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Effect of Crop Residue on Soil Water Content and Yield of Deficit-Irrigated Corn and Soybean

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Abstract. *It is believed that reduced tillage, with more crop residue on the soil surface, conserves water, especially in arid and semi-arid climates. However, the magnitude of water conservation is not clear. In 2007, a study was initiated on the effect of residue on soil water content and crop yield at North Platte, Nebraska. The experiment was conducted on plots planted to field corn (Zea mays L.) in 2007 and 2008, and soybean (Glycine max) in 2009. There were two treatments: residue-covered soil and bare soil. Bare-soil plots were created in April 2007 by using a dethatcher and subsequent hand-raking. In April 2008 and 2009, bare-soil plots were recreated on the same plots as in 2007. The experiment consisted of eight plots (two treatments with four replications each). Each plot was 12.2 m by 12.2 m. The crop was sprinkler-irrigated, but purposely water-stressed, so that any water conservation in the residue-covered plots might translate into higher yields.*

In 2007, mean corn yield was 12.4 Mg ha^{-1} in the residue-covered plots and 10.8 Mg ha^{-1} in the bare-soil plots. Other research has shown that it takes 65-100 mm of irrigation water to produce this extra 1.6 Mg ha^{-1}, which may be considered water conservation due to the residue. In 2008, the residue-covered soil held approximately 60 mm more water in the top 1.83 m compared to the bare soil towards the end of the growing season. In addition, mean corn yield was 11.7 Mg ha^{-1} in the residue-covered plots and 10.6 Mg ha^{-1} in the bare-soil plots. It would take 30-65 mm of irrigation water to produce the difference. Thus, the total amount of water conservation due to the residue was 90-125 mm in 2008. In 2009, the residue-covered soil held approximately 90 mm more water in the top 1.83 m compared to the bare soil towards the end of the growing season. Also, mean soybean yield was 4.5 Mg ha^{-1} in the residue-covered plots and 3.9 Mg ha^{-1} in the bare-soil plots. Between 70-90 mm of irrigation water would be required to produce the difference.

Keywords. Water conservation, crop residue, soil water, irrigation, corn, soybean

Introduction

In western Nebraska, as in many other parts of the USA, irrigation water is becoming scarcer. Groundwater levels in the High Plains Aquifer have been falling (McGuire, 2004; McGuire and Fischer, 1999), and stream flow has been decreasing, leading to some issues. For example, it has been a challenge for Nebraska to supply the required amount of water to Kansas through the Republican River. Irrigated agriculture is a major consumer of water and a reduction in use of irrigation water throughout the Republican River Basin could provide additional water that can help meet stream flow requirements in the Republican River. Also, by saving irrigation water, irrigators will reduce pumping cost and more water will be available for competing needs such as wildlife habitat, endangered species, and municipalities.

It is generally believed that increasing crop residue levels leads to water conservation. However, crop residue that is removed from the field after harvest is gaining value for use in livestock rations and bedding, and as a source of cellulose for ethanol production. The water conservation value of crop residue needs to be quantified so crop producers can evaluate whether to sell the residue or keep it on their fields (Klocke et al., 2009).

Producers have expressed concerns about production practices where high levels of crop residue are present on the soil surface. These concerns include wetter soil and lower soil temperatures delaying planting and retarding plant development during early vegetative growth, and less uniform germination and emergence using planting equipment that cannot operate adequately in the residue. However, in the semi-arid climate of the western Great Plains, vegetative growth of crops under no-till management can catch up to the growth of crops under tilled management by the reproductive growth stage. In the hot and dry summers of this environment, reduced soil temperatures and increased soil water under crop residue during and after the reproductive stage benefit the crop and outweigh the drawbacks experienced earlier in the cropping season (Klocke et al., 1985).

Crop residue reduces the energy of water droplets impacting the soil surface and reduces the detachment of fine soil particles that tend to seal the surface, leading to crust formation. This sealing and crusting process can be enhanced by subsequent soil surface drying. It reduces infiltration and promotes runoff because precipitation or irrigation rates may be greater than the rates at which the soil is able to absorb water. Residue may also increase surface storage of rain or irrigation water. In addition, it slows the velocity of runoff water across the soil surface, allowing more time for infiltration (Steiner, 1994). Dickey et al. (1983) used a rainfall simulator at Sidney, Nebraska to demonstrate differences in infiltration and runoff from no-till wheat stubble and plowed soils. In the experiment, 76 mm of water was applied resulting in 44 mm of runoff on the plowed soil and only 5 mm on the no-till soil.

Standing residue helps to conserve water by causing snow to settle, rather than blow to field boundaries, by slowing the wind velocity just above the residue (Black and Siddoway, 1977; Steiner, 1994). Subsequent melting snow is more likely to infiltrate into the soil because the stubble slows runoff, enhancing soil water storage. This water can then be used for crop production in the subsequent growing season.

Research conducted near North Platte, Nebraska (Todd et al., 1991) and Garden City, Kansas (Klocke et al., 2009), showed that soil water evaporation from bare fine sand and silt loam soils can be as much as 30% of evapotranspiration (ET) during the irrigation season of corn and soybean. Evaporation was only 15% of total ET when wheat straw or no-till corn stover completely covered the soil surface from early June to the end of the growing season, translating into a 63 mm- to 75-mm water savings for the growing season. Soil water content increases with increasing amounts of residue in dryland cropping systems and wheat stubble can save an additional 50 mm of water during the non-growing season (Nielsen, 2006) if the soil profile can retain the water. These water savings in the growing and non-growing seasons would combine to a total of 125 mm per year. Not all of this can be expected to be effective for crop growth and yield. However, if only half of the 125-mm water savings can contribute to crop yield, yield increases may be as much as 0.67 Mg ha^{-1} for soybeans and 1.88 Mg ha^{-1} for corn in water-short areas or areas where water allocations are below full crop water requirements.

Van Donk et al. (2004) enhanced the process-based energy and water balance model (ENWATBAL; Van Bavel and Lascano, 1993; Evett and Lascano, 1993) with the capability to simulate the effect of mulch on evaporation and soil water content, and showed, in a simulation study, reduced evaporation from a mulched surface. Lamm et al. (2009) found that strip-till and no-till generally had greater water use than conventional tillage (chisel/disk plowing). This small increase in total seasonal water use (less than 10 mm) for strip-till and no-till compared to conventional tillage can probably be explained by the higher grain yields for the strip-till and no-till systems.

Research to quantify the effect of crop residue on the soil water balance has been limited and has produced a range of results. Some of the data and anecdotal evidence are based on rainfed cropping systems and results may be different for irrigated systems. More research is needed to quantify the effect of crop residue on components of the soil water balance, especially for irrigated agriculture. Therefore, this field study was conducted to determine the effect of crop residue on soil water content and crop yield under conditions of deficit irrigation.

Methods

The study was conducted at the University of Nebraska-Lincoln, West-Central Research and Extension Center in North Platte, Nebraska (41^{o} 10’ N, 100^{o} 45’ W, 861 m elevation above sea level) on a Cozad silt loam (Fluventic Haplustolls) with an average water content at field capacity of 0.29 m^3 m^{-3} and at wilting point of 0.11 m^3 m^{-3} (Klocke et al., 1999). The climate at North Platte is semi-arid, with an average annual precipitation of 508 mm and a reference evapotranspiration of 1403 mm. On average, about 80% of the annual precipitation occurs during the growing season, which extends from late April to mid October (USDA, 1978).

The experiment was initiated in 2007. There were two treatments: residue-covered soil and bare soil. In April 2007, bare-soil plots were created using a dethatcher and subsequent hand-raking and shoveling, effectively removing the residue. The residue-covered plots were left untreated. In April 2008 and 2009 (Figure 1), the same bare-soil plots were recreated by using similar methods as in 2007. The residue-covered plots were again left untreated. The experiment was conducted on plots planted to field corn (Zea mays L.) in 2007 and 2008, and soybean (Glycine max) in 2009. All plots were in no-till corn in 2004 and in no-till soybean in 2005 and 2006.

The experiment consisted of eight plots (two treatments with four replications each, Figure 2). Within each replication, the treatments (bare soil and residue-covered soil) were assigned randomly to the plots. Each of the eight plots was 24.4 m by 24.4 m. The actual experimental plots were 12.2 m by 12.2 m, centered in these larger plots. The areas outside the smaller experimental plots were border (buffer) zones.

No-till management was practiced on the plots. The only residue disturbance came from the planting operation and from the shredding of corn stalks shortly before planting in the spring of 2008 and 2009. The shredding operation left no corn stalks standing.

Residue cover and mass were measured in June and October 2007, July 2008, and July 2009. Residue cover was measured with the line-transect method (USDA-NRCS, 2002) using a 15.2-

m (50-ft) measuring tape. Residue hits or misses were evaluated at each of the 50 footmarks. The tape was laid out over the two diagonals of each plot. This way, 100 points per plot were evaluated. The percent residue cover equals the total number of residue hits out of 100 point evaluations.

Figure 1. Removing crop residue to create four bare-soil plots using a flail chopper, April 2009. After the flail chopper, additional residue was removed by hand-raking and shoveling. Residue was removed from the same four plots in April 2007 and 2008 using similar methods.

Residue mass was measured by collecting three samples from each residue-covered plot. Only two samples were taken from each bare plot, because there was very little residue present on these bare plots. The area of each sample was 0.76 m (equal to the row spacing) by 0.51 m. Sample locations within a plot were selected randomly. Before sampling, a picture was taken of each sample area. Minimum, maximum, and average residue thickness was measured inside each sample area. The average thickness was area-weighted and was an estimate rather than a measurement. Residue was cut on the boundaries of the sample area and collected by hand. If a piece of residue was partially buried, the entire piece was collected, unless it broke off easily at the soil surface.

All collected residue was dried in an oven for 24 hours at 60 ^{o}C. Subsamples were ground through a 1-mm sieve using a grinder (Udy Corporation Cyclone Mill, Model 3010-030). The resulting fine material was mixed and three subsamples were collected, weighed, and then ashed at 500 ^{o}C for six hours. Samples were then weighed again to determine the soil-free mass of each residue component.

During late spring and summer, precipitation was measured using several rain gauges located adjacent to the study plots. For the rest of the year, precipitation data from a High Plains Regional Climate Center (HPRCC, http://www.hprcc.unl.edu/) weather station, located less than 2 km west of the study site, were used. Measurement of precipitation in the form of snow at this HPRCC station did not seem very reliable. Therefore, for water equivalent data from snow, data from the WCREC dryland farm, which is located 4 km south of the study plots, were used. Using these three data sources, a precipitation record was constructed for the entire calendar years 2007 - 2009. Precipitation for the growing season portion of these three years is shown in Figure 3.

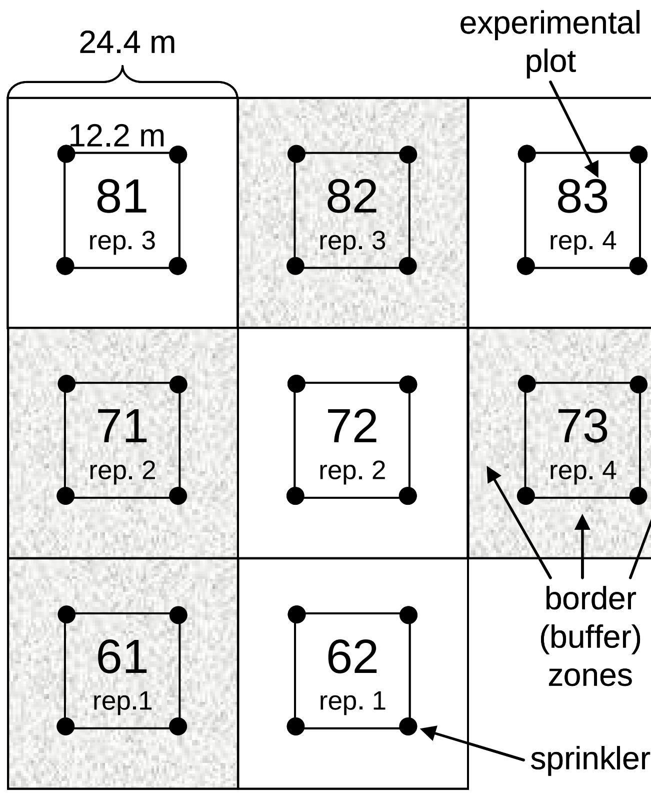

Figure 2. Physical layout of the eight experimental plots in the study (two treatments and four replications). The shaded plots are the residue-covered plots, the others are the bare-soil plots. Plots 61 and 62 made up replication 1, plots 71 and 72 made up replication 2, plots 81 and 82 made up replication 3, and plots 73 and 83 made up replication 4. Within each replication, the treatments (bare soil and residue-covered soil) were assigned randomly to the plots. The areas outside the 12.2 m by 12.2 m experimental plots are border (buffer) zones.

All three years had above average precipitation at North Platte (Figure 3, Table 1). The corn crop was irrigated three times with a total of 120 mm of water in 2007 (Figure 3a), two times with a total of 60 mm in 2008 (Figure 3b), and again two times with a total of 76 mm in 2009 (Figure 3c). The irrigation scheduling was conducted to slightly stress the crop on the residue-covered plots. By doing so, more stress and lower crop yield would be expected on the bare-soil plots.

During the growing season, soil water content was measured seven times in 2007, 17 times in 2008, and nine times in 2009 in each of the plots at six depths (0.15, 0.46, 0.76, 1.07, 1.37, and 1.68 m) using a neutron probe (CPN Hydroprobe). There were two neutron probe access tubes per plot: one in the crop row and one between the rows. The two tubes were located less than 1 m from each other.

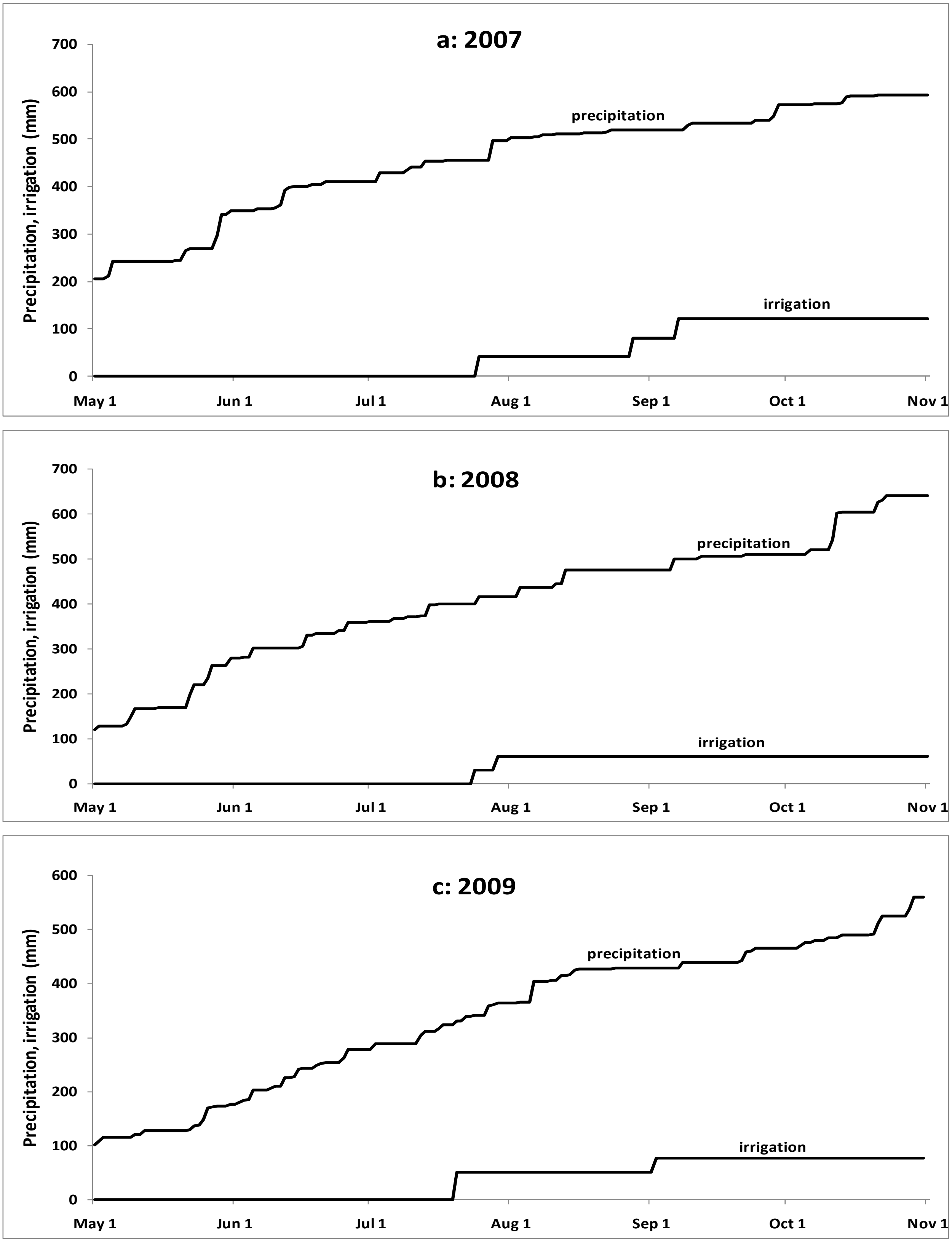

Figure 3. Cumulative precipitation and irrigation at the experimental site.

Table 1. Monthly, seasonal, and annual precipitation at the experimental site.

Month	2007 mm	2008 mm	2009 mm
Jan	11	0	7
Feb	25	4	19
Mar	59	18	8
Apr	110	100	62
May	144	158	80
Jun	63	80	102
Jul	86	58	85
Aug	22	59	65
Sep	54	34	37
Oct	20	130	94
Nov	0	10	4
Dec	15	4	10
Total	**608**	**654**	**574**
May-Sep	**368**	**389**	**369**

In 2007 and 2008, corn was hand-harvested along 6.1-m long rows in the center of each plot. In 2009, soybean was machine-harvested using a two-row plot combine. Guess rows (outside rows of the four-row planter) were not used in the yield calculation. The two-tailed, paired t-test was used to determine whether differences in yield between residue-covered plots and bare-soil plots were statistically significant.

Results and discussion

In June 2007, the bare-soil plots were almost totally without residue (Table 2). For the residue-covered plots, the average residue cover was 63%. It would have been higher if the planting equipment had not moved residue away from the corn rows. In October, the bare-soil plots were no longer bare, because many newly-senesced corn leaves covered the soil surface, explaining the average residue cover of 81% (Table 2). These leaves provided much cover at relatively low residue amounts in terms of mass: only 1322 kg ha^{-1} on average. In the residue-covered plots, average residue cover was also greater in October than it was in June, but residue mass was slightly less. Apparently, the mass increase due to newly-senesced leaves was more than offset by mass lost to residue decomposition (decay).

In July 2008, residue mass and cover on the bare-soil plots was again minimal after residue removal in April 2008 (Table 2). The residue-covered plots had a mean residue cover of 91% and a mean residue mass of 6704 kg ha^{-1}, which was much more than in 2007. This was due to the fact that in 2008 the majority of the residue was corn stalks from the 2007 corn crop. In 2007, most of the residue was soybean material from the 2006 soybean crop. In July 2009, residue cover was 92% on the residue-covered plots, very similar to the cover in 2008. In both years the residue was mostly from the previous years' corn crop. As in 2007 and 2008, residue cover was well below 10% on the bare-soil plots (Table 2).

Table 2. Residue cover, mass, and thickness for bare-soil and residue-covered plots. Mean and standard deviation of four plots.

	Bare-soil plots					Residue-covered plots				
				Thickness					Thickness	
		Cover %	Mass kg ha^{-1}	Avg. mm	Max. mm		Cover %	Mass kg ha^{-1}	Avg. mm	Max. mm
JUNE	Mean	2	146	<1	14	Mean	63	3646	13	35
2007	St. dev.	1	56	0	4	St. dev.	2	428	1	5
OCT.	Mean	81	1322	1	7	Mean	94	3418	10	30
2007	St. dev.	4	280	1	2	St. dev.	2	334	1	4
JULY	Mean	2	394	<1	17	Mean	91	6704	15	49
2008	St. dev.	1	174	0	7	St. dev.	4	1166	2	9
JULY	Mean	5	-	<1	23	Mean	92	-	13	44
2009	St. dev.	2	-	0	2	St. dev.	6	-	2	8

In 2007, the corn plants used water from all six depths, down to 1.68 m (Figure 4). In July, soil water content decreased rapidly because the corn crop was transpiring at full canopy cover, rainfall was modest, and no irrigation water was applied (Figure 4a). In late July, irrigation was followed by a large rain, which greatly increased soil water content at shallower depths (Figure 4a, b). In August, soil water content again decreased rapidly because of high crop water use, little precipitation and no irrigation until late in August. As mentioned before, the crop was purposely water-stressed, so that any water conservation in the residue-covered plots might translate into higher yields. In September and October, irrigation and precipitation filled up the soil profile at the shallower depths. This water stayed in the soil, because of much reduced crop water needs.

In 2007, differences in soil water content between the residue-covered and the bare-soil plots were small (Figure 4). From June through August, the bare-soil plots were somewhat drier than the residue-covered plots at most depths. In September and October, the bare-soil plots were wetter at some depths (Figure 4b, c), which may be explained by the field observation that the corn in the bare-soil plots dried out more and matured earlier than the corn in the residue-covered plots, apparently induced by water stress. Thus, the corn in the residue-covered plots used more water in late August and September and yielded more than the corn in the bare-soil plots.

In 2008, the soil dried out quickly at the shallower depths (Figure 5a, b) during late June and July, especially in the bare-soil plots. This may be due to greater evaporation in the bare-soil plots, but most likely also because the corn plants were bigger in the bare-soil plots at this time, therefore using more water than the plants in the residue-covered plots. This difference in plant development was visually observed in all four replications and likely caused by soil temperatures being cooler in the residue-covered soil in May and June. A difference in plant size was not observed in 2007 when the weather during the early growing season was warmer than in 2008, thus making cooler temperatures under residue less of an issue for the growth of corn plants.

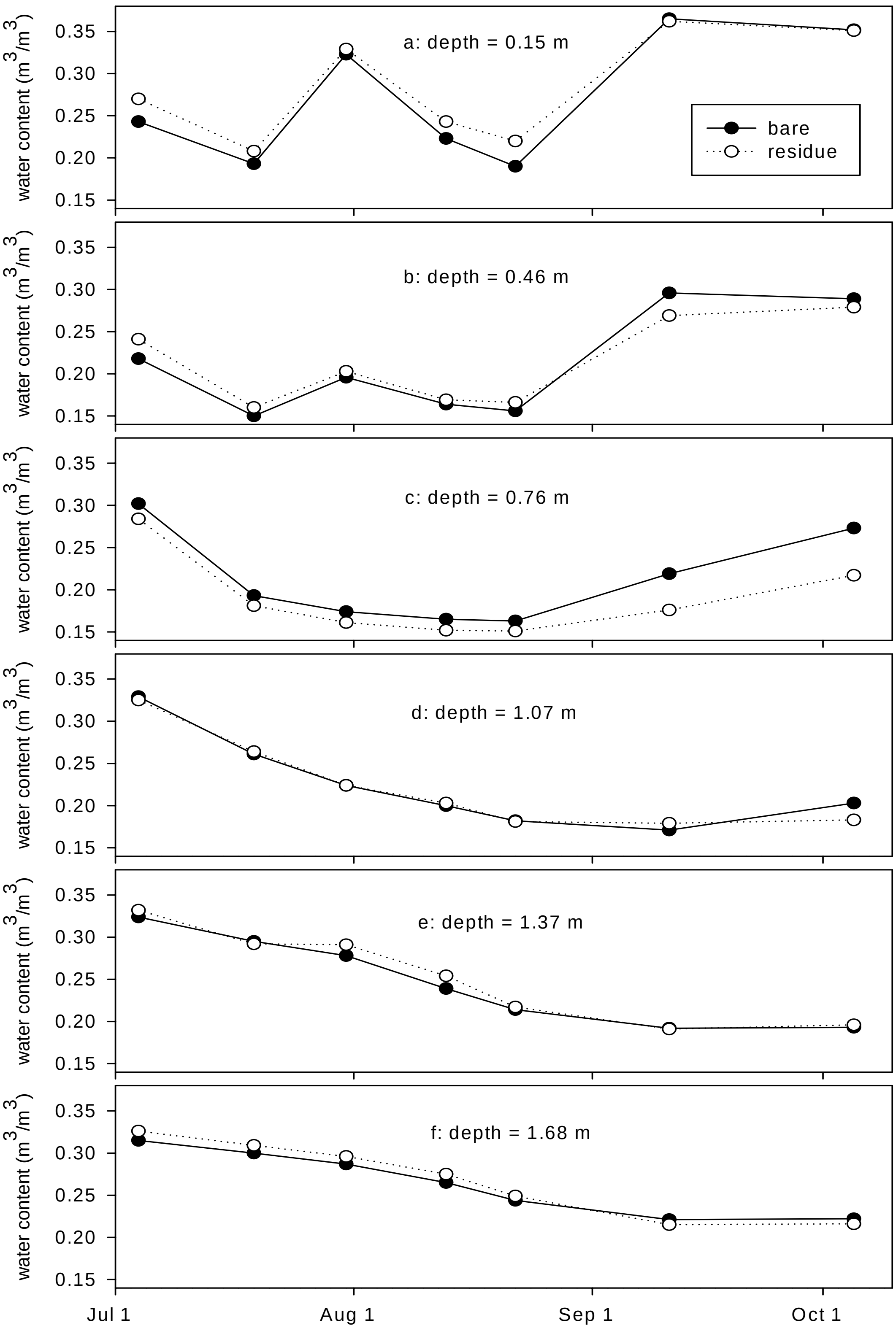

Figure 4. Mean soil water content at six depths in bare-soil plots and in residue-covered plots, 2007.

Two irrigations during late July 2008 made the soil water content increase at the shallower depths (Figure 5a, b). By the first half of August, the bare-soil plots were much drier than the residue-covered plots in the top meter of soil (Figure 5a, b, c, d) but not yet at the greater depths (Figure 5e, f). During late August and September, the soil dried out faster in the bare-soil plots than in the residue-covered plots at the two deepest depths (Figure 5e, f). At the shallower depths (Figure 5b, c, d), the bare-soil plots no longer dried out, whereas the residue-covered plots did. Apparently, in the bare-soil plots, the corn plants could no longer easily find water at the shallower depths, but they could find it at the deeper depths.

At the beginning of the soil water measurements in June, there was not much difference in soil water content in the measurement zone (top 1.83 m) between the bare-soil plots and the residue-covered plots (Figure 6). The difference developed rapidly in late June and July reaching a difference of almost 100 mm in August. In late September and early October the gap narrowed again, which was caused by greater crop water use in September by the corn in the residue-covered plots and heavy rains in October filling up the shallower soil layers to capacity in both treatments (Figure 5).

In 2009, soil water content followed a similar seasonal pattern as in 2008 (Figure 7). The soil again dried out quickly at the shallower depths (Figure 7a, b) during late June and early July, especially in the bare-soil plots. The same two causes as in 2008 were likely responsible for the faster drying of the bare soil: 1) greater evaporation in the bare-soil plots and 2) bigger soybean plants in the bare-soil plots during the first part of the growing season, using more water than the plants in the residue-covered plots. This difference in plant development was again visually observed in all four replications. At the beginning of the soil water measurements in June, there was 33 mm more soil water in the residue-covered plots than in the bare-soil plots (Figure 8). By late August, the residue covered plots contained 89 mm more water.

In 2007, corn yield was significantly ($p = 0.0036$) greater in the residue-covered plots compared to the bare-soil plots (Table 3). The average yield of the four bare-soil plots was 10.8 Mg ha^{-1} and the average yield of the four residue-covered plots was 12.4 Mg ha^{-1}. In 2008, corn yield was again significantly ($p = 0.0165$) greater in the residue-covered plots compared to the bare-soil plots. The average yield of the four bare-soil plots was 10.6 Mg ha^{-1} and the average yield of the four residue-covered plots was 11.7 Mg ha^{-1}. In 2009, soybean yield was also significantly ($p = 0.0049$) greater in the residue-covered plots compared to the bare-soil plots. The average yield of the four bare-soil plots was 3.9 Mg ha^{-1} and the average yield of the four residue-covered plots was 4.5 Mg ha^{-1} (Table 3).

Estimates were made to translate these yield differences into the amount of water it would take to produce this extra yield assuming that the yield differences were entirely due to the crop in the bare plots experiencing more water stress than the crop in the residue-covered plots. Five different references were used for this estimate (Table 4).

An analysis with the Water Optimizer (Martin et al., 2007), using a medium textured soil and an application efficiency of 0.75, indicated that it would take an additional 66-86 mm of irrigation water to raise corn yield from 10.8 to 12.4 Mg ha^{-1} (2007 yields) at North Platte, Nebraska. It would take an additional 43-66 mm of irrigation water to raise corn yield from 10.6 to 11.7 Mg ha^{-1} (2008 yields). The greater estimates of additional irrigation water needed are based on a fully-watered corn yield of 12.7 Mg ha^{-1}, which is the Water Optimizer default for North Platte, and the smaller estimates on a fully-watered corn yield of 13.8 Mg ha^{-1}.

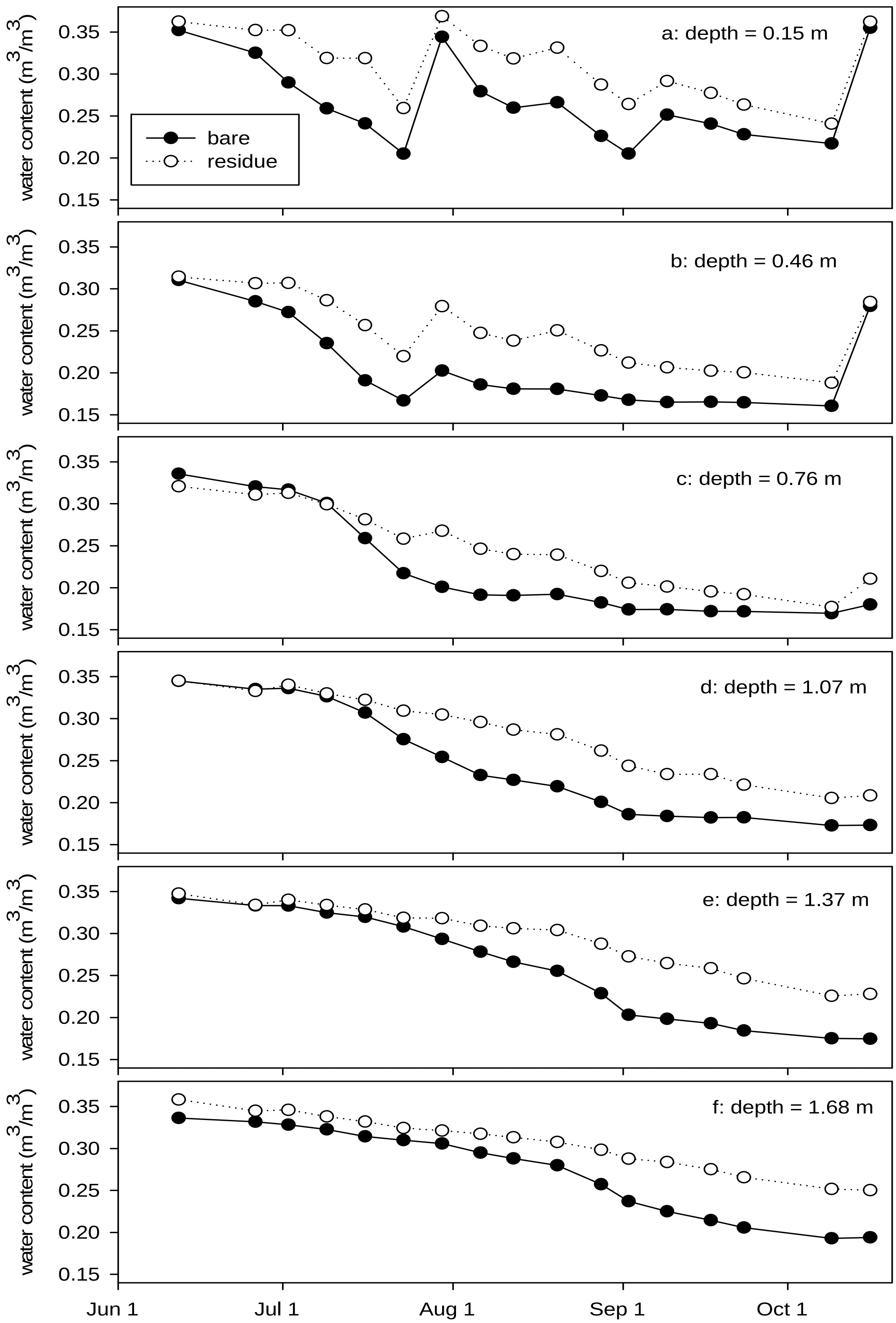

Figure 5. Mean soil water content at six depths in bare-soil plots and in residue-covered plots, 2008.

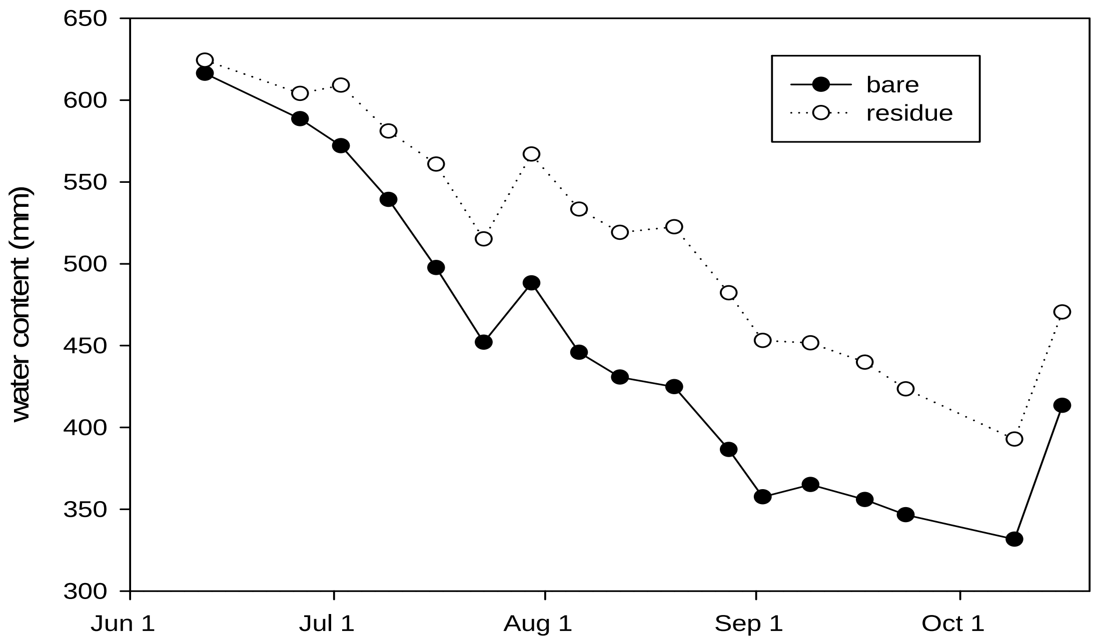

Figure 6. Total soil water content of the top 1.83 m in bare-soil plots and in residue-covered plots, 2008.

The Water Optimizer estimated that it would take an additional 74-91 mm of irrigation water to increase soybean yield from 3.9 to 4.5 Mg ha^{-1} (2009 yields). The 91-mm estimate is based on a fully-watered soybean yield of 4.7 Mg ha^{-1} and the 74-mm estimate on a fully-watered yield of 5.1 Mg ha^{-1}. The default Water Optimizer fully-watered soybean yield of 4.0 Mg ha^{-1} for North Platte was below our soybean yields and therefore not used in this analysis. Based on Specht et al. (1986), it would take 85 mm more water to produce the extra soybean yield of 0.6 Mg ha^{-1} that we had in 2009.

Using small plots, Melvin and Payero (2007) compared three different irrigation management strategies, from fully watered to deficit irrigation, for seven locations in West-Central Nebraska for four years (2003-2006). They reported the amount of irrigation water applied and corn yields. Since then, they have added two more years of data (Melvin, unpublished). Based on the findings from six years of data, our 2007 yield difference would translate into an additional 79 mm of irrigation water needed to produce the extra yield and our 2008 yield difference would translate into an additional 30 mm of irrigation water.

Another study, similar to the one above but on much larger fields, compared four different irrigation management strategies for six locations in West-Central Nebraska for six years (1996-2001) (Klocke et al., 2004; Schneekloth et al., 2006). Based on their findings, our 2007 yield difference would translate into an additional 114 mm of irrigation water needed to produce the extra yield and our 2008 yield difference would translate into an additional 66 mm of irrigation water.

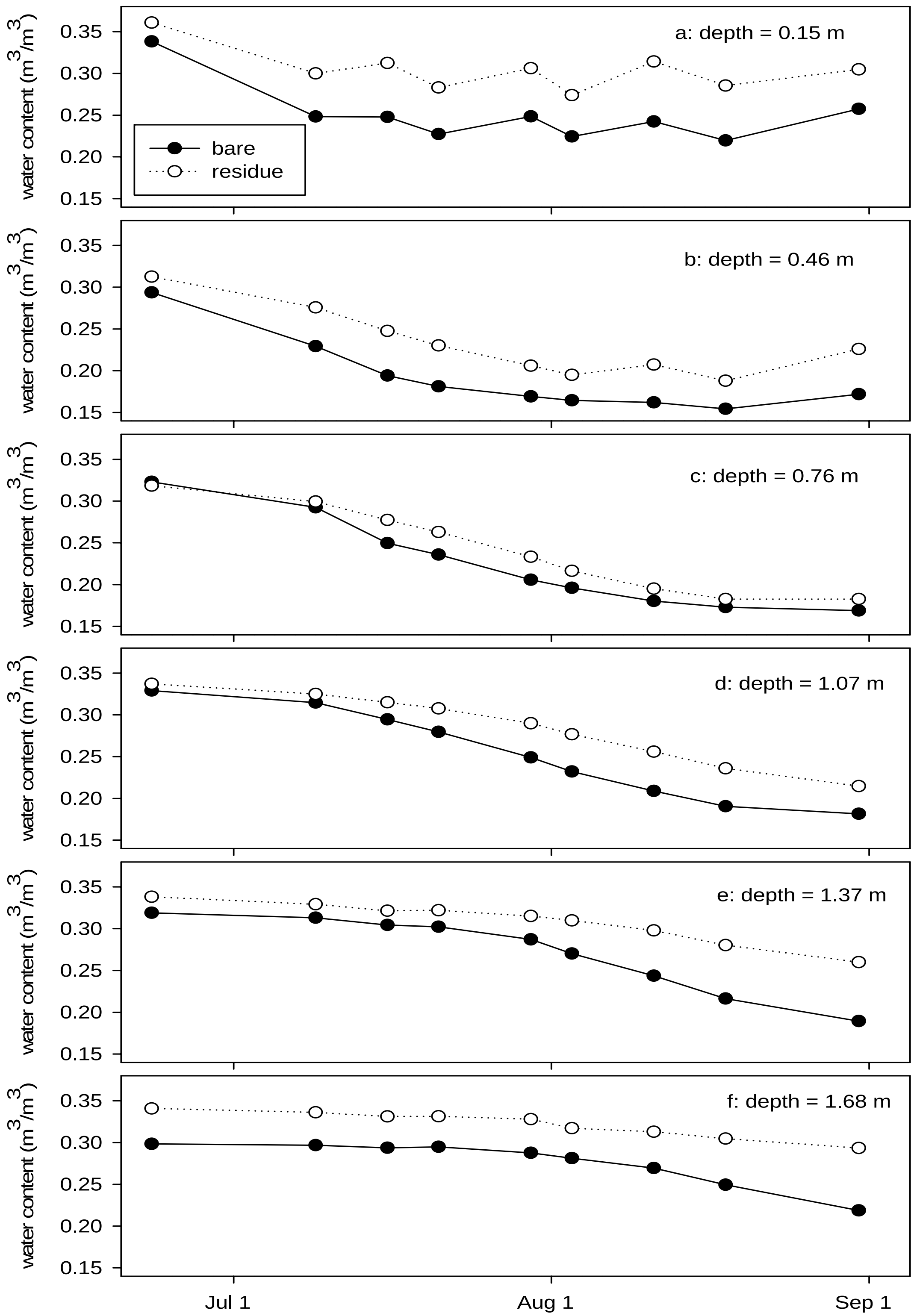

Figure 7. Mean soil water content at six depths in bare-soil plots and in residue-covered plots, 2009.

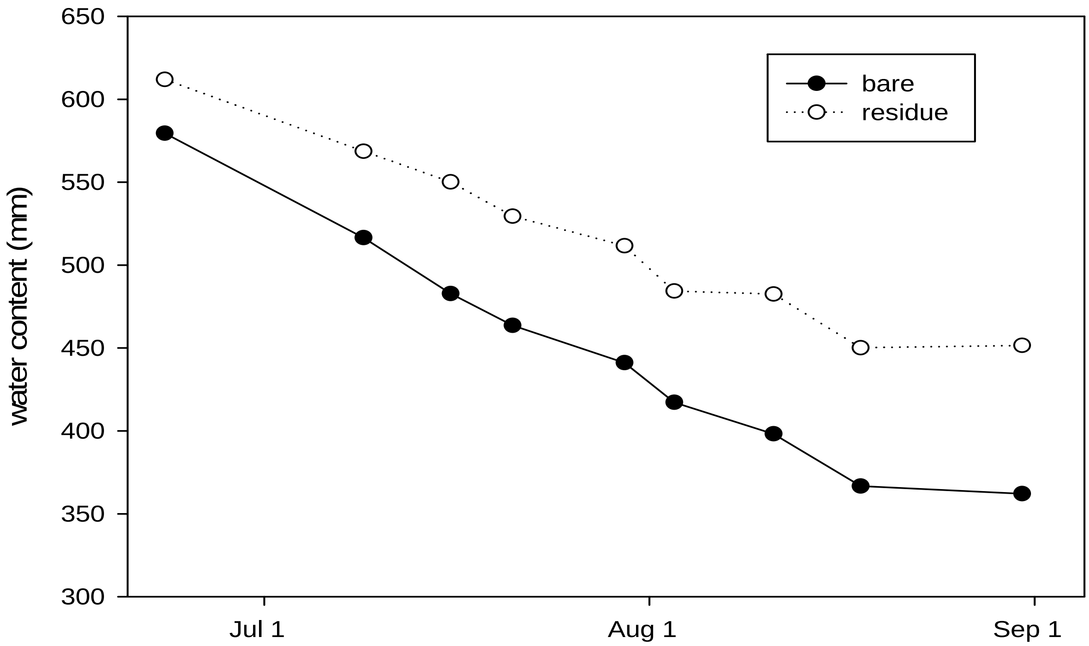

Figure 8. Total soil water content of the top 1.83 m in bare-soil plots and in residue-covered plots, 2009.

Table 3. Mean crop yield for the two treatments (residue-covered soil and bare soil). Yields are the means of four plots (four replications). Yield differences are statistically significant (p < 0.05) in all three years.

		Yield (Mg ha^{-1})			
Year	**Crop**	**Residue**	**Bare**	**Difference**	**p**
2007	Corn	12.4	10.8	1.6	0.0036
2008	Corn	11.7	10.6	1.1	0.0165
2009	Soybean	4.5	3.9	0.6	0.0049

Table 4. Amount of additional irrigation water (mm) required on the bare-soil plots to produce the extra yield produced on the residue-covered plots, estimated using five different references.

Year	Crop	Extra yield (Mg ha^{-1})	Martin et al. (2007)	Specht et al. (1986)	Melvin and Payero (2007)	Klocke et al. (2004); Schneekloth et al. (2006)	Klocke et al. (2008)
2007	Corn	1.6	66-86	-	79	114	71-85
2008	Corn	1.1	43-66	-	30	66	48-58
2009	Soybean	0.6	74-91	85	-	-	-

The last of the five references is Klocke et al. (2008) who concluded that, at Garden City, Kansas, corn yields increase 0.63 Mg ha^{-1} for each inch (25.4 mm) of irrigation water that is transferred from evaporation to transpiration. Based on this, the 2007 yield difference of 1.6 Mg ha^{-1} would translate into an additional 64 mm of crop-available water. Extra irrigation water that needs to be applied would be more than 64 mm, because the application efficiency will be less than 100%. At a 90% efficiency, the extra irrigation water needed would be 71 mm and at a 75% efficiency it would be 85 mm. The 2008 yield difference of 1.1 Mg ha^{-1} would translate into an additional 43 mm of crop-available water. At a 90% efficiency, the extra irrigation water needed would be 48 mm and at a 75% efficiency it would be 58 mm (Table 4).

All of these estimates assume that the yield differences were entirely due to the crop in the bare plots experiencing more water stress. There are good reasons for this assumption. Visually, there were signs that the crop in the bare-soil plots was more water-stressed than the crop in the residue-covered plots: in September of 2007 and 2008 the corn plants on the bare-soil plots turned brown earlier than the corn in the residue-covered plots and in September of 2009 the soybean leaves of the plants on the bare-soil plots turned yellow earlier than those in the residue-covered plots. In all years, fertility was adequate in all plots, so it is unlikely that the yield differences were caused by a lack of nutrients in the bare-soil plots. Also, it is unlikely that differences in compaction caused the differences in yield because all plots had the same history up to the residue removal in April 2007. Compaction differences may be expected in long-term no-till plots compared to long-term tilled plots, but not over this short time frame.

Conclusions

From June through August 2007, the bare-soil plots were somewhat drier than the residue-covered plots at most depths. Mean corn yield was 12.4 Mg ha^{-1} in the residue-covered plots, which was significantly ($p = 0.0036$) greater than the 10.8 Mg ha^{-1} in the bare-soil plots. Other researchers have shown that it takes 65-100 mm of irrigation water to grow this extra 1.6 Mg -ha^{-1}. This amount may be considered water conservation due to the residue.

In 2008, the residue-covered soil held approximately 60 mm more water in the top 1.83 m compared to the bare soil towards the end of the growing season. In addition, mean corn yield was 11.7 Mg ha^{-1} in the residue-covered plots, which was significantly ($p = 0.0165$) greater than the 10.6 Mg ha^{-1} in the bare-soil plots. It would take 30-65 mm of irrigation water to produce this extra 1.1 Mg ha^{-1}. Thus, the total amount of water conservation due to the residue was 90-125 mm in 2008.

In 2009, the residue-covered soil held approximately 90 mm more water in the top 1.83 m compared to the bare soil towards the end of the growing season. Also, mean soybean yield was 4.5 Mg ha^{-1} in the residue-covered plots, significantly ($p = 0.0049$) greater than the 3.9 Mg ha^{-1} in the bare-soil plots. Between 70-90 mm of irrigation water would be required to produce this extra 0.6 Mg ha^{-1}. Thus, the total amount of water conservation that may be attributed to the residue was 160-180 mm in 2009. Water conservation of such a magnitude will help irrigators to significantly reduce pumping cost and more water would be available for competing needs including those of wildlife, endangered species, municipalities, and compacts with other states.

Additional research on water balance and crop yield is needed in the context of actual agricultural systems, for example systems where residue is removed by grazing or baling, or systems where surface residue is reduced by tillage. In this experiment, residue was artificially removed from the plots without any tillage. The difference in residue cover created in our experiment was quite extreme: more than 90% on the residue-covered plots in 2008 and 2009 and less than 10% cover on the bare-soil plots in all three years. In the ‘real world’, such low surface residue levels are only created with considerable tillage possibly combined with mechanical residue removal. If the difference in residue cover is less extreme than in our study, a smaller water conservation benefit would be expected.

On the other hand, water conservation may be greater in the real world than in our study for several reasons. A tillage pass usually results in loss of water by evaporation since, typically, it brings moist soil to the soil surface, exposing it directly to atmospheric drying forces. In addition, long-term no-till could increase infiltration and decrease runoff compared to long-term conventional tillage. We did not have this tillage contrast in our study. Finally, when comparing to a real world scenario with fall tillage (we removed residue each spring), no-till may conserve water by reducing overwinter evaporation and increasing snow trapping.

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