is an increasing amount of sugar beet production under center pivot irrigation due to labor and other considerations, and these techniques should work well under sprinkler irrigation.

The objectives of the study are to (1) examine the effect of strip tillage on yields, sucrose content and other quality parameters as compared to conventional grower practice in the area; and (2) to develop a way to grow high yield beets using fewer machinery passes across the field — an important factor with today's high cost of diesel fuel. The researchers are also looking at effects of soil erosion from wind, weed control, and conservation of soil moisture while maintaining high sugars and yields.

Previous Strip Tillage Research on Sugar Beets

Relatively little work has been done on strip tillage of sugarbeets over the years although its potential was widely recognized. Pervious strip till work on sugarbeets at Sidney, Montana used multiple row rototiller type devices to make 7-inch strips in the grain stubble on heavy clay soils (Halverson and Hartman, 1984, 1988). This work was not generally adopted by growers for a number of reasons. The procedure 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, so the researchers were forced to develop 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 more common practice of a few holes cut into an earthen ditch between border dikes.

It was fairly difficult not to deform the beds during the harvest of the small grain crop and the subsequent removal of the straw which this method required. If the soil was very dry, the beds stood up to the traffic quite well, but if the soil was somewhat moist a combine with a full hopper would flatten the bed tops to the furrow level. The straw was also removed which was somewhat time consuming because traffic was restricted to the direction of travel parallel to the beds, and the tires used on the baling and loader tractors didn't always fit the predetermined row spacing. The problems created by the deformation of the bed-furrow structure weren't 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 would be compromised. A row crop cultivator for high surface residue conditions was not available to the researchers, so the strip tiller was also used 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. The tiller tines were moved over to till between the crop rows. 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. Weed escapes on the shoulder of the deformed beds were common. The second cultivation was sometimes tedious due to plugging caused by the excessive straw residue.

Fertilizer was broadcast in the fall for these early strip till trials. Only the fertilizer that was in the path of the 7 inch tilled strip was incorporated. In order to minimize the loss of nutrients from the fertilizer left on the soil surface, it was desirable to delay the application until late fall when air and soil temperatures were lower. If it rained before the strip tillage operation was completed, it was impossible to strip till a moist clay soil with the residue because the tiller hoods would 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.

In 1981, a frost on 8 May (Halvorson and Hartman, 1984) killed the sugarbeets in all plots. The beets were reseeded on 12 May but had to be sprinkler irrigated using handlines to achieve germination. Most commercial growers in the area would not have had this option. Furrow irrigation was not practical in this case because the grain stubble in the furrows restricted water flow so the water would tend to overflow the furrows and run down the soft tilled strips where the sugarbeet seed was planted, washing out the seeds.

Despite these perceived 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. By the mid 1990s these efforts were largely abandoned in the lower Yellowstone Valley. In addition to the previously mentioned issues, other problems that discouraged the growers were 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 sugarbeets in muddy conditions was enhanced by the extra residue still present at harvest time in significant though 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 would also form balls in the linked chain. This did not happen with conventional tillage under the same moisture conditions and growers preferred to stay with older tried and trusted methods, thus abandoning strip tillage until it could be refined. However, high grower interest in strip tillage continued because of the large potential advantages in reducing production costs and wind erosion, and sugarbeet growers from Canada to Colorado are experimenting with the concept.

Current Strip Tillage Research on Sugarbeets

The research uses a custom-built, six-row strip tiller (Schlagel Mfg., Torrington, WY[1]) that leaves alternating strips of tilled and untilled small grain residue. The machine tills a 12” strip and leaves 12 inch standing stubble rows in between each tilled row. The centers of the tilled strips are 24” apart.

The strip tillage system was designed to eliminate unnecessary tillage operations by accomplishing the same objectives in one pass during fall operations as conventional operations, but with substantial savings in time and fuel. Fertilizer is banded in at the same time as tillage. All the dry fertilizer was shanked in a band during the same operation in the fall. We used dry fertilizer but liquid fertilizers should also work great.

[1] Mention of a trademark, vendor or proprietary product does not constitute a guarantee or warranty of the product by 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.

Figure 1. Picture of the custom-built strip tiller showing the progression of disks, rippers and packer wheels.

The NPARL machine was designed so that it doesn't bury the straw in a layer, but mixes it with the soil in the strip. Each row of the tiller has a single straight coulter in front centered on each strip that cuts through the residue, a semi-parabolic ripper shank is located immediately behind the straight coulters to lift and break up the ground (about 8 inch depth). Fertilizer tubes and a "shoe" behind each ripper shank deposit dry fertilizer about 2 inches below and 2 inches to each side of where the seed would be placed. The depth of fertilizer application can be changed by moving the fertilizer tube up or down on the shank. Some fertilizer does dribble through the soil clumps to the bottom of the tilled zone. The shank is followed by two angled-in fluted coulters that cut the sides of the strip, mix the residue in the soil, and help squeeze the soil to close the ripper slot to form the seed bed. Two "crows-feet" packer wheels then compact the seed bed strip. The packer wheels carry the weight of the entire machine, about 600 pounds of down force for each strip during the operation. This helps ensure the firm seed bed required for sugar beet seed. Operation of the strip tiller requires about 25 tractor HP per row so tractor size is important (front wheel assist or tracked tractors seem to work best).

Figure 2. Picture of the strip tiller in operation.

A simple guidance system was added to the tiller in 2005 to facilitate spring planting operations. Two fluted coulters are mounted on the front bar of the machine to slice the residue immediately behind the tractor wheels (same spacing as spring planting). These are followed in the rear by two bull-tongue chisels to cut a narrow furrow. Rolling V-wheels then form the furrow into a small ditch that will guide the mono-rib tires on the planting tractor in the spring. This has worked well as a means to place the seed close to the center of each strip. However, available auto-steer systems should also work well.

Fertilizer Box. A divided, gravity feed fertilizer box was added to the strip tiller in 2003 to enable one-pass operation. Application rate is controlled by a ground driven a Model Y1 Zero-Max Adjustable speed drive (Zero-Max, Plymouth, MN; http://www.zero-max.com/products/drives/drivesmain.asp), which is infinitely adjustable over their range. Amazone metering cups (Amazone Farm Machinery Ltd., Brandon, Manitoba, 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 sufficiently accurate and repeatable.

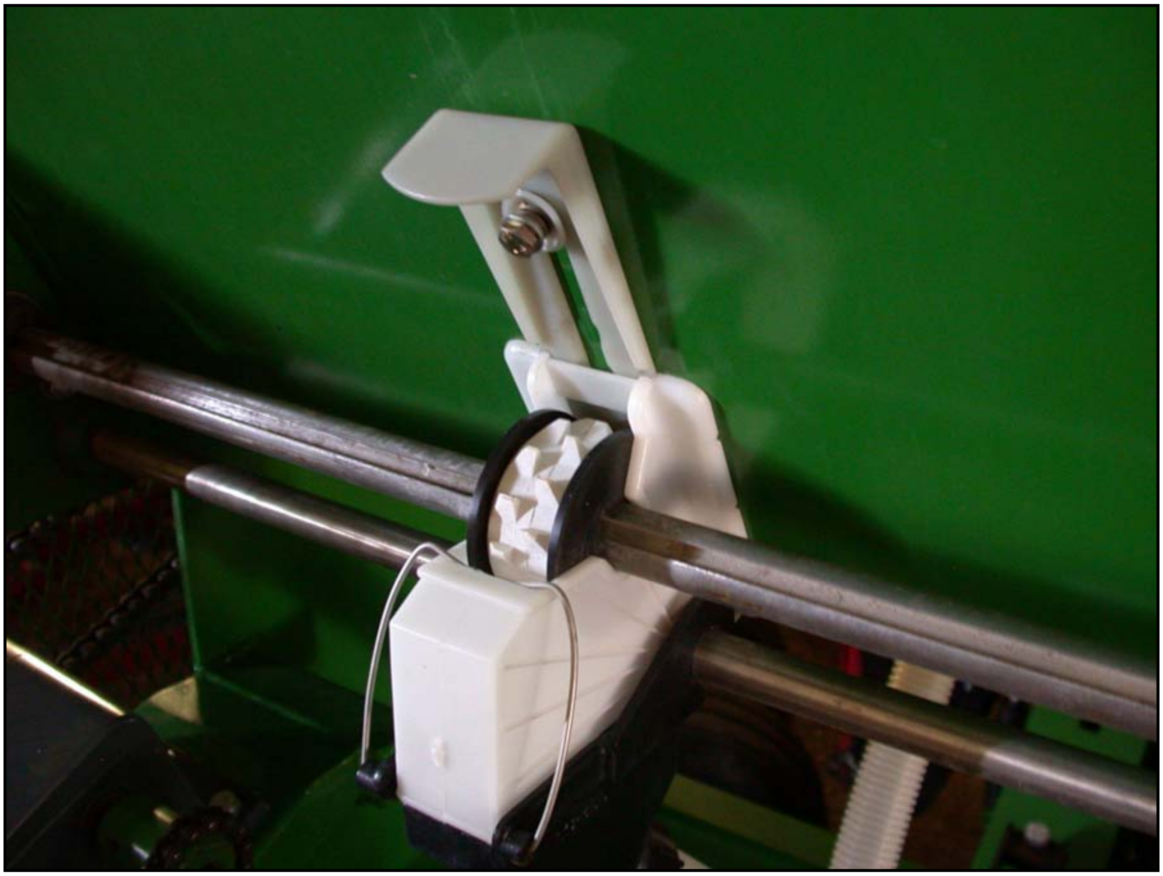


Figure 3. Photograph of the adjustable Amazone metering cup arrangement on the fertilizer box.

Experimental Design

The experiment was conducted at the Eastern Agricultural Research Center, Montana State University farm in Sidney, MT in 2004. The soil is a Savage silty clay loam (fine, montmorillonitic Typic Argiborolls) with sand content of 209 g kg^{-1}, silt 463 g kg^{-1}, and clay 328 g kg^{-1} soil, pH 7.8, organic C 8.9 g kg^{-1}, and total N 0.65 g kg^{-1} at the 0 to 20 cm depth. Growing season average monthly air temperature from April to September 2004 ranged from 7 to 21^{o}C and total rainfall 191 mm. All plots were fertilized and planted at the same time.

Two-year rotations of sugar beets and spring grains are a common practice in the MonDak area. The recent addition of an elevator facility by Busch Agricultural Resources Inc has made six-row malt barley the primary spring grain. Surface irrigation techniques are the common methods of water application. The small grains are typically grown in borders whereas the beets are furrow irrigated. The presence of standing small grain residue before each sugarbeet crop potentially makes strip tillage a viable way to reduce production costs as well as reduce the risk of crop damage due to wind erosion in the spring.

Because all the plot area was sprinkler irrigated and furrows were not needed, all the plots were flat-planted and ridges were not used for conventional till. There was no special soil preparation in off years to accommodate the strip tilled beets. At the time of seedbed preparation, N and P fertilizers (as urea and monoammoniun phosphate), based on the soil test results and crop requirement, were applied at 130 kg N ha^{-1} and 105 kg P ha^{-1} to both sets of plots. However, as mentioned, the conventionally tilled plots were broadcast whereas the strip tilled fertilizer was shanked into the tilled strips.

Irrigations for this experiment were applied with a linear sprinkler irrigation system consisting of five 160’ spans. The 56 48’x80’ plots were arranged in an unbalanced stripped block design. There were 32 plots devoted to sugarbeets in 2004; 16 were strip tilled and 16 were conventionally tilled. The remaining 24 plots were planted to barley. In 2005 12 of the plots that had been in barley were strip tilled and the other 12 were conventionally tilled and planted to sugarbeets. Two irrigation treatments (MESA – mid elevation spray application and LEPA – low energy precision application) were superimposed on the tillage treatments. The MESA sprinklers were spaced 10 ft (3.3 m) apart and about 40 inches (1 m) from the ground, while the LEPA heads were 8 inches (20 cm) above the soil surface and 4 feet (1.2 m) apart to place one in every other crop row. Both irrigation treatments delivered the same amount of water.

Sugarbeets (cv. ACH 927 Large bare, American Crystal Co., Eden Prairie, MN) were planted at 55,000 seeds per acre (135,000 seeds ha^{-1}) at a 24 inch (60 cm) row spacing to a depth of 1 inch (2.5 cm). All plots 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, the planting was done with a new John Deere 1700 MaxEmergePlus machine equipped with toothed wheel row cleaners (John Deere, Moline, IL).

Certified malt barley (cv. Tradition, Busch Agricultural Resources, Inc., West Fargo, ND) was seeded at 80 lbs. ac (90 kg ha^{-1}) at a 8 inch (20 cm) row spacing to a depth of about 1.5 inches (3.8 cm) using a small grain drill.

In 2003 (for the 2004 crop year), most of the fertilizer appeared to end up in the bottom of the ripper trench, about 8 inches (20 cm) deep. The fertilizer tube and shoe on the ripper shank were modified in 2004, and most of the fertilizer was placed about three inches below the soil surface although a small amount still ended up at the 8 inch depth.

The barley crops in both years yielded in the range of 100-120 bushel per acre. After combine harvesting, the standing stubble was 6 to 8 inches high. A straw and chaff spreader on combine 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 reside. The net result was that we were working with more trash than many farmers because most growers bale the straw and remove it from the field. Our feelings are that if it will work under these conditions, it should certainly work for those who remove the straw.

Starting in 2003, tillage for both conventional and strip till plots was done in the fall (August) after the barley was harvested. After broadcasting the fertilizer, conventional tillage operations were performed. The sequence of operations in all years consisted of tilling the soil with a ripper (Case IH, Racine, WI) to a depth of 9 inches (23 cm), 2 passes with a 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.

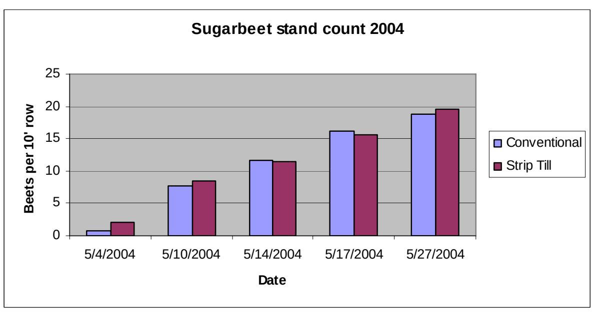
Both strip till and conventional till were cultivated once during the season at about the 6 leaf stage using a high trash cultivator (H&S, Stephen, MN) with rolling disk shields to keep residue and soil off the beet seedlings.

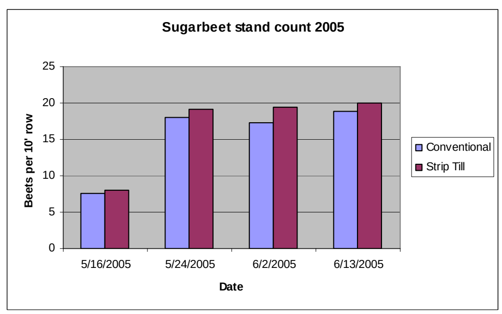
Results and Discussion

In 2004, the conventionally tilled plots averaged 23.23 tons per acre (tpa) (52 metric tons ha^{-1}), 19.83% sugar and 9225 lbs sucrose per acre (10360 kg ha^{-1}). The strip till beet plots averaged 22.95 tpa (51.4 metric tons ha^{-1}), 20.05% sucrose and 9208 lbs (10,342 kg ha^{-1}) sucrose per acre. None of the differences were statistically significant.

In 2005, conventionally tilled beets yielded 9014 lbs sugar per acre (10,124 kg ha^{-1}) with a 19.96% sugar content and 23.1 tpa (51.8 metric tons ha^{-1}), while the strip tilled plots at the same location averaged 10,768 lbs (12,094 kg ha^{-1}) of sugar per acre at 19.93% sugar content and 27.95 tpa (62.6 metric tons ha^{-1})). We believe that the highly significant yield differences were largely due to a severe dust storm in May 2005 that caused substantial damage to the conventional beets while no damage was observed in the adjacent strip tilled plots. This dust storm severely damaged the conventionally tilled beets but they were able to recover without replanting. However, this substantially delayed the development of the conventionally tilled beets leading to the yield decrease.

The research has shown that beets planted in strip till situations have consistently germinated and sprouted earlier than the conventional beets over the last two years, primarily because of higher soil moisture at planting. We have observed that the strip till method has uniform and deeper snow catch and retains more moisture.





Emergence Data for 2004-2005

Wind Erosion. The effectiveness of strip tillage in preventing wind erosion was demonstrated in the spring of 2005. We had 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 strong winds and blowing soil blasted the leaves on the young beets in the conventional plots, but the young beets had no damage and were not affected in the strip till in all four sets of plots. The beets in the strip tilled plots were protected from the blowing soil particles by the strips of standing stubble between rows. Fortunately, cool weather conditions after the wind storm allowed most of the conventional beets to re-grow so we did not have to replant, but it delayed them sufficiently such that there were significant yield differences in the fall. In 2005, the average number of harvestable beets in the conventional till was 14.42 per 10' of row compared to 16.33 in the strip till. This difference was not statistically significant at the .05 level. The average number of beets, including those under 2-1/4" in diameter (our breakpoint for harvestable size) was 18.6 in the conventional till and 20.1 in the strip till, which was significantly different. We are considering a slightly lower planting population for next year to avoid producing so many small beets.

Fertilizer Implications. Fertilizer recommendations currently used for sugarbeets 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 system.

Observation by NPARL scientists have indicated further experimentation with the proper amounts and the depth of fertilizer placement may be required under strip till. Two things were happening: 1) the strip tilled beets grew faster initially, but slowed down part way through the season and yellow up 2-3 weeks earlier; and 2) sucrose percentage under the strip tillage is consistently higher than the conventionally treated plots. Higher sucrose has also been found in other strip tillage experiments on sugarbeets (e.g., Halverson and Hartman, 1984, 1986), which appears to be due to lower soil nitrogen levels at harvest under strip till than in the conventional plots. We hypothesize that this is due to heavier earlier usage by the strip tilled beets because the banded fertilizer is more quickly available and less nitrogen being tied up by the residue. Thus, the strip tilled beets may use up all their nitrogen earlier than the conventional beets. It may also be possible that when the soil warms up, the bacteria that decompose the straw become active and immobilize the soil nitrogen near the surface (Kanal, 1995).

On the other hand, the conventional tilled beets had their fertilizer broadcast and incorporated in the fall. Their small root zones don't have access to all of the nitrogen early, so more is left for later in the season.

These observations suggest that it might be possible to increase nitrogen fertilizer amounts for strip tilled beets to increase tonnage without negatively affecting sucrose content. Research will be started in 2006 to look at ways to better manage nitrogen fertilizer under strip till. We have started fertility rate and timing studies in 2006 on strip tilled beets to help optimize the nutrient applications under overhead irrigation. This may include some liquid fertilizers.

Irrigation. No significant differences were observed between the LEPA and MESA treatments in the two years of the study. There was a low incidence of Cercospora Leaf Spot in 2004 and 2005 compared to the 10 year average. It is possible that with a higher C*ercospora beticula* spore population in the area the LEPA treatment may have a lower infection incidence because the leaf canopy is not sprayed with water at each irrigation. Free water must be present on the leaf surface for the spore to infect the plant (Wolf and Verreet, 2004).

Other Considerations. Strip tillage is not a method to enhance weed control. Weed control programs can'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 trash.

Maintaining standing stubble is desired for wind erosion control and to trap snow in the winter. Standing stubble should be at least 6 inches or higher and needs to be sustained until the beets are sufficiently large to withstand spring wind storms.

Strip till also requires a planter for high residue conditions such as the John Deere MaxEmerge with row cleaners or "trash-whippers" on the front to clear off 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 seeds.

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 its 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 very little straw decomposition prior to planting which would probably make a poorer seed bed.

Because of wheel compaction due to grain harvesting, it would be desirable to strip till at an angle to the direction of the combine travel. Otherwise, tillage in the wheel rows may still have large clods and a potentially poor seedbed.

Surface soil moisture is higher in strip tilled plots compared to adjacent conventional till plots so beets in a dry spring get an earlier start with strip till. This may save an irrigation to get the beets germinated. Even though the moisture may be higher, it is generally more uniform (smaller snow drifts at the field edges) so cultural operations may begin a few days earlier.

There is a lot of grower interest because yields have not been negatively affected by strip tillage. One local grower has used a modified form of strip tillage on 1200 acres in the fall of 2005 using a 12 row strip tiller. About half is furrow irrigated and half under center pivots.

Conclusions and Future Plans

Preliminary results have shown that strip tillage will produce yields comparable to conventionally tilled sugar beets in the Lower Yellowstone River Valley. This technology should also provide substantial savings in fuel and time for local growers.

We are still working to improve the operation of the strip tiller in breaking up heavy soils.

Would like to look at the application of liquid fertilizers to improve distribution and reduce losses.

We are primarily focused on sprinkler irrigation where extra leveling and bedding would not be required. However, the technique 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 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. (Berg, R.D., 1984; Brown, M.J. and W.D. Kemper, 1987; Lentz, R.D. and D.I. Bjorneberg, 2003)

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