2-2012

Tillage and Crop Residue Removal Effects on Evaporation, Irrigation Requirements, and Yield

Simon van Donk
University of Nebraska-Lincoln, simon.vandonk@unl.edu

Norman L. Klocke
Kansas State University, Garden City, KS, nklocke@ksu.edu

Tillage and Crop Residue Removal Effects on Evaporation, Irrigation Requirements, and Yield

Simon J. van Donk
Assistant Professor, Biological Systems Engineering
University of Nebraska
West Central Research and Extension Center
North Platte, Nebraska
Voice: 308-696-6709 Fax: 308-696-6780
Email: svandonk2@unl.edu

Norman L. Klocke
Professor, Water Resources Engineering
Kansas State University
Southwest Research and Extension Center
Garden City, Kansas
Voice: 620-276-8286 Fax: 620-276-6028
Email: nklocke@ksu.edu

Irrigators in the western Great Plains and other irrigated regions face water restrictions caused by decreased well capacity, water allocations imposed by water policy, and/or rising energy costs. These growers require water management practices that optimize grain production. When not enough water is available to produce full yields, the goal for water management is to maximize transpiration and minimize nonessential water losses such evaporation of soil water.

It is generally believed that increasing crop residue levels leads to reduced evaporation. 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. It is important to know the water conservation value of crop residue so crop producers can evaluate whether to sell the residue or keep it on their fields.

Tillage also greatly affects the amount of residue on the soil surface. The effects of no-till and conventional tillage on soil and water dynamics are controversial. Producers have expressed concerns about production practices where high levels of crop residue are present on the soil surface. These concerns include the increased use of chemicals, and 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.

INFILTRATION AND 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, 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 also increases 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. University of Nebraska-Lincoln (UNL) researchers 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, 3.0 inches of water was applied, resulting in 1.7 inches of runoff on the plowed soil and only 0.2 inches 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. 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.

EVAPORATION OF WATER FROM THE SOIL

When the soil surface is wet from a recent irrigation or precipitation event, evaporation from bare soil will occur at a rate controlled by atmospheric demand (Figure 1). The evaporation rate decreases as the soil surface dries over time because water that is deeper in the soil is not transported to the surface quickly enough to maintain the rate of wet-soil evaporation; the drying surface soil starts to act as a barrier to water transport (Figure 1).

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 bare soil. Surface moisture under the residue will continue to evaporate slowly, but a number of days after the wetting event, the evaporation rate from the residue-covered surface can exceed that of the bare surface (Figure 1).

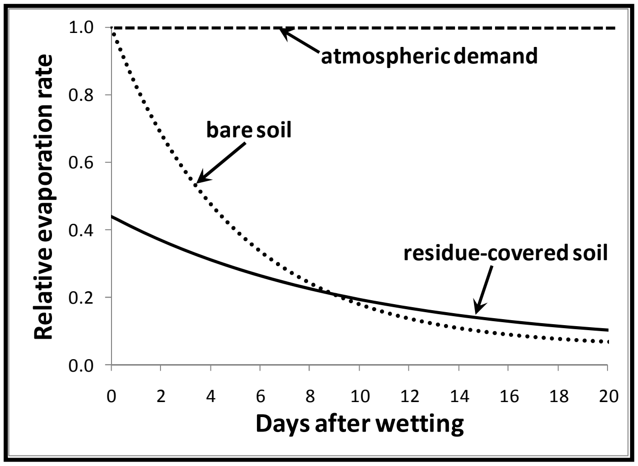

Figure 1. Evaporation rates, relative to atmospheric demand, from bare and residue-covered soil after a single wetting event (irrigation or rainfall) – conceptual diagram.

Eventually, after many days without rain or irrigation, the cumulative evaporation from the bare and residue-covered soils will be the same. In the conceptual diagram in 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 is expected to be greater from bare soil.

Crop residue does not eliminate evaporation entirely. It still takes place from the crop canopy, the residue itself, and the soil every time they are wet. This loss is fairly constant for each wetting event, no matter how light or heavy the wetting event is. 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 inches each time. Percent wise, the evaporation losses are relatively large when applying such small amounts. When adopting continuous no-till, a 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. 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.

EXPERIMENTS AT GARDEN CITY, KANSAS

Field Study Under Corn Canopy

A study was conducted to find the effect of crop residue on soil water evaporation at Kansas State University's Research and Extension Center near Garden City, Kansas (Klocke et al., 2009). Soil water evaporation (E) was measured from a soil surface covered with no residue, corn stover, or wheat stubble under a corn canopy during the summers of 2004, 2005, and 2006. Mini-lysimeters**,** 12 inches in diameter and 5.5 inches deep were used for the E measurements. The mini-lysimeters were filled by pressing PVC cylinders into undisturbed crop residue and soil following corn or wheat harvest the previous year. E was determined daily by weighing the lysimeters. Weighing precision was ± 1 gram producing E measurements with a resolution of ± 0.00006 in/day. Surface residue cover in the mini-lysimeters was greater than 90% when they were placed in the field (Table 1).

Average daily E from June 12 through September 16 was significantly different among the surface cover treatments for all years (Table 1). Corn stover surface cover was more than wheat stubble cover in 2005 and 2006 which led to significantly less E from the corn stover. The trend in E was reversed in 2004, primarily because the wheat stubble amount (mass) was more that the corn stover amount. The crop residue decreased bare soil E by approximately 50%. Corn evapotranspiration (ETc) was different among the years, but the residue significantly reduced E/ETc. Even though there were differences in peak leaf area index (LAI) among years, E was nearly the same all years indicating that crop residue influenced E more than shading by the corn crop. For the entire measurement period between June 12 and September 16, there was about 3 inches more E from the bare soil compared to the residue-covered surfaces.

Table 1. Evaporation of water from soil shaded by a corn canopy at Garden City, Kansas.

	Residue Type	Surface Cover %	Residue Amount (tons/ac)	Avg E[1] (in/day)	ETc[2] (in/day)	E/ETc	Peak LAI[3]
2004	Bare	0	0	0.07 a[4]	0.21	0.37 a	4.4
	Corn	97	7.3	0.04 b	0.21	0.19 b	4.4
	Wheat	98	9.8	0.03 c	0.21	0.18 c	4.4
	$LSD_{.05}$			0.003		0.006	
2005	Bare	0	0	0.06 a	0.27	0.23 a	3.4
	Corn	100	9.5	0.03 c	0.27	0.12 c	3.4
	Wheat	91	6.3	0.04 b	0.27	0.14 b	3.4
2006	$LSD_{.05}$			0.002		0.01	
	Bare	0	0	0.06 a	0.22	0.30 a	3.7
	Corn	100	7.5	0.03 c	0.22	0.14 c	3.7
	Wheat	92	4.3	0.04 b	0.22	0.18 b	3.7
	$LSD_{.05}$			0.002		0.02	

[1] Average daily evaporation from June 12 through September 16.
[2] Average daily evapotranspiration of corn shading soil surface.
[3] Peak leaf area index (leaf upper surface area/ground surface area) of corn shading soil surface.
[4] Values in the same column for the same year followed by different letters are significantly different for p=0.05

Study with Partial Residue Cover and no Crop Canopy

Evaporation was measured with mini-lysimeters that had soil surfaces fully or partially covered with corn stover or wheat stubble with no crop canopy (Figure 2). This study was conducted at Kansas State University's Research and Extension Center near Garden City, Kansas (Klocke et al., 2009). High and low irrigation frequencies of wetting events were achieved by applying water either once or twice per week for six weeks. Translucent shelters on steel tracks were rolled over the mini-lysimeters to exclude rain when needed. Otherwise, shelters were rolled away from the mini-lysimeter installation and the mini-lysimeters were exposed to ambient weather.

High and low irrigation frequency caused more E from bare soil than soil with 100% residue cover, but the differences in E due to high and low irrigation frequency decreased as residue cover increased (Figure 2). Evaporation from bare soil was 48% more from high frequency than from low frequency irrigation. The regressions of E with respect to residue cover showed that E depended more on residue cover with high frequency than low frequency irrigations, as indicated by the differences in R^2 (0.80 for high frequency and 0.54 for low frequency).

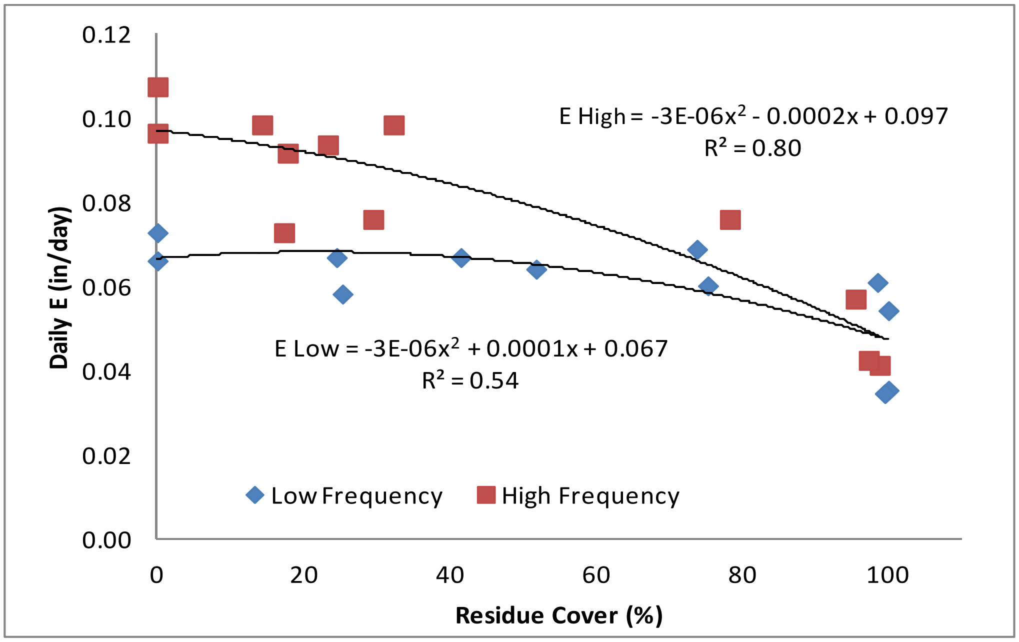

Figure 2. Daily soil water evaporation from soil surfaces that were partially to fully covered with corn stover or wheat stubble. Half of the mini-lysimeters were wetted once per week (low frequency). The other lysimeters were wetted twice per week (high frequency). There was no shading by a crop canopy.

FIELD EXPERIMENT AT NORTH PLATTE, NEBRASKA

A study was initiated in 2007 to find the effect of crop residue on evaporation, soil water content, and corn yield at the UNL West Central Research and Extension Center in North Platte, Nebraska (van Donk et al., 2010). 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 2007, bare-soil plots were created by using a dethatcher and subsequent hand-raking, removing most of the residue. Thus, the over-winter benefits of the residue were the same for both treatments. Residue removal was repeated the following three years (Table 2).

Table 2. Time table for planting corn and soybean crops and removing crop residue – field experiment at North Platte, Nebraska.

Year	Month	Event
2004	May	Plant corn
2005	May	Plant soybeans
2006	May	Plant soybeans
2007	April	Remove crop residue (mostly soybean residue) from four field plots
	May	Plant corn
2008	April	Remove crop residue (mostly corn residue) from four field plots
	May	Plant corn
2009	April	Remove crop residue (mostly corn residue) from four field plots
	May	Plant soybeans
2010	April	Remove crop residue (mostly soybean residue) from four field plots
	May	Plant soybeans

Crop residue was always removed from the same four field plots

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.

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, Table 3). An additional 3 inches of irrigation water on the bare-soil plots would be necessary to reach the same yield as obtained in the residue-covered 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 (Table 3). It would take an additional 2 inches of irrigation water on the

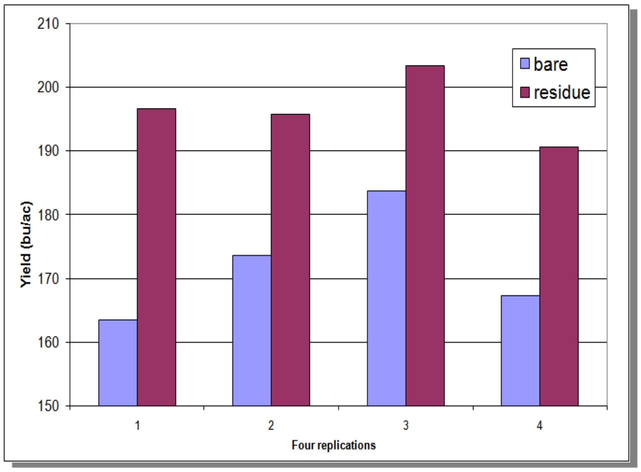

Figure 3. Corn yield on bare soil (avg. 172 bu/ac) and residue-covered soil (avg. 197 bu/ac) in 2007 at North Platte, Nebraska on small field plots.

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 (1.5 inches more than the bare-soil plots in the top 4 ft). Thus, the combined effect in 2008 is estimated to be a total of 3.5 inches of water savings on the residue-covered plots.

In April 2009 and 2010, residue was again removed from the same four plots as in the two previous years. As before, both the bare-soil and the residue-covered plots were irrigated at the same time with the same amount of water, but the crop (soybean in 2009 and 2010) 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. An extra 3 inches of irrigation water would have been necessary on the bare-soil plots to produce the same yield as obtained in the residue-covered plots. In addition, the residue-covered plots held 2 inches more water towards the end of the 2009 growing season in the top 4 ft of soil (Table 3).

In 2010, the average soybean yield was 61 bu/ac in the residue-covered plots and 53 bu/ac in the bare-soil plots. An additional 2.5 inches of irrigation water would have been necessary on the bare-soil plots to produce the same yield as obtained in the residue-covered plots (Table 3).

Table 3. Crop yield and water savings for crops grown on residue-covered soil and on bare soil at North Platte, Nebraska.

		Yield			Water savings		
		Residue	Bare soil	Difference	Yield*	Soil**	Total
Year	Crop	Bu/ac	Bu/ac	Bu/ac	Inch	Inch	Inch
2007	Corn	197	172	25	3.0	0.0	3.0
2008	Corn	186	169	17	2.0	1.5	3.5
2009	Soybean	68	58	10	3.0	2.0	5.0
2010	Soybean	61	53	8	2.5	0.0	2.5

* Additional irrigation water needed to produce the same yield on the bare-soil plots as was obtained on the residue-covered plots
** Additional soil water (in the top 4 ft of soil, at the end of the growing season) in the residue-covered plots compared to the bare-soil plots

ECONOMIC ASPECTS

The economic benefits of the water savings discussed here can be calculated. Less irrigation water needs to be pumped when water is saved when retaining more residue on the soil surface. This translates into a savings in pumping cost. An example of pumping cost savings is shown in Table 4 for a 3-inch water savings on a 130-acre field.

Table 4. Pumping cost savings ($) for a dynamic pumping lift ranging between 0 and 400 ft and a cost of diesel fuel ranging between $2.00 and $5.00 per gallon.

Lift (ft)	$2.50	$3.00	$3.50	$4.00	$4.50	$5.00
0	1281	1538	1794	2050	2306	2563
50	1836	2203	2570	2937	3304	3672
100	2390	2868	3346	3824	4302	4781
150	2945	3534	4123	4712	5301	5890
200	3499	4199	4899	5599	6299	6999
250	4054	4865	5675	6486	7297	8108
300	4608	5530	6452	7373	8295	9217
350	5163	6195	7228	8260	9293	10326
400	5717	6861	8004	9148	10291	11435

This table is based on the following conditions:

- ✓ Water savings anticipated from more residue: 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.

For example, for a dynamic pumping lift of 200 ft and diesel at $3.50 per gallon, the pumping cost savings is $4899. A calculator has been developed to make the above calculations using your own input data. It is available at *http://water.unl.edu/web/cropswater/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 2007 in the experiment at North Platte, described earlier. For corn at $6/bu, this would be $150/acre and almost $20,000 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. Research at Garden City, Kansas showed a 3-inch (50%) reduction in evaporation over a period of three summer months with a nearly 100% cover of wheat straw or no-till corn stover compared to bare soil. A full cover was needed to obtain the maximum reduction in evaporation. The study also showed that frequent rains or irrigations caused more evaporation losses than infrequent ones.

Another experiment was conducted from 2007-2010 at North Platte, Nebraska, to study 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 all four years of the study, crop yield was greater in the residue-covered plots compared to the bare-soil plots. Also, in two of the four years, there was more water left in the root zone at the end of the growing season in the residue-covered plots. This four-year study showed a 2.5 - 5.0 in/year water savings when residue was left on the field. These results are very similar to the results of the Garden City experiments, which were obtained using a very different research approach.

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. The results from the Garden City and North Platte studies did not include these effects. Thus, on typical farm fields, water savings due to crop residue may be even greater than found in these studies.

Water conservation of the magnitudes discussed here will help reduce irrigation pumping cost significantly, which can amount to a savings of more than $5,000 on a typical 130-acre field. In a deficit-irrigation situation, the economic benefits due to higher yields associated with more residue and less evaporation can exceed $20,000 for a 130-acre field. But not only irrigators would benefit; more water would be available for competing needs including those of wildlife, endangered species, municipalities, hydroelectricity plants, and compacts with other states.

REFERENCES

Klocke, N.L., R.S. Currie, and R.M. Aiken. 2009. Soil water evaporation and crop residues. Transactions of the American Society of Agricultural and Biological Engineers 52(1): 103-110.

van Donk, S.J., D.L. Martin, S. Irmak, S.R. Melvin, J.L. Petersen, and D.R. Davison. 2010. Crop residue cover effects on evaporation, soil water content, and yield of deficit-irrigated corn in west-central Nebraska. Transactions of the American Society of Agricultural and Biological Engineers 53(6): 1787-1797.