WATER SAVINGS FROM CROP RESIDUE MANAGEMENT

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INTRODUCTION

Corn growers who irrigate in the Great Plains face restrictions in water, either from lower well capacities or from water allocations, and/or rising energy costs. They need water management practices to maximize grain production. When there is not enough water available to produce full yields, the goal for water management is to maximize transpiration and minimize non-essential water losses. One avenue for reducing non-essential water use is to minimize soil water evaporation.

Evapotranspiration is the combination of a two processes, transpiration and soil water evaporation. Transpiration, water consumed by the crop, is essential for the plants and correlates directly with grain production. Non-productive soil water evaporation has little utility. Soil water evaporation rates from bare soil are controlled by two factors. When the soil surface is wet, atmospheric energy that reaches the ground drives evaporation rates (energy limited phase). As the surface dries, evaporation rates are limited by the movement of water in the soil to the surface. In sprinkler irrigation during the growing season, most of the evaporation results from the energy limited process because of frequent soil wetting. Crop residues insulate the surface from energy limited evaporation.

Crop residues which are left in the field have value for soil and water conservation during the following non-growing season and the growing season of the next crop. Crop residues that are removed from the field after harvest are gaining value for livestock rations, livestock bedding, and as a source of cellulous for ethanol production. The water conservation value of crop residues needs to be quantified so that crop producers can evaluate whether or not to sell the residues or keep them on their fields. Reducing soil water evaporation in sprinkler management is one of the values of crop residues. This project was designed to measure soil water evaporation with and without a growing corn crop.

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OBJECTIVES

1. Determine the water savings value of crop residues in irrigated corn.
2. Measure soil water evaporation beneath crop canopy of fully and limited irrigated corn.
    a. From bare soil.
    b. From soil covered with no-till corn residue.
    c. From soil covered with standing wheat residue.
3. Calculate the contribution of evaporation to evapotranspiration.
4. Quantify soil water evaporation from partially covered soil with no crop canopy.
5. Predict potential economic savings from reducing evaporation with residues.

METHODS

Soil water evaporation was measured beneath a growing corn crop during the summers of 2004, 2005, and 2006 at Kansas State University's Research and Extension Center near Garden City, Kansas. The soil at the research site was a Ulysses silt loam. Mini-lysimeters were used for the primary evaporation measurement tool. They contained undisturbed soil cores 12 inches in diameter and 5.5 inches deep. The soil cores were extracted by pressing PVC tubing into the soil with a custom designed steel bit. The PVC tubing became the sidewalls for the mini-lysimeters. The bottom of the cores were sealed with galvanized discs and caulking. Therefore, water could only escape from the soil by surface evaporation, which could be derived from daily weight changes of the mini-lysimeters. Weighing precision produced evaporation measurements with a resolution of $\pm$ 0.002 in/day.

Volumetric soil water content was measured bi-weekly in the field plots to a depth of 8 ft in 1 ft increments with neutron attenuation techniques. The change in soil water, form the start to the end of the sampling period, plus measurements of rainfall and net irrigation were the components of a water balance to estimate crop evapotranspiration (ETc).

Measurements of crop residue coverage on the soil surface were adapted from line transect techniques. A coarse screen was laid over a mini-lysimeter. Observations of the presence or absence of residue were recorded for each intersection of screen material. The fraction of the presence of residue and total observations was converted into a percentage of coverage.

Two mini-lysimeters with the same surface cover treatment were placed in a diagonal pattern between adjacent 30-inch rows under the crop canopy. Comparison of evaporation data (not shown) indicated no statistical difference between the two locations.

Four replications of bare, corn stover, or wheat stubble surface treatments were placed in high and low frequency irrigation treatments. High frequency irrigation was managed to meet atmospheric demand for full crop evapotranspiration (ETc). The low frequency irrigation treatment received approximately half this amount in half the irrigation events.

An additional experiment was conducted to find the soil water evaporation rates from soil surfaces that were partially covered with crop residues. A controlled area was established for the experiment where the mini-lysimeters were buried in PVC sleeves at ground level, arranged adjacent to one another in a geometric pattern. Movable shelters were available to cover the mini-lysimeters during rain events but were open during other times. There was no crop canopy over the mini-lysimeters, which were surrounded by mowed, irrigated grass. The mini-lysimeters were weighed daily. Two irrigation treatments, that approximated the companion field study, were watered with 1 or 2 per hand irrigations per week. Partial surface cover treatments had 25%, 50%, and 75% of the surface covered with corn stover which was placed on the mini-lysimeters. Mini-lysimeters with 100% coverage from corn stover and 85% coverage with standing wheat stubble were the same configuration as the field experiment. Evaporation results were normalized with reference ET (ETr) which was calculated with on-site weather factors and an alfalfa referenced ETr model (Kincaid and Heermann, 1984).

RESULTS

Within Canopy Field Results

Soil surface cover on the mini-lysimeters was measured at the start of the growing season. Corn stover and standing wheat stubble completely covered the mini-lysimeters in 2004 (table 1). Corn stover continued to completely cover the mini-lysimeters in 2005 and 2006, but the wheat stubble coverage was 91-92% in those years. The 2004 and 2005 wheat crops were shorter in stature due to less fall growth. This led to less wheat stubble coverage of the mini-lysimeters during the following year.

All of the surface cover and irrigation frequency treatment data were averaged so that only year-to-year differences could be evaluated (table 2). Annual differences in average daily soil water evaporation (Avg E), average daily crop evapotranspiration (ETc), average daily reference ET (ETr), and the ratios of Avg E with both ETc and ETr were calculated. The climatic conditions in 2004 were cooler and wetter than normal which produced 230 bu/ac of corn with full irrigation. Hail storms during July 2005 and July 2006 caused leaf loss, as indicated by the peak leaf area index measurements, and produced grain yields of 165 bu/ac in 2005 and 185 bu/ac in 2006. The combination of more E and less ETc and ETr in 2004 than in the other two years caused the E/ETc and E/Etr ratios to be more in 2004. The most ETc occurred in 2005 with the least peak LAI; however, more atmospheric demand for water, as indicated by more ETr, may have masked some of the effects of less leaf area.

Table 1. Crop residue percentage cover at the end of the growing season for mini-lysimeters in corn field plots during 2004-2006 near Garden City, Kansas.

Crop Residue Cover	Dry Matter tons/ac	Residue Coverage* %
-------------------2004-------------		
Bare	0.0	0
Corn	7.3	97
Wheat	9.8	98
-------------------2005-------------		
Bare	0.0	0
Corn	9.5	100
Wheat	6.3	91
-------------------2006-------------		
Bare	0	0
Corn	7.5	100
Wheat	4.3	92

*Percentage of soil surface covered by residue, determined by the modified line transect method.

Table 2. Average soil water evaporation (Avg. E) and evaporation as a ratio of crop evapotranspiration (ETc) and reference ET (ETr) for all mini-lysimeter treatments under a corn crop canopy during 2004-2006 in Garden City, KS.

Irrigation Frequency*	Avg E in/day	ETc in/day	E/ETc	ETr In/day	E/ETr	Peak LAI*
2004	0.046a	0.21c	0.25a	0.26	0.18a	4.4
2005	0.043b	0.27a	0.16c	0.36	0.12b	3.4
2006	0.042b	0.22b	0.21b	0.30	0.14a	3.7
$LSD_{.05}$	0.002	0.01	0.02		0.005	

Means with same letters in the same columns are not significantly different for alpha=.05.

When data from all years and water frequency treatments were combined, the effects of surface treatments could be isolated. Average soil water evaporation (Avg E) from the bare surface treatment was significantly more than Avg E from the two residue covered treatments (table 3). Wheat stubble surface coverage was than corn stover coverage in 2005 and 2006, resulting in more E with wheat stubble. Daily average ETc and ETr data were the same over all mini-lysimeters since the annual data was averaged over all irrigation treatments. Bare soil E for the Ulysses silt loam was 30% of ETc, which was the same result as a study with Valentine fine sandy soils in west-central Nebraska (Klocke et al., 1985). E as a ratio of ETc or ETr showed that crop residues reduced E by 50% compared with bare soil. A similar study with silt loam soils in west-central Nebraska showed that bare soil E under a corn canopy during the growing season could be reduced from

0.07 inches/day to 0.03 inches/day by adding a mulch of wheat stubble lying flat on the surface with 100% surface coverage (Todd et al., 1991).

Differences in E between bare soil and residue treatments, which were 0.02-0.03 inch per day, may seem small; however, if these daily differences were extrapolated over a 110 day growing season, total differences in E would be 2.2-3.3 inches. Similarly, E as a fraction of ETc was 0.30 for bare soil and 0.15-0.16 for the residue cover treatments. Growing season ETc values for corn can be 24-26 inches in western Kansas. Using the values of E as a fraction of ETc (table 3), potential water savings could be 3.7-4.0 inches with full soil surface coverage.

Table 3. Average soil water evaporation and evaporation as a ratio of crop evapotranspiration (ETc) and reference ET (ETr) for all bare soil and crop residue covered treatments under a corn crop canopy during 2004-2006 in Garden City, KS.

Surface Cover	Avg E in/day	ETc in/day	E/ETc*	ETr in/day	E/ETr
Bare	0.06a	0.23	0.30a	0.27	0.22a
Corn Stover	0.03c	0.23	0.15c	0.27	0.11c
Wheat Straw	0.04b	0.23	0.16b	0.27	0.12b
$LSD_{.05}$**	0.003		0.02		0.05

Means with same letters in the same columns are not significantly different for alpha=.05.

The influence of crop canopy shading canopy on soil water evaporation rates was observed by averaging data over years, surface cover treatments, and irrigation frequency treatments (table 4). Evaporation decreased as crop canopy and ground shading increased. The trend reversed as the crop matured and shading decreased. Concurrently, crop ET and reference ET increased from planting through mid-season and then decreased through the rest of the growing season. The ratio of Avg E to ETc and ETr declined during the growing season when the two factors were combined.

Table 4. Soil water evaporation (Avg E) and evaporation as a ratio of crop ET (ETc) and reference ET (ETr) during the growth stages of corn for all mini-lysimeter treatments during the 2004-2006 growing seasons at Garden City, KS.

Growth Stage	Avg Days In Growth Stage	Avg E	ETc	E/ETc	ETr	E/ETr
		in/day	in/day		in/day	in/day
Vegetative	28	0.06a	0.22b	0.27a	0.35	0.17a
Pollination	18	0.05b	0.27a	0.20b	0.33	0.15b
Seed Fill	30	0.03c	0.20c	0.15c	0.25	0.12c
$LSD_{.05}$		0.002	0.02	0.02		0.05

Means with same letters in the same columns for the same year are not significantly different for alpha = 0.05.

More frequent irrigations led to slightly more soil water evaporation and ETc (table 5). The small differences were probably because on average there were two to three more wetting events in the high versus low frequency treatments. More ETc in the high frequency treatment led to slightly smaller ratio of Avg E with ETc.

Table 5. Soil water evaporation (Avg E) and evaporation as a ratio of crop ET (ETc) and reference ET (ETr) for low and high frequency irrigation for all mini-lysimeter treatments in during the 2004-2006 growing seasons.

Irrigation Frequency	Wetting Events	Avg E in/day	ETc in/day	E/ETc in/day	ETr	E/ETr
Low	3	0.043b	0.21b	0.21a	0.30	0.14b
High	5	0.044a	0.25a	0.20b	0.30	0.15a
$LSD_{.05}$		0.0013	0.009	0.02		0.004

Means with same letters in the same columns are not significantly different.

Partial Cover Results from Control Area

Even though average daily evaporation rates among the bare and 25%, 50%, and 75% residue covered treatments could be measured and were significantly different from one another, the magnitudes of these differences were small (table 6a). The 100% covered treatment with corn stover and the standing wheat stubble with 85% cover produced significantly less E than the other treatments. Lateral heat flow from the bare portion of the partially covered surface could have caused increased surface temperatures under the corn stover. Similarly, soil water could move from under partially covered surface to the bare portion of the surface, increasing E (Chung and Horton, 1987).

Based on averages of surface cover treatments, twice per week irrigation frequency over a six week period produced 23% more evaporation than the once per week frequency (table 6b).

Summary and Significance of Results

Corn stover and wheat stubble residues that cover 85-100 % of the soil surface have the potential to reduce soil water evaporation (E). During the growing seasons of 2004 – 2006 in Garden City, Kansas, average E measured under a growing corn crop was reduced from 0.06 inch per day for bare soil to 0.03 to 0.04 inch per day for complete surface coverage with corn stover or wheat stubble. The difference in E between bare soil and residue covered surfaces over a 110 day growing season could be 2.2 to 3.3 inches. E as a fraction of crop evapotranspiration (ETc) was 0.30 for bare soil and 0.15 to 0.16 for complete soil surface coverage. The total growing season ETc for corn grown in west-central Kansas is 24-26 inches. Based on the reduction of E as a fraction of ETc, growing season water savings could be 3.4 to 3.9 inches.

Table 6. Soil water evaporation during Spring and Fall 2005 and Fall 2006 for full and partial crop residue surface covers at Garden City, Kansas.

a. Surface Cover	Avg E --in/day--	E/ETr*
Bare 0%	0.08a	0.26a
Corn 25%**	0.07b	0.25b
Corn 50%	0.07c	0.24c
Corn 75%	0.07a	0.26a
Corn 100%	0.04e	0.14e
Wheat 85%	0.05d	0.18d
$LSD_{.05}$	0.002	0.005
b. Irrigation* Frequency**		
Low	0.07a	0.20a
High	0.05b	0.18b
$LSD_{.05}$	0.0009	0.003

*Reference ETr (alfalfa based) from weather station data.
**Percent surface covered by residue found from line-transect (visual) methods.
***Once (low) and twice (high) per week irrigation frequency over a six week period.
Means with same letters in the same columns for the same variable are not significantly different at alpha = 0.05.

Crop residues that were distributed across the surface, needed to cover more than 80-85% to have an effect in reducing E when there was no crop canopy. Nearly complete surface coverage influenced E nearly the same with and without crop canopy.

Crop residues can also have an effect on non-growing season. A field study in eastern Colorado during 0ctober-April of the years 2000-2004 showed that corn residues increased stored soil water by 2 inches when compared with conventional stubble mulch tillage in dryland management (Neilson, 2006). Dryland studies in Nebraska have demonstrated that wheat stubble increased non-growing season soil water storage by 2-2.5 inches when compared with bare soil (Klein, 2007).

The Natural Resources Conservation Agency (USDA-NRCS, 2000) has calculated net irrigation requirements for corn across Kansas. Net irrigation is the water that infiltrates into the soil and is required for full crop production. The net irrigation value is 14.5 inches in the Garden City, Kansas area (Finney County) for average precipitation without the benefit of no-till management. Gross irrigation is the water delivered to the field. Current center-pivot systems can have an application efficiency of 90% and would pump 16 inches for full irrigation. Results of a field study near Garden City for 2004-2006 show that fully irrigated corn yields with no-till management can be obtained with 11 to 12 inches of irrigation (Klocke et al., 2007). The difference between NRCS estimations of full irrigation and the field study measurements indicate that irrigation savings from no-till management could be 4-5 inches annually. A related field study with fully irrigated continuous corn grown with no-till management was conducted in west-central Nebraska from 1985 to 1999 (Klocke et al., 2007b). Average annual irrigation requirements were 10 inches during the study years with somewhat less evapotranspiration than the Garden City location. Water savings from no-till management from these studies indicate that combined growing season and non-growing season could be 4-5 inches.

The water savings from crop residues can have one of three impacts on income. First, if irrigation is applied in excess of water requirements of the crop in a no-till system, there could be no economic benefits from the crop residues. The excess water could leach past the root zone with no value to crop production. Second, if water supplies are adequate to grow a fully irrigated crop, pumping costs can be reduced by the difference between tilled and no-till management. Irrigators in this situation need to monitor soil water during the growing season to find the reduction in irrigation needed from crop residue management and time irrigations accordingly. Third, if the irrigation system cannot keep up with crop water requirements, the crop may be under water stress all or part of the growing season. Water savings from crop residues in no-till management can be transferred from bare soil evaporation losses to water that can be used by the crop (transpiration) for better yield returns. In this case there would be no change in irrigation pumping.

Irrigation requirements and production costs vary from year-to-year and from one irrigator to another. Commodity prices also vary from year-to-year. As demonstrated in this study, nearly full coverage of the soil surface was needed to reduce soil water evaporation and reap benefits from the crop residues. The following is one example of economic impacts on income for irrigated corn where growing season and non-growing season crop residue management combines for saving 5 inches of water annually:

Situation 1. Irrigation applications in excess of crop needs can lead to soil water leaching below the root zone and there are no benefits from the crop residues.

Situation 2. Irrigation requirements are reduced for a fully irrigated crop from crop residue management where pumping is reduced to account for less irrigation needs.

Pumping costs = $9 per acre for each inch pumped
Total savings for 5 inches less water pumped = $45 per acre

Situation 3. The irrigation system cannot provide enough water to meet the full water requirements of the crop. Five inches of water savings from crop residue management can shift soil water evaporation to transpiration.

Corn yields increase 10 bushels per acre for each inch of irrigation that is transferred from evaporation to transpiration.

Corn price is $4.50 per bushel giving a total savings of $225 per acre.

Additional growing and non-growing season benefits from crop residues include capturing precipitation, enhancing infiltration, reducing runoff, and reducing soil erosion. All of these benefits have economic value for crop production and land values, but they are more difficult to measure than direct water conservation effects of crop residue management.

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