Furrow Irrigation in Strip Tilled Sugarbeet

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INTRODUCTION

The adoption of reduced tillage practices in sugarbeet growing areas has been slow for several reasons. An issue of primary concern in irrigated areas is the effect of residue on the flow of water in the furrow. According to one source, (http://soilhealth.net/cons-tillage-furrow/) "In the western U.S. one of the most significant stumbling blocks to using soil health building practices (or tools) is the dependence on furrow irrigation." An investigation in eastern Washington (Anderson et al., 1982) detailed the performance of different designs of furrow formers under minimum tillage conditions. Several of the evaluations mentioned plugging as a serious problem. The furrow former used for this study is different from any of these previous designs.

Surface irrigation is still used for approximately 65% of the irrigated crop production in Montana and Wyoming (http://pubs.usgs.gov/circ/1405/pdf/circ1405.pdf and 42% nationwide (Maupin et al., 2014). Crop residue can interfere with the small streams of water flowing between crop rows, so farmers have relied on extensive tillage to eliminate residue on the soil surface. This practice reduces problems with irrigation, but leaves the soil vulnerable to wind erosion. Strip tillage (ST) has been shown to reduce wind erosion and produce yields comparable to conventional tillage (CT) under sprinkler irrigation (Evans and Iversen, 2005). The objective of this study was to evaluate whether or not furrow irrigation could be practiced in sugarbeet planted in ST barley stubble.

MATERIALS AND METHODS

Field Description & Experimental Design

A study was conducted in a section of a field offered by a local producer located about 4 km (2.5 miles) south of Sidney, MT, USA 47.671° N, 104.193° W, elevation 600 m (1969 ft). The soil was mapped as a Savage silty clay loam (fine, smectitic, frigid Vertic Argiustolls), a relatively heavy soil with 210, 460 330 g kg^{-1}, respectively, of sand, silt and clay. It is one of the predominant irrigated soil series in the lower Yellowstone River valley. The study area (Fig. 1) was marked out using a randomized complete block design with 4 replications of ST and CT. The entire length of the field of 400 m (1312 ft) and a width of 58.5 m (192 ft). A 30 m (96 ft) border of conventionally tilled sugarbeet managed by the grower was on both sides of the study area. The field had been leveled many years ago, and the slope was a consistent 0.25 % when measured with a real time kinematic (RTK) GPS. For the 366 m (1200 ft) length of the field in the direction of irrigation (excluding the elevated ditch pad on the headland and the area near the drain at the lower end) this gave a drop of about 0.912 m (3 ft).

Barley had been planted in the field in 2009. After the barley was harvested, the straw was baled and removed.

Soil Measurements

Soil samples were taken at 15 locations to a depth of 1.2 m (4 ft) and analyzed for N, P and K to determine fertilizer application rates. Soil electrical conductivity (EC) was mapped on 31 August 2009 using a coulter electrode machine (Veris 3100; Veris Technologies. 2002) coupled with an RTK GPS (Trimble, Sunnyvale CA). The upper end of the field showed a lower

EC than the lower end, but the difference was present in all treatments in about the same amount. (Fig. 2)

Soil penetration resistance (PR) measurements were taken on 11 September 2009 using a Veris Profiler 3000 machine (Veris Technologies. 2002) (Sudduth et al., 2004). Soil PR measurements were taken across the width of the field about 0.8 m (2.5 ft) apart at 5 transect locations 76 m (250 ft) apart. The average PR values were 0.41, 1.76, 2.31, 2.15 and 1.99 M pa (60, 255, 335, 313 and 288 psi) at the 6, 10, 16, 22 and 26 cm (2, 4, 6, 8 and 10 in) depth. From the peak value at the 16 cm depth the PR gradually decreased to 1.34 M pa (194 psi) at the 66 cm (26 in) depth and then gradually increased to 1.55 M pa (225 psi) at 98 cm (39 in), the terminal depth of the probe.

Agronomic Practices

The field outside the study area was disk-ripped on 9 Sept 2009 by the grower. The ST treatment within the study area was performed on 18 Sept 2009. The ST machine was a six row unit with 61 cm (24 in) row spacing (Schlagel Mfg., Torrington WY) and 2 separate fertilizer boxes (Fabro Enterprises Limited, Swift Current, SK Canada). The machine is described in detail by Evans et al., 2009.

The residual nitrate-N amounts from the soil test were 42.6 and 12.8 kg ha^{-1} at 0 - 0.61 and 0.61-1.22 m (38 lb $acre^{-1}$ and 11.4 lb $acre^{-1}$ at 0-24 and 24-48 in) depths, respectively. Urea and monoammonium phosphate were applied with the strip tiller at 245 and 173 kg ha^{-1} (219 and 154 lb $acre^{-1}$), respectively. The sum of N available from the residual in the soil and the fertilizer was 185 kg ha^{-1} (165 lb $acre^{-1}$).

The same amount of fertilizer was broadcast on the plots that would be conventionally tilled on 28 September 2009. Conventional tillage operations were performed immediately after broadcasting the fertilizer, and consisted of tilling the soil with a disk (John Deere, Moline, IL) at a 10-cm depth (4 in) and then a ripper (Case IH, Racine, WI) to a depth of about 23 cm (9 in), 2 passes with a rolling mulcher (Brillion Inc., Brillion, WI), and 2 passes with a leveler (Eversman, Denver, CO). The soil was very hard and chunky because it had been quite wet during the barley harvest and the harvest equipment had caused significant compaction. The area on either side of the study area was disk ripped, mulched, leveled and fall ridged by the grower.

The sugarbeet crop (var. ACH Crystal RR156, American Crystal Sugar Company, Moorhead, MN) was planted at a depth of 3.18 cm (1 ¼ in) on 22 April 2010. The row spacing was 61 cm (24 in) and spacing between the seeds in the row was 13 cm (5 $^{1}/_{8}$ in) which equates to a seeding rate of 126,017 seeds ha^{-1} (50,997 seeds $acre^{-1}$). Stand counts were performed on 12 May 2010.

The field was sprayed on 24 June 2010. A record was kept of which inter-rows (the space between the sugarbeet rows where the furrows will be formed) had wheel tracks from the planting and spraying operations and which ones were not packed with the tractor wheel. The grower’s normal practice was to pack the rows with a tractor with duals, straddling 3 rows. This was done on the study area as well, but the operator wasn’t consistent so the pattern was variable. It must also be understood that all rows were not compacted equally, as a trip across the field at planting with the tractor carrying a mounted implement and single tires with moist soil conditions made those wheel track rows much firmer than a tractor equipped with duals and no implement attached passing over the field with drier soil conditions. The rows that are listed as compacted were verified by looking at the wheel tracks. We used 6 row equipment, with the tractor tread width at 244 cm (96 in) straddling four 61-cm (24-in) rows for the strip tilling, planting and ditching.

Ditching

The spring was wetter than normal so the field was ditched on 02 July 2010, which is a little later than average. The beet canopy was nearly covering the row and the soil was still moist enough to form a ball in the hand. The ditcher used to form the furrows was one specifically made for high residue conditions by Schlagel Manufacturing (Torrington WY). Each of the rows had two ditchers to make the furrow. The function of the first one was to roll the residue out of the way and cover it with a bit of soil, and the one following close behind it dug the furrow deeper and covered the residue with more soil. The leading point of the second ditcher is actually inside of the wings of the first ditcher so the soil does not have the chance to fall back into the furrow at normal field speeds (Fig. 3). The ditchers were adjustable in width, angle of attack and depth. It was readily apparent which rows were in the wheel tracks and which ones were not as the soil was quite hard in the wheel tracks and was scraped smooth by the ditchers (Fig. 4).

Residue Measurements

Crop residue cover samples were taken before and after the ditching operation. The residue density was based on two 0.1 m^2 samples per plot. The average residue per hectare in the CT was 150 kg ha^{-1} (134 lb $acre^{-1}$) before ditching and 0.00 after ditching. The residue cover in the ST was 2150 kg ha^{-1} (1918 lb $acre^{-1}$) before and 420 kg ha^{-1} (375 lb $acre^{-1}$) after ditching. The percent cover by the transect line method (Sloneker and Moldenhaur, 1977) was 8.00 and 1.63 for the CT before and after and 40.38 and 13.88 for the ST before and after ditching, respectively.

Prior to the first irrigation on 13 July 2010, Gen II advance / recession timers (Hunsaker et al., 2011) were installed halfway down the field and at the lower end of the field in 32 of the 48 rows in the first and second replications. These field probes were equipped with a programmable microcontroller, a 16 character x 1 line display and an optical sensor that recorded the time when the water reached the sensor and when the water receded below the detection level of the sensor. The sensors were mounted on the bottom of a length of plastic pipe and the loggers were on the top just above the crop canopy (Fig. 5). A steel rod was driven into the soil in the center of the furrow and the instrument was strapped to the vertical rod. Figure 5 shows the relative locations of sensors and flumes in the first two replications.

Powlus 60° V-notch furrow flumes (Trout, 1996) (Honkers Supreme, Twin Falls Idaho, USA) (http://www.ars.usda.gov/SP2UserFiles/Place/20540000/files/powlus-v-furrow-flumes.pdf) to measure the flow in individual rows were installed at the upper and lower end of the field. These flumes satisfy the hydraulic requirements for long-throated flumes (Bos et al., 1991) and were used rather than the more common Parshall flume because the inlet and outlet are at the same elevation, so it isn't necessary to accommodate an elevation change. The shallow furrows make it impossible to back the water up to create much rise upstream of the flume without the water overflowing the furrow. They are also pre-calibrated and direct reading (Fig. 6).

Runoff, Soil Moisture Content, and Irrigation Measurements

Collection jars were used to collect a liter of runoff water from the flumes. Imhoff settling cones (Sojka et al., 1992) (http://www.capitolscientific.com/Nalgene-1000-0010-Imhoff-Settling-Cone-For-Sediment-Testing-Polycarbonate-1000mL-Thermo-Scienti) were positioned in racks at the lower end of the field so runoff samples from the flumes could be poured into the cones and analyzed for sediment (fig. 5).

Soil Moisture and Furrow Profile Measurements

Soil moisture measurements were taken with a calibrated neutron probe at the 23, 46, 61, 76, 91 and 107 cm depths (9, 18 24, 30, 36 and 42 in). Furrow profiles were measured at the upper and lower ends of the field before and after irrigation. A mechanical contour gauge was constructed (a device similar to a carpenter's contour gauge used to transfer irregular contours such as those found on decorative moldings but much larger) (Fig. 7) that had 57 pins which were spaced 1.115 cm (0.439 in) apart. This device is sometimes referred to as a "rillmeter" (Carollo et al., 2015). The contour gauge was placed perpendicular to the furrow and the pins were allowed to drop to the soil surface. The set screws were tightened on each pin and the unit was removed from the furrow. The projection of each pin was measured and recorded.

Irrigation

The field was irrigated from an open ditch using 5.08 cm (2 in) diameter 183 cm (72 in) long aluminum siphon tubes. After the tubes were set in all of the rows for replications 1 and 2 and the water level in the ditch had stabilized, the tube's discharge end was adjusted to obtain a net head of 14.61 cm (5.75 in) from the top of the tube to the surface of the water in the ditch. This was measured using a carpenter's level with a scale mounted perpendicular to it at each end. Flow rates were measured in 8 of the furrows using the flumes, which averaged 102.86 L min^{-1} (27.17 gallons min^{-1}) at the beginning of the set and 105 L min^{-1} (27.73 gallons min^{-1}) when the set was pulled.

The length of time the first irrigation lasted was determined by the grower's usual schedule for the field of a 12 h set time. After the first set of the first irrigation, the water was returned to the grower's part of the field for the night set. Early the next morning, replications 3 and 4 were irrigated.

After the measurements were taken from the first irrigation, we suggested a much shorter set time for the next irrigation which was readily accepted. This allowed for a more efficient irrigation and less deep percolation loss and it enabled us to get all of the replications irrigated in the same day.

Disease Evaluation

Midway through the season, a number of rotten beets were noticed. Casual observation appeared to indicate that there were more rotten beets in the ST than in the CT. A more rigorous evaluation was undertaken. Seven transects were laid out across all 4 replications in the study area and also in the adjacent field that the grower had fall ridged. All of the rotten beets in any row within 5' of either side of the transect center were counted. The total number of rotten beets from all transects was 126, 172, 172 in the CT, ST and fall ridged treatments, respectively. A common cause of rot in sugarbeet is the fungi *rhizoctonia solani* and *rhizonctonia crocorum.* The "Compendium of Beet Diseases and Insects" (The American Phytopathological Society ©1986) states that for *R. solani* "Recommended control measures include tillage and fertilizing that promote good crop growth and adequate soil drainage; crop rotation with corn or small grains; avoidance of hilling-up of plants with cultivation soil; and control of weed hosts, such as pigweed, *Amaranthus retroflexus* L." p21 and for *R. crocorum* "The following control measures have been recommended: crop rotation…soil aeration…" p 23. During the ditching operation a considerable amount of soil was pushed into contact with the crown of the beet which can cause infection of the beet. The beets in the strip tilled plots were planted into undisturbed soil, and because this was the first year of these strips, they were not well aerated. It is of interest that the ST plots were no different in the numbers of rotten beets than the control on either side of the study area which was disk ripped, mulched, leveled and fall ridged. The CT in our study area was handled the same except that, lacking a disk ripper, we disked in one operation and ripped in another and it was left flat and not fall ridged.

RESULTS AND DISCUSSION

Irrigation

Advance Times

Both treatments of the study area were successfully irrigated on 14 Jul 2010 and 2 Aug 2010. The average time from the start of the first irrigation to the time the water arrived at the mid field sensors in the un-compacted rows was 149 (std dev 40) minutes in the CT and 140 (std dev 23) minutes for the ST. The compacted rows showed a smaller difference between tillage treatments, with the water progressing to midfield at virtually exactly the same time in both treatments. The sensors recorded an advance time of 123.62 minutes in the compacted CT rows and 123.33 minutes in the ST rows, with standard deviations of 18 and 29, respectively. The advance times for the individual rows that were monitored during the first irrigation are shown in fig. 8 and for the second irrigation in fig. 9. Other studies have shown that irrigation water advance times may be longer or shorter in minimum till scenarios when compared to CT due to residue dams, field slope, surface compaction and soil moisture loss to tillage operations (Wardle et al., 2015).

The averages by tillage treatment and row compaction are shown in fig. 10. The error bars are 2 standard errors of the mean and show there is no significant difference between any of the treatments. The time intervals for the water to run the full length of the field in the un-compacted rows were 356 minutes for the CT and 404 minutes for the ST. For the compacted rows, the average time in minutes for the ST was 394 and 380 for the CT.

An examination of the water advance times clearly shows that the water had no trouble advancing to the end of the field. The only concession made for ST was that the pieces of straw that would gather in front of the midfield furrow advance sensors were periodically removed. Placing obstructions in the middle of the furrow is not a practice a commercial grower would do, so we felt this was justifiable. We did not observe any other cases of the residue blocking the flow. While there definitely was some straw present in the stream, it was present in small amounts and it seemed to stay on top of the water (Fig. 11).

Outflow Rates

The initial inflow rate per furrow as measured by the flumes averaged 106.59 L min^{-1} (28.16 gal min^{-1}) and remained virtually the same until the end of the set at 107.75 L min^{-1} (28.46 gal min^{-1}). Debris in the supply ditch was a problem, and the siphon tubes were checked and the bits of debris that collected at the suction end were removed frequently to keep the flow rate as uniform as possible. The outflow rates at the end of the field were measured at 5, 10, 30, 60, 90, 120, 150 and 360 minutes after the water arrived at the lower end of the field in each furrow. The data from the 120, 150 and 360 minute readings at the first irrigation are not presented here, as the drain ditch in the field was nearly flat and as nearly all of the rows discharged water into the drain, the water level in the drain rose to the output end of some of the flumes affecting their accuracy. It has also been reported (Trout, 1996) that flow rates usually reached a steady state value within an hour after a flow reached a measurement location. Not all of the rows reached the end 150 minutes before the end of the sample set, which also reduced the sample size. Data from the 5 to 90 minute outflows are presented in fig. 12. The charts in Fig. 12 have error bars showing plus or minus two standard errors of the mean values for the ST compacted and CT compacted data series. These two series represent the extremes at the 90 minute recording time and it can be seen that the error bars do still overlap. While the difference may not be statistically significant at this replication level, the trend with the ST having lower outflow rates stayed consistent for both irrigation events and all recording time intervals. It was observed during the irrigation that the ST compacted furrows had large cracks, and that the water would flow through the cracks into the adjacent furrows. The water would not flow over the top of the furrow walls, but through these subterranean cracks. This soil cracks extensively when it dries (Abou-Najm et al., 2010). If the soil was wetter in the ST when the ditching operation took place the compaction and subsequent cracking may have been worse in that treatment. It has often been our experience in planting the two treatments that the soil in the CT will be dry enough to plant into but the ST soil will still be too wet. Unfortunately, we did not do a moisture sample prior to the ditching operation. The gravimetric samples were not taken until 10 days after ditching on 12 July 2010 at 10 cm (4 in) and results did not show any significant difference between the two treatments, nor did the neutron probe readings on that same date at 23 or 46 cm (9 or 18 in) depths.

Irrigation Efficiency

The irrigation efficiency was calculated by how much water was added to the root zone, which was defined as 0 - 1 m (3.3 ft) for this study. The set time for the first set was 12.3 h, and was determined by the grower's normal practice. The inflow rate from the siphon tube to the furrow was 107 L min^{-1}/m (28.26 gpm). Forty seven tubes were set at a time, so the rate of water delivery to the field was 5028 L min^{-1} (1328 gpm). For the full set time a total or 3711 m^3 (980,448 gal) was delivered to the 47 rows which consisted of 2 of the 4 replications. The area of one set was 3.24 ha (8.0 ac), so 3,172 m^{3}ha^{-1} (339,084 gallons ac^{-1}) was applied for a gross application depth of 31.7 cm (12.5 in). The average outflow 60 min after the water reached the end of the field was 10 L min^{-1} (27.5 gpm). This value for the fourth reading of the outflow was used as the average for the flow rate from the time the water reached the end of the field to the time the water was shut off. The average amount of time from the first outflow until the set was pulled was 316 minutes. The product of these values was 408.4 m^3 (107,895 gallons) that ran down the drain, leaving 3303 m^3 (872,552 gallons) on the field area. This equates to an application depth of 282 mm (11.1 in) of water. The percentage of water that stayed on the field area was 89%, which for surface irrigation is quite good. The calibrated neutron probe values for soil moisture before the irrigation were 0.295 m^3 m^{-3} and 0.362 m^3 m^{-3} after irrigation for an increase of 0.067 m^3 m^{-3} or 81 mm (3.2 in) of water for the 0-1200 mm (4 ft) depth. Dividing this value of beneficially applied water by the gross application, the actual efficiency drops to 25.72%. Figure 13 shows the relative values of the amount of runoff, net added water in the root zone and deep percolation loss below 1 m (40 in).

After presenting these values to the grower it was mutually agreed that we could shorten our set times for the second irrigation. The second irrigation was performed on 2 Aug 2010 per the grower's request. About 40 mm (1.56 in) of rain had fallen since the first irrigation, so the soil was still well above the maximum allowable depletion. Neutron probe readings before the irrigation showed 0.370 m^3 m^{-3} before the irrigation and 0.395 m^3 m^{-3} after the irrigation. So even with a much shorter set time of 5.1 hr, the efficiency was only 13.56% due largely to the deep percolation loss of 86 mm (3.4 in) of water due to the soil already being near field capacity.

Recession Times

The time interval from when the siphon tube delivering water to the furrow is pulled to when the water actually stops flowing at a given point is called recession time. This was measured both at the middle of the field and at the lower end. The charts summarizing the results are in Fig. 14. The results from one row in each irrigation were deleted as the recession time for them was nearly 9 times the next highest value; 414 minutes compared to the next highest value of 57 minutes for the first irrigation and 607 versus 69 minutes in the second irrigation. These anomalies were thought to be the result of bits of debris occluding the optical sensor or the sensor being placed a bit below the soil surface so the water actually ponded in the plastic tee and had little contact area with the surrounding soil. The affected treatment occurred in the ST un-compacted treatment both times. The omission of these rows left six monitored rows out of seven for that treatment.

It is interesting to note that the recession time during the first irrigation for the ST-Compacted treatment was more rapid than the other treatments. In the discussion of outflows, it was noted that this treatment saw lower outflows than the others, so it would follow that the water is soaking in more quickly. The recession times would appear to corroborate that. Another interesting observation is that there is less variability in the ST treatments, both compacted and un-compacted in the first irrigation. In field, observers noted that the straw present in the ST treatment, even though mostly covered by soil, provided conduits for quick water infiltration where it poked though the soil surface. This was not evident in the second irrigation after the soil had been settled by the first irrigation and a film of silt was deposited by the muddy irrigation water sourced from the lower Yellowstone River.

Furrow Profiles

The cross sectional views or profiles of the furrows by tillage treatment and irrigation are shown in Fig. 15. This chart shows the average of the profiles taken at the top and bottom of the field in both tillage treatments prior to and after the first irrigation. It appears that after the irrigation there is some smoothing of the furrow but no significant differences are apparent. Figure 16 shows the high portions of the furrow shoulders to be slightly higher after the irrigation than the profile taken before. This is most likely due to the limitations of using the contour gauge without precise benchmarks so that the values shown are not actual elevations but relative values. The end pins were adjusted to about 2.5 cm (1 in) below the zero mark and were set in the crop row where the soil was undisturbed by the ditching operation. The soil swelled after the irrigation as well as settled in the furrow so even though the furrow is more rounded after irrigation, its actual elevation may be as low as prior to the irrigation. From this experience it is recommended that steel benchmark pins would be used for future measurements.

In Figure 16, the profiles are split by whether the furrow was compacted or un-compacted. There was a noticeable difference between the before and after irrigation in the un-compacted furrows and very little change in the compacted furrow. This would be expected as the loose soil in the un-compacted rows is more easily redistributed by the flowing water. The observed 2 cm difference is not enough to appreciably affect the next irrigation.

Yield

There were no significant differences in yield or quality. The CT yielded 65.2 Mg ha-1 (29.1 tons acre^{-1}) and the strip till 62.3 Mg ha-1 (28.0 tons acre^{-1}). The sucrose content was 16.46% in the CT and 16.41% in ST.

CONCLUSION

There were no problems irrigating either the ST or CT plots at the field scale. The amount of time the water took to reach the end of the furrow was not appreciably different between treatments. There was slightly less variability in advance and recession times in the ST than the CT. Shorter set times and allowing the soil moisture to deplete to a lower level between irrigations would increase irrigation efficiency by reducing deep percolation loss.

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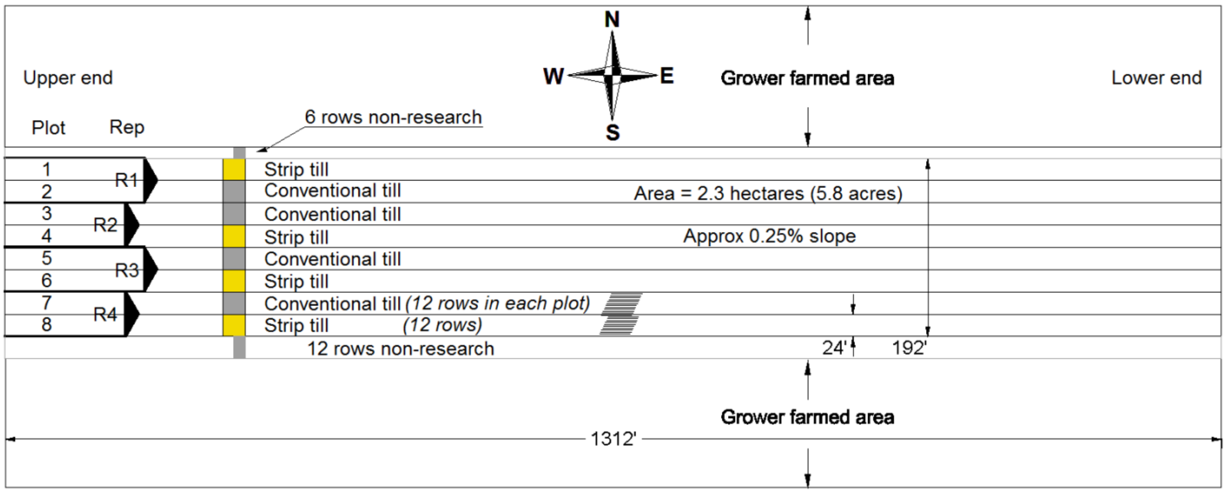


Figure 1. Experimental design and dimensions of study area.

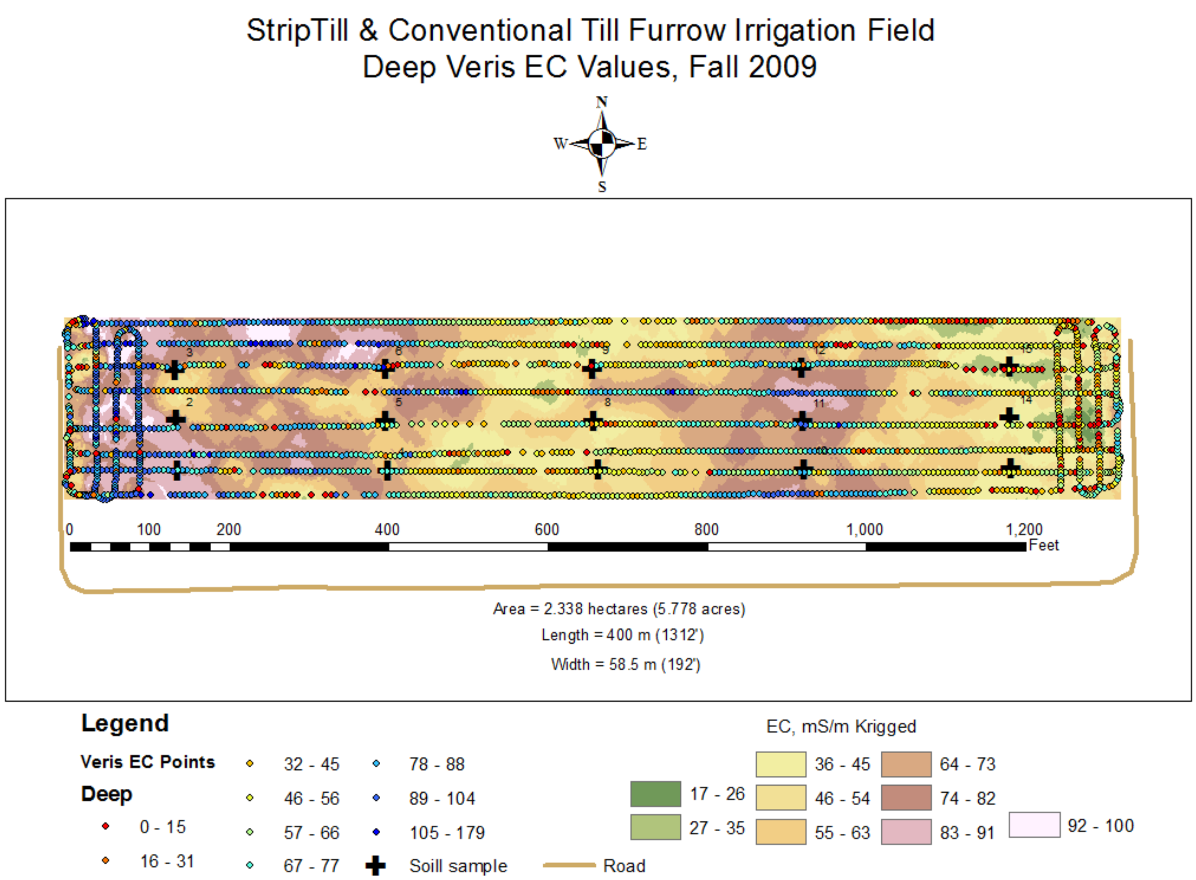


Figure 2. Electrical conductivity map and soil sample locations.

Figure 3. Double ditcher arrangement, side view and top view.

Figure 4. Furrow comparison between compacted row (left) and uncompacted (center).

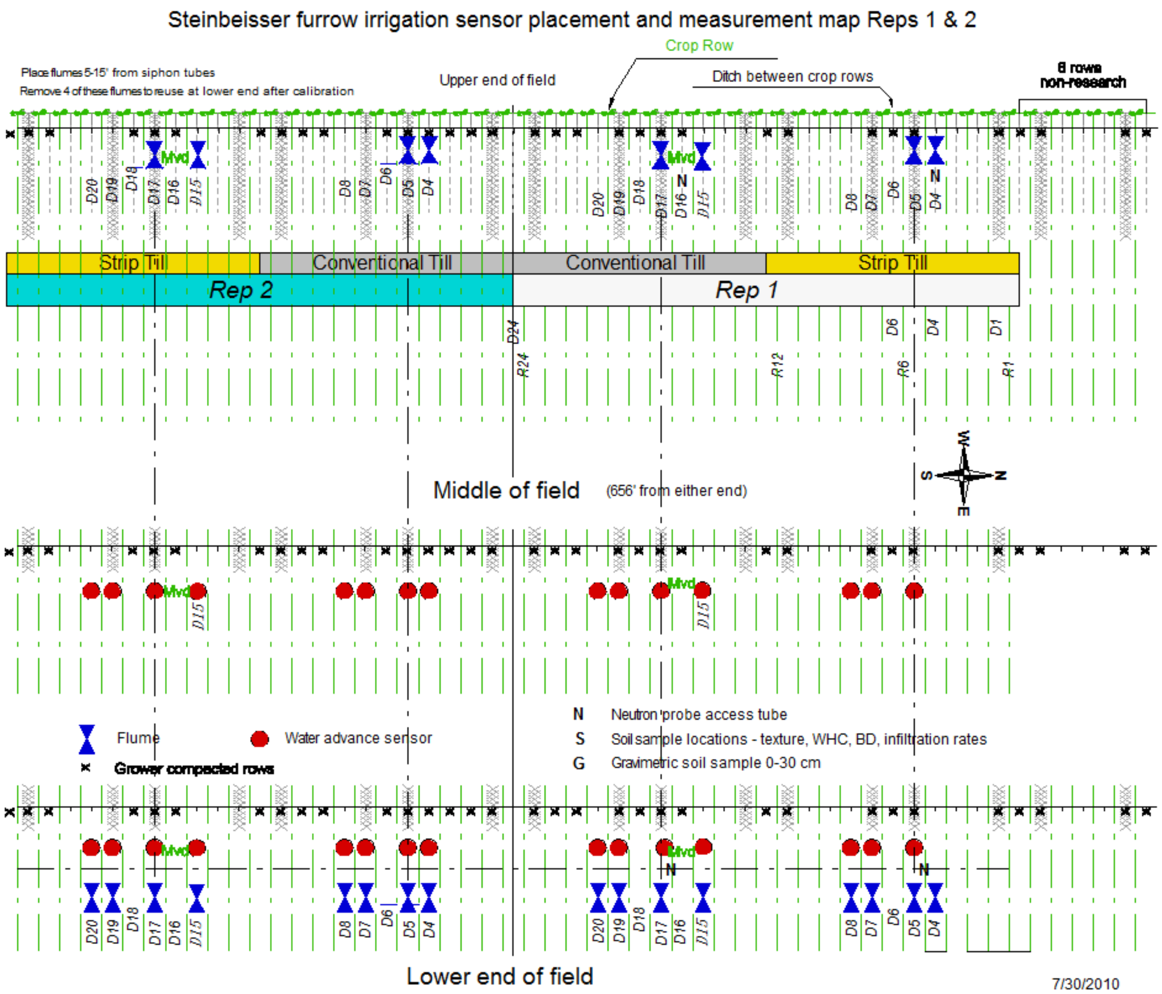


Figure 5. Plot, flume, and measurement locations for replications 1 and 2.

Figure 5. Advance timers, flumes and Imhoff cone at the lower end of the field.

Figure 6. Powlus 60° V-notch flume.

Figure 7. Contour gauge measuring furrow profile.

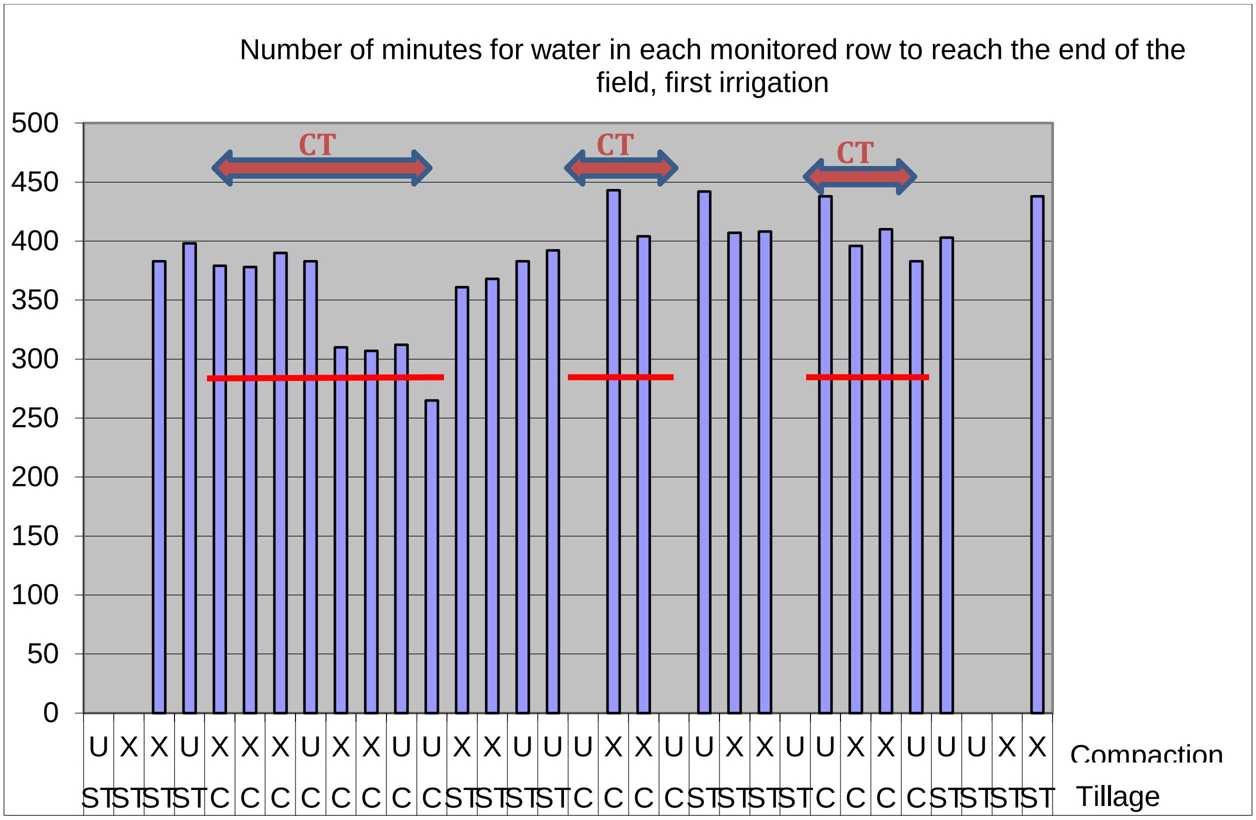


Figure 8. Minutes to reach the end of the field, first irrigation. X=compacted row.

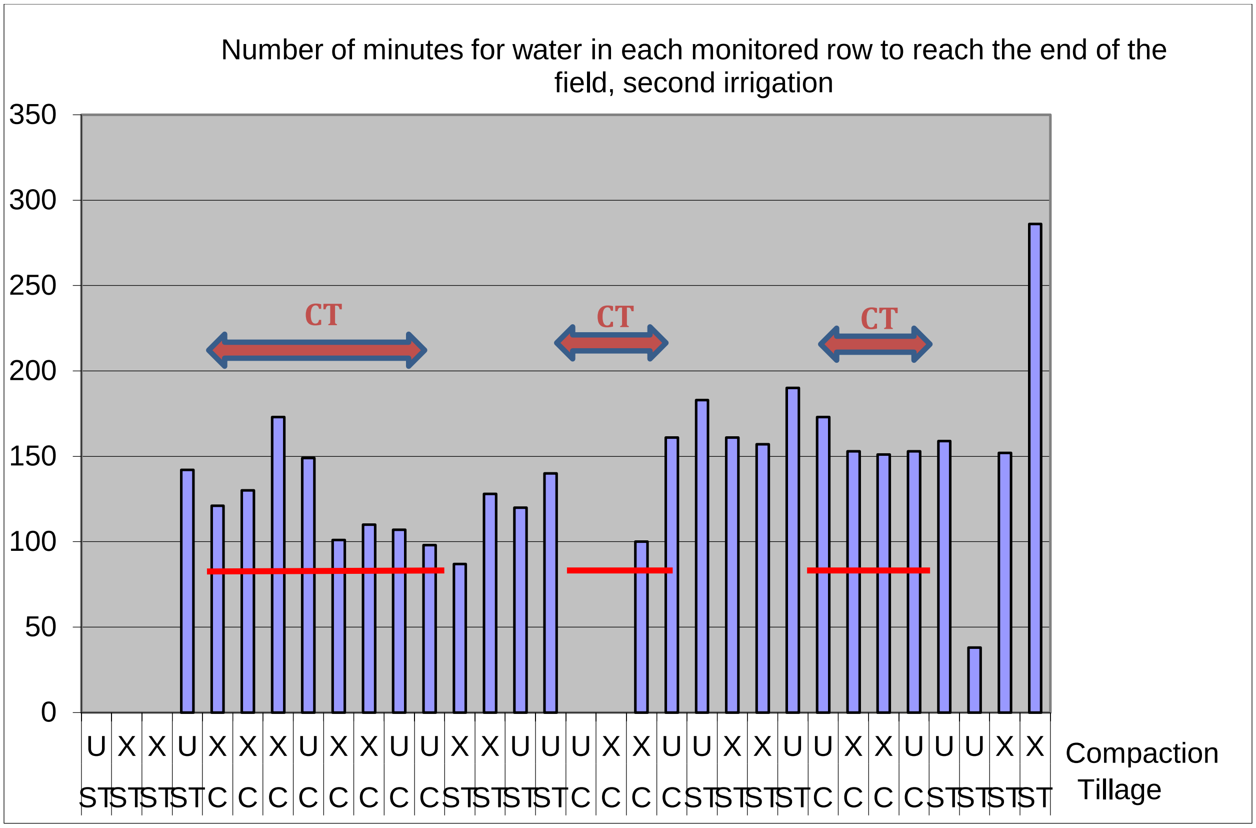


Figure 9. Minutes to reach the end of the field, second irrigation. X=compacted row.

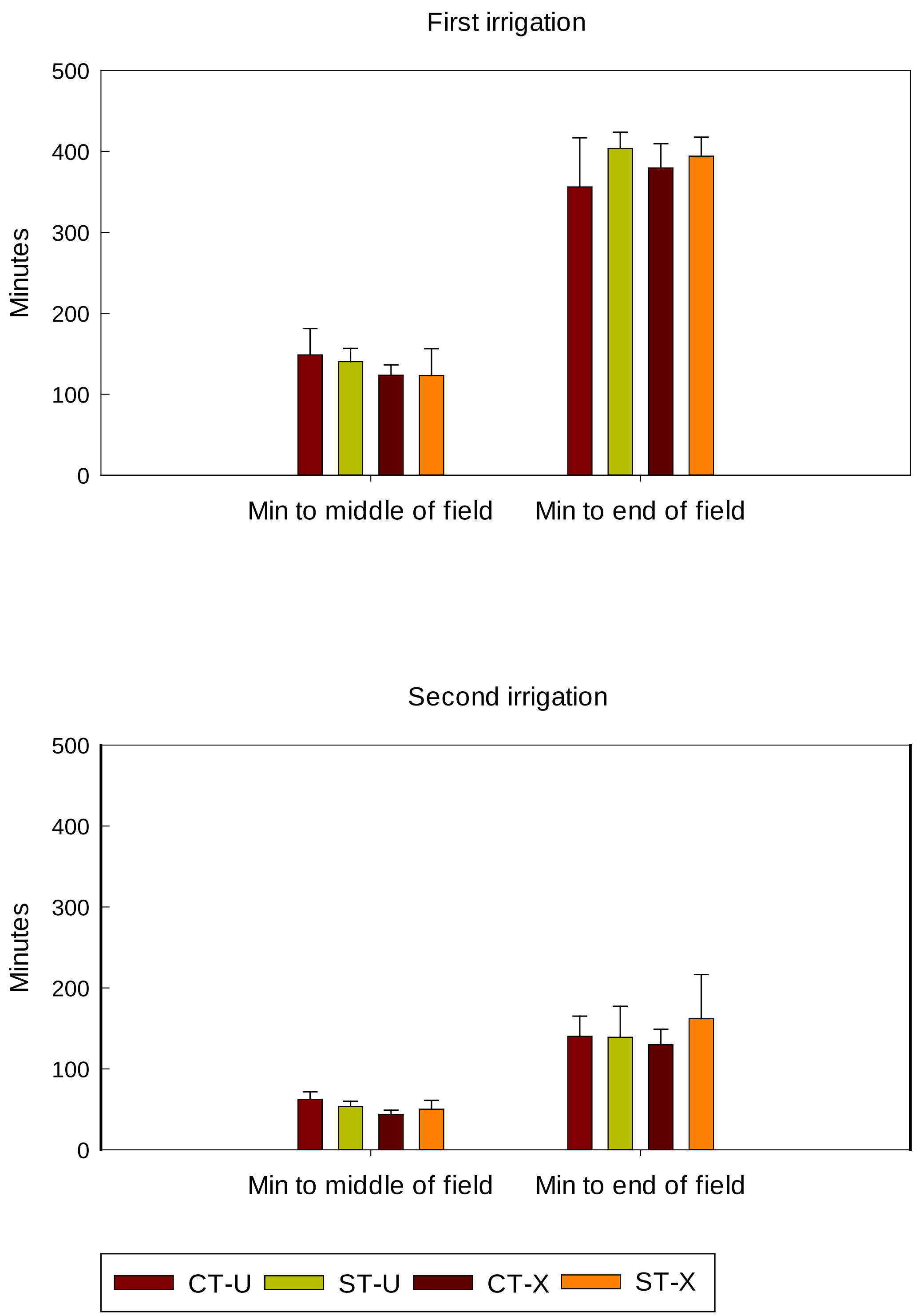


Figure 10. Water advance times to the middle and end of the field, first and second irrigations where conventional tillage (CT) or strip tillage (ST) practices were used. Within each tillage treatments rows were either compacted (X) or unaffected (U) by wheel traffic.

Figure 11. Residue on top of the water in the furrow in strip till plot.

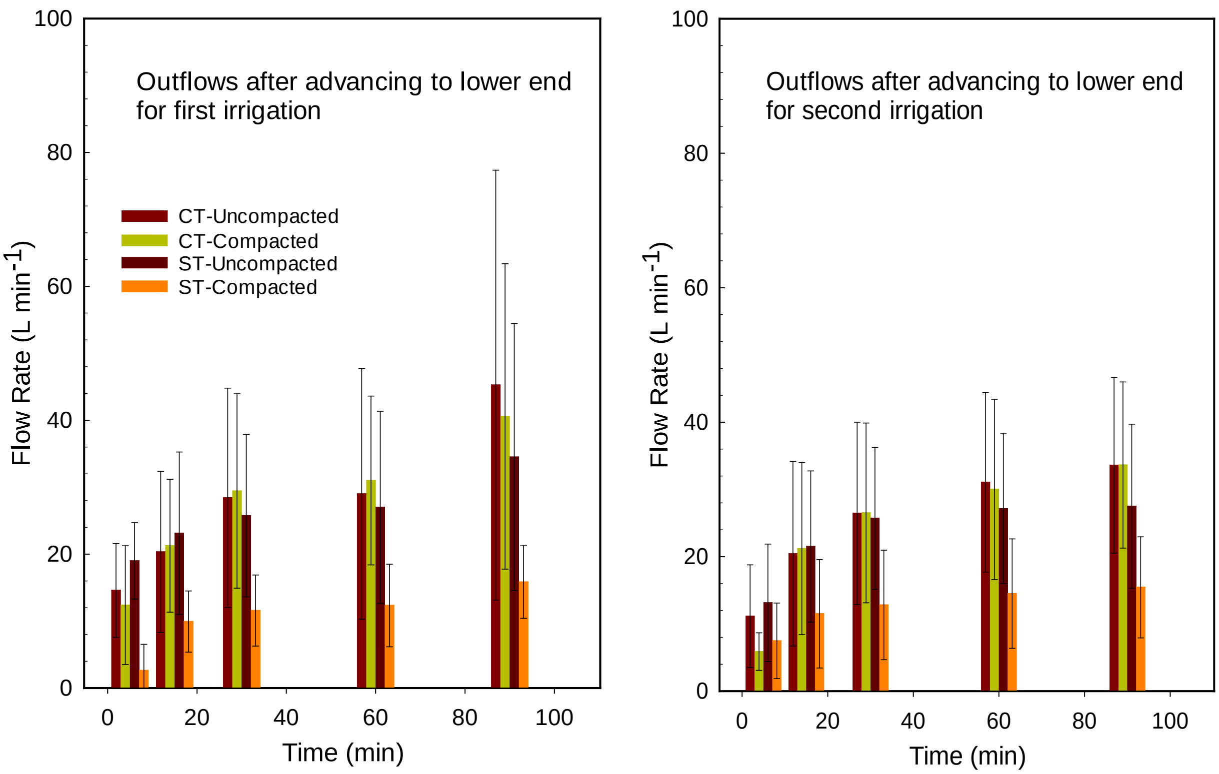


Figure 12. Outflow rates for first and second irrigations in furrows within conventional (CT) and strip tillage (ST) treatments.

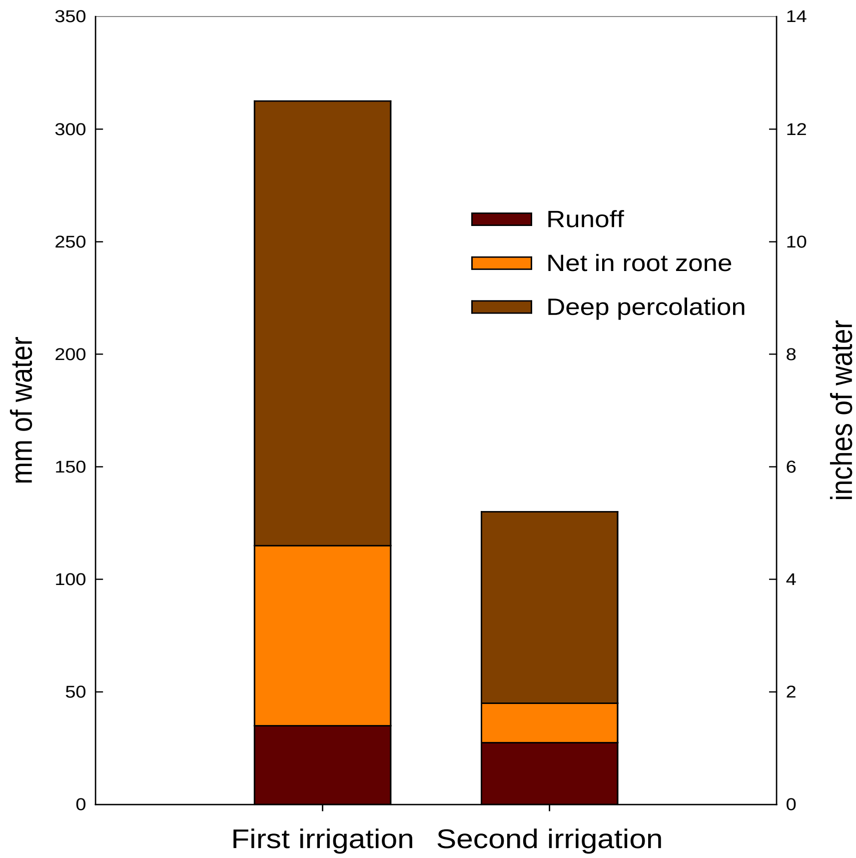


Figure 13. Runoff, net irrigation and deep percolation

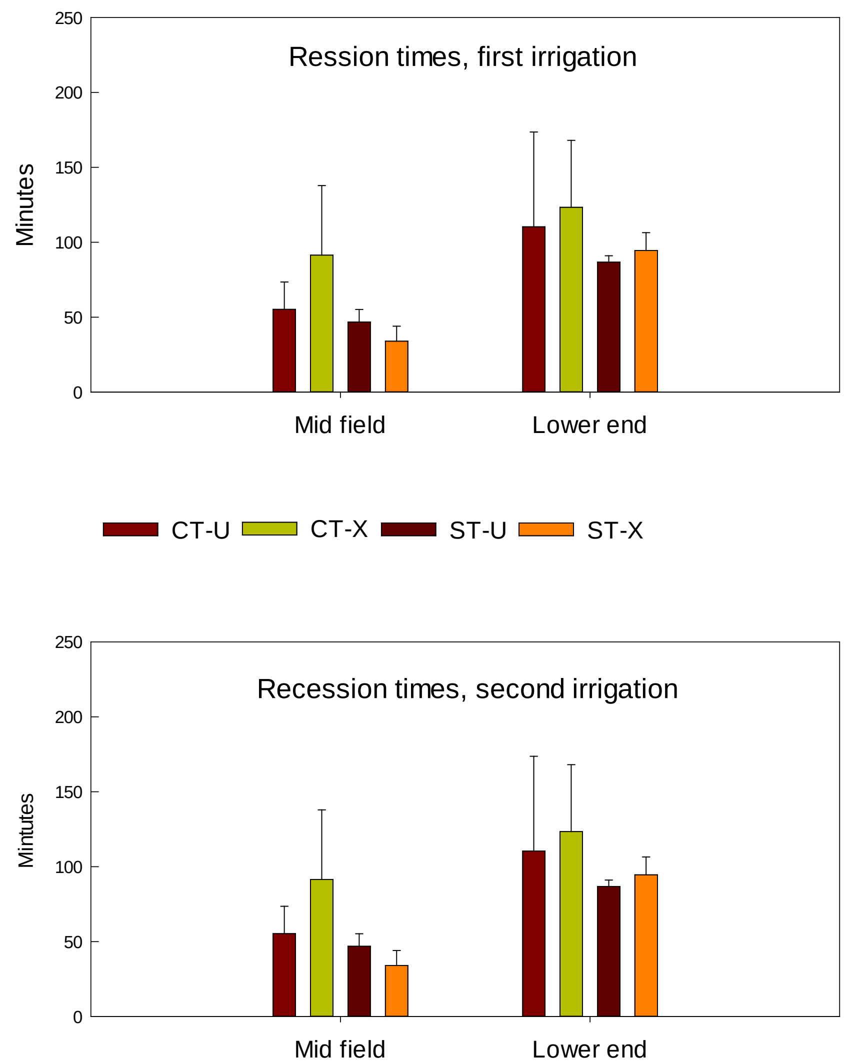


Figure 14. Recession times by treatment at mid field and the lower end of the field where conventional tillage (CT) or strip tillage (ST) practices were used. Within each tillage treatments rows were either compacted (X) or unaffected (U) by wheel traffic.

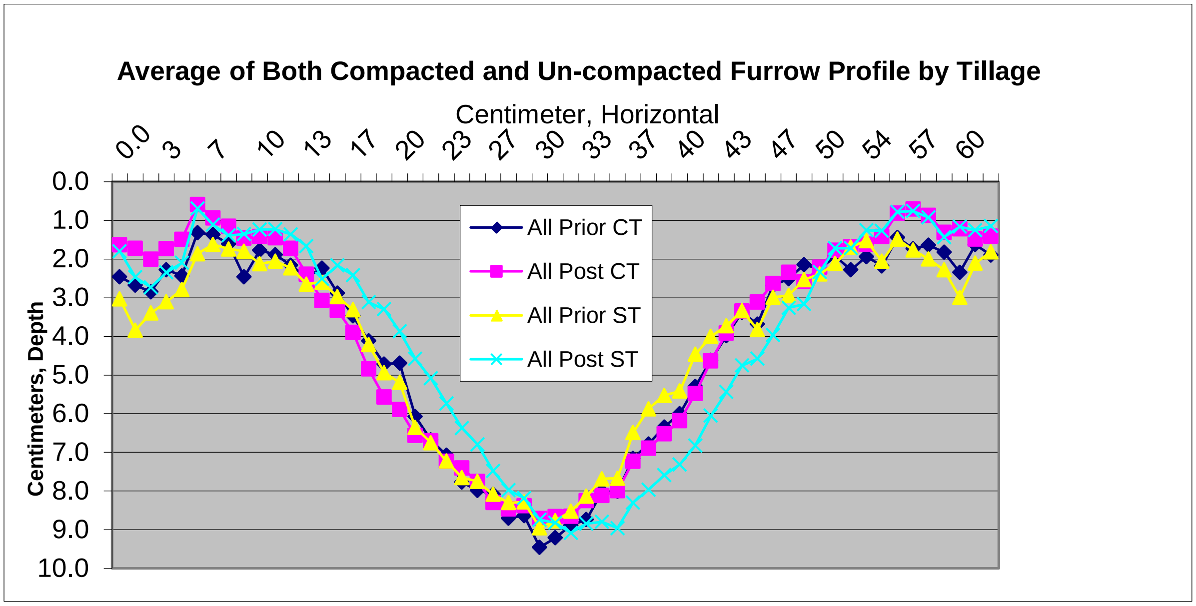
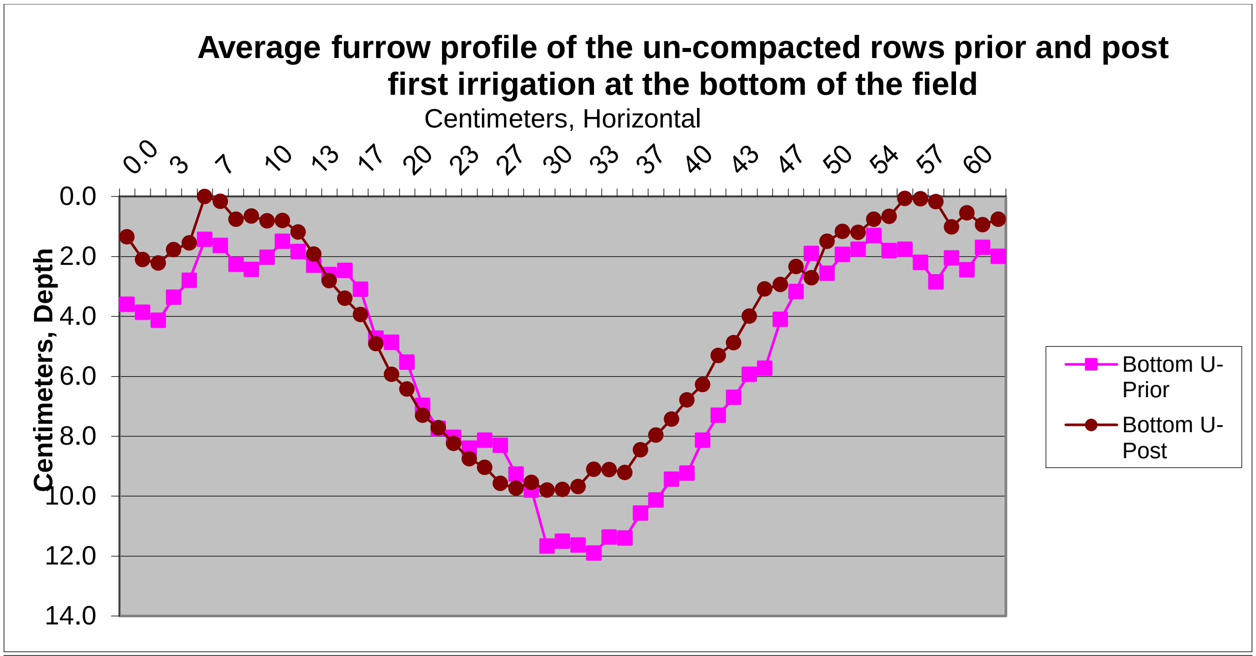


Figure 15. Furrow profiles before and after the first irrigation by tillage. CT, conventional tillage; ST, strip tillage.



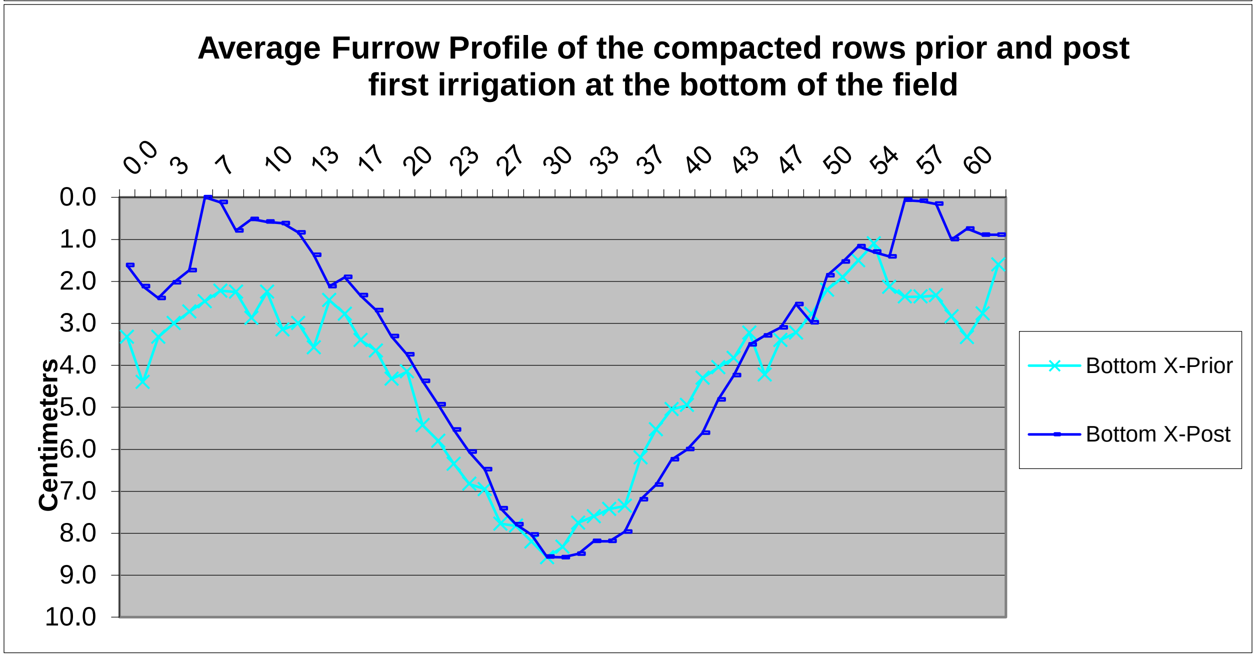


Figure 16. Furrow profiles by compaction. X, compacted row; U, uncompacted row.