



Evapotranspiration and components of corn (*Zea mays* L.) under micro irrigation systems in a semi-arid environment

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Abstract

Aim of study: This work summarizes the influence of surface drip irrigation (DI) and subsurface drip irrigation (SDI) systems on corn growth indices and actual evapotranspiration (ET_{c-act}) and its components of plant transpiration (T_p) and soil evaporation (E).

Area of study: Karaj, Iran

Material and methods: The experimental soil was loamy. The corn ET_{c-act} of each mini-lysimeter was measured based on the water balance method. The E was measured using two mini-lysimeters and T_p was estimated from the difference between ET_{c-act} and E.

Main results: The resulting data showed that the ET_{c-act} was lower under SDI (384.8 mm) than under DI (423.4 mm). The K_{cb-m} for the corn increased after sowing and peaked during the mid-season stage, with an average value of 0.47, a minimum value of 0.0 and maximum value of 1.52 under DI and 0.53, 0.0 and 1.74 respectively, under SDI. For K_{e-m} , the average, minimum and maximum values were 0.33, 0.20 and 0.58 under DI and 0.23, 0.15 and 0.46 respectively, under SDI. The biomass yield was much higher under SDI (81.90 ton/ha) than under DI (63.21 ton/ha). Less E and more T_p occurred under SDI than under DI. SDI achieved superior WUE (8.32 kg/m³) compared with DI.

Research highlights: SDI was superior to DI based on biomass yield, corn height, stem diameter, and leaf area index which contributed to more favorable soil moisture conditions and low weed incidence; Thus, the SDI system is more productive and would better increase WUE than the DI system.

Additional keywords: *Zea mays* L.; growth indices; lysimeter; LAI; plant transpiration; soil evaporation; water use efficiency

Abbreviations used: D (stem diameter); DI (surface drip irrigation); E (soil surface evaporation); ET_{c-act} (actual crop evapotranspiration); H (plant height); K_{cb} (basal crop coefficient); K_{cb-adj} (adjusted basal crop coefficient by FAO-56); K_{cb-m} (measured basal crop coefficient); K_e (soil evaporation coefficient); K_{e-adj} (adjusted soil evaporation coefficient by FAO-56); K_{e-m} (measured evaporation coefficient); LAI (leaf area index); SDI (subsurface drip irrigation); SPAC (soil-plant-atmosphere continuum); T_p (plant transpiration); WUE (water use efficiency).

Authors' contributions: HD: conceived and designed the experiments, supervised the work, interpreted the data and co-wrote the paper. EK: performed the experiments and drafted the manuscript. SA: substantial contributions to the conception of the work and acquisition, analysis, interpretation of data. All authors approved the final manuscript.

Citation: Dehghanisani, H; Kanani, E; Akhavan, S (2020). Evapotranspiration and components of corn (*Zea mays* L.) under micro irrigation systems in a semi-arid environment. Spanish Journal of Agricultural Research, Volume 18, Issue 2, e1202. <https://doi.org/10.5424/sjar/2020182-15647>

Received: 25 Aug 2019. **Accepted:** 09 Jun 2020.

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Funding agencies/institutions

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Competing interests: The authors have declared that no competing interests exist.

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Introduction

Corn (*Zea mays* L.) is a major cereal crop in Iran, ranking third in cultivated area and production after wheat and rice. Since the susceptibility of corn to drought is one of the production challenges in arid and semi-arid regions, providing enough irrigation water for its growth is required. Gi-

ven the importance of this crop and the decreasing availability of agricultural water resources, increasing water use efficiency (WUE) to produce more crops with the available water is highly important to stable agricultural development. Since water is the most limited resource in arid and semi-arid regions, the agricultural sector should produce more food with less water (Zwart & Bastiaanssen, 2004).

The use of drip irrigation (DI) systems is an effective strategy for increasing water availability in the future (Enciso *et al.*, 2015). The subsurface drip irrigation (SDI) system is the most efficient micro-irrigation methods in arid and semi-arid regions, where the evaporation rate is high during the growing season (Kalfountzos *et al.*, 2007; Sharma *et al.*, 2010). The SDI has greater WUE and saves more water, helping to preserve the nutrients used by crops in comparison to other irrigation methods (Schneider & Howell, 2001; Paul *et al.*, 2013; Panigrahi *et al.*, 2016; Liu *et al.*, 2017; Zhang *et al.*, 2017). The SDI has a larger wetted soil volume than the DI and hence, the volume of available soil for root growth is higher, while the wet radius in the SDI is smaller than that under the DI. In general, under similar irrigation conditions, access to water and nutrients under SDI is increased and root rot and other soil diseases are minimized (Phene & Ruskin, 1995; Kalfountzos *et al.*, 2007).

For the above reason, the SDI has been recommended as a high-efficiency method, reducing water losses through soil surface evaporation and creating more suitable conditions for plant transpiration (Tiwari *et al.*, 2014, Parthasarathi *et al.*, 2017; Reddy *et al.*, 2018). A large number of experiments have been conducted to define the main advantages of SDI for several crops, and its superior performance was confirmed in all of them (Seyfi & Rashidi, 2007; Van Donk *et al.*, 2013; Albasha *et al.*, 2015; Biswas *et al.*, 2015; Lamm, 2016). Thus, the SDI can be an alternative to other irrigation methods and could be used to increase the growth of fruits, vegetables and row crops due to the precise application of water and provision of adequate moisture in the root zone (Imtiyaz *et al.*, 2000). Unfortunately, knowledge of irrigation water management at the farm level is poorly developed in Iran and most of the farmers act based on their own experience. Therefore, detailed on-farm information on water and crop could support the design and management of sustainable and beneficial irrigation systems.

The aim of this work was to evaluate the corn growth indices and actual evapotranspiration (ET_{c-act}), *i.e.*, plant transpiration (T_p) and soil evaporation (E) under DI and SDI systems to understand how the advanced irrigation systems could benefit growers from the point of view of yield and water use.

Material and methods

Experimental site

The experiments were carried out at the Agricultural Engineering Research Institute (35°46' N, 50°55' E, 1260 m a.s.l.) during the 2014 and 2015 growing seasons. The area is semi-arid with an average annual precipitation of approximately 279.3 mm. Daily meteorological data

(air temperature, relative humidity, wind speed, rainfall, and solar radiation data) were collected from a synoptic meteorology station, 5 km from the field site. Average daily values of meteorological characteristics are shown in Fig. 1. The minimum air temperature during the 2014 and 2015 corn growing seasons ranged from 5.7 to 23.6°C and 9.5 to 25.5°C, respectively. Also, the average maximum air temperature ranged from 20.8 to 41.4°C and 23.2 to 39.7°C, respectively. The daily relative humidity was 11 to 90% and 15 to 87%, respectively. On average, wind speed and solar radiation were higher in 2014 by about 6.4 and 2.7%, respectively (Fig 1).

The experimental soil was loamy with mean volumetric field capacity and permanent wilting point of 22.3 and 9.63%, respectively; the mean soil bulk density was 1.42 g/cm³ (Table 1).

To monitor water consumption by corn under DI and SDI, eight mini-lysimeters (Dugas & Bland, 1989; Kong *et al.*, 2012) were placed within a corn farm of 18-ha considering having adequate fetch and filled with soil excavated from the study site to resemble the original soil profile conditions. The mini-lysimeters had a diameter of 40 cm and a depth of 70 cm. Every 6 mini-lysimeters were used as three replicates for DI and SDI, respectively. The DI and SDI were equipped with 40 cm emitter apart and discharge of 4 L/h. For the subsurface drip irrigation, the drip-line was buried 30 cm below the soil surface. Inside each mini-lysimeters, three forage corn (Single Cross 704) seeds were planted with 13 cm spacing on 6th August 2014 and 2015. Water and nutrients were optimally provided for the mini-lysimeters. Each of the treatments received the same amount of water and nutrients through DI or SDI during each growing season. The depth of water applied for each of the two experimental seasons is shown in Fig. 2. Additionally, two unplanted mini-lysimeters were used to measure evaporation from the soil surface under DI and SDI, and were placed near the other mini-lysimeters.

Irrigation management

The required irrigation water depth was estimated daily using the FAO-Penman-Monteith model (Allen *et al.*, 1998; Eqs. (1) and (2)) confirmed for the Karaj region by Dehghanisanij *et al.* (2004) and corn crop coefficient (K_c) recommended for Karaj by Farshi *et al.* (1997) according to the following equations:

$$ET_c = ET_0 \times K_c \quad (1)$$

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma [890 (T + 273)] U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \quad (2)$$

where ET_c is the crop evapotranspiration; ET_0 is the reference evapotranspiration (mm/day); R_n is the net radiation

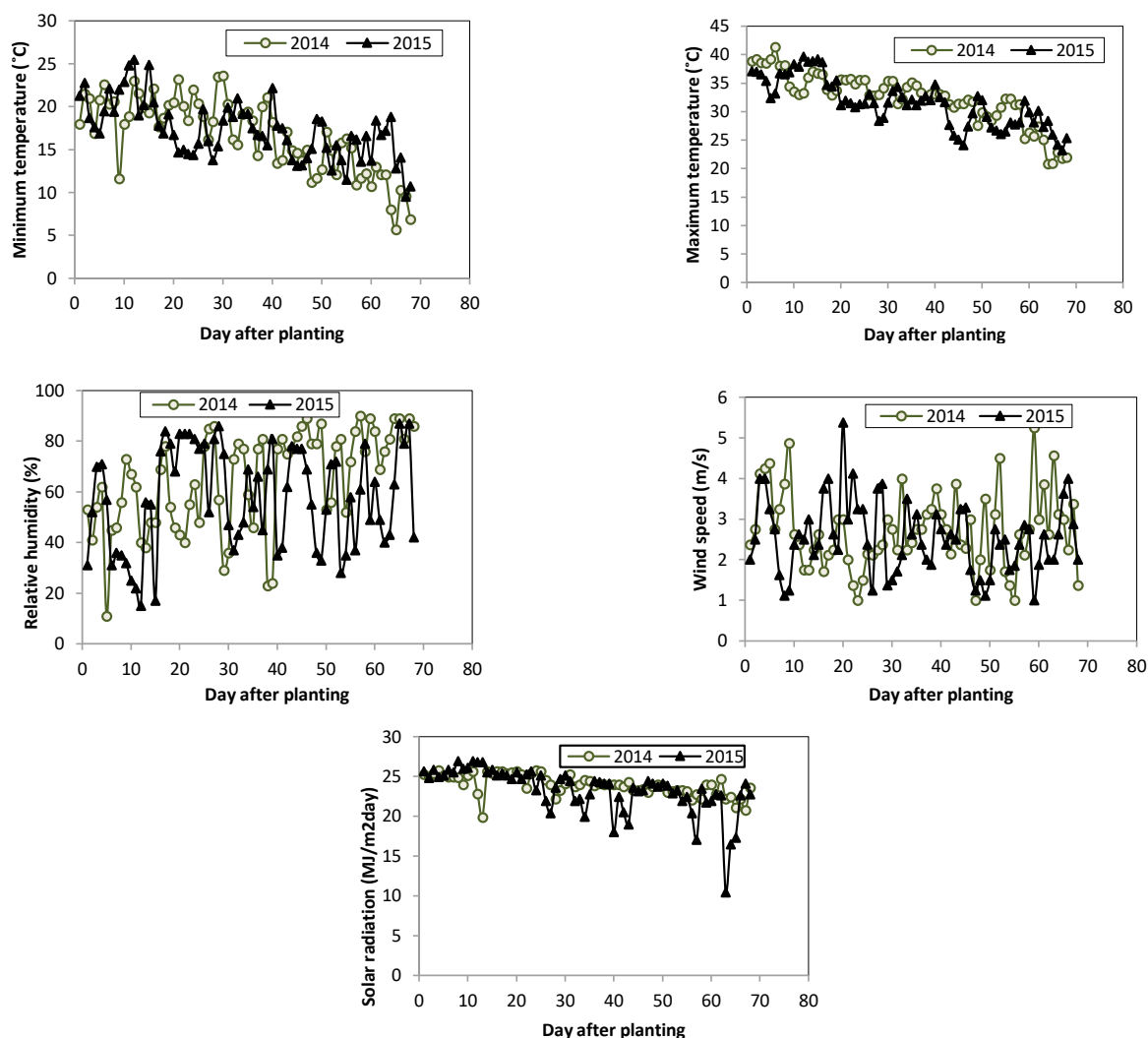


Figure 1. Climate variables: daily maximum and minimum temperature, daily relative humidity, daily wind speed and daily solar radiation during 2014 and 2015 corn growing seasons.

Table 1. Soil physical characteristics at the experimental site.

Soil depth (cm)	BD (g/cm ³)	FC (%)	WP (%w)	pH	EC (dS/m)	Soil texture
0-20	1.42	22.5	9.8	7.8	1.41	Loam
20-40	1.42	22.4	9.6	7.9	1.21	Loam
40-60	1.42	22.1	9.5	8.14	2.46	Loam

BD: bulk density. FC: field capacity. WP: permanent wilting. EC: electrical conductivity.

(MJ/m²/day); G is the soil heat flux density (MJ/m²/day); T is the mean temperature (°C); U_2 is the wind speed at 2-m height (m/s); γ is the psychrometric constant (kPa/°C); Δ is the slope vapor pressure curve (kPa/°C); e_a is the actual vapor pressure (kPa); e_s is the saturation vapor pressure (kPa).

Fertilizers were applied through the irrigation water from the 3 and 4 leafed stage of corn growth to 45 days before harvesting. The corn received 250 kg/ha ammonium phosphate and 200 kg/ha urea.

Measurements

Actual evapotranspiration (ET_{c-act})

Daily corn water consumption or actual evapotranspiration (ET_{c-act}) of each mini-lysimeter was measured based on the water balance method using Eq. (3) (Allen *et al.*, 1998):

$$ET_{c-act} = P + I - D_p - R - \Delta S \quad (3)$$

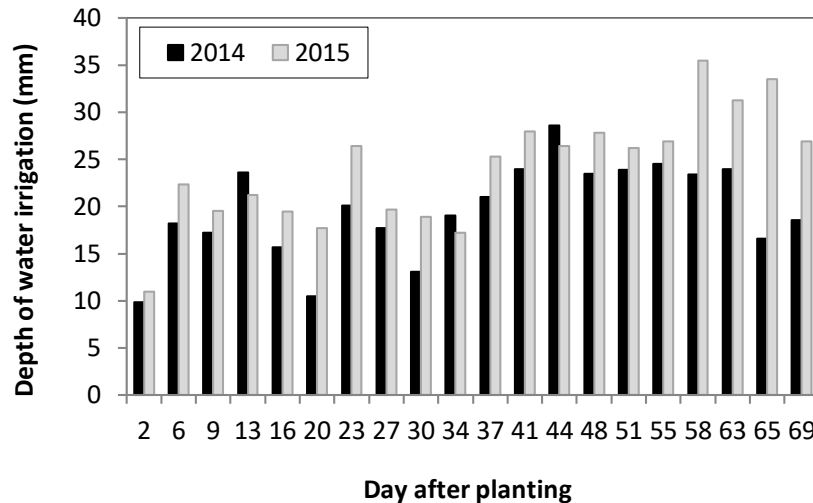


Figure 2. Variations in applied water for corn during the 2014 and 2015 corn growing seasons.

where P is the rainfall (mm); I is the irrigation depth (mm); D_p is the water loss through drainage from the mini-lysimeter (mm); R is the runoff (mm) which here was zero and Δs is the change in soil water storage in the mini-lysimeter (mm). The change in soil water storage (Δs) was determined using Eq. (4) (Allen *et al.*, 1998):

$$\Delta S = S_t - S_{t-1} \quad (4)$$

where S_t and S_{t-1} are the available water in the root zone at the beginning and end of the selected period (mm), respectively.

Soil surface evaporation (E) and plant transpiration (T_p)

Evaporation from the soil surface (E) was measured using two mini-lysimeters. When these mini-lysimeters were placed inside the soil, their edges were about one cm above the soil surface, and the soil inside the mini-lysimeter was about 1 to 1.5 cm below the edge. The E was estimated from the difference between the amount of intake and drainage water in the mini-lysimeter at each irrigation interval. Plant transpiration (T_p) was estimated from the difference between ET_{c-act} and E , by the following equation (Moran *et al.*, 2009):

$$T_p = ET_{c-act} - E \quad (5)$$

Basal crop coefficient (K_{cb}) and soil evaporation coefficient (K_e)

Crop coefficient can be applied as a single crop coefficient which is influenced by evaporation and transpiration together and dual crop coefficient that is expres-

sed by soil evaporation coefficient (K_e) and basal crop coefficient (K_{cb}), separately (Allen *et al.*, 1998). The measured K_e and K_{cb} (K_{cb-m} and K_{e-m}) are defined using Eqs. (6) and (7) (Majnooni-Heris *et al.*, 2012):

$$K_{cb-m} = \frac{ET_{c-act} - E}{ET_o} = \frac{T_p}{ET_o} \quad (6)$$

$$K_{e-m} = \frac{E}{ET_o} \quad (7)$$

K_{cb-m} and K_{e-m} were also compared with estimated values based on FAO-56 (Allen *et al.*, 1998). In this study, the K_{cb} and K_e suggested by FAO-56 were adjusted (K_{cb-adj} and K_{e-adj}) based on the climatic conditions of the study area.

Corn growth indices and water use efficiency (WUE)

Leaf area index (LAI), plant height (H), stem diameter (D) and yield (biomass) were measured during the growing season. LAI was measured with the electronic leaf area-meter, CI-202, seven times during the growing season. WUE (kg/m^3) was calculated using Eq. (8) (Sakthivadivel *et al.*, 1999) where yield represents the biomass of corn:

$$WUE = \frac{Yield (kg)}{ET_{c-act} (m^3)} \quad (8)$$

Statistical analysis

Statistical analysis was done to evaluate the influence of different point source irrigation systems on actual evapotranspiration (ET_{c-act}) and growth indices of corn by using the SAS package. LSD (least significant difference)

tests were used to compare and rank the treatment means. Differences were declared significant at $p \leq 0.05$.

Results and discussion

Variations in actual evapotranspiration (ET_{c-act}), plant transpiration (T_p) and soil evaporation (E)

The values for ET_{c-act} and T_p of corn and E under DI and SDI during the corn growing season are shown in Fig. 3. The ET_{c-act} varied from 2.1 to 9.7 mm/day, depending on the crop growth stage and climatic condition. The daily ET_{c-act} and T_p increased rapidly and peaked 48 days after planting at the mid-season stage with average values of 9.7 and 7.6 mm/day under DI and 9.5 and 8.7 mm/day under SDI. The minimum ET_{c-act} values occurred at the initial stage with an average of 2.5 and 2.1 mm/day under DI and SDI. During the first week after planting, the most share of ET_{c-act} was E, because the soil was kept wet for corn seed germination. Transpiration increased faster under the SDI than the DI (Fig. 3) because of moisture distribution close to the root mass and better root development under the SDI at the initial stage.

Significantly lower corn ET_{c-act} and E values were obtained under the SDI than under DI but for both seasons, the T_p was higher under SDI than DI (Table 2). The average annual ET_{c-act} was 423.49 mm under DI and 384.84 mm under SDI. Similar results have been reported by Chuan-yan & Zhongren (2007), Liu *et al.* (2017) and Zhang *et al.* (2017). Evaporation accounted for a small proportion of ET_{c-act} and decreased with time and increasing LAI. Transpiration was smaller than E at the initial growth stage (Fig. 3), and the total contribution to ET_{c-act} at that stage was from E because more water was lost through soil surface evaporation and the crop canopy was not fully developed yet as reported in Allen *et al.* (1998) and Valentin *et al.* (2020). The T_p increased to a peak at the mid-season stage (Liu *et al.*, 2002; Kang *et al.*, 2003; Majnooni-Heris *et al.*, 2012). During this stage, E was reduced and the reduction was compensated with higher amounts of water for T_p , coinciding with increasing LAI until the crop achieved near or full ground cover (Table 2).

The average annual T_p during the two growing seasons was 221.9 and 250.2 mm, and that for E was 198.0 and 157.6 mm under DI and SDI, respectively. Under SDI, the soil surface usually remained drier than under DI. Accordingly, the total T_p was 53.0 and 64.2% of corn ET_{c-act} under DI and SDI. Also, the average annual E was 46.9 and 35.9 % of corn ET_{c-act} under DI and SDI during two growing seasons (Table 2). At the initial stage during which the portion of the bare or low covered soil surface was high and considering that under DI, moisture accumulation occurred on the soil surface, the DI showed 27.70% more evaporation (82.9 mm) than SDI (64.9 mm).

Relationship between the ratio of plant transpiration (T_p) and soil evaporation (E) to actual corn evapotranspiration (ET_{c-act}) and leaf area index (LAI)

Based on the soil-plant-atmosphere continuum (SPAC), the variations in T_p , and ET_{c-act} are affected by meteorological data, soil moisture and plant factors (Zhou *et al.*, 2017). The variations in T_p/ET_{c-act} and LAI for each growing season are presented in Fig. 4. The data indicated that the ratio was controlled by soil surface cover and LAI. The average T_p/ET_{c-act} varied from 0.0 at sowing to 82 and 87% at full growth under DI and SDI. The value of T_p/ET_{c-act} increased faster when LAI was smaller than 3.0. Thus, two polynomial functions were computed to show the relation between the ratio of T_p/ET_{c-act} and E/ ET_{c-act} with LAI under SDI and DI (Eqs. 8 and 9; Fig. 4), as reported by other authors (*e.g.*, Kang *et al.*, 2003; Majnooni-Heris *et al.*, 2012).

$$\frac{T_p}{ET_{c-act}} = -10.27 LAI^2 + 58.716 LAI \quad R^2=0.93 \text{ (DI)} \quad (9)$$

$$\frac{T_p}{ET_{c-act}} = -5.791 LAI^2 + 40.697 LAI + 21.087 \quad R^2=0.92 \text{ (SDI)} \quad (10)$$

It was presumed, as occurred for the T_p/ET_{c-act} ratio, that the E/ ET_{c-act} was also affected by LAI and surface soil moisture (Liu *et al.*, 2002). Fig. 5 shows the trends in the ratio of E/ ET_{c-act} with LAI under DI and SDI during the growing seasons. The E/ ET_{c-act} decreased significantly with increases in LAI. The relationship between LAI and E/ ET_{c-act} based on the experimental data was calculated as follows:

$$\frac{E}{ET_{c-act}} = 11.716 LAI^2 - 65.137 LAI + 105.18 \quad R^2=0.97 \text{ (DI)} \quad (11)$$

$$\frac{E}{ET_{c-act}} = 5.636 LAI^2 - 40.175 LAI + 79.887 \quad R^2=0.93 \text{ (SDI)} \quad (12)$$

From these relationships, the E/ ET_{c-act} decreased sharply when LAI was at about 3, which was attributed to lower evaporation due to the development of crop canopy (Fig. 5). Under SDI, the soil surface between crops usually remains dry, so that evaporation loss from the soil surface is low but moisture distribution at the root zone is suitable for crop growth. Thus, the SDI can improve water uptake by reducing soil evaporation (Liu *et al.*, 2002).

Variations in basal crop coefficient (K_{cb}), soil evaporation (K_e) and LAI

The mean variations for the two years for K_{cb-m} and K_{e-m} compared to K_{cb-adj} , and K_{e-adj} are presented in Fig. 6. The values of K_{cb-m} increased from 0.0 to its peak value in the mid-season stage. The average, minimum

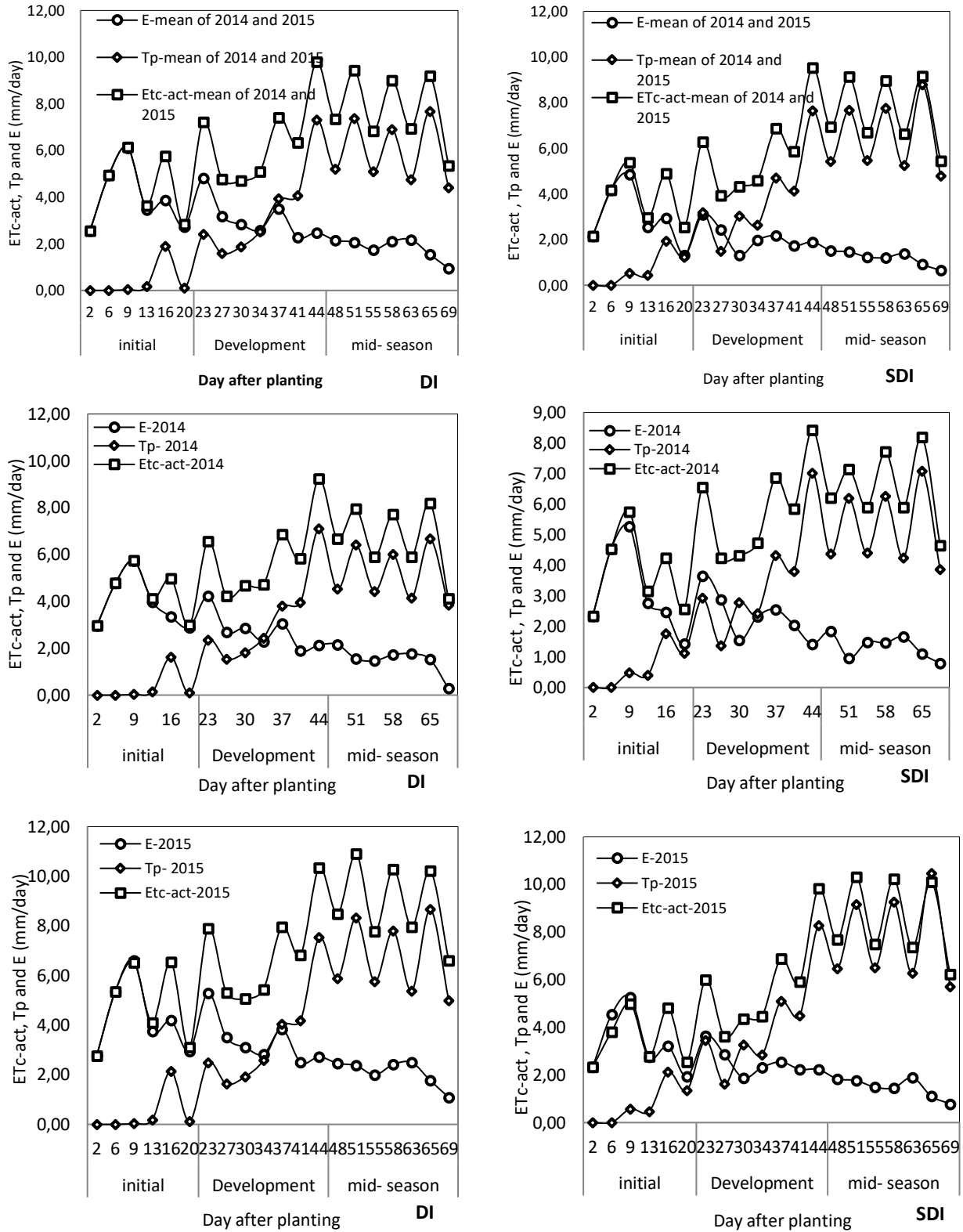


Figure 3. Variations in actual corn evapotranspiration (ET_{c-act}), plant transpiration (T_p) and soil evaporation (E) during the 2014 and 2015 corn growing seasons

and maximum values of K_{cb-m} were 0.47, 0.0 and 1.52 under DI and 0.53, 0.0 and 1.74 under SDI; for K_{e-m} the values were 0.33, 0.20 and 0.58 under DI and 0.23, 0.15 and 0.46 under SDI, respectively. The peak value of K_{cb-m}

was observed in the mid-season stage when LAI was maximum.

For the whole growing season, the values of K_{cb-m} were smaller than the adjusted values based on FAO-56.

Table 2. The ratio of soil evaporation (E) and plant transpiration (T_p) to actual corn evapotranspiration (ET_{c-act}) under surface drip irrigation (DI) and subsurface drip irrigation (SDI) systems during 2014 and 2015 corn growing seasons.

Treatment	Stage	2014		2015		Mean	
		DI	SDI	DI	SDI	DI	SDI
$\sum ET_{c-act}$ (mm)	Initial	85.6a	75.6b	95.0a	70.7b	90.3a	73.1b
	Development	141.2a	137.7b	164.0a	137.1b	152.6a	137.4b
	Middle	153.7a	151.5a	207.3a	196.9b	180.5a	174.2b
	Sum	380.5a	364.8b	466.3a	404.7b	423.4a	384.7b
$\sum E$ (mm)	Initial	79.7a	62.8b	86.1a	67.0b	82.9a	64.9b
	Development	64.4a	56.4b	80.2a	60.6b	72.3a	58.5b
	Middle	35.5a	32.5a	50.0a	35.9b	42.7a	34.2b
	Sum	179.6a	151.7b	216.3a	163.5b	197.9a	157.6b
$\sum T_p$ (mm)	Initial	5.8b	12.7a	7.7b	15.3a	6.8b	14.0a
	Development	76.8b	81.3a	81.4b	95.9a	79.1b	88.6a
	Middle	118.2a	118.9a	153.7b	176.0a	135.9b	147.5a
	Sum	200.8b	212.9a	242.8b	287.2a	221.8b	250.1a
$\sum T_p/ET_{c-act}$ (%)	Initial	6.7b	16.7a	8.1b	21.6a	7.5b	19.1a
	Development	54.3b	59.0a	49.6b	69.9a	51.8b	64.4a
	Middle	76.9a	78.4a	74.1b	89.3a	75.2b	84.6a
	Sum	52.7b	58.4a	52.0b	70.9a	52.3b	65.0a
$\sum E/ET_{c-act}$ (%)	Initial	93.1a	83.0b	90.6a	94.7a	91.9a	88.7b
	Development	45.6a	40.9b	48.9a	44.2b	47.2a	42.5b
	Middle	23.0a	21.4a	24.1a	18.2b	23.6a	19.6b
	Sum	47.2a	41.5b	46.3a	40.4b	46.7a	40.9b

For each year, means within a column bearing the same letter do not differ significantly at the 0.05 level of probability

This was attributed to the overestimation of ET_o by FAO-Penman-Monteith model for this region (Dehghani-saniy *et al.*, 2004).

For the different irrigation systems, the peak values of K_{cb-m} were obtained under SDI at the mid-season stage, and the K_{e-m} under the DI peaked at the initial stage. The K_{e-m} decreased with crop development during the growing

season due to the increase in the percentage of the shaded area by the plant canopy. Again, Fig. 6 emphasizes that the evaporation from soil surface was higher than the transpiration from the crop at the initial stage and with an increase in plant shading, evaporation was lower than transpiration during crop development and mid-season stages. Moreover, the K_{e-m} varied temporally during the

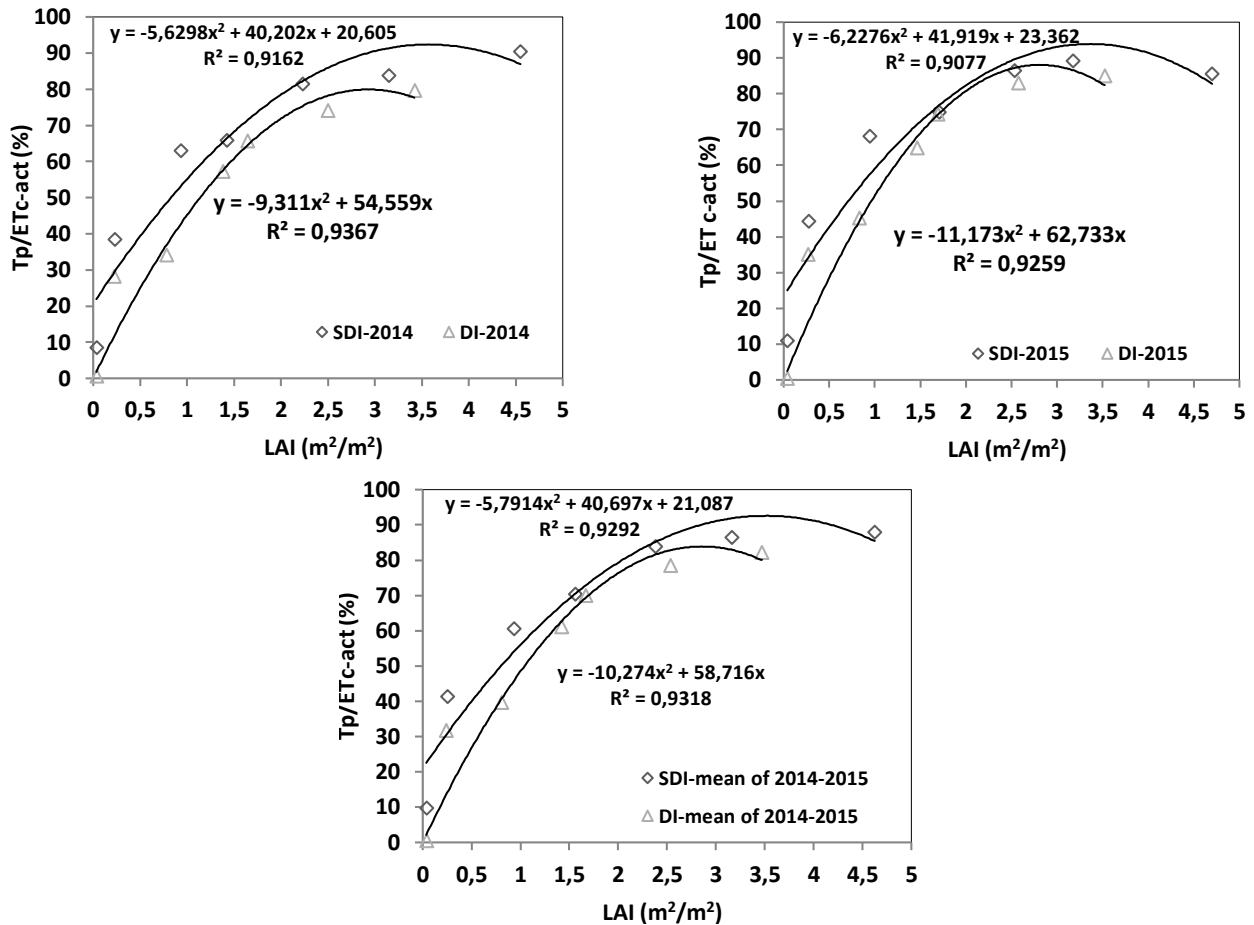


Figure 4. Relationship between the variation in the ratio of plant transpiration (T_p) to actual corn evapotranspiration (ET_{c-act}) and leaf area index (LAI) under surface (DI) and subsurface drip irrigation (SDI) during the 2014 and 2015 corn growing seasons.

corn growing season. Thus, the average K_{e-m} peaked at the initial stage, and decreased gradually during the growing season, reaching a minimum value at the mid-season stage (Table 3).

The amounts of K_{cb-FAO} during the initial stage, crop development and mid-season stage of corn growth (K_{cb-ini} , K_{cb-dev} , and K_{cb-mid}) were 0.15, 0.15-1.15 and 1.15, respectively (Allen *et al.*, 1998). The values of K_{cb-dev} and K_{cb-mid} changed on the basis of plant height, wind speed and relative humidity in different regions. Therefore, the recommended K_{cb} values were adjusted to 0.15, 0.70, and 1.20 under DI and 0.15, 0.76, and 1.29 under SDI during the initial stage, crop development, and mid-season stages, respectively (Table 3). The maximum value of K_{cb-adj} was 1.30 under SDI at the mid-season stage, which was attributed to the higher T_p . The K_{e-adj} varied temporally during the corn growing season. Also, the K_{e-adj} value was higher at the initial stage and gradually decreased, reaching a minimum value of only 0.14 under SDI at the mid-season stage (Fig. 6).

The K_{cb-adj} and K_{e-adj} were higher than K_{cb-m} and K_{e-m} during the initial stage and crop development. Whe-

ther for DI or SDI, the K_{cb-adj} values were overestimated when compared to K_{cb-m} for the whole growing season. Comparisons of K_{cb-m} and K_{e-m} vs K_{cb-adj} , and K_{e-adj} values are shown in Fig. 7. For both DI and SDI, the relationships between K_{cb-m} and K_{e-m} as well as K_{cb-adj} , and K_{e-adj} were linear. The K_{cb-adj} under DI performed better than that under SDI. The slopes of the linear regression were 0.93 and 0.85 with a coefficients of determination of 0.75 and 0.71 for K_{cb-adj} under DI and SDI, respectively.

The K_{e-adj} under DI and SDI was overestimated as compared to K_{e-m} during the initial and crop development stages and underestimated during the mid-season stage. Also, K_{e-adj} under DI provided a better performance than that under SDI. The slopes of the linear regression were 0.67 and 0.67 with a coefficients of determination of 0.25 and 0.19 for K_{e-adj} under DI and SDI, respectively.

The difference between K_{cb-m} and K_{e-m} and adjusted values by FAO-56 clearly emphasizes the difficulty of applying K_{cb} and K_e values across locations due to varying climatic and agricultural management factors like irrigation method and frequency (Katerji & Rana, 2014).

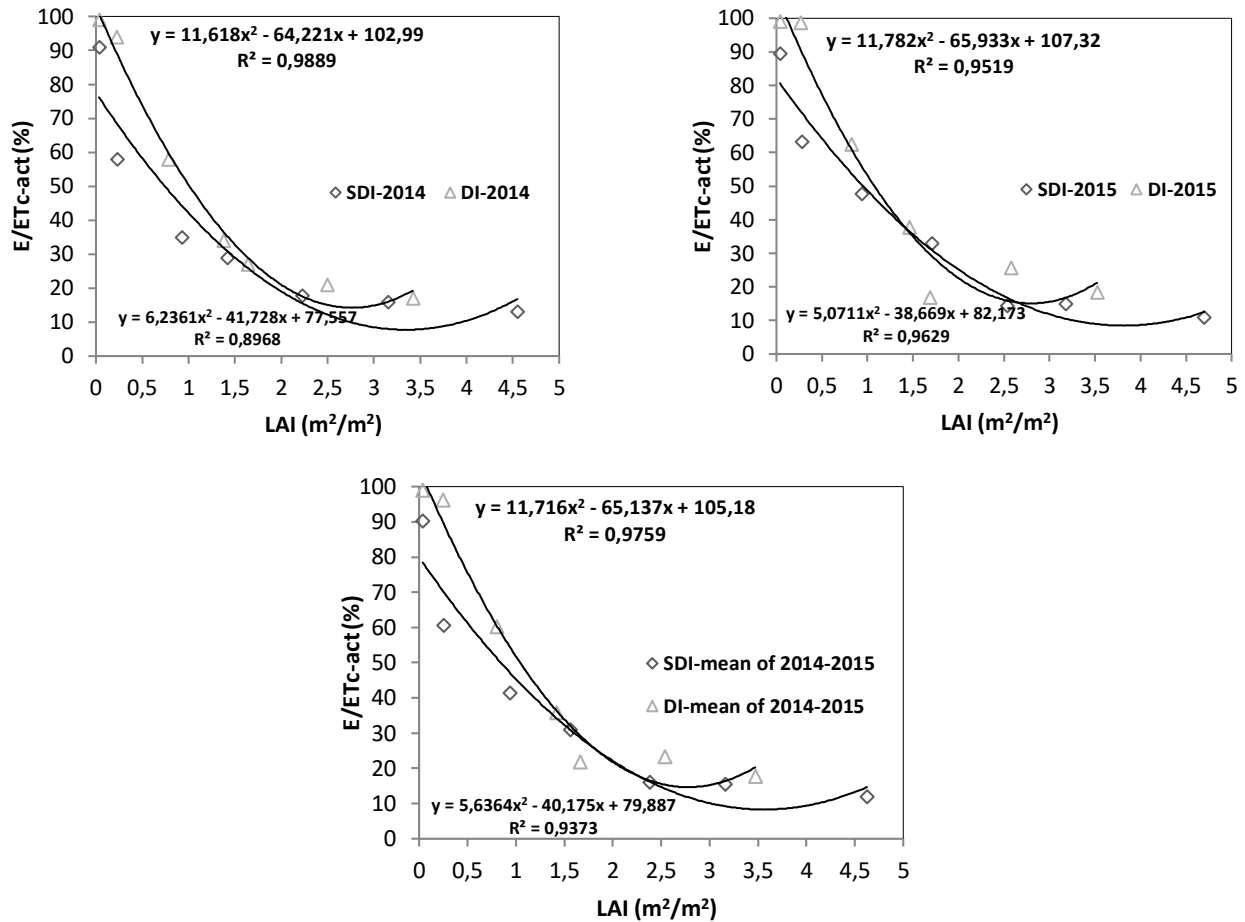


Figure 5. Relationship between the variation in the ratio of soil evaporation (E) to actual corn evapotranspiration (ET_{c-act}) and leaf area index (LAI) under surface (DI) and subsurface drip irrigation (SDI) during the 2014 and 2015 corn growing seasons.

As a response to the crop development, the K_e was higher than the K_{cb} at the initial stage, and with an increase in LAI and plant shading, the resulting decreases in soil surface evaporation could be used to estimate the variations in K_{cb} and K_e as functions of LAI (Fig. 8).

Overall, the relationship between LAI and K_{cb} and K_e based on the experimental data was calculated using second-order polynomial equations with high coefficients of determination (R²) as follows:

$$K_{cb-m} = -0.0645LAI^2 + 0.56LAI - 0.1005 \quad R^2=0.93 \text{ (DI)} \quad (13)$$

$$K_{cb-m} = -0.0761LAI^2 + 0.5962LAI + 0.04 \quad R^2=0.94 \text{ (SDI)} \quad (14)$$

$$K_{e-m} = 0.0484LAI^2 - 0.2661LAI + 0.5308 \quad R^2=0.92 \text{ (DI)} \quad (15)$$

$$K_{e-m} = 0.0242LAI^2 - 0.1687LAI + 0.3996 \quad R^2=0.91 \text{ (SDI)} \quad (16)$$

The K_{cb} of corn at the mid-season stage was larger because of the large LAI at this stage and consequently, the smaller soil evaporation, compared to plant transpiration.

Similar relationships have been reported for bean and canola (De Medeiros *et al.*, 2001; Majnooni-Heris *et al.*, 2012).

Variations in leaf area index (LAI), plant height (H), stem diameter (D), wet and dry mass yield and water use efficiency (WUE)

The variations in mean LAI, H, D, biomass yield and WUE under DI and SDI are presented in Table 4 and Fig. 9. The LAI increased slowly in the initial stages and more rapidly reached its peak at about 3.4 m²/m² under DI and 4.6 m²/m² under SDI. Also, the H increased slowly at the initial stages and more rapidly at the mid-season stage, with the tallest plants (229.2 cm) under SDI at the mid-season stage. Moreover, the D also increased during the growing season and peaked during mid-season with values of 3.2 cm under DI and 3.6 cm under SDI. Between the irrigation systems, the lowest values of LAI, H and D occurred under DI (Table 4 and Fig. 9) as reported in Chuanyan & Zhongren (2007).

Table 3. Mean values of measured (m) and adjusted (adj) soil evaporation coefficient (K_e) and basal crop coefficient (K_{cb}) under surface drip irrigation (DI) and subsurface drip irrigation (SDI) systems during 2014 and 2015 corn growing seasons.

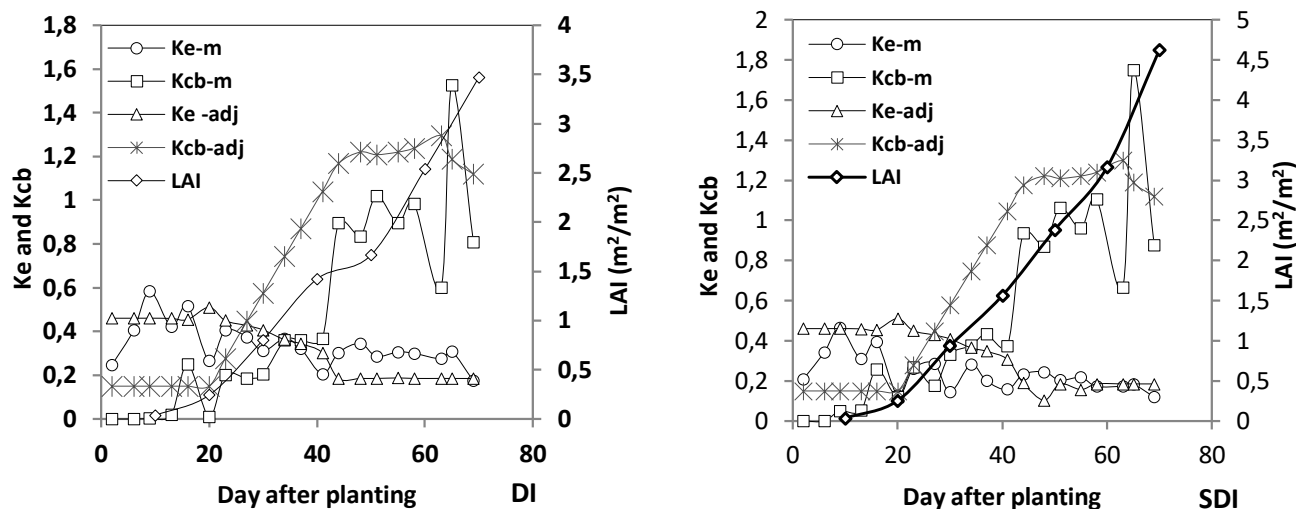
Treatment	Stage	2014		2015		Mean	
		DI	SDI	DI	SDI	DI	SDI
K_{cb-m}	Initial	0.03b	0.07a	0.04b	0.09a	0.04b	0.08a
	Development	0.35a	0.37a	0.36b	0.45a	0.35b	0.41a
	Middle	0.82a	0.83a	1.08b	1.25a	0.95b	1.04a
K_{e-m}	Initial	0.37a	0.29b	0.43a	0.31b	0.40a	0.30b
	Development	0.28a	0.20b	0.32a	0.22b	0.32a	0.22b
	Middle	0.23a	0.15b	0.28a	0.18b	0.28a	0.18b
K_{cb-adj}	Initial	0.15a	0.15a	0.15a	0.15a	0.15a	0.15a
	Development	0.68a	0.72b	0.72b	0.80a	0.70b	0.76a
	Middle	1.19b	1.22a	1.21b	1.36a	1.20b	1.29a
K_{e-adj}	Initial	0.46a	0.38b	0.50a	0.42b	0.48a	0.40b
	Development	0.36a	0.32b	0.42a	0.40b	0.39a	0.36b
	Middle	0.16a	0.13b	0.18a	0.15b	0.17a	0.14b

For each year, means within a column bearing the same letter do not differ significantly at the 0.05 level of probability

The highest yield (biomass) was 81.90 ton/ha under SDI compared to only 63.21 ton/ha under DI. Also, the WUE (kg/m^3) of corn was 8.32 under SDI and 6.67 under DI (Table 4). This better performance under SDI could be explained by the conservation of optimal moisture status in the root zone, which favoured water and nutrient uptake by the crop (Zotarelli *et al.*, 2008; Badr *et al.*, 2010).

In summary, the results of this study showed that the lowest ET_{c-act} for corn occurred under SDI, mainly

because of reduced evaporation (E) from the soil surface in comparison to the DI system. Consequently, higher T_p and lower E rates were observed under the SDI system. The T_p/ET_{c-act} started from 0 at sowing and peaked at the mid-season stage when the LAI was also at peak levels. The DI and SDI systems had different influences on the LAI of corn during the growing season. A better understanding of these components (T_p , E, E/ET_{c-act} and T_p/ET_{c-act}) can provide important insights to water saving under

**Figure 6.** Variations in measured basal crop coefficient (K_{cb-m}), soil evaporation (K_{e-m}) and LAI during the growing seasons (mean of 2014 and 2015).

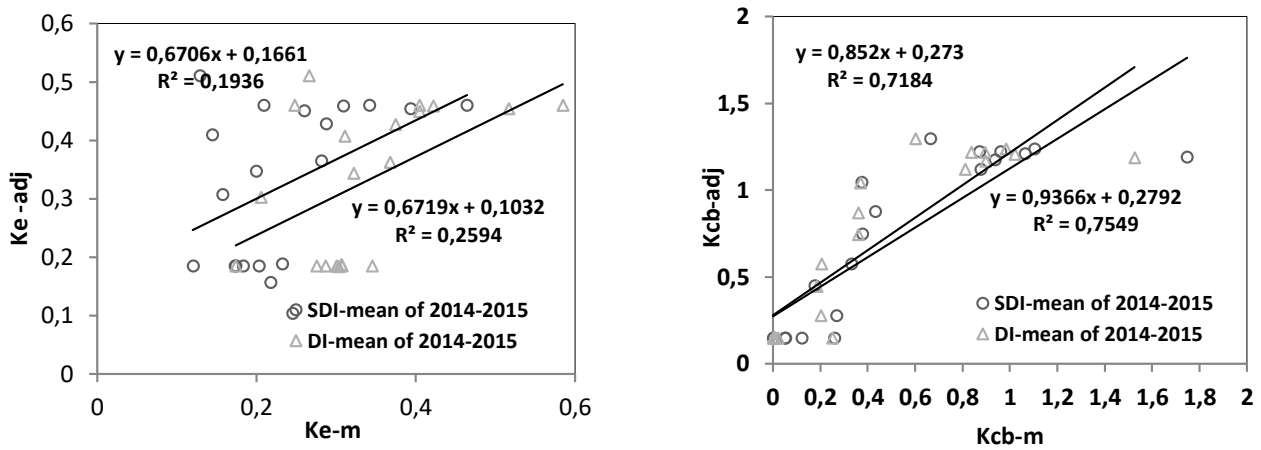


Figure 7. Comparison of measured basal crop coefficient (K_{cb-m}) vs adjusted basal crop coefficient based on FAO-56 (K_{cb-adj}) and measured soil evaporation coefficient (K_{e-m}) and soil evaporation coefficient by FAO-56 (K_{e-adj}) (mean of 2014 and 2015).

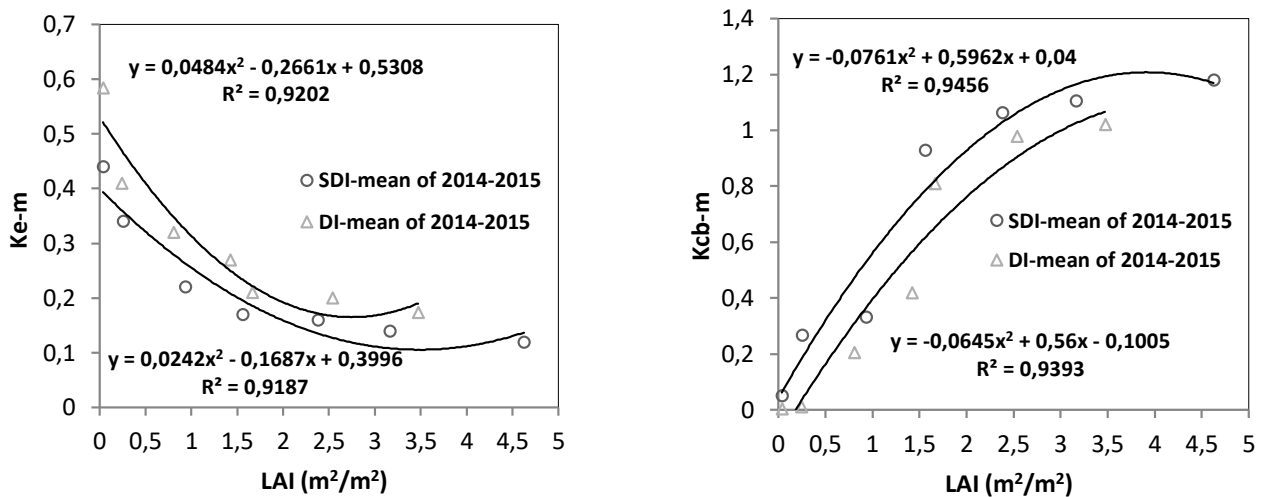


Figure 8. Relationship between the variation in the measured basal crop coefficient (K_{cb-m}), measured soil evaporation (K_{e-m}) and leaf area index (LAI) (mean of 2014 and 2015).

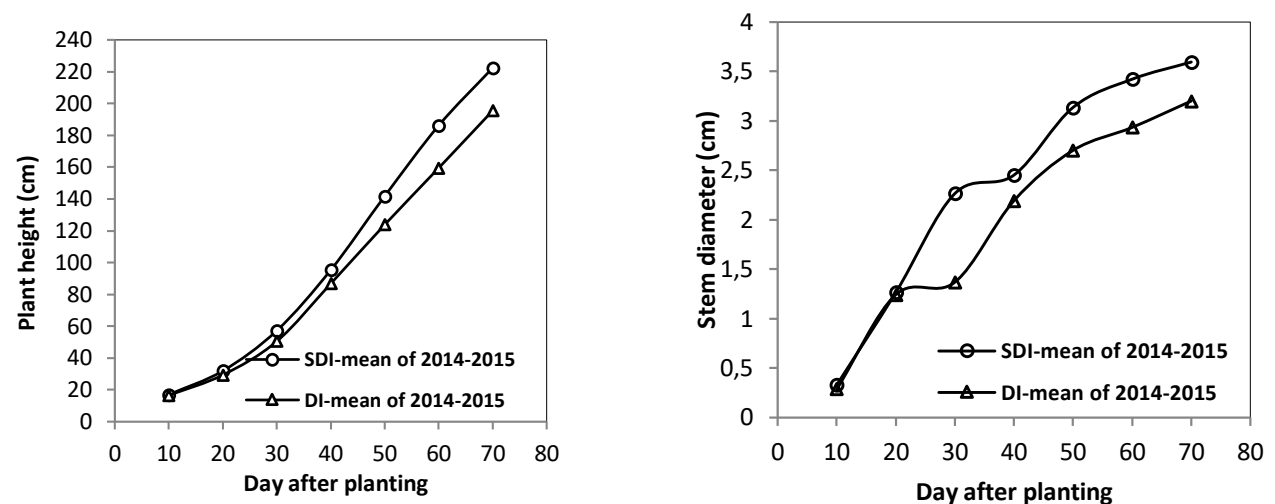


Figure 9. Variations in plant height (H) and stem diameter (D) during the growing seasons (mean of 2014 and 2015).

Table 4. Corn yield and growth attributes under surface drip irrigation (DI) and subsurface drip irrigation (SDI) during 2014 and 2015 corn growing seasons.

Treatment	Stage	2014		2015		Mean	
		DI	SDI	DI	SDI	DI	SDI
H (cm)	Initial	26.5b	29.8a	29.1b	33.9a	27.8b	31.8a
	Development	101.6b	111.2a	108.7b	124.7a	105.1b	117.9a
	Middle	191.3b	215.3a	199.6b	229.2a	195.4b	222.2a
D (cm)	Initial	1.13a	1.10a	1.27a	1.30a	1.20a	1.20a
	Development	2.33b	2.41a	2.47b	2.99a	2.40b	2.70a
	Middle	2.83b	2.95a	3.57b	4.25a	3.20b	3.60a
LAI (m ² /m ²)	Initial	0.17a	0.18a	0.22a	0.23a	0.20a	0.20a
	Development	1.42b	1.82a	1.58b	1.98a	1.50b	1.90a
	Middle	3.08b	4.31a	3.72b	4.89a	3.40b	4.60a
Yield (ton/ha)	Total	60.18b	77.36a	66.24b	86.44a	63.21b	81.90a
WUE (kg/m ³)	Total	6.14b	7.96a	7.20b	8.68a	6.67b	8.32a

H: plant height. D: stem diameter. LAI: leaf area index. Yield (biomass). WUE: water use efficiency. For each year, means within a column bearing the same letter do not differ significantly at the 0.05 level of probability

irrigated corn production. The highest LAI occurred under the SDI system. Overall, the SDI system reduced soil evaporation loss and increased the efficiency of water consumption; it also produced superior biomass yield. Thus, the SDI system is more productive and would better increase WUE than the DI system.

Acknowledgments

The authors wish to render heartfelt gratitude to Egrinya Eneji, Professor of Agronomy & Honourable Commissioner, Ministry of Training and Doctrine, Cross River State, Nigeria, for carefully editing the manuscript linguistically and technically.

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