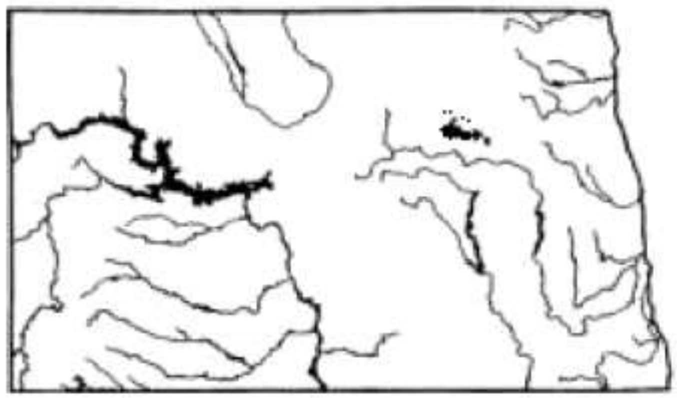

Technical Report No: ND12-02

REFERENCE EVAPOTRANSPIRATION AND ACTUAL EVAPOTRANSPIRATION MEASUREMENTS IN NORTH DAKOTA

Ishara Rijal and Xinhua Jia
Department of Agricultural and Biosystems Engineering
North Dakota State University
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Ishara Rijal[1] and Xinhua Jia[2]

Water Resources Research Institute Fellow[1] and Assistant Professor[2]

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ABSTRACT

Water balance field study was conducted at Fairmount, ND in 2010. The total area of the field (44 ha) was divided into two plots, subsurface drained (SSD) and undrained (UD) with drain line at approximately 1.1 m depth and drain spacing of 18.2 m. Evapotranspiration (ET) rates were measured in both the SSD and UD plots using eddy covariance (EC) systems. The changes in soil moisture content and water table were measured continuously in both the SSD and UD plots. Crop coefficient (K_c) values were developed using the ET measured by the EC system and the reference ET (ET_{ref}) estimated using the American Society of Civil Engineers Environmental and Water Resources Institute (ASCE-EWRI) alfalfa method. According to the results, shallow water table and high soil moisture content in the spring and fall resulted in a higher ET in the UD plot. In the summer, the ET in the SSD field was higher than that in UD field by 13 % in 2010. However, during the entire growing season, ET measured between the SSD and UD field did not yield any significant difference. The K_c reached its maximum in the SSD field during July and August.

ACKNOWLEDGEMENTS

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INTRODUCTION

Evapotranspiration (ET), a major component of water balance, can be directly measured via soil water balance (SWB) or energy balance approaches. Lysimeter, soil water balance and eddy covariance (EC) are widely used direct methods to measure the actual ET. Lysimeter and EC methods have been considered as the standard methods to measure ET compared to all other methods (Farahani et al., 2007).

Soil water balance is a widely used method in North Dakota (ND) to estimate the ET. In ND, crop coefficients for several crops (corn, soybean, potato, sorghum, etc.) were developed using ET estimated by soil water balance and reference evapotranspiration rate (ET_{ref}) by Jensen-Haise method (Jensen and Haise, 1963). The measurement of all components of water balance becomes challenging in areas which have fluctuating water table and subsurface drainage (Nachabe et al., 2005). Both the lysimeter and soil water balance methods undergo site disturbance and can provide only a point ET measurement. Measuring ET with lysimeter is challenging in areas with shallow water table (Jia et al., 2006).

The EC method does not require the measurement of all the components in the water balance (Twine et al., 2000). It is concentrated on an aerial ET measurement, which is above the crop canopy and has less site disturbance compared to the lysimetry method (Sumner, 2001). Modern, precise, and high speed instruments are used in the system. Sensors for measuring vertical wind speed (~ 10 Hz), temperature and humidity have enabled rapid computation of ET electronically (Campbell and Norman, 1998). The EC system measures the ET above the crop canopy, overcomes the site disturbance and the need of measuring individual component of water balance, and is independent of the soil surface condition (Sumner, 2001; Twine et al., 2000). The EC system also covers a large area of measurement to account for the upwind distance of about 100 times the sensor height above the crop canopy (Campbell and Norman, 1998).This system has been used to measure the ET of several vegetation types in the U.S. (Sumner, 2000; Jia et al., 2007, 2009) and around the world (Li et al. 2008; Testi et al., 2004).

The ET rates can also be estimated indirectly utilizing crop coefficient (K_c) and reference ET. Different weather parameters, including temperature, rainfall, wind speed and solar radiation are used to estimate the ET_{ref} (Allen et al., 1998; Doorenbos and Pruitt, 1977). Among all the methods, the American Society of Civil Engineers, Environmental and Water Resources Institute (ASCE-EWRI) method by Allen et al. (2005) is considered as the standardized and widely accepted method for ET_{ref} calculation (Allen and Pereira, 2009; Farahani et al., 2007).

The ET of a particular area depends on the change in the water table (Cooper et al., 2006; Nachabe et al., 2005). Though the subsurface water contributes to ET, it is difficult to directly measure the precise amount contributing into the ET (Nachabe et al., 2005). A shallow ground water table results in a higher ET. Under optimum soil moisture content, the ET is higher (Payero et al., 2008). Thus, ET of the particular crop depends on the soil moisture content and the depth of water table.

In humid areas, the presence of excess water in the root zone is always problematic. Subsurface drainage (SSD) is a process to remove excess water from the root zone at some depth below the soil surface via perforated conduits (Skaggs et al., 1999). The SSD maintains the optimum soil moisture condition, lowers the water table depth and enhances the nutrient and the water uptake by the plants (Ayars et al., 2006; Skaggs et al., 1999). The SSD can help improve the field condition and traction of the field, and support easy planting and harvesting of the crops. Application of the SSD system affects the quantity of water in the SSD field as well as the surface water system that it drains to (Skaggs et al., 1994).

Majority of SSD research is focused on hydrology and water quality (Kahlown and Azam, 2002; Skaggs et al., 1994). None of the research focus on the development of crop coefficient (K_c) in SSD and undrained (UD) field. A comparison of ET between controlled drainage and UD (having no artificial subsurface drainage system) field yielded the higher ET in the SSD field in summer and lower in spring and fall than that of UD field (Tan et al., 2002). It is thus expected that the artificial modification of the water table via SSD could change the ET of the crop and reversely, crop ET can affect the drainage water amount that alters the surface water hydrology and a regional water balance. Therefore, it is important to accurately measure the ET and compare its difference between two agricultural water management practices, SSD and UD system.

OBJECTIVES

The major objective of this study is to develop crop coefficients (K_c) for soybean using the ET measured by the EC system and the ET_{ref} estimated by ASCE-EWRI equation such that the K_c results can be transferred and used to estimate ET of similar fields.

1. Evaluate the ET for both subsurface drained and undrained soybean fields using the EC system.
2. Compare the reference ET estimated by the ASCE-EWRI 2005, and the Jensen-Haise 1963.

MATERIALS AND METHODS

Study area and field layout

The experimental site (46^{o}00’45” N and 96^{o}35’47” W) was located in the southeastern part of North Dakota at Fairmount, Richland County. The total area of the experimental site was 44 ha, which was divided into two treatments: SSD field (≈22 ha), and UD field (22 ha). Within the SSD field, 50% of the field (11 ha) also had a subirrigation (SI) treatment (Figure 1). There was no isolation device installed between the SSD and the SI fields, therefore, a small amount of water may flow unintentionally into the SSD field. The SSD system was installed in August 2002 at an approximate depth of 1.1 m and a spacing of 18.3 m (Jia et al., 2008). The main drainage pipe was located on the east side of the field extending to the outlet buried at a depth of 1.8 m.

The experimental site has a typical continental climate. The average monthly air temperature varies from -14^{o}C in January to 22^{o}C in July. The area is covered by snow for 4-5 months (Nov-Mar). The average annual precipitation of the study area is 557 mm, with the major rainfall events observed from May to September (NDAWN, 2011). Corn and soybean are the major crops grown in the study area. They are normally grown in rotation at the site. In 2010, soybean was planted.

The total width of the field was 806 m and the length 546 m. Two alleys, each 3 m wide, were made in the field 366 m apart from each other (Figure 1). The alleys were used for transportation and instrument installation. A lift pump and standard national weather service manual rain gage was located to the north-eastern corner of the field. A weather station with a complete EC system was installed in both the UD and SSD fields. The EC stations were operated from May 8, to September 29, 2010; soybeans were planted on May 22, emerged on June 1 and harvested on September 30, 2010. The height of the EC station was determined such that the source area (footprint) of the measurements was confined within the extent of each sub-field (Zhang et al., 2010).

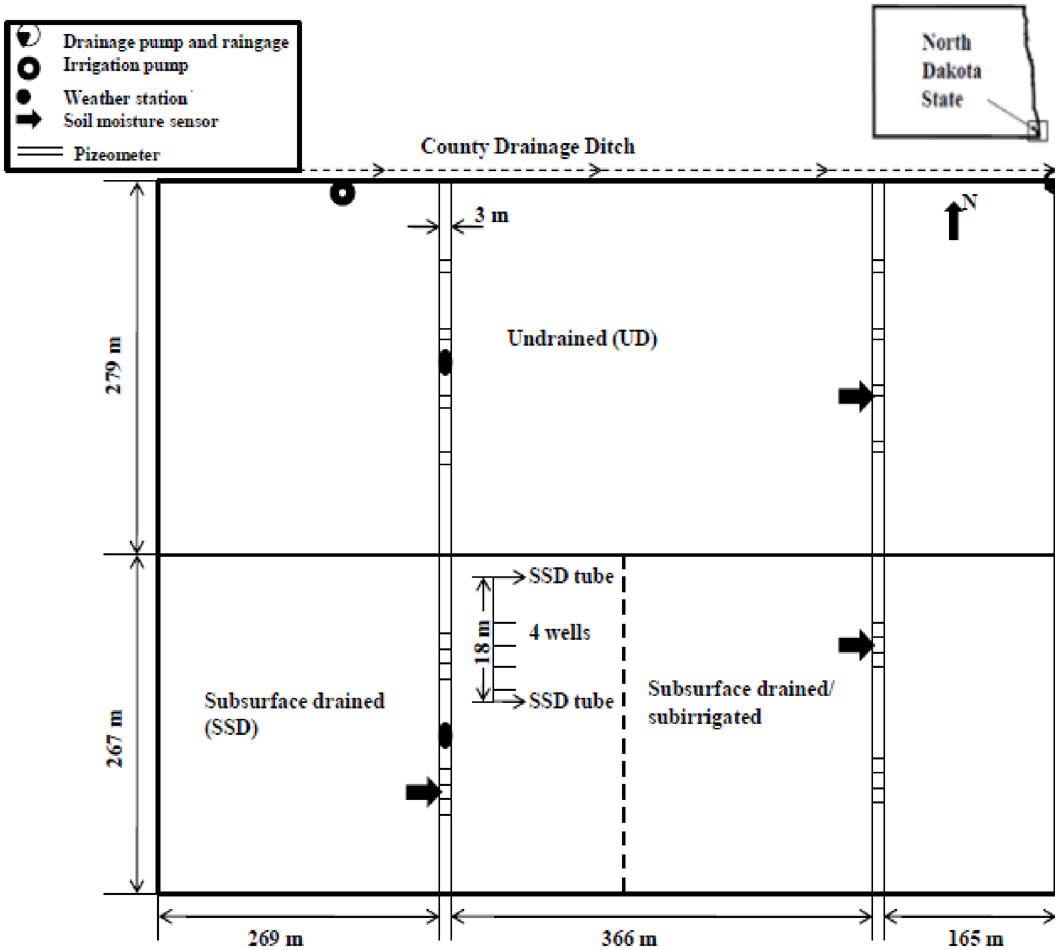

Figure 1. Field layout and instruments location.

In fall 2007, 24 piezometers (shallow wells) were installed along the two alleys that ran north to south in the field; with eight piezometers in each water management field. Water level transducers (Model U 20-001-01, Onset Computer, PocA11asset, MA, USA) were installed in each piezometer. Water level changes were automatically recorded at 30-minutes intervals. Twelve soil moisture sensors, Hydraprobe II (Stevens Water Monitoring Systems, Portland, OR) were installed at two locations at six different depths; 15, 30, 45, 60, 90 and 120 cm from the soil surface. The horizontal spacing in the SSD field was set at 4 m and 7 m from the SSD line, whereas, in the UD field, the two sets were 3 m apart from each other.

Instrumentation

Two weather stations with complete EC systems were installed in the UD and SSD portion of the field. Instruments used in this project were either newly purchased or calibrated before installation. The EC system consisted of CSAT3 sonic anemometer, CSI KH20 Krypton hygrometer, and other setup as shown in Table 1. The scan interval of the sensors was 50 msec (20 Hz) and the recording was averaged to every 30-minute values.

Table 1. Complete eddy covariance weather stations and their instrument height, at Fairmount, ND in 2010. Negative height values indicate depth below the soil surface.

	Height of instruments (m)	
	2010	
Instruments	**SSD**	**UD**
CSI CSAT3 3D Sonic Anemometer	2.49	1.85
CSI KH20 Krypton Hygrometer	2.49	1.85
R.M. Young Wind Sentry Set	2.88	2.09
Texas Elec. TE525WS Tipping Bucket	3.12	3.12
REBS Q7.1 Net Radiometer	1.75	1.46
Vaisala HMP45C Temp/RH Sensor	2.58	2.14
HFP01SC Hukseflux Self-Calibrating Soil Heat Flux Plate (1)	-0.08	-0.08
HFP01SC Hukseflux Self-Calibrating Soil Heat Flux Plate (2)	-0.08	-0.08
TCAV Averaging Soil Thermocouple Probe (1)	-0.02	-0.02
TCAV Averaging Soil Thermocouple Probe (2)	-0.06	-0.06
CS616 Water Content Reflectometer (1)	-0.05	-0.05
CS616 Water Content Reflectometer (2)	-0.15	-0.15

ET calculation

The ET measured by the EC system is equivalent to latent heat flux (LE). Sensible heat (H) and LE fluxes were measured using the CSAT3 sonic anemometer and the CSI KH20 hygrometer, respectively. The fluctuation of vapor density and vertical wind speed was used to estimate LE (equation 1) (Sumner, 2001). Similarly, H was calculated using the fluctuation of vertical wind speed and fluctuation of air temperature (equation 2) (Sumner, 2001).

$$LE = \lambda \overline{w' \rho_v'} \tag{1}$$

$$H = \rho C_P \overline{w' T'} \tag{2}$$

where ρ_v' is the fluctuation of water vapor density in kg/m^3; w' is the fluctuation of vertical wind speed in m/s; and λ is the latent heat of vaporization in J/kg. The overbar represents average over the sampling period and prime is the deviation from the mean values during the averaging period. H is sensible heat flux in W/m^2; ρ is the density of air in kg/m^3; C_p is the specific heat in J/g ^{o}C; and T' is the fluctuation of air temperature in ^{o}C.

Data analysis was performed using only daytime values. At night, the energy fluxes were considered to be zero. Data from KH20 hygrometer might not be available in the early morning and after rainfall due to the vapor in its lens.

The LE recorded every half hour was corrected for temperature induced fluctuations in air density (Webb et al., 1980). The sensible heat flux was corrected to account for the difference between the virtual and actual air temperature. Both sensible heat flux and the latent heat flux were corrected for the error due to natural wind coordinate system (Baldocchi et al., 1988), and the average vertical wind speed was forced to zero. The Bowen ratio method was used to close the energy balance for each 30 minute period (Twine et al., 2000). This Bowen ratio closure method assumes that the EC system measures the Bowen ratio correctly. Moreover, it overcomes the underestimation of the LE flux measured by the EC system.

The modified Priestley Taylor (PT) approach was used to fill in the missing 30- minute LE values (Priestley and Taylor, 1972). The required empirical coefficient (α) in the PT equation was determined from the available LE, H, R_n, G and temperature data using equation 3. The monthly value of α ranging from 0.74 to 1.23 was used to estimate the 30 minute LE in that month instead of a constant α 1.26 for all season (Priestley and Taylor, 1972).

$$\alpha = \frac{\lambda E(\Delta + \gamma)}{\Delta(R_n - G)} \qquad (3)$$

where α is the PT constant, λE is latent heat flux in W/m^2, R_n is the solar radiation in W/m^2, G is soil heat flux in W/m^2, Δ is slope of the saturation vapor pressure curve, in $Pa/^oC$, and γ is psychrometric constant, in $Pa/^oC$.

The soil heat flux (G) sensors were not functioning properly in 2010. However, the soil temperature and soil moisture were measured. Using the measured data in 2009, a relationship was developed based on soil moisture at the depths of 5 and 15 cm and soil temperature between 2 and 6 cm from the soil surface. It showed a good agreement with R^2 greater than 0.7 when the data of growing season 2009 were used. Detail calculation steps are explained in Rijal (2011). Stored soil energy was estimated following Campbell Scientific (2007).

Reference evapotranspiration and crop coefficient

ET_{ref} was estimated using the weather parameters recorded in Wahpeton weather station of NDAWN. The ET_{ref} was estimated using three different methods, ASCE-EWRI (2005) for grass and alfalfa reference crop and Jensen- Haise (1963) methods.

The crop coefficient value for soybean was developed for the SSD and UD fields using the ET_{ref} methods ASCE-EWRI (alfalfa and grass) and JH and the ET by the EC system. The K_c value was estimated following FAO 56 (Allen et al., 1998).

Statistical analysis

One way ANalysis Of VAriance (ANOVA) was conducted using Sigma Plot (11.0) (Systat Software Inc., Chicago, IL) to compare the daily ET of the SSD and UD field. The data were tested for normality using the Shapiro Wilk test. Kruskal-Wallis one way ANOVA was conducted if the normality test failed, otherwise, a regular ANOVA test was performed. Similarly, the comparisons were done between ET_{ref} value obtained from the ASCE-EWRI and the JH method. Additionally, the K_c values (ET from the EC system and ET_{ref} from ASCE-EWRI, alfalfa) between the SSD and UD field were compared.

RESULTS AND DISCUSSION

Distribution of soil moisture

The soil moisture distribution is affected by water management practices, soil properties, and soil textures. As expected, soil moisture values were different at different depths at a particular field condition. The available soil moisture (AW) in the root zone, down to 135 cm depth, exceeded 50% of the total available soil moisture (TAW) most of the time during the growing season 2010 in both the fields, indicating adequate soil moisture supply.

In 2010, both the fields had almost the same soil moisture content at deeper depths. At the depth of 75-135 cm from soil surface, the soil moisture in the UD field was greater compared to that in the SSD field. The higher rainfall observed in summer 2010 might have helped to maintain the optimal soil moisture content in entire depth at both fields. Similar, result was observed by Tan et al. (2002) during the cool growing season. Otherwise, they recorded higher soil moisture in the controlled drained field compared to that in the freely drained one. During summer, optimum soil moisture was maintained by preventing the drainage water outflow. Also, it was possible that the water from the subirrigated portion had moved to the SSD field through the SSD tubes.

Variation in water table depth

The water table in spring and late fall was close to the soil surface in the UD, and was shallower compared to that in the SSD field. The deeper water table in the SSD area was due to the pumping of water out of the field via the SSD system. However, from July to September, water table in the SSD field was shallower than that in the UD field. Soybean demands maximum water during the pod filling period (60-70 days after planting) and throughout maturity. Therefore, the drop in water table from late July to early September is likely due to the higher water demand of the soybean (Figure 2). The water conserved in the soil and SSD line supported the water uptake by the crop root in SSD field. In addition, the irrigation water from the subirrigation section might have flowed via SSD tube to the SSD field because there is no isolation device installed between the two fields. The water table in the SSD field was maintained below the SSD line (1.1 m) during most of the period in the growing season.

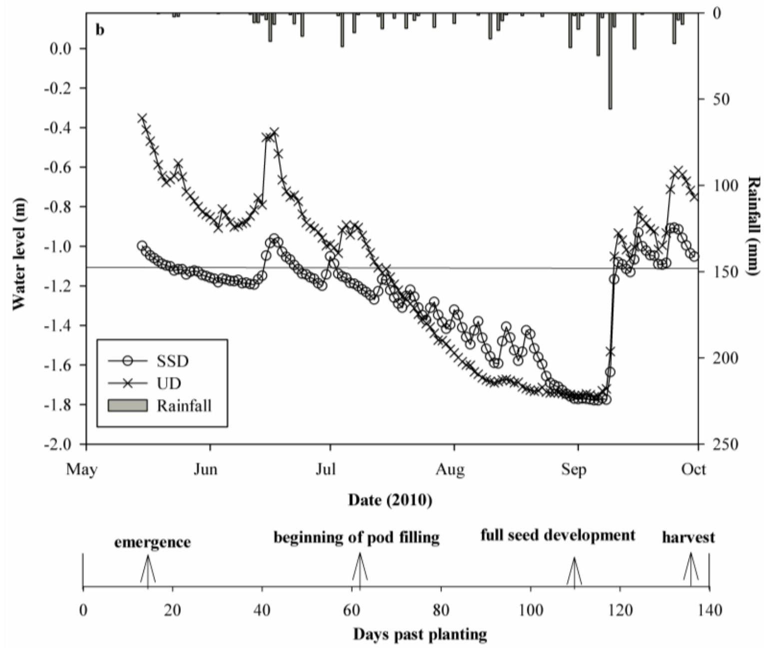

Figure 2. Measured water level in SSD and UD field during the growing season, 2010 along with the daily rainfall and stages of soybean development.

Temperature and precipitation

The average daily and monthly temperature of experimental area were higher by few degrees in peak growing season 2010 (July- August) than the average normal temperature of the Wahpeton station (Table 2). The evapotranspiration would be higher in sunny and bright days than on cool and cloudy days.

Rainfall was lower in the summer and higher in the fall. Frequent rainfall events during the active growing season contributed to the water requirement of crops in both fields. The rainfall received in summer 2010 might have met the water requirement of the field, which made the irrigation inefficient comparing to dry years.

Table 2. Average monthly air temperature and monthly rainfall amount of experimental site in growing season 2009 and 2010.

	Temperature, °C		Rainfall, mm	
Month	**Monthly average***	**2010**	**Monthly Total***	**2010**
Jun	19	21	85	62
Jul	22	24	90	72
Aug	21	23	68	64
Sept	15	15	62	152
Average/Total	**19**	**21**	**305**	**350**

* Average recorded from 2001 to 2009, Wahpeton, ND (NDAWN, 2010)

Energy fluxes

The monthly averages of LE, H, R_n, and G for both fields are listed in Table 3. The net radiation (R_n) in SSD field was higher compared to UD field during July and August. However, for other period of the season it was lower than the UD field. In 2010, the LE in the SSD field was higher in July, August and September (Table 3). Soybeans require more water during flowering and pod filling periods. The frequent and higher amount of rainfall in summer months (Table 2) might have supported the water requirement in both fields. The LE in both fields was higher in July and decreased in the late growing season. Maximum LE for soybean was noticed by Irmak (2010) at about 56 days after planting. Similar, pattern of LE was observed at our experimental field. Though LE and H did not show any confined relationship throughout the season, LE was higher than H values during July-August, indicating a larger fraction of energy available for the ET process.

Table 3. Average monthly energy fluxes (W/m^2) in the subsurface drained (SSD) and undrained (UD) fields during the growing season 2010.

Energy Fluxes (W/m^2)									
		SSD				UD			
Year	**Month**	**R_n**	**G**	**LE**	**H**	**R_n**	**G**	**LE**	**H**
2010	May	330	51	131	148	343	41	171	131
	Jun	296	36	127	134	324	35	144	145
	Jul	303	20	243	40	280	14	227	39
	Aug	264	18	211	34	287	17	208	62
	Sept	200	17	123	60	213	23	112	77

Daily actual evapotranspiration

Higher ET was observed during the summer and early fall. In the SSD field, higher ET was observed during peak growing season, especially from late June to the end of August. In May-June 2010, ET in the UD field was greater than that in the SSD field. In September, 2010 ET in both UD and SSD fields were comparable (Figure 3). The higher ET in the UD field during spring and late fall might be due to excess water in the soil near the surface. Also, during the spring, the evaporative ratio was higher in the UD field along with the low Bowen ratio. The higher ET during that period is probably due to higher evaporation in the UD field compared to the SSD field. In the UD field, water is either infiltrated into the soil, disappeared as runoff from the field, or evaporated back into the atmosphere. The higher evaporation rate might have resulted in the higher ET.

The ET was higher in the SSD field during July and August in response to the actual water consumed by crops. During July-August 2010, the total seasonal ET in the SSD field was greater by 13% compared to that in UD field. The shallower water table in the SSD field might have supported the water uptake of the plant. In 2010, the maximum ET in SSD and UD field was 6.44 mm/day in July 18 and 5.37 mm/day on July 26 respectively.

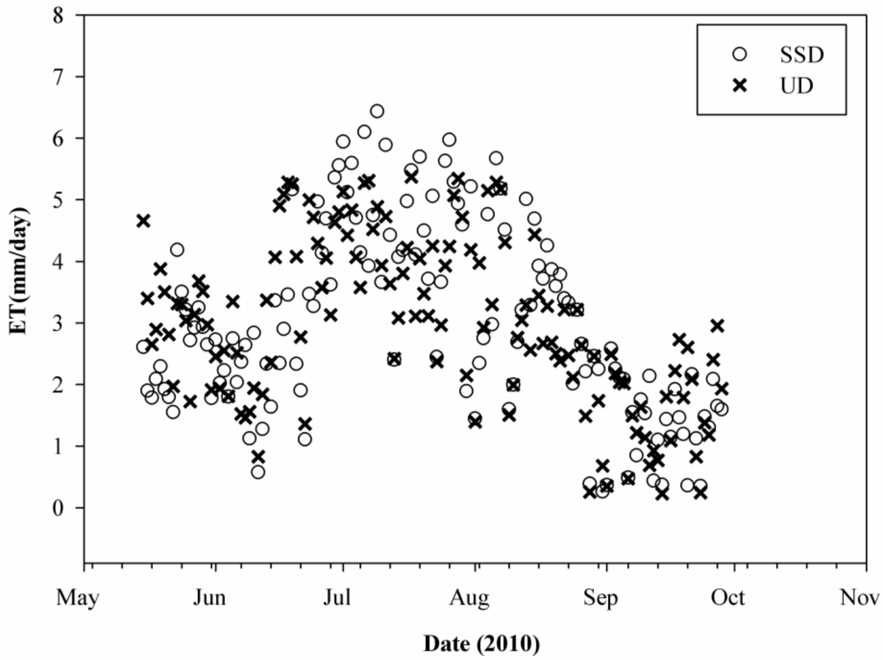

Figure 3. The daily average evapotranspiration observed in SSD and UD field during the growing season 2010.

In the summer (July-September), the water table became lower when ET started to increase, probably because soybean absorbed water from the root zone and caused lowering of water table from the soil surface. The drop in water table with the rise in ET rate was also observed by Skaggs et al. (1999) and Nachabe et al. (2005).

Comparing the daily ET values for the entire growing season, the ET measured in both the SSD and UD field did not yield any statistical difference. Throughout the growing season, the available soil moisture was more than 50% of total available soil moisture content to meet the crop water requirement. Though there was 0.2 m difference in the water table depth between the SSD and UD fields in summers (July-September) 2010, the difference was not large enough to cause large ET difference.

Reference evapotranspiration

The ET_{ref} estimated by the ASCE-EWRI method for both grass and alfalfa reference crops were higher than the ET_{ref} estimated by the JH method during the growing seasons 2010 (Table 4). During the entire growing season 2010 (20 May-30 September), the ET_{ref} estimated using ASCE-EWRI for alfalfa and grass were 846 mm and 665 mm respectively and the one from JH method is 625 mm.

Table 4. Monthly average reference ET (May 15- Nov 30) 2010, based on weather parameter of Wahpeton station, NDAWN* (NDAWN, 2011).

		ET_{ref} (mm/day)		
Year	**Month**	**ASCE, alfalfa**	**ASCE, grass**	**JH**
	May	9.61	7.17	5.97
	Jun	6.85	5.34	4.95
	Jul	6.95	5.67	5.96
2010	Aug	5.99	4.83	4.88
	Sept	3.87	2.99	2.25
	Oct	4.08	2.85	1.45
	Nov	1.54	1.06	0.33

*NDAWN- North Dakota Agricultural Weather Network

The JH method estimated lower ET_{ref} value compared to ASCE-EWRI method throughout the growing season. However, during mild wind conditions, the ET_{ref} values by JH method were comparable to that by the ASCE-EWRI (grass) method. The monthly ET_{ref} values were different depending on the type of method used. The JH method was found to underestimate ET_{ref} values during the windy conditions. The underestimation of the ET_{ref} by the JH method during May-June and September-November was attributed to the presence of high wind during those days. Similar, result had been reported by Irmak et al. (2008), and Trajkovic and Kolakovic (2009). The underestimation of ET_{ref} will yield underestimation of actual ET, which could lead to errors in water balance estimation and water management practices. The ET_{ref} estimated by the ASCE-EWRI grass and alfalfa references and JH methods showed a statistical difference ($P < 0.001$) throughout the experimental period.

Soybean crop coefficient

The soybean K_c (from ET by EC system and ET_{ref} ASCE, alfalfa) obtained was higher in the SSD field in June, July and August compared to that in the UD field. The highest monthly K_c value in the SSD field was obtained in July ($K_c = 0.76$). The average monthly soybean K_c was higher in the UD field in May (Figure 4) compared to that in the SSD field. The monthly average K_c was the same in both the fields in September. The higher K_c value indicated higher crop water use in the SSD field during the peak growing season. Though some variations was observed in K_c values (ET from EC and ET_{ref} from ASCE- EWRI, alfalfa) between SSD and UD fields, it did not yield any statistical difference.

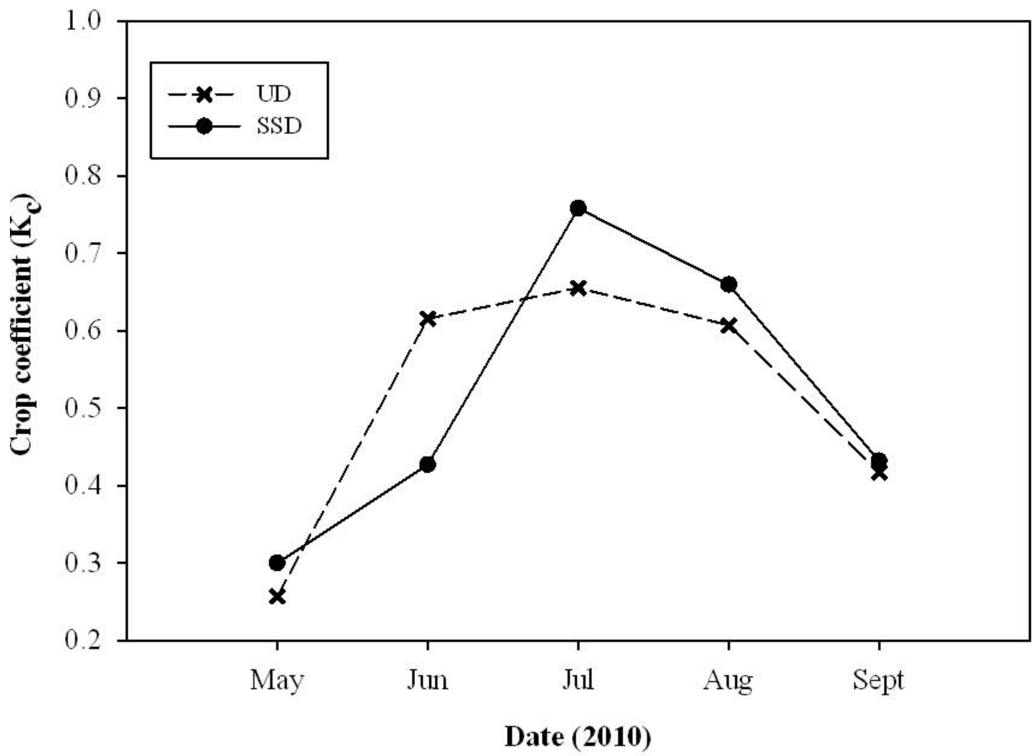

Figure 4. Soybean crop coefficient of SSD and UD field, using ET measured by the EC system ET_{ref} estimated from ASCE-EWRI (alfalfa).

Stegmen et al. (1977) obtained maximum monthly K_c (1.08) in August. The delay in peak K_c from July to August implied a difference in soybean variety. The soybean variety planted in the experimental field, Pioneer Hi-Bred 90M60, was a special high protein soybean variety, typically grown in South Dakota and Iowa. The delay in peak indicated a late maturity and late harvesting of soybean in the past. Also, the difference in K_c value could be due to method used to estimate the actual ET and ET_{ref} (Table 5). Stegmen et al. (1977) used the SWB method to estimate ET and JH method to estimate the ET_{ref}. As they ignored the deep percolation in the SWB method, it could mislead both the ET and K_c values. In contrast, the soybean K_c in the experimental site was developed using ET estimated from the EC system and the ET_{ref} estimated using ASCE-EWRI (alfalfa reference) method (Table 4) which could have yielded different results. The differences in the ET_{ref} estimated between ASCE-EWRI references methods produce difference in K_c values. The same principle applies when comparing ASCE-EWRI (grass and alfalfa) and JH method.

Table 5. The soybean crop coefficient (K_c) value of SSD and UD fields estimated from ET measured by the EC system and ET_{ref} from both JH and ASCE-EWRI (grass and alfalfa) along K_c developed by FAO 56, Stegmen et al. (1977) with the reference ET method they used and standard deviation.

Crop coefficient (K_c) of soybean

Month	FAO 56	Stegmen* et al. (1977) JH	SSD JH	SSD ASCE-EWRI, grass	SSD ASCE-EWRI, alfalfa	UD JH	UD ASCE-EWRI, grass	UD ASCE-EWRI, alfalfa
May	0.4	0.18 (0.003)	0.44 (0.13)	0.37 (0.10)	0.30 (0.08)	0.54 (0.21)	0.45 (0.20)	0.35 (0.17)
Jun	0.4	0.38 (0.14)	0.6 (0.18)	0.54 (0.17)	0.43 (0.15)	0.88 (0.75)	0.75 (0.60)	0.61 (0.52)
Jul	0.88	0.90 (0.13)	0.82 (0.14)	0.89 (0.13)	0.76 (0.12)	0.72 (0.28)	0.78 (0.26)	0.65 (0.22)
Aug	1.15	1.08 (0.05)	0.80 (0.18)	0.80 (0.18)	0.66 (0.16)	0.75 (0.22)	0.74 (0.23)	0.61 (0.21)
Sept	0.71	0.63 (0.21)	0.70 (0.29)	0.52 (0.24)	0.43 (0.19)	0.73 (0.18)	0.53 (0.21)	0.42 (0.17)

* Stegmen et al. (1977) estimated ET using SWB methods.

CONCLUSIONS

The soybean ET rates were measured in the growing season 2010 in the SSD and UD fields in the southeastern part of ND. Though some difference in magnitude between the daily ET rates of the SSD and UD field was observed, it did not yield any statistical difference in ET between the two fields for the entire season. The K_c was derived using the ET measured from the EC system and the ET_{ref} from ASCE-EWRI (alfalfa) methods. The soybean K_c was the highest in July, 0.76 and 0.65 in the SSD and UD field, respectively. In early and late growing season, K_c

was comparable in both the fields. The higher soybean K_c in May in the UD could be due to higher ET in the UD field during that period.

The continuous recording of data of energy fluxes and other weather parameters were disturbed by the battery power. Though the battery was incessantly charged with the solar panel, the battery was out of power during gloomy and rainy days. In future, while conducting such a field experiment, other alternative source of power, such as wind energy, should be used.

A year of study in the particular crop may not be sufficient to study the ET of certain crop and field. The study should be continued for some more years at least to catch the two growing season for a particular crop.

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