Variation of Actual Corn (Zea Mays L.)
Evapotranspiration, Single and Dual Crop Coefficient
Under Different Point Source Irrigation Systems in a
Semiarid Region

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Research Article

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Variation of actual corn (Zea mays L.) evapotranspiration, single and dual crop coefficient under different point source irrigation systems in a semi-arid region

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Abstract

Paying attention to irrigation of corn could have significant attention on water resources. The experiment was carried out to consider the influence of porous capsule irrigation (PCI), surface drip irrigation (DI) and subsurface drip irrigation (SDI) systems under mulch condition on actual evapotranspiration ($ET_{c_{act}}$), crop coefficients ($K_{c_{single}}$ and $K_{c_{dual}}$), yield and water use efficiency (WUE) of corn in a semi-arid region of Iran. The experiment was arranged in a split-plot design with three irrigation systems as the main-factor and two soil coverage with mulch ($M_1$) and non-mulch ($M_2$) as sub-factor. The results showed that corn $ET_{c_{act}}$ varied significantly with different irrigation systems ($P<0.05$), and was reported 389.8, 377.0 and 372.8 mm for PCI, DI and SDI systems, respectively. The highest value of $K_{c_{average}}$ and $K_{cb}$ (0.82 and 1.22, respectively) and the minimum value of $K_e$ (0.12) were seen in PCI system. The dry and wet biological yield were the highest in (PCI + $M_1$) treatment (29.98 and 107 ton/ha, respectively), and the lowest dry and wet biological yield were recorded in (DI+$M_2$) treatment (23.19 and 58.54 ton/ha, respectively). The highest WUE (7.89 kg/m$^3$) were recorded in (PCI + $M_1$) treatment. Using PCI system leads to higher biological yield, WUE and IWUE in comparison to DI and SDI systems. Accordingly, PCI system as an alternative to drip irrigation system can be a viable option for water scarce area particularly for smallholder farmers.

Keywords: Basal crop coefficient, Soil evaporation, Lysimeter, Point source irrigation, Porous capsule
1. Introduction

Agriculture section is the main consumer in arid and semiarid countries. This is the first source of exploitation to compete for water (Postel 1992; Ayars et al. 2015). Evapotranspiration (ETc) loss is one of the major challenges of irrigated agriculture. Evaporation occurs predominantly from the exposed soil fraction in the field and free water surface (Allen et al., 1998). Recently, mulching is a recommended for water management practice to reduce water loss due to evaporation from the soil surface and to create more favourable condition for plant transpiration (Tarara 2000; Tiwari et al. 2014, Reddy et al. 2018). Improving irrigation management methods under mulching conditions is a new agricultural water-saving irrigation technology, which can be effective to prevent water loss due to evaporation from the soil surface. In recent years, drip irrigation under mulch condition has been widely used in arid and semiarid regions (Qin et al. 2016). The effect of drip irrigation method under mulch makes soil temperature changeable, reduces the amount of water loss due to decrease soil evaporation, maintains soil moisture and improves soil fertility, prevents the growth of weeds and also helps to evenly distribute moisture to reduce plant stress (Singh 2005; Sharma et al. 2010; Paul et al. 2013; Panigrahi et al. 2016). A large number of researchers recorded that an increase of crop yield and water use efficiency are improved by application drip irrigation with mulch in different agro-climatic region and soil condition (Biswas et al. 2015; Thentu et al. 2016; Liu et al. 2017; Zhang et al. 2017). But there is gape between the research sites and the actual farm conditions. Moreover our knowledge about some traditional irrigation system and its relation with crop development is limited. Drip irrigation systems are well known, and researchers showed that intensive irrigation management of drip irrigation increased water use efficiency significantly. There is a traditional irrigation system in arid and semiarid regions with same specification while are not well studied and promoted (Bainbridge et al. 2008). Porous capsule irrigation is an effective promoted adaptation of buried clay pot irrigation (Silva et al. 1981a, b; Bainbridge 2002; Bainbridge et al. 2008). Supply of water with small porous capsules is one of the methods that can be used in small scale farms in arid and semi-arid regions. Porous capsule irrigation method introduced for planting of a wide range of annual and perennial plants including: horticultural crops (Setiawan et al. 1998), corn (Bainbridge 2001), watermelons (Soomro 2002), tomatoes (Tesfaye et al. 2012), turnip, okra and eggplant (Siyal et al. 2011). Crop coefficient (Kc) is slightly affected by climate, but significantly affected by crop and Irrigation scheduling or environmental conditions, that can lead to water stress conditions for crop (Zhang et al. 2013). The Kc can be applied as single crop coefficient (Kc single) which is influenced by effect of evaporation (E) and plant transpiration (Tp) together and dual crop coefficient (Kc dual) that is expressed by soil evaporation coefficient (Ke) and
basal crop coefficient \( (K_{cb}) \), separately (Allen et al. 1998). The \( K_{c\text{ dual}} \) can provide a more accurate assessment of the effects of soil moisture by to rainfall or irrigation and also the effects of using mulches to control soil evaporation. Hence, to some extent, the \( K_{c\text{ dual}} \) can improve the accuracy of \( ET_{c} \) estimation when used with appropriate calibrated base data (Allen et al. 2011; Rosa et al. 2012; Zhang et al. 2013). Corn is one of the main cereal crop in the world and it ranks third in cereal production in cultivated area and production (FAO 2011). Accordingly paying attention to irrigation of corn could have significant attention on water resources. To improve our ability on corn \((Zea\ mays\ L.)\) irrigation management under different localized irrigation systems in arid and semiarid condition, this study aimed to investigate variation of evaporation and transpiration during growth stages, soil evaporation coefficient, and basal crop coefficient in different irrigation systems and climate condition.

2. Materials and methods

2.1. Experimental site

The experiment was conducted at the farm of Agricultural Engineering Research Institute, Karaj, Iran. The site was located at 35°46´ N latitude, 50°55´E longitude and at an elevation of 1260 m above sea level. The local climate is semiarid, with mean annual precipitation of 279.3 mm, mean annual temperature of 16.6 °C, cold and dry winters, and hot and humid summers. The daily climate data for growing season (August to November 2014) were collected from a synoptic meteorology station located in 5 km far from the farm. Table 1 summarizes the monthly average climatic data for the corn growing seasons.

\begin{table}
\centering
\begin{tabular}{|c|c|}
\hline
Month & Monthly Average Temperature (°C) \\
\hline
August & 25.3 \\
September & 24.5 \\
October & 21.8 \\
November & 18.2 \\
\hline
\end{tabular}
\end{table}

The seasonal average air temperature was 24°C during corn growing season, however, air temperature were hotter in August, and cooler in November. On average, wind speed and relative humidity were higher in August and November, respectively. The average solar radiation, however was higher in August. The soil samples were taken from 0-10, 10-20 and 20-30 cm soil depths. The soil was loam with a mean bulk density of 1.42 gr/cm3 and slightly alkaline with a pH of 7.9. Soil characteristics and irrigation water for experimental site are given in Tables 2 and 3.

\begin{table}
\centering
\begin{tabular}{|c|c|}
\hline
Soil Depth & Bulk Density (gr/cm3) \\
\hline
0-10 cm & 1.42 \\
10-20 cm & 1.45 \\
20-30 cm & 1.48 \\
\hline
\end{tabular}
\end{table}

\begin{table}
\centering
\begin{tabular}{|c|c|}
\hline
Parameter & Value \\
\hline
pH & 7.9 \\
\hline
\end{tabular}
\end{table}

In order to monitor water consumption by corn under different irrigation systems, 21 volumetric lysimeters were applied in the soil of a corn farm with an area of 18 ha, that was filled with excavated soil. The lysimeters were in
cylindrical shape with diameter of 40 cm and depth of 70 cm and is considered as a mini-lysimeter (Dugas and Bland 1989; Kong et al. 2012). Inside each mini lysimeter, three forage corn seeds (Single Cross 704) were planted with 13 cm seeds spacing on 6th August 2014 (Fig. 1).

(Fig. 1 here)

2.2. Irrigation management

The corn was irrigated with porous capsule irrigation (PCI), surface drip irrigation (DI) and subsurface drip irrigation (SDI) system. The DI and SDI system were equipped with 40 cm emitter spacing and discharge of 4 L/h, and also SDI system was buried 30 cm below the soil surface. In this design, porous capsule buried at 30 cm soil depth. Each porous capsule has a length of 30 cm and with a diameter of 6.5 cm as shown in Fig. 2. Irrigation interval was twice a week for DI and SDI system and daily for PCI system.

(Fig. 2 here)

The daily irrigation requirement was estimated using FAO-Penman-Monteith model (Allen et al. 1998; Eqs. (1) and (2)) confirmed for Karaj region by Dehghanisaj et al. (2004) and Akhavan et al. (2018).

\[
\begin{align*}
ET_0 & = \frac{0.408 \Delta (R_n - G) + \gamma [0.90 (T+273)] U_2 (e_a - e_s)}{\Delta + \gamma(1+0.34 U_2)} \\
ET_c & = ET_0 \times K_c
\end{align*}
\]

Where \(ET_c\) is crop evapotranspiration; \(ET_0\) is reference evapotranspiration (mm/day); \(R_n\) is net radiation (MJ/m\(^2\)/day); \(G\) is soil heat flux density (MJ/m\(^2\)/day); \(T\) is mean temperature (°C); \(U_2\) is wind speed at 2 m height (m/s); \(\gamma\) is psychrometric constant (k Pa/°C); \(\Delta\) is slope vapor pressure curve (k Pa/°C); \(e_a\) is actual vapor pressure (k Pa); \(e_s\) is saturation vapor pressure (k Pa). In this study, corn \(K_c\) is crop coefficient recommended for Karaj by Farshi et al. (1997).

Fertilizer injected to the irrigation water, and was started from the stage of 3 and 4 leafed of corn growth to 45 days before harvesting. The amount of 250 kg/ha ammonium phosphate fertilizer and 200 kg/ha nitrogen fertilizer was delivered to the crop.

2.3. Experimental design

The experiment was laid out in a split plot design keeping three irrigations methods (i) PCI, (ii) DI and (iii) SDI system as main- factor and two soil coverage (i) with mulch \((M_1)\) and (ii) non- mulch \((M_2)\) as sub-factor. Each treatment was replicated three times in a randomized complete block design.
2.4. Measurements

2.4.1. Actual corn evapotranspiration ($ET_{c\, act}$)

Daily actual corn evapotranspiration ($ET_{c\, act}$) of each mini-lysimeter was calculated by applying the water balance method using the Eqs. (3) and (4) (Allen et al., 1998):

\[
ET_{c\, act} = P + I - D - R - \Delta S
\]  
(3)

\[
\Delta S = S_t - S_{t-1}
\]  
(4)

Where $P$ is the rain (mm); $I$ is the irrigation depth (mm); $D$ is the water loss through drainage from the mini-lysimeter (mm); $R$ is the runoff (mm); and $\Delta S$ is the change of soil water storage in the mini-lysimeter (mm), $S_t$ and $S_{t-1}$ are the amount of water in the root zone at the beginning and end of the period (mm), respectively.

2.4.2. Soil surface evaporation ($E$) and plant transpiration ($Tp$)

In order to measure evaporation ($E$) from the soil surface, another three mini-lysimeters were placed on the farm which filled-out with same soil but without cultivating corn. The $E$ was measured from the difference between the amount of intake and drainage water in mini-lysimeter at the irrigation interval. Finally, plant transpiration ($Tp$) was estimated from the difference between $ET_{c\, act}$ and $E$, by the following general equation (Moran et al. 2009; Dehghanisani et al. 2020):

\[
Tp = ET_{c\, act} - E
\]  
(5)

2.4.3. Crop coefficient ($K_c$)

Two forms of $K_c$ are presented for calculate of crop coefficient including single and dual crop coefficient forms. In this study, single crop coefficient ($K_{c\, single}$) and dual crop coefficient ($K_{c\, dual}$) by FAO-56 method (Allen et al. 1998) were modified based on the climatic conditions of the study area.

2.4.4. Water use efficiencies

Water use efficiency ($WUE$, kg/m$^3$) and irrigation water use efficiency ($IWUE$, kg/m$^3$) were calculated by using Eqs. (6) and (7) (Sakthivadivel et al. 1999; Ati et al. 2012):

\[
WUE = \frac{\text{Yield (kg)}}{ET_c (m^3)}
\]  
(6)

\[
IWUE = \frac{\text{Yield (kg)}}{\text{Total applied water (m$^3$)}}
\]  
(7)

2.4.5. Plant and yield sampling
leaf area index (LAI), plant height (H) and stem diameter (D) dry and wet biological yield was measured during growth stages. Leaf area index (LAI) was measured with the electronic leaf area-meter CI – 202, seven times during the growing season.

2.4.6. Statistical analyses

Analysis of variance was carried out to evaluate the effect of the three irrigations systems and mulch treatments on the evapotranspiration, yield and water use efficiency of corn by using the SAS package. Compare and rank the treatment means was done by Least Significant difference (LSD) tests. Differences were declared significant at $P \leq 0.05$.

3. Results and discussion

3.1. Actual corn evapotranspiration ($ET_{c\ act}$) and crop coefficient ($K_c$)

Table 4 shows the total corn $ET_{c\ act}$ during the growing season of corn. The total corn $ET_{c\ act}$ was 379.8, 377.0 and 371.9 mm for PCI, DI and SDI systems in the growing seasons, respectively.

(Lowest values of corn $ET_{c\ act}$ occurred at the initial stage with a value of 3.31, 2.34 and 2.34 mm/day for PCI, DI and SDI systems, during the growing season, respectively. Daily corn $ET_{c\ act}$ increased rapidly and reached its maximum value at the mid-season stage. Highest values of corn $ET_{c\ act}$ occurred 44 days after planting at the mid-season stage with a value of 11.61, 9.33 and 9.24 mm/day for PCI, DI and SDI systems during the growing season, respectively. Previous studies showed that seasonal variation of corn $ET_{c\ act}$ ranged from 200 to 663 mm for different climatic and regional conditions (Dehghanisanij et al. 2006; Chuanyan and Zhongren 2007; Liu et al. 2017; Zhang et al. 2017; Akhavan et al. 2018; Dehghanisanij et al 2020). Variation of corn $ET_{c\ act}$ during the growing season was shown in Fig. 3.

(Daily corn $ET_{c\ act}$ varied from 3.31 to 11.61 mm/ day, 2.34 to 9.33 mm/ day and 2.34 to 9.24 mm/ day in PCI, DI and SDI systems, respectively. Highest corn $ET_{c\ act}$ was observed for PCI system. It should be noted that the total actual corn evapotranspiration under the PCI system was as crop transpiration ($T_p$). Because of the type of system, the wet soil surface was not exposed to air and the total amount of irrigation water applied to the plant was the T. There was no $E$, drainage and deep percolation in PCI system, and results in zero percent of $E$ loss from the soil surface (Fig. 4).
When porous capsule is used, the soil surface usually remains dry than DI and SDI systems, this leads to the reduction of E and an increase in transpiration, WUE and IWUE (Romero et al. 2004; Badr et al. 2010). The lowest $ET_{c\text{,}act}$ values were obtained in SDI system in the growing season of corn, because less soil moisture faced with the free air surface, and accordingly the rate of $E$ is lower in comparison with DI system.

Statistical analysis of $ET_{c\text{,}act}$ and $K_c$ indicated that the effects of irrigation systems were significant on corn $ET_{c\text{,}act}$ and $K_c$ ($P \leq 0.01$). However, there were no significant differences between the mulch and interaction of irrigation systems and mulch on corn $ET_{c\text{,}act}$ and $K_c$ (Table 5).

The results showed that PCI system produced higher corn $K_c$ values in comparison with DI and SDI system over the whole crop season ($P < 0.01$). Highest mean $K_c$ value (0.82) was obtained in PCI system. Also, the lowest $K_c$ values were obtained under with mulch condition, because using mulch reduced $E$ compared with non-mulch treatments (Table 5). These results are in agreement with the findings of Vickers (2001), Mata et al. (2002) and Yaghi et al. (2013). Compare the results with the findings of other researchers show the crop coefficient changes in different regions or in specific region can be different with different planting dates, so that $K_c$ extraction of regional and the calculated corn $ET_{c\text{,}act}$ for different climatic conditions and different planting times is essential. The changing of $K_c$ and LAI for the corn crop is plotted as a function of days after planting (DAP) (Fig. 5).

Analysis of changes in $K_c$ values was done by using the relationship between LAI and $K_c$ observed on the same days when LAI was measured. On the basis of these data, a new $K_c$ curve was plotted for seven days of LAI sampling as illustrated (Fig. 5). This was done to divest days with wet plants and soil because it is assumed that there were not irrigation and precipitation when LAI was sampled in middle stage of growing season. Fig. 5 showed that with the increase of LAI, the $K_c$ increases markedly and LAI generally peaked, as did $K_c$.

### 3.2. Variation in single and dual crop coefficient ($K_c\text{,}single$ and $K_c\text{,}dual$)

Single crop coefficient ($K_c\text{,}single$) and dual crop coefficient ($K_c\text{,}dual$) values for corn growth stage given in Table 6, and the variation of $K_c\text{,}single$ and $K_c\text{,}dual$ for the corn are plotted as a function of days after planting (DAP) and are presented in Fig. 6.
The corn $K_{c\text{ single}}$ values suggested by FAO-56 were 0.3, 0.3-0.9 and 1.2 for the initial stage, crop development and mid-season stages, respectively. In this study, the recommended $K_{c\text{ single}}$ values were modified based on the climatic conditions of the study area and changed to 0.3, 0.88 and 1.35 for PCI, 0.3, 0.86 and 1.34 for DI and 0.3, 0.87 and 1.35 for SDI systems for the initial, development-season and mid-season stages, respectively (Table 6).

The $K_{c\text{ dual}}$ included the basal crop coefficient ($K_{cb}$) and evaporation coefficient ($K_e$). The amounts of $K_{cb}$ suggested by FAO-56 for the initial stage, crop development and mid-season stages ($K_{cb\text{ ini}}, K_{cb\text{ dev}}$ and $K_{cb\text{ mid}}$) were 0.15, 0.15-1.15 and 1.15, respectively. The amount of $K_{cb\text{ dev}}$ and $K_{cb\text{ mid}}$ modified on the basis of plant height, wind speed and relative humidity in different regions. The recommended $K_{cb}$ values were adjusted to 0.15, 0.77, and 1.22 for PCI, 0.15, 0.70, and 1.20 for DI and 0.15, 0.71, and 1.21 for SDI system for the initial, development-season and mid-season stages, respectively (Table 6).

Maximum value of $K_{cb}$ was obtained equal to 1.22 for PCI system at the mid-season stage. The $K_c$ varied temporally during the corn growing season. Average $K_c$ value was higher at initial stage, and decreased gradually in all treatments, and reaching a minimum value as low as 0.12 for PCI system at the mid-season stage (Table 6). These results indicated that soil evaporation coefficient decreased during corn growth season, because of increase in more shade of the plant. The $K_{c\text{ dual}}$ was higher than $K_{c\text{ single}}$ in initial, development and mid-season stages. Also, Fig. 6 showed that the $E$ was higher than the transpiration from crop in initial-season stage, and with increase in plant shading $E$ was lowest than the transpiration from crop in development and mid-season stages.

### 3.3. Biological characteristics of corn

For each treatment, leaf area index (LAI), plant height (H) and stem diameter (D) during growth season are listed in Table 5. The result showed that irrigation systems had effect ($P < 0.05$) on LAI, H and D, and mulching treatments had significant effect ($P < 0.05$) on LAI and D for the growth season, but had no effect on H. The highest values of LAI, H and D were belonged to PCI system and recorded 4, 182 and 2.9 cm, respectively. When PCI system is used, the percentage of $E$ loss was zero and due reduce water loss from the soil surface created more favorable condition for plant transpiration and also increase in biological characteristics of corn (Siyal et al. 2011; Tiwari et al. 2014). The LAI, H and D increased with mulching and recorded 4.1, 18 and 2.9 cm, respectively (Table 5). The interaction effects of irrigation methods and mulching treatments had no effect on LAI, H and D. PCI system in combination with mulch (PCI M1) treatment had the highest values of LAI, H and D with 4.23, 191.6 and 3.0 cm. The lowest values obtained in DI system and non-mulch (M2) and recorded 3.4, 169.2 and 2.9 cm. In all irrigation and mulch treatments, the
lowest values of \( LAI, H \) and \( D \) during the growing season, occurred at the initial stage, then increased rapidly and reached its maximum value at mid-season stage (Fig 7).

(Fig. 7 here)

Larger value of \( LAI, H \) and \( D \) of corn was found at during mid-season stage (70 days after sowing) of growing season. Positive effect of mulching on \( LAI \) in wheat was previously reported by Xie et al. (2005). Interaction of irrigation methods and mulching showed no significant effect on the \( LAI, H \) and \( D \) in during growing season. The temporal variations of the \( H \) and \( D \) of corn for all treatments are shown in Fig. 7.

3.4. Yield (biomass)

\( PCI, DI \) and \( SDI \) systems had significant effect \((p<0.05)\) on total dry and wet biological yield of corn (Table 5). Overall average dry and wet biological yield resulted from \( PCI \) system was significantly higher (28.41 and 97.70 ton/ha) over \( DI \) (25.13 and 63.21 ton/ha) and \( SDI \) (26.67 and 81.99 ton/ha). The better performance under \( PCI \) system explained maintenance of favorable moisture status in the root zone and help the plants to utilize moisture and efficient nutrients from the wetted area (Zotarelli et al. 2008; Badr et al. 2010). The \( M_1 \) treatment had also significant effect \((p<0.05)\) on dry and wet biological yield and recorded the highest biological yield which was 27.86 (ton/ha). There were significant reductions on total yield under \( M_2 \) treatment condition. Previous studies have also reported significant yield with using mulch (Nijamudeen and Dharmasena 2002; Seyfi and Rashidi 2007). Mulching is known for reducing the weed dry matter due to physical hindrance and by reducing the amount of solar radiation reaching the weeds on soil surface and thus maintaining the optimal yield have shown the multiplier effect of mulching on biological yield crop in corn (Khurshid 2006). The \( PCI \) system with mulch \((M_1)\) prevent the \( E \) from the soil surface. With the reduction in \( E \) is a general increase in \( T \) from corn. Increase of corn yield with mulch \((M_1)\) in comparison with non- mulch \((M_2)\) treatment was observed and is in agreement with the findings of Stein et al. (1998), Chakraborty et al. (2010), Balwinder et al. (2011) and Ram et al. (2013). \( PCI \) system with mulch \((PCI M_1)\) produced highest total dry and wet biological yield in comparison with \( DI \) and \( SDI \) system with non- mulch cover. The lowest value of total dry and wet biological yield was obtained in \( DI \) in combination to non-mulch \((DI M_2)\) treatment (23.19 and 58.54 ton/ha), respectively. \( E \) increased during the first week after transplanting when plants did not have enough canopies to shade the soil. Mulch directly affected the microclimate around the plant (absorptivity vs. reflectivity) of the surface and decreasing the soil water loss. These results are in agreement with the findings of El-Nemr (2006), Korir et al. (2006), Ertek et al. (2007), Dagedelen et al. (2009) and Tesfaye et al. (2016).
3.5. Water use efficiency (WUE)

Differences in irrigation methods caused significant effect \((p<0.05)\) in the water use efficiency (WUE) and irrigation water use efficiency (IWUE) (Table 5). PCI system produced higher WUE and IWUE in comparison to DI and SDI systems. With using porous capsule the soil surface usually remains dry than DI and SDI systems, and this leads to an increase in \(T\), WUE and IWUE (Romero et al., 2004). The \(M_1\) treatment had also significant effect \((p<0.05)\) on WUE and IWUE which was 7.46 and 7.33 \((\text{kg/m}^3)\). Interaction of irrigation methods and mulching showed no significant effect on the IWUE and WUE in during growing season (Table 5). The IWUE of all the treatment ranges was from 6.10 to 7.89 \((\text{kg/m}^3)\), while the WUE of all the treatment ranges from 6.14 to 7.89 \((\text{kg/m}^3)\), which this finding can indicate the difference in irrigation IWUE and WUE compared between irrigation methods. PCI system with mulch (PCI \(M_1\)) treatment produced higher values of IWUE and WUE, because PCI system had \(E\) and deep percolation losses than other irrigation methods. The lowest IWUE and WUE values were obtained in DI system in combination with non-mulch (DI \(M_2\)) treatment which was 6.10 and 6.14 \(\text{kg/m}^3\) in the growing season of corn. Uniform mulching on the soil surface reduces \(E\), increases soil moisture content, and decreases water consumption, saving water without reducing grain yield and leading to a higher WUE (Jin et al. 2009; Wang et al. 2015; Shen et al. 2012).

4. Conclusions

This study evaluated the influence of porous capsule irrigation (PCI), surface drip irrigation (DI) and subsurface drip irrigation systems (SDI) under mulch condition on actual evapotranspiration (\(ET_{act}\)), single and dual crop coefficient (\(K_{c\ single}\) and \(K_{c\ dual}\)), yield and water use efficiency (WUE) of corn (Zea mays L.) in the semiarid climate of Iran. The resulted indicated that the effects of irrigation systems were significant on evapotranspiration. Maximum value of \(K_{c\ b}\) was obtained for PCI treatment at the mid-season stage. The \(K_c\) varied temporally during the corn growing season. The mean \(K_c\) was estimated to be 0.83, 0.74 and 0.73 for PCI, DI and SDI systems in the growing seasons, respectively. Highest total dry and wet biological yield was recorded in the PCI system in comparison to DI and SDI systems. Application of mulch was effective on the increase dry and wet biological yield of corn. PCI system under mulch conditions (PCI \(M_1\)) produced highest total dry and wet biological yield, WUE and IWUE in compared to non-mulch. The better performance under PCI system can be explained to the maintenance of favorable moisture status in the root zone, that helped the plants to utilize moisture and efficient nutrients from the wetted area According to the results of this study, it can be concluded that using PCI system leads to higher biological yield, WUE and IWUE in comparison to DI and SDI system.
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Availability of data and material
The datasets generated during and/or analyzing for the current study are available from the corresponding author on reasonable request.

Authors contributions: Elahe Kanani: Performed the experiments and drafted the manuscript. Hossein Dehghanisanij: Conceived and designed the experiments, supervised the work, interpreted the data and co-wrote the paper. Samira Akhavan: Substantial contributions to the conception or design of the work; analysis, or interpretation of data for the work. All authors read and approved the final manuscript.

Code availability
For this publication we did not used any code.

Ethics approval
This approval is attached.

Compliance with ethical standards
Work is approved by technical committee in Agricultural Engineering Research Institute.

Conflict of interest
The authors declare they have no conflict of interest.

Consent to participate
The authors declare they have consent to participate.

Consent for publication
The authors declare they have consent to publication.

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Figure Captions

Fig. 1. The layout of experimental setup (mulch, plants, and the mini-lysimeter).

Fig. 2. Porous capsule used for installation in the farm.

Fig. 3. Variation of actual corn evapotranspiration in irrigation methods: a – Porous capsule irrigation (PCI), b- Surface drip irrigation (DI), c- Subsurface drip irrigation (SDI) during the corn growing season.

Fig. 4. Variation of soil evapotranspiration and corn transpiration in irrigation methods: a – Porous capsule irrigation (PCI), b- Surface drip irrigation (DI), c- Subsurface drip irrigation (SDI) during the corn growing season.

Fig. 5. Variation of crop coefficient and leaf area index (LAI) of corn in irrigation system: a – Porous capsule irrigation (PCI), b- Surface drip irrigation (DI), c- Subsurface drip irrigation (SDI) during the corn growing season.

Fig. 6. Daily single and dual crop coefficient during the corn growing season.

Fig. 7. Variation of crop height (H) and stem diameter (D) of corn in irrigation system: a – Porous capsule irrigation (PCI), b- Surface drip irrigation (DI), c- Subsurface drip irrigation (SDI) during the corn growing season.
Fig. 2
Fig. 3
Fig. 4

ETc (mm/day)

Day after planting

PCI

0 2 4 6 8 10 12

initial Development mid-season

ETc (mm/day)

Day after planting

DI

0 2 4 6 8 10 12

initial Development mid-season

ETc (mm/day)

Day after planting

SDI

0 2 4 6 8 10 12

initial Development mid-season
Fig. 5
Fig. 6
Fig. 7
| Month    | $T_{\text{min}}$ | $T_{\text{max}}$ | $T_{\text{avg}}$ | RH$_{\text{avg}}$ | $U_2$  | RS        |
|----------|------------------|------------------|------------------|-------------------|-------|-----------|
|          | (ºC)             | (ºC)             | (ºC)             | (%)               | (m/s) | (Mj/m$^2$ day) |
| August   | 20.4             | 36.5             | 28.4             | 32                | 5.0   | 24.9      |
| September| 18.2             | 33.5             | 25.8             | 38                | 4.1   | 23.7      |
| November | 11.5             | 24.7             | 17.8             | 49                | 4.8   | 22.7      |
| Total    | 16.7             | 31.5             | 24               | 39.6              | 4.7   | 23.8      |

$T$: air temperature. RH: relative humidity. $U_2$: wind speed. RS: solar radiation
Table 2. Physicochemical properties of the experimental site soil

| Soil depth (cm) | BD (g/cm³) | FC (%) | WP (%w) | PH | EC (dS/m) | Soil textures |
|-----------------|------------|--------|---------|----|-----------|---------------|
| 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     | 8.1| 2.46      | loam          |

*BD*: bulk density. *FC*: feld capacity. *WP*: permanent wilting. *EC*: electrical conductivity.
Table 3. Chemical characteristics of irrigation water

| Water source | pH  | EC (dS/m) | Cations and anions (meq/L) | Anions   | SAR (%) |
|--------------|-----|-----------|-----------------------------|----------|---------|
|              |     |           | Na⁺ | Mg²⁺ | Ca²⁺ | SO₄²⁻ | HCO₃⁻ |     |
| Well         | 7.8 | 0.8       | 3   | 2.4  | 2.4  | 1.8   | 2.4   | 1.82 |
Table 4. Amounts of actual corn evapotranspiration ($ET_{c\,act}$) during growing season

| stage after planting | $ET_{c\,act\,(PCI)}$ (mm) | $ET_{c\,act\,(DI)}$ (mm) | $ET_{c\,act\,(SDI)}$ (mm) | Irrigation amount (mm) |
|---------------------|----------------------------|----------------------------|----------------------------|------------------------|
| Initial             | 79.7                       | 79                        | 77.8                       | 79.7                   |
| Development         | 143.4                      | 142.5                     | 140.1                      | 143.4                  |
| Middle              | 156.7                      | 155.5                     | 153.9                      | 156.7                  |
| sum                 | 379.8                      | 377.0                     | 371.9                      | 379.8                  |

$PCI$: Porous capsule irrigation, $DI$: Surface drip irrigation, $SDI$: Subsurface drip irrigation
Table 5. Influence of irrigation systems and mulching on actual crop evapotranspiration ($ET_{\text{c act}}$), crop coefficient ($K_c$), leaf area index (LAI), plant height (H) and stem diameter (D) dry and wet biological yield, water use efficiency (WUE) and irrigation water use efficiency (IWUE).

| Treatment | $ET_{\text{c act}}$ (mm) | $K_c$ average | LAI (m²/m²) | H (cm) | D (cm) | Dry biological yield (ton/ha) | Wet biological yield (ton/ha) | IWUE (kg/m³) | WUE (kg/m³) |
|-----------|--------------------------|---------------|-------------|--------|--------|-------------------------------|-------------------------------|--------------|--------------|
| PCI       | 379.9 a                  | 0.82 a        | 4.0         | 182    | 2.9    | 28.41 a                      | 97.70 a                      | 7.47 a       | 7.47 a       |
| DI        | 374.1 b                  | 0.74 b        | 3.7         | 179    | 2.8    | 25.13 b                      | 63.21 b                      | 6.56 b       | 6.67 b       |
| SDI       | 370.2 b                  | 0.73 b        | 3.9         | 182.5  | 2.9    | 26.67 ab                     | 81.99 ab                     | 7.07 ab      | 7.26 ab      |
| Prob > F  | <0.004                   | <0.0001       | Ns          | Ns     | Ns     | 0.040                        | 0.054                        | 0.034        | 0.042        |
| Mulching  |                          |               |             |        |        |                               |                               |              |              |
| $M_1$     | 373.1                    | 0.77          | 4.1 a       | 189    | 2.9 a  | 27.86 a                      | 84.13 a                      | 7.33 a       | 7.46 a       |
| $M_2$     | 376.1                    | 0.76          | 3.6 b       | 172.5  | 2.8 b  | 25.61 b                      | 73.78 b                      | 6.74 b       | 6.80 b       |
| Prob > F  | NS                       | NS            | 0.014       | NS     | 0.01   | 0.023                        | 0.22                         | 0.031        | 0.017        |
| Interaction |                        |               |             |        |        |                               |                               |              |              |
| PCI $M_1$ | 379.9                    | 0.82          | 4.2         | 191.6  | 3.0    | 29.98                         | 107.8                        | 7.89         | 7.89         |
| PCI $M_2$ | 379.9                    | 0.82          | 3.7         | 183.5  | 2.9    | 26.83                         | 75.63                        | 7.05         | 7.05         |
| DI $M_1$  | 370.8                    | 0.74          | 3.5         | 173.1  | 2.8    | 26.80                         | 67.88                        | 7.02         | 7.19         |
| DI $M_2$  | 377.2                    | 0.75          | 3.4         | 169.2  | 2.7    | 23.19                         | 58.54                        | 6.10         | 6.14         |
| SDI $M_1$ | 368.5                    | 0.73          | 3.7         | 189.2  | 2.9    | 27.07                         | 87.15                        | 7.09         | 7.30         |
| SDI $M_2$ | 371.9                    | 0.74          | 3.7         | 179.3  | 2.8    | 26.53                         | 76.64                        | 7.06         | 7.21         |
| Prob > F  | NS                       | NS            | NS          | NS     | NS     | NS                           | NS                           | NS           | NS           |

$M_1$: with mulch, $M_2$: non- mulch and NS: not significant
Table 6. Average values of soil evaporation coefficient \((k_e)\), basal crop coefficient \((k_{cb})\), single crop coefficient \((k_{c \ single})\) and dual crop coefficient \((k_{c \ dual})\) at different growing stages of corn

| Irrigation Methods         | Factor     | Initial | Development | Mid-season |
|---------------------------|------------|---------|-------------|------------|
| Porous capsule irrigation (PCI) | \(k_{cb}\) | 0.15    |      0.77   | 1.22       |
|                           | \(k_e\)   | 0.26    |      0.12   |            |
|                           | \(k_{c \ single}\) | 0.30    |      0.88   | 1.35       |
|                           | \(k_{c \ dual}\) | 0.48    |      1.03   | 1.34       |
| Surface drip irrigation (DI) | \(k_{cb}\) | 0.15    |      0.70   | 1.20       |
|                           | \(k_e\)   | 0.45    |      0.36   | 0.16       |
|                           | \(k_{c \ single}\) | 0.30    |      0.86   | 1.34       |
|                           | \(k_{c \ dual}\) | 0.60    |      1.06   | 1.36       |
| Subsurface drip irrigation (SDI) | \(k_{cb}\) | 0.15    |      0.71   | 1.21       |
|                           | \(k_e\)   | 0.40    |      0.36   | 0.14       |
|                           | \(k_{c \ single}\) | 0.30    |      0.87   | 1.35       |
|                           | \(k_{c \ dual}\) | 0.55    |      1.07   | 1.35       |