H2Open Journal

H_2Open Journal Vol 5 No 4, 642 doi: 10.2166/h2oj.2022.030

Determination of water requirement and crop coefficient for strawberry using lysimeter experiment in a semi-arid climate

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ABSTRACT

This research is aimed at measuring the water requirement, crop coefficient, and strawberry canopy coverage for efficient water consumption management. Two volumetric lysimeters were installed during the growing season of 2018 and 2019 at an agricultural research station in Kurdistan provinces, Iran. In one of the lysimeters, the grass crop was cultivated as the reference crop. Queen Elisa, the dominant strawberry cultivar of the study area, was planted in the other lysimeter. To determine the crop coefficient, strawberry and grass evapotranspiration at different stages of plant growth was measured and evaluated. The results showed that the average evapotranspiration of strawberries was 3.8 mm/day and the amount of water consumed during the whole growing season was 873.4 mm. The evapotranspiration of grass was calculated as 1143.5 mm with an average of 4.7 mm/day. Initial, middle, and ultimate crop coefficients were measured as 0.45, 0.86, and 0.8, respectively. During the growing season, the strawberry canopy cover increased by 73% and then decreased by 65%. There was a linear relationship ($R^2 = 0.94$) between crop coefficient and strawberry canopy coverage.

Key words: evapotranspiration, irrigation, lysimeter, strawberry, water consumption

HIGHLIGHTS

- Crop coefficient (K_c) and evapotranspiration (ET_c) are vital for water management.
- Two volumetric lysimeters were used for K_c and ET_c measurements.
- The evapotranspiration of the strawberry and grass were 905.4 and 1137.8 mm.
- The initial, maximum, and final values of K_c of the strawberry were 0.45, 0.86, and 0.8.
- The canopy coverage extended up to 73% of the total area and then dropped to 65%.

GRAPHICAL ABSTRACT

1. INTRODUCTION

Water is one of the most vital resources required by human society and the preservation and exploitation of which are thought to be among the principal challenges in the current century (Miguel Costa *et al.* 2007). Weighing up the crop water requirements for the design and implementation of soil and water management policies seems indispensable (Igbadun 2012; Sedri *et al.* 2019). Water requirement is referred to as the total amount of water consumed through evapotranspiration (Hafizul Islam *et al.* 2016). Iran is a semi-arid country which faced severe drought in recent years (Amini *et al.* 2014). Moreover, agricultural withdrawals for irrigation have caused an intense decline in the water resources in the region (Hesami & Amini 2016). Therefore, the minimization of agricultural water consumption in this area has been of particular interest to decision-makers and stakeholders. Inadequate optimal use of irrigation water, water constraint, and the increasing human need for more food dictate modern management practices to save water and increase irrigation efficiency. This is not feasible without an estimation of the crops' water requirement (El-Nady & Borham 2009).

Thanks to its many comparative advantages, the strawberry is one of the most important small fruits in the world that enjoys great nutritional value. According to the Food and Agriculture Organization (FAO 2018), the total area of world strawberry cultivation in 2018 is 372,361 ha and the total production across the globe is over 8 million tons. Strawberry is a shallow-root plant that is very sensitive to water and mineral deficiency (Kruger *et al.* 1999). The yield and growth of strawberries are severely abated during flowering and fruiting periods under dehydration and drought stresses (Blatt 1984). The vegetative and reproductive growth of strawberries is very sensitive to environmental circumstances. This plant grows with the increase in day length, appropriate temperature, and nutrients. All of these are quantitative reactions so that different varieties are the results of different feedbacks (Sønsteby & Heide 2006). Different strawberry varieties grow in relatively wide climates. Certain abiotic factors such as water logging, drought, salinity, soil acidity reaction, frostbite, and air temperature may cause fertility cutback (Hancock *et al.* 1991). Permeability and high moisture-holding capacity, light texture and appropriate depth, relatively low salt level, being free of harmful weeds, and pH range of 5.8–6.5 are all the specifications of a soil apt for planting strawberries (Sharma 2002). Perea *et al.* (2016) developed software to facilitate irrigation scheduling in the strawberry sector. This tool uses soil data, agro-climatic, and hydraulic information and offers farmers information about the required irrigation.

García-Tejero *et al.* (2018) estimated strawberry crop coefficients (K_c) using *in situ* data from three lysimeters for 2 years. They recorded agro-climatic information from weather stations located inside and outside of the macro-tunnels. They found that K_c values estimation depends on the methodology used to estimate ET_0 and irrigation water requirements depending on the climatic conditions. Harfoush & Jumaah (2020) conducted a field experiment to estimate the strawberry K_c and water consumption. They found different values of water consumption under various irrigation standards and soil characteristics. The values of K_c were found from 0.35 to 0.75.

Lysimeter is applied to the measurement of evapotranspiration, evaluation of the crop water requirement, and crop coefficient aimed at efficiency improvement (Marek *et al.* 1988; Bergström 1990; Young *et al.* 1996; Yang *et al.* 2010). The noteworthy effects of irrigation on strawberry growth, berry yield, and quality were reported in previous research works (Serrano *et al.* 1992; Kruger *et al.* 1999). Liu *et al.* (2007) used a field lysimeter to study the effects of partial root-zone drying on strawberry irrigation water use efficiency, berry yield, and yield components. They found that given the same amount of irrigation water, partial root-zone drying had no advantage compared to deficit irrigation in maintaining plant water status and berries yield. Moreover, they found that a reduction in irrigation water led to significant reductions in berries yield. Using soil and water balance for irrigation management entails the estimation of the amount of water in the crop's development area (Li *et al.* 2010). Determination of water requirement for strawberries is a requisite for countries in a semi-arid area. In Iran, most strawberry is traditionally cultivated on open-field systems. In recent years, protected cultivation has also been developed in greenhouses and under plastic tunnels. Most family members are involved in its production, creating high-value goods and employment.

A great deal of research has been carried out thus far around the estimation of the crop water requirement. With due regard to the above-mentioned issues, it is essential to have efficient irrigation to achieve optimal crop quality (Fallahi *et al.* 2010). Despite the widespread use of drip irrigation, there is still indecision about the accurate amount of strawberry water requirement (Lozano *et al.* 2016). The objective of this study was to measure evapotranspiration, crop coefficients, and crown coverage of strawberries in a semi-arid area using the volumetric lysimeter installed in the field. The main innovation of this research is to measure evapotranspiration in a direct way and determine the characteristics of strawberries in a semi-arid climate. This study is a major step toward managing limited water resources in semi-arid regions and is the first attempt to determine the characteristics associated with strawberry growth and water use. The results will directly affect the livelihoods of a large proportion of farmers in the region.

2. MATERIALS AND METHODS

Containers or tanks with a specific boundary to contain water soil and permit measurement called lysimeters which are foremost devices to measure either the soil–water balance or the volume of water percolating vertically (Howell 2005). The present research was carried out in 2018 and 2019 in the Grizeh Research Station affiliated with the Kurdistan Agricultural and Natural Resources Research and Education Center, AREEO, Sanandaj, Iran to determine water requirement and crop coefficient of strawberry. Covering an area of 56 ha, the research station of Grizeh is situated 12 km southeast of Sanandaj City at 47° 1′E and 35° 16′N and is 1,405 m above the sea level. Its annual average precipitation is 380 mm and the average relative humidity is reported to be 47% (Amini *et al.* 2018). The annual average temperature at the Sanandaj Synoptic Station during 1960–2017 is 14.3 °C. The maximum temperature is recorded at 44 °C in July and the absolute minimum is recorded at −31 °C in February. While the minimum absolute temperature analysis indicates that the below-zero temperature begins in November and continues until April and the total number of frost days at this station is 101 days (Fatehi & Shahoei 2021). It should be noted that in the west and center of Kurdistan province, Iran, the strawberry mostly is cultivated in the vicinity of Sirwan River and provides a high rate of employment and high economic value goods. The location of the Grizeh Station in Iran is shown in Figure 1.

2.1. Lysimeter installation and experiments

In this research, two drainage lysimeters were used to plant strawberry and grass on the research farm of AREEO. The lysimeters, manufactured of concrete brick, were in the form of rectangular cubes with a square base of 3 m in length and a depth of 2 m. They are so implemented in the research farm that a necessary protective ring was created around them. The area surrounding the lysimeter was cultivated like inside. To make the lysimeter, the first pits of 4 m × 4 m (larger than the lysimeter dimensions) were dug. Then, the bottom of the lysimeters was applied with a 3% slope foundation and with 20 cm thick bricks of sand and cement mortar. To prevent any leakage and breakage of the lysimeter walls, the wall thickness was cemented as 20 cm concrete bricks. The sloped bottoms of the lysimeters were guided by pipes to the drainage

Figure 1 | Location of the Grizeh Agricultural Research Station and Sanandaj City in Iran.

measurement sites. A 15 cm sand filter was created on the floor of the lysimeters. Then, the lysimeters were filled with soil in the excavation pit, taking into account the order of the soil profile layers before being compressed on several occasions. To consolidate the soil inside the lysimeters, water was added to the soil several times prior to cultivation and then the lysimeters were re-filled to the desired level after complete soil settlement. The filling of the lysimeter was done manually and filled with disturbed soil material from the natural soil profile. Each layer that was removed from the natural soil profile was filled in the same layers in the lysimeter. After installing the pipe as a drainage system to direct the outflow of water, the wall and floor of the lysimeters as well as the water collection sinkholes were carefully bonded. Figure 2 shows the used lysimeters at the time of manufacture and after installment.

2.2. Cultivation and irrigation systems

Similar to the strawberry crop pattern in Kurdistan Province, *Queen Elisa* which is a short-day variety and the dominant cultivar in the region was used. The strawberry transplants in a double row-raised bed system were

Figure 2 | Preparation steps of research lysimeters: (a) lysimeters bonding and (b) irrigation system and buffer area around lysimeters.

equipped with drip irrigation. Analysis of soil physicochemical properties was performed at the cultivation site. The operations of soil preparation including the distribution of rotten manure and fertilizers were run based on soil test results. The same transplants were arranged and planted on three stacks inside the lysimeter. The raised bed center spacing was 120 cm and strawberry transplants were planted out in two rows at a distance of 35 cm on a raised bed, 60 cm wide, and 20 cm high so there were 18 strawberry plants in two rows of nine in each experimental unit. Agronomic care including weed control was conducted in several stages along with regular interval irrigation as measured by soil moisture content. Soil moisture status was measured per lysimeter by Time-Domain Reflectometry, TDR, three times a week at 15 cm depth between the drip tapes and rows. Depending on the weather conditions, irrigation was done two to three times a week, as recommended by Létourneau & Caron (2019) at the time when soil suction reached −10 kPa so that it is kept within the readily available water, RAW, level (Allen *et al.* 1998). To attain RAW, the field capacity, FC, and moisture are to be determined. To measure FC, the soil inside the lysimeters was first saturated, afterwards, water was allowed to infiltrate for 24 h. Once the amount of inlet and outlet water was balanced, the rate of FC was attained. After establishing the moisture balance, the moisture percentage of the samples was measured using an oven. Based on the soil moisture curve of the test area, the percentage of gravimetric soil moisture at the FC and wilting points were 27.3 and 13.1%, respectively. Considering the soil texture, these values are in the ranges recommended by Allen *et al.* (1998) and Rai *et al.* (2017).

Besides measuring the quantity of water consumed and calculating evapotranspiration at different phases of growth, it was also recorded the alterations in plant growth by measuring the canopy cover area per plant. In the other lysimeter, grass seed sowing was carried out. To secure a similar bulk density as in the field, each layer of soil inside the lysimeter needs to be manually compacted (Meissner *et al.* 2020). For this purpose, after preparing and leveling the soil employing a manual roller, the planting bed was entirely uniform and dense as shown in Figure 3. Then, grass seeds were strewn uniformly on the planting bed inside the lysimeter, and a layer of 1 cm thick rotten manure was applied to the seeds. Irrigation was performed immediately after planting. To create a buffer layer and the same experimental conditions, the grass seed sowing was done on the lysimeter border of 0.5 m wide.

The irrigation system was run as drip tape in both lysimeters, and the inlet water measurement was rendered by a flowmeter with 0.1 l/s accuracies. The total water consumption in liters was calculated for each irrigation by this flowmeter and based on the duration of irrigation. The flow meter was installed at the beginning of the irrigation system.

2.3. Soil moisture

The TDR instrument was employed to measure soil moisture. To log the captured data, the data logger of the TDR model SMS-T1IDRG was used. This device is capable of saving 2,000 temperature and moisture data in its

Figure 3 | Grass seed sowing and raised bed for strawberry cultivation inside lysimeters.

memory and can monitor and record data independently of or connected to the computer. The irrigation and drainage systems were installed according to the offered standards (Yang *et al.* 2010). The device probes were positioned vertically at depth of 15 and the environs of which completely covered with soil. In certain cases, soil moisture content was calculated by the gravimetric method through laboratory sampling. The device possesses a microcontroller core, non-volatile memory, and other peripherals.

The gravimetric technique was adopted to calibrate the TDR instrument. Taking a certain volume of soil, the sensor was inserted into the soil and allowed to balance with the soil environment for half an hour. The temperature and humidity of the sensor were then read and recorded through the data logger. At the same time, the soil was manually sampled and the samples' moisture was determined via the gravimetric method. The bulk density of the soil at a depth of 15 cm was measured as 1.53 g/cm^3 and used to convert the gravimetric soil moisture (g/cm^3) into volumetric soil moisture (cm^3/cm^3). The comparison of the correlation between the average percentage of volumetric moisture content by TDR sensors with actual volumetric moisture content indicated the reliability of TDR data (Figure 4). Data analysis using SPSS software showed that there is no difference between the moisture data measured by TDR sensors and the samples measured by the gravimetric method with 99% confidence.

2.4. Physical and chemical properties of soil

The soil samples of the lysimeters were taken from 0 to 30 cm depth and soil characteristics were analyzed based on the methods recommended by Hazelton & Murphy (2016). Also, to measure the quality of the water used, water samples were taken from the well and went into analysis in the laboratory of the Soil and Water Research Department of AREEO. The physicochemical properties of the soil sample are given in Table 1.

Table 1 shows that the soil at the experiment site is relatively calcareous with an alkaline pH, and while containing organic matter the absorbability of its phosphorus concentration is moderate and that of its potassium is high. The soil texture is sandy clay loam and lacks salinity which is a positive issue since strawberry is very sensitive to salty soil. According to the results, nutrient requirements for strawberries including nitrogen and phosphorus were determined, respectively from urea (%46 N) and triple superphosphate (TSP) fertilizers and added to the soil before cultivation at 15 cm depth. Nitrogen fertilizer was used in the amount of 100 kg of pure nitrogen per hectare from the source of urea fertilizer in three equal installments before planting the strawberry plant, 2 weeks before flowering, and after the first fruit harvest. Phosphorous fertilizer from the source of TSP fertilizer at the rate of 75 kg P_2O_5/ha was placed at a depth of 8 cm in the soil and at a distance of 5 cm from the plant next to the crop line.

2.5. Lysimeters drainage system

The 10-cm pipes were set on the floor and at the side walls of the lysimeters to drain water out. The excess water in both lysimeters was directed to two graduated cylindrical containers. After filling the containers, the total volume of water was discharged by a graduated vessel and its volume was calculated. Thus, following each

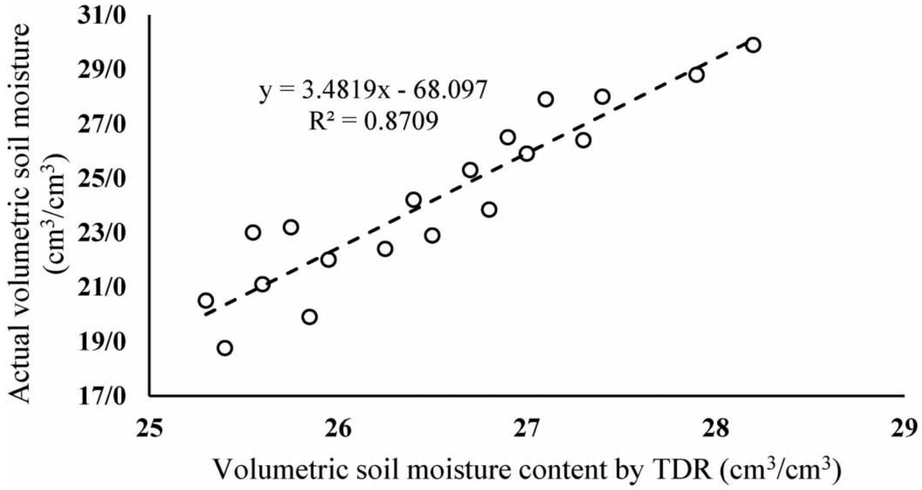

Figure 4 | The actual soil moisture versus TDR measurements.

Table 1 | Soil characteristics (0–30 cm depth) of the experimental site

Soil property	Value
Clay (%)	20.9 ± 0.30
Silt (%)	26.8 ± 0.56
Sand (%)	51.6 ± 0.77
Textural class	Sandy clay loam
pH (1:5 soil:water)	7.08 ± 0.02
Electric conductivity (dS m^{-1}) (1:5 soil:water)	1.13 ± 0.02
Total organic carbon (%)	1.17 ± 0.01
Total N (% by weight)	0.18 ± 0.002
P_{av}^{a} (mg.kg^{-1})	11.7 ± 0.29
K_{av}^{a} (mg.kg^{-1})	365.2 ± 1.73
T.N.V.[b] (% $CaCO_3$)	9.25 ± 0.14
Sp[c] (%)	36.28 ± 0.64
Bulk density (g/cm^3)	1.53 ± 0.02

[a]P_{av}: available phosphorus, K_{av}: available potassium.
[b]T.N.V.: total neutralizing value, the percentage of the limestone capable of neutralizing an acid.
[c]Sp: the saturation percentage, equals the weight of water required to saturate the pore space divided by the weight of the dry soil.

irrigation or precipitation, the drain volume was measured in liters and then converted to a value in millimeters by dividing it by the lysimeter's area to water depth.

2.6. Evapotranspiration

Reference crop evapotranspiration is defined as the evapotranspiration from an unlimited area of grass with a uniform height of 8–15 cm, with an active growth without any water scarcity, nutrients, air and pests and diseases that cover the entire ground surface with its shade (Bhantana & Lazarovitch 2010). The reference crop is referred to by FAO as having 12 cm height and surface resistance of 70 s/m with Albedo coefficient-light reflection capability (Allen *et al.* 1998). Being a climate-related profile, the notion of reference crop evapotranspiration is discussed to examine the evaporation rate in the atmosphere regardless of the plant type parameters, growth stage, and crop management operations. Due to irregular recording of radiation, air temperature, air humidity, and wind speed data at the synoptic station near the study area, direct calculation of ET_0 and crop evapotranspiration (ET_c) was used based on the guidelines provided by FAO 56 in the lysimeters in 2018 and 2019. In the present research, evapotranspiration of the reference crop and strawberry was estimated directly by the cultivation of these plants in the lysimeters in 2018 and 2019.

2.7. Precipitation

To measure the precipitation rate during the growing season, an automatic rain gauge was set up in the research area. Moreover, the precipitation data were received from the meteorological stations located in the Sanandaj Synoptic Station around 3 km from the research area. These data were used in the calculation of water balance in the lysimeters.

2.8. Water balance

During the growing season, the water requirement of strawberry (ET_c) was determined at regular intervals using water balance in the soil as follows (Lozano *et al.* 2016).

$$ET_c = I + R - d \pm \Delta s \tag{1}$$

where ET_c is the actual crop evapotranspiration in the interval of soil moisture measurement in the lysimeter, I stands for the irrigation water value, R designates the height of rainfall, d represents the amount of drainage water and Δs stands for the change in the amount of stored water in mm. These data were recorded in both lysimeters during the experiment time.

2.9. Crop coefficient

The crop coefficient (K_c) expresses the effect of differences between the characteristics of a certain crop and the grass crop. Therefore, different crops have different crop coefficients. Since the evaporation from the surface soil may fluctuate due to precipitation or daily irrigation, the crop coefficient describes merely the average effect of the circumstances upon crop evapotranspiration during the growth period (Vaziri *et al.* 2008). Given that K_c varies mainly with specific crop characteristics and only to a limited extent with climate, it allows the transfer of standard values for K_c between different locations and climates. Therefore, K_c has been widely accepted and developed as a useful product coefficient approach. This coefficient represents the integration of the effects of the four main characteristics including crop height, reflectance, canopy resistance, and evaporation from soil that distinguish a product from the reference grass (FAO 2018). The crop coefficient is obtained from Equation (2):

$$K_c = \frac{ET_c}{ET_o} \tag{2}$$

Factors affecting crop coefficient are classified as plant type, climate, evaporation status of soil surface, and stages of plant growth (Grattan *et al.* 1998).

2.10. Canopy coverage

The percentage of canopy coverage was measured at different stages of plant growth according to the method suggested by Grattan *et al.* (1998). For this purpose, the diameter of the canopy cover was measured every 15 days in the lysimeter at noon and the average shading area of each plant was figured out. To determine the percentage of canopy cover per unit area, the average canopy diameter of a plant was multiplied by the number of plants per unit area (Grattan *et al.* 1998). As recommended by Cahn (2015) the regression relationship between the canopy cover percentage and the crop coefficient of strawberry as well as the concerning function was determined by MS-Excel 2016.

3. RESULTS AND DISCUSSION

The rate of water requirement, as well as the characteristics of strawberry growth in normal circumstances, was investigated. Hence, the irrigation interval was so adopted that no stress was applied to the plant. Table 2 contains the results of evapotranspiration measurements and the irrigation rate in a 15-day time interval as recommended by Lozano *et al.* (2016).

Table 2 shows that during 240 days, as the growing season, the rates of evapotranspiration and irrigation water in the grass crop in 2018 were 1,108 and 994.8 mm, respectively. These values in 2019 were 1,179 and 1,037 mm. In 2018, these amounts for the strawberry crop were 878.7 and 848.7 mm, and in 2019 were equal to 932.1 and 898.6 mm, respectively. In previous works, a wide range of consumptive water, as 300 mm (Trout & Gartung 2004) and 797 mm (Strand 2008), has been reported. There are discrepancies between the consumptive water rate obtained in this investigation and that reported by Sahraee *et al.* (2015) and Lozano *et al.* (2016) for strawberry which is owing to differences in the type of cultivation system, the cultivar type, and the conditions of the site of the experiments. It is worth noting that Lozano *et al.* (2016) and Sahraee *et al.* (2015) have used, respectively, plastic tunnels and a greenhouse for the cultivation of strawberry. Long-term data analysis from 1977 to 2014 from the Synoptic Station shows 3.58 mm/day evapotranspiration for Sanandaj city (Heydari & Heidari 2019). Based on data presented in Heydari & Heidari (2019), evapotranspiration for the growth period of strawberry was calculated as 1,114.5 mm which is in agreement with the results of this research. In addition, examining the long-term changes of evapotranspiration shows its slow increasing trend in spring and summer (Heydari & Heidari 2019).

3.1. Evapotranspiration

3.1.1. Reference crop

The grass was planted in one of the lysimeters to calculate the evapotranspiration of the reference crop. The evapotranspiration was directly measured from April until the end of November 2018 and 2019. The parameters of the balanced equation were estimated and recorded through the field data, irrigation and precipitation rate, and

Table 2 | Water consumption in strawberry and grass crop in lysimeters

		Strawberry				Grass			
Date	Rainfall (mm)	ET_c (mm/day)	ET_c (mm)	Irrigation (mm)	Drainage (mm)	ET_0 (mm/day)	ET_0 mm	Irrigation (mm)	Drainage (mm)
Year	**2018**								
21 Mar–4 Apr	39	0.0	0.2	0.0	39.1	0.0	0.5	0.0	38.7
05 Apr–20 Apr	35	1.0	15.5	9.0	29.0	2.0	30.5	0.0	5.0
21 Apr–05 May	35	1.0	15.5	10.8	30.6	2.3	34.5	1.8	2.6
06 May–21 May	17	3.8	57.0	40.0	0.1	5.2	78.0	63.0	2.1
22 May–05 Jun	0	3.9	58.5	58.9	0.4	4.8	72.0	73.1	1.1
06 Jun–21 Jun	0	4.4	65.9	67.2	1.3	5.2	78.0	80.0	2.0
22 Jun–06 Jul	0	5.4	81.0	86.1	5.1	6.5	97.5	98.1	0.5
07 Jul–22 Jul	0	5.8	87.0	95.0	8.0	6.9	103.5	103.5	0.0
23 Jul–06 Aug	0	6.1	91.5	99.1	7.6	7.4	111.0	112.1	1.1
07 Aug–22Aug	0	6.3	94.5	95.1	0.6	7.1	106.5	107.0	0.5
23 Aug–06 Sep	0	5.5	82.5	83.2	0.7	7.2	108.0	108.0	0.0
07 Sep–22 Sep	0	5.4	80.3	81.1	0.8	6.5	97.5	98.1	0.6
23 Sep–06 Oct	0	4.3	64.5	65.2	0.7	5.3	79.5	80.6	1.1
07 Oct–22 Oct	0	3.1	47.1	47.2	0.1	4.0	59.3	59.4	0.1
23 Oct–06 Nov	208	1.5	22.7	0.0	185.6	1.9	27.8	0.0	180.5
07 Nov–22 Nov	5	1.0	15.3	10.6	0.4	1.7	24.8	20.2	0.5
Average (mm/day)	1.42	3.7	3.7	3.53	1.29	4.6	4.6	4.1	1
Sum (mm)	340	878.7	878.7	848.3	310	1,108	1,108	994.8	236
Year	**2019**								
21 Mar–4 Apr	63.0	0.9	13.5	0.0	49.5	2.1	31.4	0.0	31.7
05 Apr–20 Apr	16.0	1.3	20.1	14.2	10.1	2.9	42.9	34.9	8.0
21 Apr–05 May	86.0	1.9	28.5	24.2	81.7	3.0	44.6	3.5	45.0
06 May–21 May	13.0	3.1	47.1	44.2	10.1	4.3	63.8	52.7	2.0
22 May–05 Jun	4.0	3.8	57.2	61.9	8.8	4.8	71.6	70.1	2.6
06 Jun–21 Jun	0.0	4.5	67.1	75.6	8.6	5.4	81.3	82.2	0.9
22 Jun–06 Jul	0.0	5.6	84.2	91.1	6.9	6.7	100.5	101.4	0.9
07 Jul–22 Jul	0.0	6.1	91.1	93.9	2.8	7.2	108.3	108.5	0.2
23 Jul–06 Aug	0.0	6.5	97.7	98.5	0.9	7.7	115.8	116.2	0.4
07 Aug–22 Aug	0.0	6.4	96.5	96.8	0.4	7.7	116.0	117.0	1.1
23 Aug–06 Sep	0.0	5.7	85.5	85.8	0.3	6.9	103.5	104.0	0.5
07 Sep–22 Sep	0.0	5.1	77.0	78.6	1.6	6.2	93.6	94.6	1.0
23 Sep–06 Oct	0.0	4.5	67.1	68.4	1.4	5.5	81.9	83.1	1.2
07 Oct–22 Oct	0.0	3.1	46.7	47.3	0.6	3.8	57.5	57.9	0.4
23 Oct–06 Nov	32.0	2.2	32.6	18.1	17.6	2.7	40.7	11.4	2.8
07 Nov–22 Nov	34.0	1.4	20.7	0.0	13.3	1.7	26.1	0.0	7.9
Average (mm/day)	1.0	3.9	3.9	3.7	0.9	4.9	4.9	4.3	0.44
Sum (mm)	248.0	932.1	932.1	898.6	214.5	1,179	1,179	1,037.4	106.3

the amount of water taken from the lysimeters. Figure 5 represents the reference crop evapotranspiration changes during the growth stages.

As shown in Figure 5, the reference crop evapotranspiration changes versus the planting time first follow an irregular increasing trend up till the lapse of the sixth 15-day period, i.e., 90 days following the beginning of cultivation. Then, in the second half of August, it reaches the maximum value. With the onset of September and temperature decline, the evapotranspiration shows a downward development. Considering the data obtained

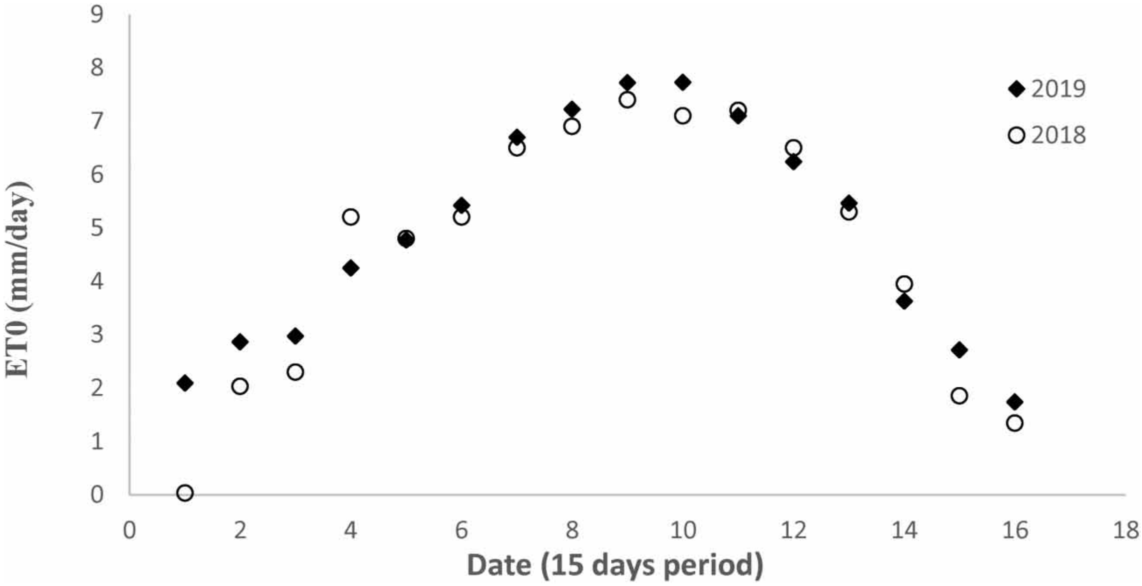

Figure 5 | Reference crop evapotranspiration.

in two growth years, the seasonal average evapotranspiration, ET_0, was 1,143.5 mm and its daily average was 4.7 mm/day. The maximum and minimum values of ET_0 were attained in the second half of August and the first half of April respectively. As expected typically, the plant's demand for water is higher in the warm seasons. With due regard to the fact that the end of the time interval corresponds to the autumn months, the decreasing trend of evapotranspiration in the last days is more justifiable. The evapotranspiration measured in Kurdistan Province quite agrees with that obtained in the surveys conducted by Faghih (2015) and Sahraee *et al.* (2015). For instance, the most evapotranspiration for the grass crop as given by Sahraee *et al.* (2015) is rather less than 10 mm/day which conforms to the maximum value estimated in this research. As held by Allen *et al.* (1998), the utmost evapotranspiration reported by FAO 56 occurred on the 230th day. Since a 15-day period was considered in this research, the highest grass evapotranspiration happened in the 11th period, that is, 170 days later. Comparatively, the results of this research indicate a 50-day period difference. By the way, the evapotranspiration rates in both investigations comply with each other. It should be noted that in the case of Kurdistan province, the analysis of long-term data confirms that rainfall and temperature have experienced changes so that rainfall decrease and temperature increase mostly occurred in the months of March and February (Amini 2020). Therefore, the data of this research may need to be modified according to climate changes in the coming years.

3.1.2. Strawberry

The evapotranspiration of strawberry was computed from the water balance equation (Equation (1)). The values of the equation's parameters were taken from the lysimeter allocated to strawberry. The ET_c alterations are shown in Figure 6. At the beginning of the growth period, evaporation climbs gradually up till the end of August which gains its maximum value before taking a decreasing trend afterwards.

Referring to Figure 6, one observes a mild slope in the evapotranspiration changes at the beginning of the growth period. With the commencement of the heating season, the evapotranspiration process would experience a momentous upward trend and would soar to its top value in the first half of August. The daily average evapotranspiration of strawberries in the whole crop season of 2018 and 2019 were 3.7 and 3.9 mm/day, respectively, and the average of both years was 3.8 mm/day. The most evapotranspiration happened in the first half of August, and the least value took place in the second half of November. The higher evapotranspiration rate of strawberries late in the time interval relative to the grass is a token of the water requirement of the former in this period. The results of the current research were compared to those of Sahraee *et al.* (2015) to the conclusion that both surveys share similar maximum evapotranspiration values. Incidentally, the maximum value reported by Sahraee *et al.* (2015) has occurred 92 days following the start of the experiment (the growth period), whereas that for the

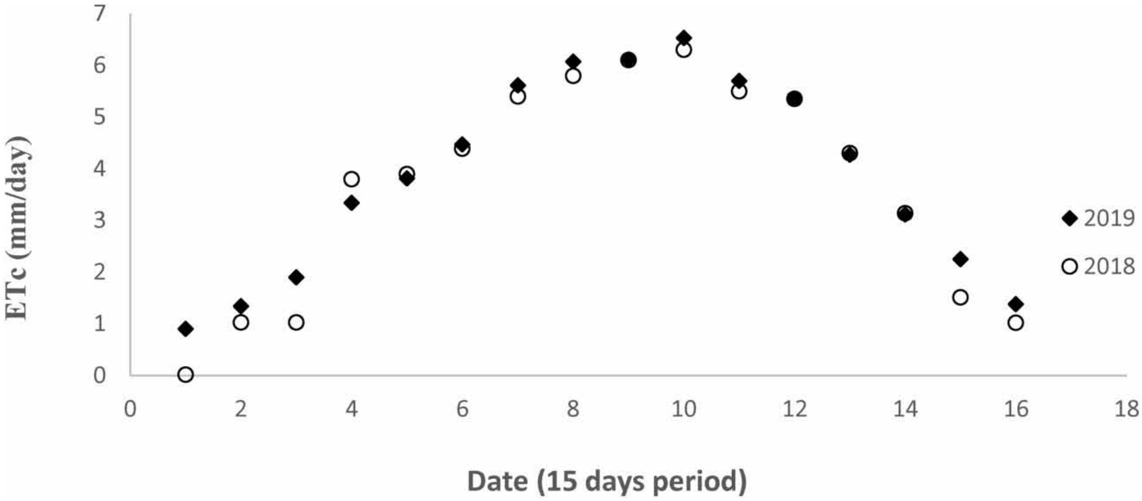

Figure 6 | Strawberry evapotranspiration.

present research emerged about 150 days after cultivation. The difference is due to how Sahraee *et al.* (2015) conducted their tests in the greenhouse conditions.

3.2. Crop coefficient

The diagram of K_c alterations as well as strawberry canopy cover in various growth phases are depicted in Figure 7.

The first inference drawn from Figure 7 is that the irrigation and precipitation intervals in the initial days of cultivation are wider than in the other seasons whence fewer changes in the K_c values. This could be regarded as the initial phase of the strawberry growth with $K_c = 0.45$. In the developmental stage when the plant is growing, evaporation from the soil surface diminishes along with increasing plant shading. Also, the crop coefficient increases proportional to the crop's growth and vegetation and was obtained in this stage as $K_c = 0.86$. In the middle stage and with the development of the crop's aerial organs, the transpiration rate increased and the crop coefficient reached its maximum level equal to 0.88 in 2018. The lowest value of K_c was 0.43 in 2019, and it remains constant at 0.8 in the time interval of summer. A comparison between the K_c results and the

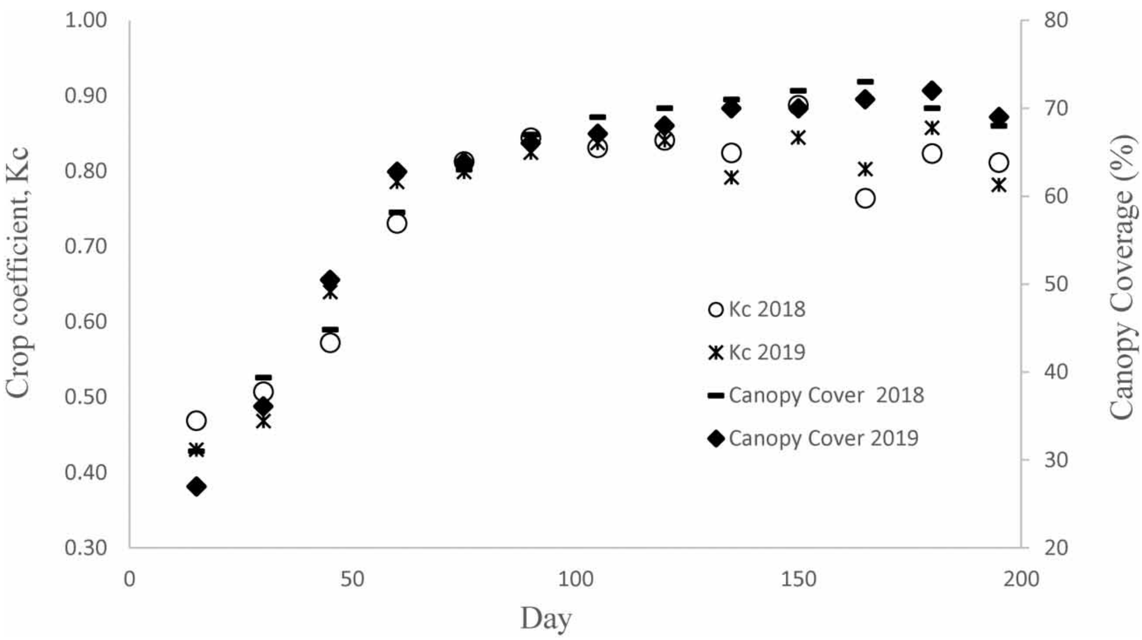

Figure 7 | Strawberry crop coefficients and the canopy cover percentage.

standard of FAO indicates that the growth changes are the same. The coefficients corresponding to the initial, middle, and ultimate growth phases for strawberry were obtained, respectively, as 0.45, 0.86, and 0.8, which are in conformity with the figures reported by Allen *et al.* (1998) as 0.4, 0.85, and 0.75, respectively. García-Tejero *et al.* (2018) on the basis of the agro-climatic information estimated K_c in Southern Spain and found that values ranged between 0.3–0.8 and 0.4–1.4 for outside and inside tunnel, respectively. The crop coefficient obtained in an arid area in Iraq was ranged from 0.37 to 0.75 (Harfoush & Jumaah 2020). García-Tejero *et al.* (2018) for drip-irrigated strawberry plants calculated monthly crop coefficients in a humid area in US. They found that monthly crop coefficients increased linearly from months 2 through 6 after transplant establishment. These findings are consistent with this research for changes in K_c.

Figure 7 also shows the changes in the canopy cover of strawberry. Both canopy cover and crop coefficient at the initial phase of the crop's growth are set at their lowest values. With the increase in temperature, these two variables would rise with almost the same trend. The canopy cover would increase up to 73% in 2018 and then plummet to the value of 65%. The rapid growth of the canopy occurred from April to late June. However, the highest percentage of strawberry's canopy cover occurred in August with 72% coverage of the whole farm which was due to the increase in the number of crowns as well as shading of daughter plants. The significant and linear increment of crop coefficient during May and June may be attributable to the rapid canopy development and the peak crop production from late May to mid-June. As the shrubs matured near the end of the growing season, the evapotranspiration of the strawberries partially decreased. The results of this investigation are in agreement with those given by Cahn (2015) and Grattan *et al.* (1998) on the subject of the positive and significant relationship between the changes in crop coefficient and the changes in the plant canopy coverage. The linear and direct relationship between K_c and the canopy coverage percentage is shown in Figure 8. The relation arising from the regression of these two indexes was extracted as Equation (3) with the coefficient of determination, $R^2 = 0.94$.

$$K_c = 0.0098C + 0.1508 \tag{3}$$

where C stands for the canopy cover percentage. Therefore, the strawberry canopy coverage could be identified as a reliable indicator to estimate the crop coefficient and water requirement of strawberry.

4. CONCLUSION

In this study, the growth and evapotranspiration of strawberry and grass plants were measured by field measurement using two volumetric lysimeters in 2018 and 2019. The most important results of this research can be stated as follows.

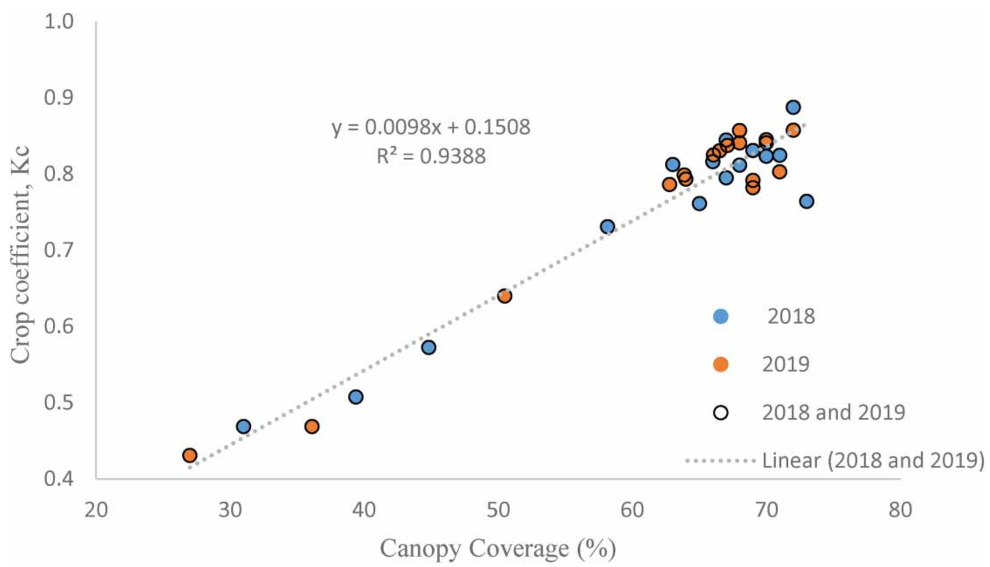

Figure 8 | Changes in crop coefficient versus canopy coverage of strawberry in various growth stages.

- The average evapotranspiration of the strawberry plant and the total consumed water in the whole period were, respectively, as 905.4 and 873.5 mm. The daily average for both years was found as 3.8 mm/day. The maximum rate of strawberry evapotranspiration occurred in the first half of August, and the minimum value corresponded to the second half of November.
- The total evapotranspiration of the grass plant during the growing period reached 1,143.5 mm with a daily average of 4.7 mm/day. The highest and lowest corresponding values as to the grass evapotranspiration were obtained to be 7.73 in 2019 and 0.03 mm/day in 2018 happening in the second half of August and the first half of April.
- The initial crop coefficient pertaining to strawberry was 0.45, with its maximum rate of 0.86, and the ultimate value as 0.8.
- During the growth period, the canopy coverage extended up to 73% of total area and then dropped to 65% in the late stages of growth. A positive linear relation between the changes in the canopy coverage and the crop coefficient was observed.

FUNDING

This work was conducted under financial support from The Ministry of Agriculture Jihad (Jahad-e-Keshaverzi Kurdistan) contract No. 37-1-108 and technical support from Soil and Water Research Institute, AREEO, research No. 24-53-10-034-961003.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 29 June 2022; accepted in revised form 3 October 2022. Available online 18 October 2022