Soil Water Evaporation and Residue Management in Sprinkler Irrigation

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Introduction:

Soybean and corn growers who irrigate in the Great Plains face restrictions in available water, either from lower well capacities or from water allocations, and rising energy costs. They need management practices to manage water supplies for useful grain production. Water savings, even a few inches, can convert water into yield increases. Research (Schneekloth et al., 1991) has shown that each acre-inch of water captured or saved in the root zone potentially can be transformed into soybean yield through transpiration at the rate of 4 bu/ac. The same is true for corn at a rate of 12-14 bu/ac for each acre-inch.

Evapotranspiration is a two part process. Transpiration, or water consumed principally by evaporation near leaf and stem surfaces is used productively to produce grain. Non-productive soil water evaporation process vaporizes water directly into the air with little utility. Soil water evaporation rates are controlled by two factors. After wetting, atmospheric energy that reaches the ground drives evaporation rates (energy limited). As the surface dries, evaporation rates are limited by the movement of water through the soil to the surface. Generally, energy limited evaporation rates are more than soil limited rates during the growing season. Crop residues on the surface can influence energy limited evaporation by reducing energy reaching the ground.

Measuring methods to reduce wasteful soil water evaporation is the goal of this project. Past projects have demonstrated that reducing soil water evaporation under irrigated corn canopies is possible with flat wheat stubbles on the soil surface (Todd et al. 1991). Irrigators need to know what value crop residues, including corn stalks and standing wheat stubble, have for reducing soil water evaporation. They need concrete measurements of the soil water evaporation rates in soybean canopies with crop residue and irrigation management techniques.

Objectives:

Determine the water savings value of crop residues in irrigated corn and soybean production.

1. Measure soil water evaporation beneath crop canopy of fully irrigated and limited irrigated corn and soybean production.

    a. Measure evaporation from bare soil
    b. Measure evaporation from soil with no-till corn residue
    c. Measure evaporation from soil with standing wheat residue

2. Calculate the contribution of evaporation to evapotranspiration, based on mini-lysimeter and soil water balance techniques.

3. Predict potential savings in evaporation due to crop residues to equivalent grain yield gains and economic impacts in water limited areas in western Kansas.

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Methods:

Soil water evaporation was measured during the summer of 2003, 2004, and 2005 at Kansas State University's Research and Extension Center near Garden City, Kansas. 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 was 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 $\pm$ 0.001 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 calculate crop evapotranspiration (ETc).

Two mini-lysimeters with the same surface cover treatment were placed in a diagonal pattern between adjacent 30-inch rows under the crop canopy. There were four replications of bare, corn stover, or wheat stubble surface treatments in each of two irrigation treatments in 2004 and 2005 (high and low frequency irrigation), but only the high irrigation treatment was conducted in the 2003 soybeans. High frequency irrigation was managed to meet atmospheric demand for water (full ETc). The low frequency irrigation treatment received approximately half the amount of water as the high treatment.

A hail event on July 4, 2005 completely destroyed the soybean crop and damaged the corn. Therefore, an additional non-field experiment was conducted with soil surfaces partially covered with crop residues. The objectives were to (1) quantify the relationships between surface cover dry matter and soil water evaporation without a crop canopy, and (2) quantify the relationship between percentage of surface cover and soil water evaporation. A controlled area was established for the experiment where the mini-lysimeters were buried in PVC sleeves at ground level, but they were arranged adjacent to one another in a geometric pattern. Rain-out shelters were available to exclude rain from the mini-lysimeters. The movable shelters covered the mini-lysimeters during rainfall but were open during other times. There was no crop canopy and the mini-lysimeters were surrounded by clipped, irrigated grass. The mini-lysimeters were weighed daily. Two irrigation treatments, that approximated the companion field study, were imposed with once and twice per week watering.

Partial cover treatments with 25%, 50%, and 65% of the surface covered with corn stover were established by placing the material on undisturbed bare soil mini-lysimeter cores. The percentages of surface covered were confirmed with the line transect method by counting the presence of residue at intersections of a grid. The 100% corn and 89% wheat treatments used mini-lysimeters from 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. (Penman, 1948).

Results:

Within Canopy Field Results

Trends in dry matter and crop residue coverage may help explain the following discussion of soil water evaporation. Corn dry matter and surface coverage, both sampled from the actual mini-lysimeters, were similar in 2003 and 2004 (table 1). Decreases in corn residue coverage corresponded to less dry matter. The protocol in this experiment was to obtain the maximum possible coverage from corn stover. The intent was to find the maximum potential influence on soil water evaporation by the corn stover. The wheat stubble dry matter and coverage decreased each year (table 1). The effects of wheat planting immediately following a summer annual crop may have been responsible for this trend. The wheat was planted on approximately November 1, which was 40 days later than wheat planted following fallow. The 2005 wheat crop was especially short in stature due to less fall growth.

Table 1. Crop residue mass and percentage cover at the end of the growing season for mini-lysimeters in soybean and corn field plots during 2003, 2004, 2005 near Garden City, Kansas.

Surface Cover	Dry Matter tons/ac	Residue Coverage* %
-------------------2003---------------------		
Bare	0.0	0
Corn	10.4	100
Wheat	15.2	N/A
-------------------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

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

The effects of surface cover type on soil water evaporation were analyzed in the soybean and corn crops (tables 2 and 3). The high frequency irrigation treatment in soybeans was imposed during 2003 and 2004, but the low frequency treatment was only used in 2004. Both irrigation frequency treatments were used in both years in corn. Both water treatments and all three vegetative growth observations were averaged together to obtain the results in tables 2 and 3. Average soil water evaporation for the bare surface treatments were significantly different from the two residue covered treatments in the corn and soybean crops in all years. Corn stover behaved somewhat differently in both crops except under soybeans during 2004. More dry matter for the wheat stubble in the 2003 lysimeters under soybeans promoted less evaporation losses. Less wheat stubble led to more evaporation, compared with the corn stover, in the corn crop during 2005

The crop ET, measured with soil water balance techniques, was the same for all surface cover treatments for each year, since all other treatments were averaged over surface cover. The 2004 cropping year was cooler and had more rainfall than 2003 and 2005. This is reflected in the ETc values for each year and crop. The ratios of E and ETc become a direct result of E. These results show the relative influence of surface residues coverage on soil water evaporation. The crop residues reduced the evaporation approximately by half compared with a bare surface.

Table 2. Average soil water evaporation (E), crop evapotranspiration (ETc), and evaporation as a ratio of crop evapotranspiration for all bare soil and soil covered with crop residues under a soybean crops during 2003 and 2004 in Garden City, KS.

Surface Cover	------------2003------------ Average Evaporation --in/day----	ETc --in/day---	E/ETc*	------------2004------------ Average Evaporation --in/day----	ETc --in/day----	E/ETc
Bare	0.080a	0.23	0.37a	0.06a	0.19	0.36a
Corn Stover	0.044b	0.23	0.21b	0.03b	0.19	0.18b
Wheat Straw	0.038c	0.23	0.18b	0.03b	0.19	0.18b
$LSD_{.05}$**	0.0005		0.03	0.0016		0.02

*E/ETc is the ratio of soil water evaporation and crop ET, measured with the water balance method.
**LSD is the least significant difference.
Means with same letters in the same columns are not significantly different for alpha=.05.

Table 3. Average soil water evaporation and evaporation as a ratio of crop evapotranspiration (ET) for all bare soil and soil covered with crop residues under a corn crop canopy during 2004 and 2005 in Garden City, KS.

Surface Cover	------------2004------------ Average Evaporation --in/day----	ETc --in/day--- -	E/ETc*	------------2005------------ Average Evaporation --in/day----	ETc --in/day----	E/ETc
Bare	0.07a	0.21	0.37a	0.06a	0.27	0.23a
Corn Stover	0.04b	0.21	0.19b	0.03c	0.27	0.12c
Wheat Straw	0.03c	0.21	0.17b	0.04b	0.27	0.14b
$LSD_{.05}$**	0.003		0.05	0.0002		0.01

*E/ETc is the ratio of soil water evaporation and crop ET, measured with the water balance method.
**LSD is the least significant difference.
Means with same letters in the same columns are not significantly different for alpha=.05.

Comparing soil water evaporation rates from one growth stage to the next can elucidate the influence of crop canopy development. The expected trend in energy limited evaporation is to decrease as shading increases until the crop starts to mature and lose leaf area. Concurrently, evaporative demand on the crop increases from planting through mid-season and then decreases later in the growing season.

Tables 4 and 5 summarize average soil water evaporation and crop ET by growth stage. Data for these tables were averaged over cover type and irrigation frequency. The soybean study in 2003 did not include irrigation frequency as a variable. Soybean results (table 4) are similar for both years, except during the pollination periods. Ten more days of data were collected during the pollination period in 2003, which may have influenced the outcome. Also, ETc was less during the 2003 pollination period, which further influenced E/ETc.

Results for E and ETc in the corn canopy (table 5) followed predictable patterns. E decreased as the crop developed and ETc increased from vegetative growth to pollination and decreased from pollination to seed fill. The proportion of E to ETc declined during the growing season when the two factors were combined.

Table 4. Soil water evaporation and evaporation as a ratio of crop ET during the growth stages of soybeans for all mini-lysimeter treatments during the 2003 and 2004 growing seasons at Garden City, KS.

Growth Stage	Measurement Periods	Average Evaporation	ETc	E/ETc
2003	2003	--in/day--	-in/day-	
Vegetative	Jul 18-31	0.067a	0.227a	0.31b
Pollination	Aug 1-20	0.065a	0.181b	0.36a
Seed Fill	Aug 21- Sep 6	0.027b	0.238a	0.12c
$LSD_{.05}$		0.005	0.016	0.04
2004	2004			
Vegetative	Jul 13-Aug 9	0.064a	0.131b	0.51a
Pollination	Aug 10-21	0.026b	0.208a	0.13b
Seed Fill	Aug 22-Sep 20	0.028b	0.212a	0.13b
$LSD_{.05}$		0.002	0.009	0.02

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

Table 5. Soil water evaporation and evaporation as a ratio of crop ET during the growth stages of corn for all mini-lysimeter treatments during the 2004 and 2005 growing seasons at Garden City, KS.

Growth Stage	Measurement Periods	Average Evaporation	ETc	E/ETc
2004	2004	--in/day--	-in/day-	
Vegetative	Jun 30-Jul 19,	0.071a	0.21a	0.36a
Pollination	Jul 20-Aug 12	0.04b	0.23a	0.23b
Seed Fill	Aug 13-Sep 20	0.027c	0.18b	0.15c
$LSD_{.05}$		0.003	0.02	0.049
2005	2005			
Vegetative	Jun 21-Jul 19	0.046b	0.26b	0.18a
Pollination	Jul 20-Aug 3	0.053a	0.31a	0.17a
Seed Fill	Aug 4-Sep 2	0.03c	0.23c	0.13b
$LSD_{.05}$		0.002	0.013	0.01

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

Cover type and growth stage variables were averaged to more easily explain the irrigation frequency variable (tables 6 & 7). Only 2004 soybean crop results were analyzed because 2003 did not have a water variable. More frequent irrigations led to more soil water evaporation and ETc in the high frequency than low frequency water treatments (table 6). Combining these two factors led to slightly less E in proportion to ETc for the high frequency irrigation treatment. The leaf area index (LAI) was not significantly different for the two irrigation frequencies.

Table 6. Soil water evaporation and evaporation as a ratio of crop ET for low and high frequency irrigation for all mini-lysimeter treatments in soybeans during the 2004 growing season.

Irrigation Frequency*	Average Evaporation --in/day--	ETc -in/day-	E/ETc	LAI**
Low	0.038b	0.173b	0.25a	4.7a
High	0.040a	0.205a	0.23b	5.1a
$LSD_{.05}$	0.0012	0.0063	0.02	0.34

*Number of irrigation events—4 for Low and 7 for High.
**LAI is leaf area index (leaf top surface area/ground area)
Means with same letters in the same columns are not significantly different.

Peak LAI shows the effect of the hail damage on the corn crop in 2005 (table 7). LAI was reduced in 2005 compared with 2004. During 2004 average E, ETc and E/ETc were more in the high irrigation frequency treatment than the low frequency treatment. Results in 2005 did not suggest a clear trend in average E and ETc. Again, ETc was more in the high frequency treatment than the low frequency. More ETc in 2005 may reflect more evaporative demand due to loss of leaf area from hail damage.

Table 7. Soil water evaporation and evaporation as a ratio of crop ET for low and high frequency irrigation for all mini-lysimeter treatments for corn during the 2004 and 2005 growing seasons.

2004 Irrigation Frequency*	Average Evaporation --in/day--	ETc -in/day-	E/ETc	LAI**
Low	0.042b	0.194b	0.22b	3.9b
High	0.05a	0.218a	0.28a	4.9a
$LSD_{.05}$	0.002	0.02	0.04	0.28
2005				
Low	0.046a	0.242b	0.185a	3.0b
High	0.042b	0.29a	0.143b	3.8a
$LSD_{.05}$	0.002	0.01	0.01	0.18

*Number of irrigation events—__ for Low and __ for High.
**LAI is leaf area index (leaf top surface area/ground area)
Means with same letters in the same columns for the same year are not significantly different.

Partial Cover Results from Control Area

Average daily evaporation decreased with increasing percentage of surface coverer (SC) and increases in surface cover dry matter (DM) (figures 1 and 2). There was a closer correlation of average E with dry matter than percentage of surface cover.

Twice per week irrigation frequency (high) produced 15% more evaporation than the once per week frequency (low) (table 8b). These data were from all surface cover types including bare and crop residue covered. Energy limited evaporation may have played a different roll in the types of surfaces.

The entire experimental period was subdivided into watering cycles consisting of approximately one week intervals. The data show some differences in average daily evaporation across the experimental period, but they also show the precision for the measurement process through the small significant differences that can be identified. Except for the first cycle, reference ET was consistent during the experimental period.

Table 8. Soil water evaporation study for full and partial crop residue surface covers conducted during September 7-October 6, 2005 at Garden City, Kansas.

		Average Evaporation	E/ETr*	Surface Cover Dry Matter
a. Surface Cover		--in/day--		--tons/ac---
Bare 0%		.054b	0.2b	0.00f
Corn 25%**		.066a	0.26a	0.51e
Corn 50%		.052c	0.19c	2.28c
Corn 65%		.065a	0.24a	1.64d
Corn 100%		.031e	0.12e	8.83a
Wheat 89%		.039d	0.15d	7.06b
$LSD_{.05}$		0.0016	0.0047	0.32
b. Irrigation* Frequency**				
Low		.055a	0.20a	
High		.048b	0.18b	
$LSD_{.05}$		0.0009	0.0027	
c. Water Cycle****				Reference ET -----in/day---
	1	.057a	0.16d	0.35
	2	.051c	0.21b	0.24
	3	.047d	0.19c	0.25
	4	.047d	0.17d	0.28
	5	.054b	0.24a	0.23
	6	.051c	0.19c	0.27
$LSD_{.05}$		0.0016	0.0047	

*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.
***Irrigation cycles were approximately one week in duration during Sept. 6 through Oct. 7, 2005.
Means with same letters in the same columns for the same variable are not significantly different.

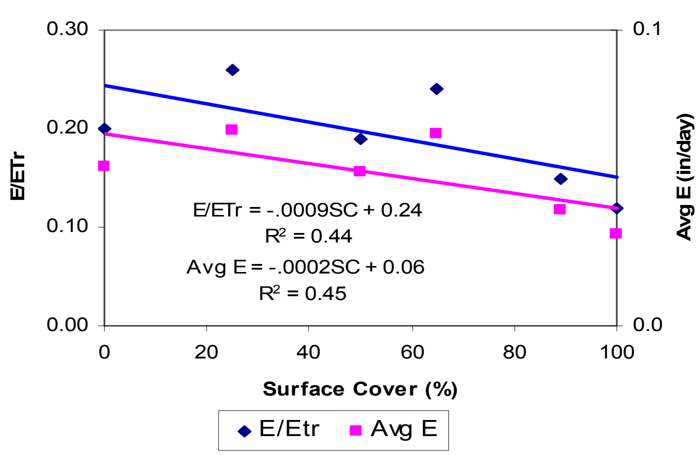

Fig. 1. Average soil water evaporation (AvgE) and E/ETr correlated with surface cover (SC) for corn stover and wheat straw residues on mini-lysimeters during Sept. 7-Oct. 6, 2005 near Garden City, KS.

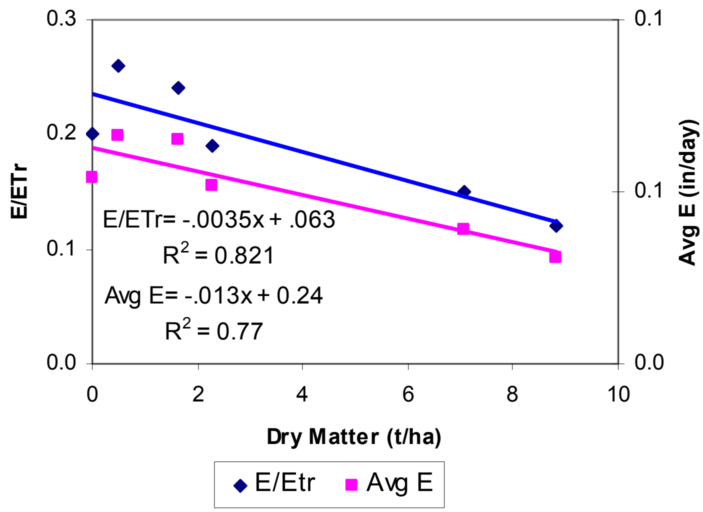

Fig. 2. Average soil water evaporation (AvgE) and E/ETr correlated with dry matter (DM) of corn stover and wheat straw residues on mini-lysimeters during Sept. 7-Oct. 6, 2005 near Garden City, KS.

Significance of Results:

The research showed that soil water evaporation in sprinkler irrigation could be reduced by crop residues by approximately 18% of ETc in soybeans and 9-11% in corn (tables 2 and 3). Because these measurements were collected from late vegetative to late seed fill growth stages, whole growing season savings would be more. Average growing season ETc for soybeans and corn would be 21 and 24 inches, respectively, in western Kansas. Over 120 day growing seasons, water savings could be 3.8 and 2.4 inches for soybean and corn, respectively.

If crop residue management techniques were adopted across all irrigated fields in western and central Kansas, very significant economic gains are possible. There were 139,000 ac of irrigated soybeans in the western third of Kansas and 227,300 ac in the central third for a total of 366,300 ac as reported in 2005.

Recent reports show that center pivots irrigate 80% of total irrigated land. If this holds true for soybean production in western 2/3 of Kansas, 293,000 acres could benefit from this research.

These water savings would have two major impacts on profitability. Irrigation pumping costs for average well depths in western Kansas have risen to $5-$9/ac-in recently, which means the operating cost of the evaporation savings would be impacted by $15-$27/ac. For irrigators with limited water supplies the water savings translates into crop production because the water becomes available to the crop. For top producers, an inch of water could be translated into 4 bushels of soybeans or 12 bushels for corn if water is a limiting factor. This would convert into an extra 15 bu/ac of soybeans and 29 bu/ac bushels of production from management of crop residues for evaporation suppression.

Assuming that soybean production in western Kansas is predominately in 30-inch rows, the overall economic impact of this research, if adopted, could be significant. For those fields with adequate well capacity, the economic impact of this research would be the pumping cost reduction. Assuming half the acreage in western Kansas has adequate well capacity, the pumping cost savings on 146,520 acres would be approximately $2.2 to $3.9 million annually. For the remainder of fields with inadequate well capacity, the economic impact from this research would be 12 bu/ac at $5/bu over 146,520 acres for a total of $8,791,000 annually.

Non-growing season benefits combine with the growing season benefits of crop residues for soil water evaporation suppression, infiltration enhancement, runoff reduction, soil erosion reduction, water quality enhancement, fertilizer savings, and snow entrapment. Dryland research indicated that off-season water conservation benefits from crop residues are worth at least 2 inches annually in the central plains states. These benefits all add to the growing season advantages of crop residues studied in this project.

The project gives irrigators concrete data to justify saving crop residues on the surface for suppression of soil evaporation. Also, water policy makers will have documented information on the economic impact of crop residues on water savings from irrigation in western Kansas. This will be important to justify funding for conservation programs and realistic water allocation programs in the future.

References:

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