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VALUE OF CROP RESIDUE FOR WATER CONSERVATION

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Practicing less tillage and retaining more crop residue on the soil surface reduce the rate of evaporation of water from the soil. These practices also increase the amount of soil water by increasing the amount of water that infiltrates into the soil and by decreasing the amount of water that runs off across the soil surface. Less tillage and more residue coverage can significantly reduce the amount of irrigation water needed to grow a crop.

EVAPORATION

When the soil surface is wet, evaporation from a bare soil will occur at a rate controlled by atmospheric demand. The evaporation rate decreases as the soil surface dries over time (Figure 1). Water that is deeper in the soil cannot be transported to the surface quickly enough to maintain wet-soil evaporation. The drying surface soil starts to act as a barrier to water transport.

If the soil surface is covered with residue, it is shielded from solar radiation and air movement just above the soil surface is reduced. This reduces the evaporation rate from a residue-covered surface, compared to a bare soil. Surface moisture under the residue will continue to evaporate slowly. A number of days after the wetting event, the evaporation rate from the covered surface can exceed that of the bare surface (Figure 1).

Eventually, after many days without rain or irrigation, the total evaporation from the bare and residue-covered soil would be the same. In the conceptual diagram of Figure 1, this point has not yet been reached after 20 days. In reality, this point is seldom reached, because more frequent wetting events result in more days with higher evaporation rates from bare soil than from residue-covered soil. The net effect over a season is that total evaporation will be greater from a bare soil.

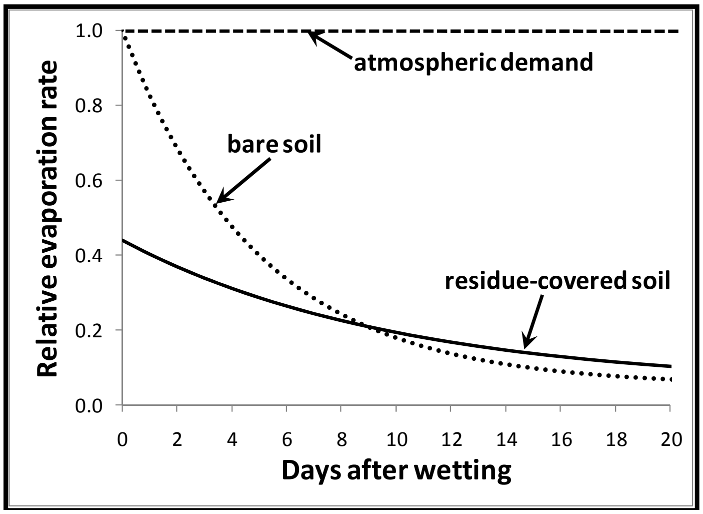

Figure 1. Evaporation rates, relative to atmospheric demand, from bare and residue-covered soil after a single wetting event (irrigation or rainfall) – conceptual diagram.

Residue reduces, but does not eliminate evaporation, which still takes place from the crop canopy, the residue itself, and the soil every time they are wet. This loss has been estimated to be 0.08 to 0.1 inch for each wetting event. Therefore, light, frequent rains or irrigations are less effective than heavy, infrequent ones. Some center pivot irrigators experience runoff on tilled soils so they apply small amounts frequently, typically only 0.5 inch each time. One tenth of an inch of evaporation out of 0.5 inch is a 20 percent loss. When adopting continuous no-till, the pivot can apply a greater amount of water before runoff occurs. With more water applied per event, but less often, the evaporation losses are reduced.

Also, when soils are tilled, they often dry to the depth of tillage. Each tillage operation can cause 0.5 to 0.75 inch of soil water evaporation. With multiple tillage events, soil water may not be adequate in the seed zone for uniform germination and emergence, resulting in lower yields, even though there may be sufficient soil water the rest of the year.

INFILTRATION AND RUNOFF

Long term no-till management leads to better soil structure, less soil crusting, higher infiltration rates, and less surface runoff. 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. Subsequent soil surface drying can cause further crusting. This sealing and crusting process 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 also slows the velocity of runoff water across the soil surface, allowing more time for infiltration.

Researchers of the University of Nebraska-Lincoln (UNL) 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, more than 3.75 inches of water was applied in 90 minutes to no-till soils before runoff started compared with 1.0 inch of water applied in 20 minutes on plowed soil before runoff started.

Standing residue can also conserve water by causing snow to settle, rather than blow to field boundaries, by slowing the wind velocity just above the residue. Subsequent melting snow is more likely to infiltrate because the stubble slows runoff thus storing more water, which can be used for crop production later in the growing season.

CROP YIELD, RESIDUE MASS AND COVER

The amount of residue produced at harvest by a crop can be estimated from crop yield. For wheat, yield (bu/ac) is multiplied by 100 to get residue mass in lb/ac. For example, a 60 bu/ac wheat crop is expected to produce approximately 6000 lb/ac of residue. For corn, yield is multiplied by 50 and for soybean by 60. Thus, a 180 bu/ac corn crop is expected to produce approximately 9000 lb/ac of residue.

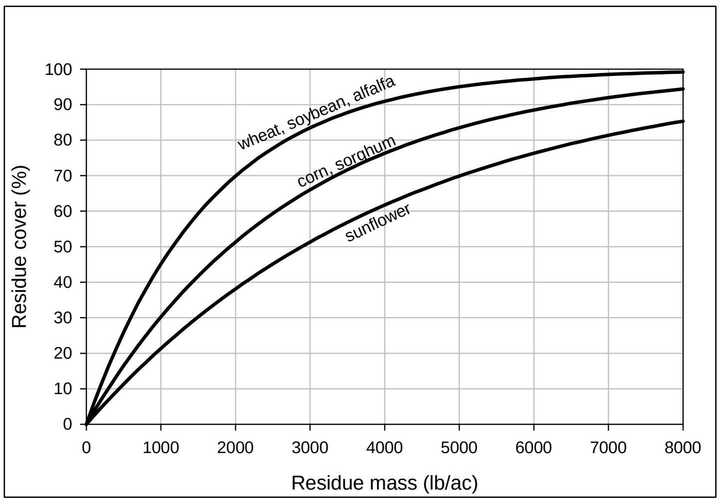

Figure 2. Relationship of residue mass to percent residue cover for various crops (USDA-NRCS, 2002).

The amount of residue cover is also important to gage the soil and water conservation benefits of the residue. The relationship of residue mass and residue surface cover is shown in Figure 2. For example, for wheat, 6000 lb/ac corresponds to a residue cover of almost 100% and 1000 lb/ac of corn residue corresponds to a cover of 30%. The thickness of residue also affects conservation benefits and is related to residue mass and residue cover.

EFFECT OF CROP RESIDUE ON EVAPORATION – SEVERAL EXPERIMENTS

Research conducted near North Platte, Nebraska and Garden City, Kansas (Klocke et al., 2009; Klocke et al., 2008; Todd et al., 1991), 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. The studies suggested that evaporation is 15% of total ET when wheat straw or no-till corn stover completely cover the soil surface from early June to the end of the growing season. This translates into a 2.5- to 3-inch water savings. Dryland research indicates that wheat stubble can save an additional 2 inches of water during the non-growing season if the soil profile can retain the water (Nielsen, 2006). The water savings in the growing and non-growing seasons would combine to a total of 5 inches per year. Not all of this can be effective for later crop growth and yield. Assuming that 50% of the 5-inch water savings can contribute to crop yield, yield increases may be as much as 10 bu/ac for soybeans and 30 bu/ac for corn.

EFFECT OF CROP RESIDUE ON SOIL WATER CONTENT AND CROP YIELD - NORTH PLATTE EXPERIMENTS

In 2007, a study was initiated on the effect of crop residue on soil water content and crop yield at the UNL West Central Research and Extension Center in North Platte, Nebraska. The experiment was conducted on a Cozad silt loam soil with a set of plots planted to corn. There were two treatments: residue-covered soil and bare soil. In April, bare-soil plots were created by using a dethatcher and subsequent hand-raking, removing most of the residue (Table 1). The residue-covered plots were left undisturbed.

The experiment consisted of eight plots (two treatments times four replications). Each plot was 40 by 40 ft. Winter and spring 2007 were very wet at North Platte and the corn was only irrigated three times with a total of 4.5 inches of water on all plots. The crop was purposely water-stressed, so that any water conservation in the residue-covered plots might translate into higher yields.

Residue cover was measured with the line-transect method (USDA-NRCS, 2002) using a 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. Residue mass was measured by collecting three (residue-covered plots) or two (bare-soil plots) samples from each plot. The area of each sample was 30 inch (equal to the row spacing) by 20 inch. Maximum and average residue thickness was measured inside each sample area using a ruler. The average thickness was area-weighted and was an estimate rather than a measurement.

The residue mass, mostly from previous no-till soybean crops, on the residue-covered plots was slightly greater than 3000 lb/ac in 2007 (Table 1). In October 2007, 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 1). Differences in soil water content between the residue-covered and the bare-soil plots were small throughout the growing season. However, average corn yield was 197 bu/ac in the residue-covered plots and 172 bu/ac in the bare-soil plots (Figure 3). An additional <u>2.5 to 3.5 inches</u> of irrigation water on the bare-soil plots would be required to produce the same yield as obtained in the residue-covered plots.

Table 1. Residue cover, mass, and thickness for bare-soil and residue-covered plots. Residue cover data is the result of evaluating 100 points for the presence or absence of residue (2 times 50 points on a 50-ft measuring tape). Mass and thickness data is the mean of three (residue-covered plots) or two (bare plots) samples per plot.

JUNE 2007									
Bare-soil plots					**Residue-covered plots**				
			Thickness					**Thickness**	
plot #	**Cover %**	**Mass lb/ac**	**Avg. inch**	**Max. inch**	**plot #**	**Cover %**	**Mass lb/ac**	**Avg. inch**	**Max. inch**
62	2	113	<0.04	0.31	61	63	2950	0.47	1.30
72	1	216	<0.04	0.59	71	60	3263	0.59	1.50
81	1	91	<0.04	0.79	82	66	2925	0.47	1.10
83	3	102	<0.04	0.51	73	63	3873	0.51	1.57
Mean	**2**	**130**	**<0.04**	**0.55**	**Mean**	**63**	**3253**	**0.51**	**1.38**
St. dev.	**1**	**50**	**0.00**	**0.16**	**St. dev.**	**2**	**382**	**0.04**	**0.20**
OCTOBER 2007									
Bare-soil plots					**Residue-covered plots**				
			Thickness					**Thickness**	
plot #	**Cover %**	**Mass lb/ac**	**Avg. inch**	**Max. inch**	**plot #**	**Cover %**	**Mass lb/ac**	**Avg. inch**	**Max. inch**
62	82	1203	0.08	0.20	61	91	2671	0.39	0.98
72	77	1533	0.08	0.28	71	95	2868	0.47	1.10
81	79	1153	<0.04	0.39	82	95	3218	0.39	1.38
83	87	828	<0.04	0.20	73	94	3438	0.35	1.26
Mean	**81**	**1179**	**0.04**	**0.28**	**Mean**	**94**	**3049**	**0.39**	**1.18**
St. dev.	**4**	**250**	**0.04**	**0.08**	**St. dev.**	**2**	**298**	**0.04**	**0.16**
JULY 2008									
Bare-soil plots					**Residue-covered plots**				
			Thickness					**Thickness**	
plot #	**Cover %**	**Mass lb/ac**	**Avg. inch**	**Max. inch**	**plot #**	**Cover %**	**Mass lb/ac**	**Avg. inch**	**Max. inch**
62	2	150	<0.04	0.51	61	88	5281	0.51	1.46
72	1	249	<0.04	0.51	71	89	6854	0.67	2.36
81	3	503	<0.04	1.18	82	90	4656	0.51	1.77
83	2	502	<0.04	0.51	73	97	7132	0.71	2.09
Mean	**2**	**352**	**<0.04**	**0.67**	**Mean**	**91**	**5981**	**0.59**	**1.93**
St. dev.	**1**	**155**	**0.00**	**0.28**	**St. dev.**	**4**	**1040**	**0.08**	**0.35**

This assumes that the yield difference was entirely due to the corn in the bare plots experiencing more water stress. There are good reasons for this assumption. Visually, there were signs that the corn in the bare-soil plots was water-stressed more than the corn in the residue-covered plots: in September the corn on the bare-soil plots turned brown earlier than the corn in the residue-covered plots. It is unlikely the yield difference was caused by a lack of nutrients in the bare-soil plots, because the corn was fertilized adequately in all plots. Also, it is unlikely differences in compaction caused the difference 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.

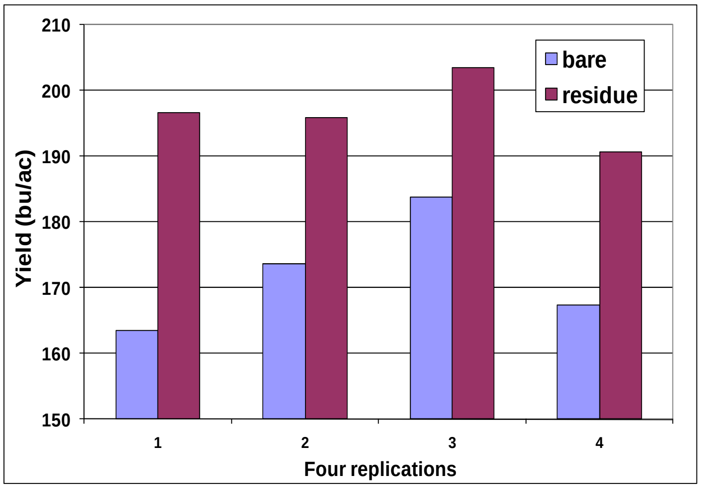

Figure 3. Corn yield on bare soil (avg. 172 bu/ac) and residue-covered soil (avg. 197 bu/ac) in 2007 at North Platte on small field plots.

In April 2008, residue was removed from the same four plots as in 2007. As in 2007, all plots were irrigated at the same time with the same amount of water, but the crop was again somewhat water-stressed. The average corn yield in 2008 was 186 bu/ac in the residue-covered plots and 169 bu/ac in the bare-soil plots. It would take an additional 1.5 to 2.5 inches of irrigation water on the bare-soil plots to reach the same yield as obtained in the residue-covered plots.

In addition, the residue-covered plots held more water towards the end of the season (Figure 4). The soil dried out quickly at the shallower depths (Figure 4a, b) during late June and July, especially in the bare-soil plots. This may have been because of 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.

Two irrigations during late July 2008 caused the soil water content to increase at the shallower depths (Figure 4a, b). By the first half of August, the bare-soil plots were much drier than the residue-covered plots in the top 4 ft of soil (Figure 4a, b, c, d) but not yet at the greater depths (Figure 4e, 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 4e, f). At the shallower depths (Figure 4b, c, d), the bare-soil plots no longer dried out, whereas the residue-covered plots still 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.

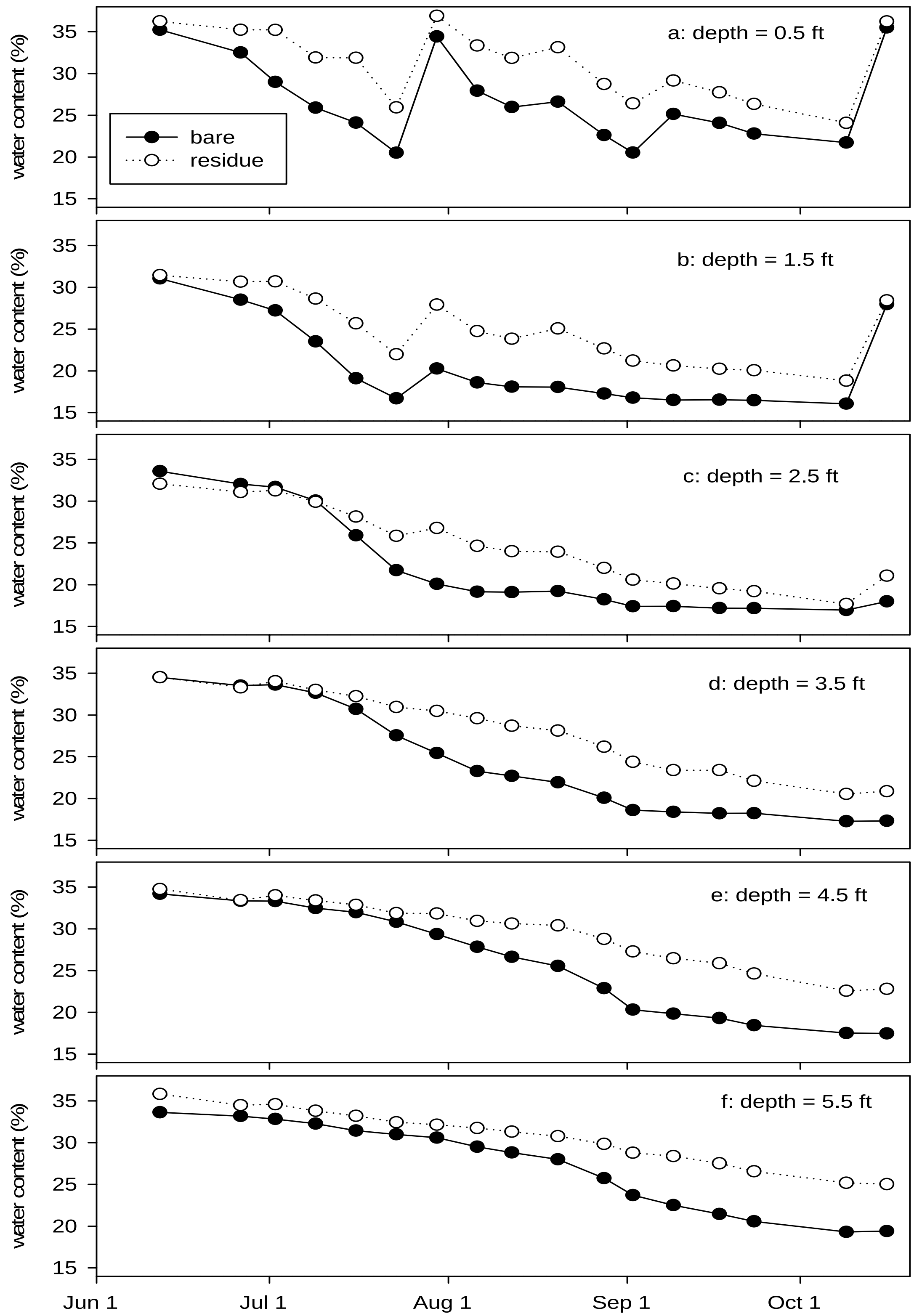

Figure 4. Mean volumetric soil water content in 2008 at six depths in bare-soil plots and in residue-covered plots.

At the end of the 2008 growing season, there was 1.5 inches more water in the residue-covered plots than in the bare-soil plots in the top 4 ft. Thus, the combined effect (actual water plus water needed to produce the extra yield of 17 bu/ac) in 2008 is estimated to be a total of 3 to 4 inches of water savings on the residue-covered plots.

In April 2009, residue was again removed from the same four plots as in the two previous years. As before, all plots were irrigated at the same time with the same amount of water, but the crop (soybean this time) was again somewhat water-stressed. The average soybean yield in 2009 was 68 bu/ac in the residue-covered plots and 58 bu/ac in the bare-soil plots. As in 2008, the residue-covered plots held 1.5 inches more water towards the end of the 2009 growing season in the top 4 ft.

ECONOMIC BENEFITS

The economic benefits of the water savings discussed here can be calculated. Less irrigation water needs to be pumped when water is saved with more residue/less tillage. This translates into a savings in pumping cost. An example follows:

- Water savings anticipated from more residue/less tillage: 3 inches on a 130-acre field.
- Pump discharge pressure: 50 psi.
- Performance rating: 80%. This is a rating according to the Nebraska Pumping Plant Performance Criteria; 80% is an average rating for Nebraska.
- Pumping cost savings is shown in Table 2.

Table 2. Pumping cost savings ($) resulting from the above conditions for a dynamic pumping lift ranging between 0 and 400 ft and a cost of diesel fuel ranging between $2.00 and $4.00 per gallon.

Lift (ft)	$2.00	$2.50	$3.00	$3.50	$4.00
0	$1025	1281	1538	1794	2050
50	1469	1836	2203	2570	2937
100	1912	2390	2868	3346	3824
150	2356	2945	3534	4123	4712
200	2799	3499	4199	4899	5599
250	3243	4054	4865	5675	6486
300	3687	4608	5530	6452	7373
350	4130	5163	6195	7228	8260
400	4574	5717	6861	8004	9148

For example, for a dynamic pumping lift of 150 ft and diesel at $2.50 per gallon, the pumping cost savings is $2945. A calculator was developed to make the above calculations using your own input data. It is available at *http://water.unl.edu/reduceneed*. Scroll down to the bottom of the page where you will find the calculator.

In a deficit-irrigation situation there are economic benefits because of higher yields associated with more residue and less tillage. For example, corn yield may be 25 bu/ac higher, as was the case in the 2007 experiment at North Platte, described above. For corn at $3/bu, this would be $75/acre and almost $10,000 for a 130-acre field. For a soybean yield that is 10 bu/ac higher (2009 case at North Platte), with soybean at $10/bu, this would be $100/acre and $13,000 for a 130-acre field.

SUMMARY

With more residue cover, less solar energy reaches the soil surface and air movement is reduced near the soil surface, resulting in a reduction of evaporation of water from the soil beneath the residue cover. Light, frequent rains or irrigations are less effective than heavy, infrequent ones, because, with every wetting event, evaporation takes place from the crop canopy, the residue, and the soil.

In addition to reducing evaporation, higher residue levels and long-term no-till increase infiltration and reduce runoff, thus directing more water to where the crop can use it. Similarly, in the winter, more standing residue means that more snow stays where it falls, thus storing more water in the soil once the snow melts.

Research at Garden City, Kansas showed that a 5-inch water savings is possible with a cover of wheat straw or no-till corn stover. Earlier UNL research results at North Platte, Nebraska largely agree with the findings from Kansas. Another study was initiated in 2007 at North Platte, on the effect of crop residue on soil water content and crop yield. The crop on residue-covered and bare-soil plots was purposely water-stressed, so that any water conservation in the residue-covered plots might translate into higher yields. In 2007, the average corn yield was 25 bu/ac more in the residue-covered plots compared to the bare-soil plots. It would take approximately 3 more inches of irrigation water on the bare-soil plots to reach the same yield as obtained in the residue-covered plots. Results were similar in 2008 and 2009.

Water conservation of the magnitudes discussed here will help reduce pumping cost significantly, which can amount to a savings of a few thousand dollars on a typical 130-acre field. But not only irrigators would benefit, because more water would be available for competing needs including those of wildlife, endangered species, municipalities, hydroelectricity plants, and compacts with other states.

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