Evapotranspiration and crop coefficient of okra under subsurface drip with and without plastic mulch

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Field experiments using lysimeters were conducted in sub-humid climatic condition to estimate water balance parameters, regional crop coefficient development and to evaluate yield response of okra crop under subsurface drip (SSD) irrigation with and without plastic mulch. In the year 2016, total crop evapotranspiration under SSD with and without plastic mulch was 403 and 512 mm respectively, whereas in 2017 it was 363 and 468 mm respectively. Average crop coefficient of okra was 0.31, 0.42, 0.68, 0.77 and 0.48 measured under SSD with plastic mulch condition, and 0.51, 0.72, 0.92, 0.93 and 0.53 without plastic mulch. High yield of okra with minimum crop evapotranspiration was observed under SSD with plastic mulch treatment due to lower irrigation water requirement, minimum evaporation and less weed transpiration under plastic film compared to non-mulch condition.

Keywords: Crop coefficient, evaporation, okra, plastic mulch condition, subsurface drip irrigation.

SUBSURFACE drip (SSD) irrigation is the most advanced method of irrigation, which enables the application of water directly to the crop root zone using drippers placed below the soil surface[1]. Improved yields are obtained from SSD compared to surface drip systems because less evaporation under SSD favours more water availability in plant rooting profile[2]. SSD drippers are commonly placed deep in the soil to reduce evaporation or facilitate tillage operations; hence SSD often provides insufficient surface soil moisture to meet the demands of young seedlings and shallow-rooted vegetable crops[3]. Placement of SSD tubing as well as irrigation regime can impact the potential for surface wetting and weed growth. Dry weed biomass of 0.05 tonnes per acre was obtained under SSD with depth of lateral below 0.25 m used for tomato crop[4]. Further yield of okra was higher under SSD with 0.1 m depth of lateral than 0.15 m (ref. 5). Thus possibility of weed intensification under SSD with shallow depth of dripper is high.

The use of black plastic mulch could be an effective and non-chemical weed control solution by restricting weed growth under SSD for shallow rooted vegetable crops like okra. High degree of impermeability of plastic mulch prevents unproductive water loss (soil evaporation, weed transpiration loss), and increases quantity and/or efficiency of productive water loss (transpiration). An earlier study had reported that drip irrigation alone or in combination with mulch can increase okra yield over furrow by 45–72% under Kharagpur sub-humid agro-climatic conditions[6]. However, information of okra crop response under SSD with and without plastic mulch in sub-humid agro climatic conditions is limited. Further, accurate crop coefficient (K_C) value and water dynamics study within soil, vegetation and atmospheric system under SSD with and without plastic mulch is essential for proper irrigation water management. Therefore, the present study was undertaken to examine water balance parameters, regional K_C development and okra yield response under SSD with and without plastic mulch.

Material and methods

Study site

The field experiment was conducted at the Precision Farming Development Centre (PFDC) project area in the Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, India. The study site is located at 48 m amsl, 22°19′N and 87°19′E. Soil type of the experimental area is lateritic sandy loam, which is taxonomically grouped under the order of Alfisol (Oxyaquic haplustalf). Table 1 gives the soil sample analysis from the experimental plots. The root zone depth (60 cm) of the soil is acidic in nature (pH = 5.2). Sand and clay content of the soil varies from 45.6% to 59.4% and 14.3% to 29.7% respectively. The soil profile depth is sandy loam with medium bulk density, i.e. 1.63 g cm^{-3}. Soil saturated hydraulic conductivity varies between 0.34 and 9.84 cm day^{-1}. Similarly, field capacity and wilting point of the soil vary from 0.24 to 0.28 cm^3 cm^{-3} and 0.10 to 0.13 cm^3 cm^{-3} respectively. Top 15 cm soils have low plant available nitrogen (i.e. 214 kg ha^{-1}).

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Table 1. Physical properties of the soil

Soil depth (cm)	Particle size distribution (%) Clay	Silt	Sand	Bulk density (g cm^{-3})	Saturated hydraulic conductivity (cm d^{-1})	Field capacity (cm^3 cm^{-3})	Wilting point (cm^3 cm^{-3})
0–15	14.3	26.2	59.5	1.69	9.84	0.26	0.10
15–30	21.0	19.3	59.7	1.56	6.72	0.24	0.10
30–45	27.3	20.2	52.5	1.59	0.89	0.25	0.10
45–60	28.6	19.2	52.2	1.63	0.74	0.26	0.12
60–90	29.7	24.7	45.6	1.69	0.34	0.28	0.13

Field set-up and irrigation schedule

In the years 2016 and 2017, field experiments were set-up to determine fresh pod yield and biometric response of okra crop under SSD with plastic and without plastic mulch, whereas lysimetric study was incorporated to determine water balance parameter and regional K_C development under the same conditions. A field plot 28 m long × 9.5 m wide was divided into six blocks of size 26 × 1 m^2 for SSD with and without plastic mulch (Figure 1). Each treatment was replicated thrice, arranged randomly in a uniform environmental condition. The SSD system consisted of buried laterals at 0.1 m depth and inline emitters of 4 L h^{-1} discharge capacity at 0.3 m interval with 97.19% emission uniformity. Black plastic mulch of 25 μm thickness was placed at the top of the soil cover and anchored tightly from the side with soil to prevent entry of air and water from the top of mulching plots. Before starting the irrigation treatment, root zone soil was saturated and then allowed to bring at field capacity. For both treatments, irrigation water was supplied on every fourth day and depth of irrigation water was assessed from soil water requirement measured from volumetric soil moisture to refill the plant-root zone (0.6 m) up to field capacity using eq. (1) below. Our 2015 study had reported that okra root length varies between 0.40 and 0.60 m. Therefore, water goes beyond 0.6 m depth becomes deep drainage[7]. Total supplied irrigation water was 518 and 433 mm, under non-mulch treatment, and 410 and 347 mm under plastic mulch treatment during the years 2016 and 2017 respectively.

$$D = (\mathrm{FC} - \theta) \times \mathrm{RZ}, \qquad (1)$$

where D is the depth of irrigation water (mm), FC the field capacity of soil in rooting depth profile (mm m^{-1}), θ the volumetric soil moisture in rooting depth profile before irrigation (mm m^{-1}) and RZ is the rooting depth (m).

Lysimeters

Two drainage lysimeters of dimension 1 × 1 × 1.1 m were installed in the okra field plots to quantify all the water balance parameters and K_C under SSD with and without plastic mulch (Figures 1 and 2 *a* and *b*). The lysimeters were constructed using low-carbon steel sheets of 2.5 mm thick plates supported by 5 mm steel bars and welded diagonally. The lysimeters were then installed by digging pits slightly larger than their size. While digging the pits, soil from each profile was carefully removed in 20 cm layers and stored in a safe place for repacking inside the lysimeters. The natural sequence of the soil profile was maintained during repacking of the soil from 20 to 90 cm depth. Each soil layer was compacted to its dry bulk density using wooden hammers. Operation of alternate wetting and drying cycles of soil was done inside the lysimeters for settling of soil particles. The soil profile in each lysimeter was uniformly set with no signs of swelling and settling. To capture drainage from the lysimeters, each had a corrugated perforated PVC strainer placed at the bottom followed by a 5 cm layer of gravel and sand, for free drainage. A 12.5 mm diameter pipe was attached at the bottom of the each lysimeter, which was further extended to collect the drainage water. Run-off captured within each lysimeter was collected in a run-off sump which was placed away from the lysimeter. Irrigation water was delivered to the lysimeter by the same laterals which supply irrigation to the field plots. Three inline emitters were provided at 0.1 m depth of lateral inside the lysimeters to irrigate the okra crop. Row-to-row and plant-to-plant distance of 0.45 m and 0.3 m respectively, was kept similar to that of field inside the lysimeters to analyse accurate water balance parameters.

Precise assessment of soil moisture content in the entire soil profile is needed to account for changes in soil water storage and irrigation scheduling. Assessment of soil water storage was done using portable capacitance-based single-sensor soil moisture profile probe (model: Diviner-2000; Sentek Sensor Technologies, Stepney, Australia)[7,8]. Measurement was done at every 10 cm depth by swiping the probe in and out of fixed access tubes installed in the lysimeters[9]. Before initiating the experiment, profile probe was calibrated up to 0.1 m depth by gravimetric method and methodology suggested in the probe manual.

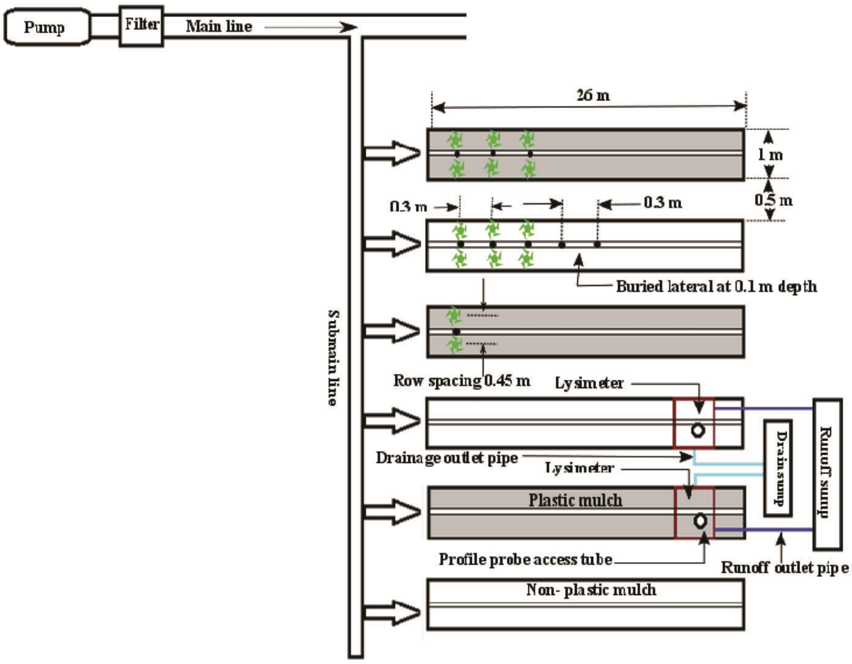


Figure 1. Subsurface drip irrigation layout with lysimetric set-up.

Meteorological conditions

The climate of this region is sub-humid with average annual rainfall of 1200–1500 mm (ref. 10). The average temperature of the region normally varies from 21°C to 32°C. The minimum and maximum relative humidity varies from 19% to 78% and 76% to 99% respectively. The weather data were measured from the weather monitoring station situated at the PFDC Centre, IIT Kharagpur. Observed weather parameters were rainfall, temperature, wind speed, relative humidity, sunshine hour and saturation vapour pressure. Other parameters such as solar radiation, psychometric constant, latent heat of vapourization, etc. were obtained from the measured weather data. Solar radiation was estimated using the recorded sunshine hour[11]. Figure 3 *a* and *b* shows the daily values of temperature (maximum and minimum; °C) and rainfall (mm) for 2016 and 2017 respectively, during the experimental period. Daily maximum temperature ranged from 27°C to 45.5°C and minimum temperature from 18°C to 31°C for 2016 and 2017 (Figure 3 *a* and *b*). During the experimental trial maximum rainfall was observed in 2017 (138 mm) followed by 2016 (29 mm).

Water balance, evapotranspiration and crop coefficient

During the experimental period, the following equation was used to quantify water balance parameters

$$\mathrm{ET_C} = I + R - \Delta s - \mathrm{RO} - \mathrm{DP}, \quad (2)$$

where $\mathrm{ET_C}$ is the crop evapotranspiration (mm), I the irrigation (mm), R the rainfall (mm), Δs the change in soil water storage during the period for which $\mathrm{ET_C}$ and K_C are computed (mm), RO the surface run-off (mm) and DP is the deep drainage water (mm).

Water balance analysis was done in the lysimeter to estimate all water balance parameters. Deep drainage water was collected in a drainage sump through a drainage pipe connected at the bottom of each lysimeter, it was collected at every four-day time-interval. Further, changes in the amount of soil water below 0.6 and above 0.6 m depth in the lysimeter were measured by profile probe at every four-day time-interval in which below 0.6 m depth value was added in deep drainage calculation, whereas above 0.6 m depth value was used to determine changes in soil water storage in the root zone profile. Similarly, surface run-off from each lysimeter was collected in the run-off sump and measured after every rainfall and irrigation event. Rainfall was measured from weather monitoring station and depth of irrigation was determined from eq. (1). During lysimetric studies, experimental data for two seasons were used for development of regional K_C under SSD with and without plastic mulch.

To determine K_C under mulch and non-mulch conditions, the following equation was used

$$\mathrm{ET_C} = \mathrm{ET_0} \times K_C, \quad (3)$$

where $\mathrm{ET_C}$ is the crop evapotranspiration (mm), $\mathrm{ET_0}$ the reference evapotranspiration (mm) and K_C is the crop coefficient (dimensionless).

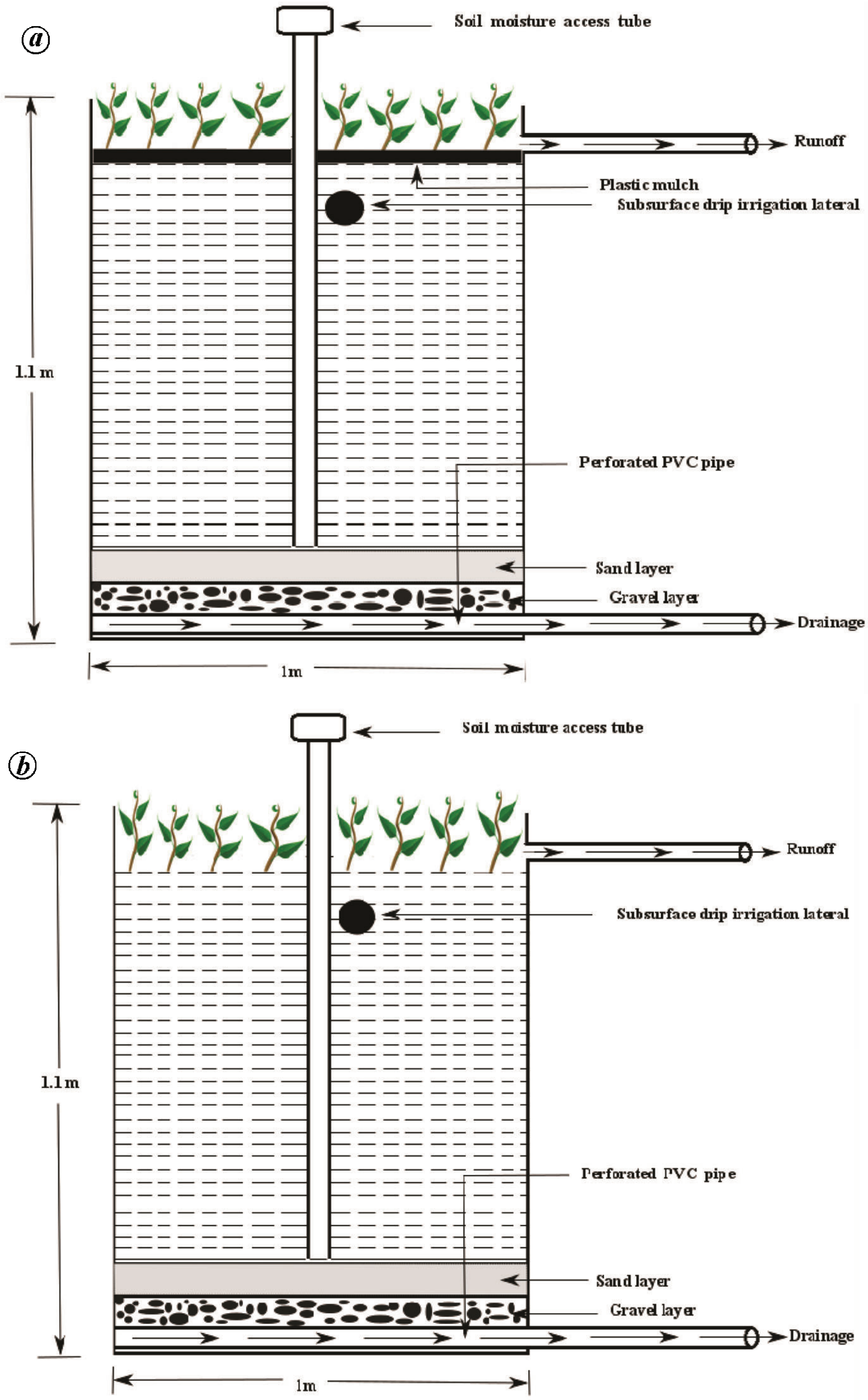
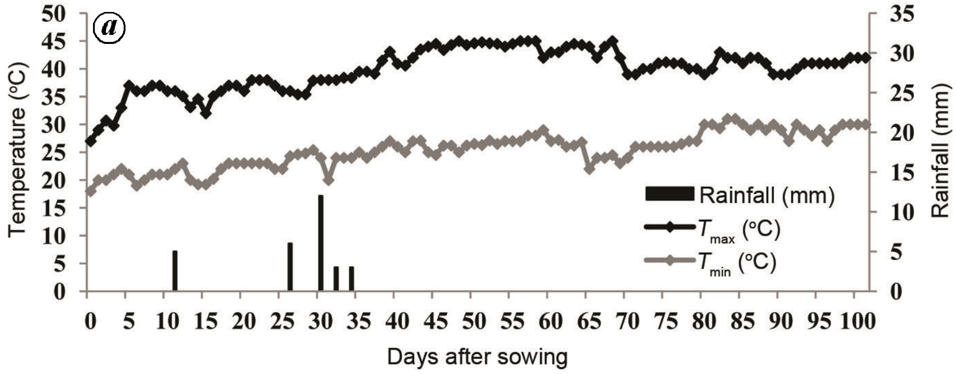


Figure 2. Drainage lysimeter under (***a***) plastic mulch and (***b***) non-plastic mulch conditions.

Reference evapotranspiration is the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling evapotranspiration from an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water[9,12]. An earlier study conducted under sub-humid climatic conditions reported that FAO-56 Penman–Monteith (PM) method can be used for the determination of crop evapotranspiration using TDR in comparison to soil water balance budget[11]. Hence in the present study, estimation of daily ET_0 was done by FAO-56 PM methodology using the equation.



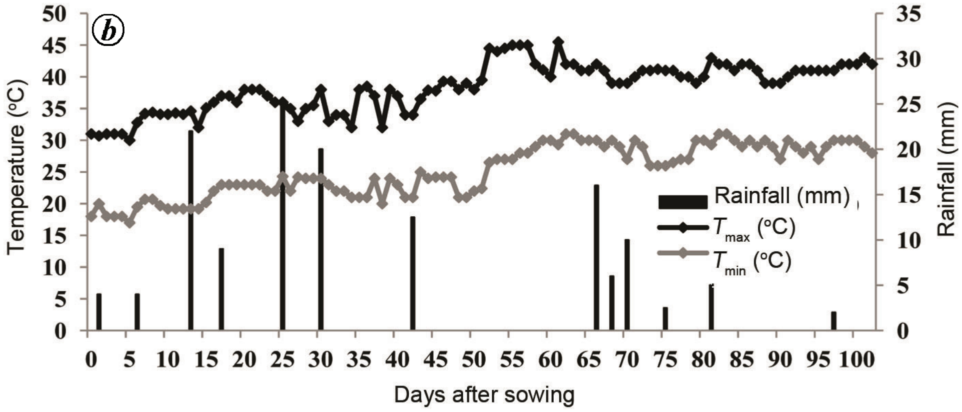


Figure 3. Variation of T_{max}, T_{min} and rainfall for (***a***) 2016 and (***b***) 2017 during okra growing period.

$$ET_0 = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times \dfrac{900}{T_a + 273} U_2 \ (e_s - e_a)}{\Delta + \gamma \times (1 + 0.34 \times U_2)}, \tag{4}$$

where ET_0 is the reference evapotranspiration (mm), R_n the net radiation (Wm^{-2}), γ the psychrometric constant ($kPa°C^{-1}$), U_2 the wind speed ($m s^{-1}$) at 2 m height, G the soil heat flux density (Wm^{-2}), T_a the mean daily air temperature (°C), Δ the slope of vapour pressure curve ($kPa°C^{-1}$), e_a and e_s are the actual and saturation vapour pressure (kPa) respectively.

Crop coefficient (K_C) was estimated as a function of days after sowing (DAS). K_C was referenced to the third day of the four-day time interval in water balance period to develop a regression equation. However, an earlier study had reported that K_C should be referenced in the middle of the water balance time step, if water balance analysis is done for longer than daily time steps[13]. A fourth-degree polynomial regression eq. (5) was fitted to the K_C development as follows

$$K_C = C_1x^4 + C_2x^3 + C_3x^2 + C_4 \ x + C_5, \tag{5}$$

where x represents days after sowing, and C_1–C_5 are the regression coefficients.

K_C for the crop was calculated by averaging the four-day K_C values derived for the two seasons (2016 and 2017) under plastic and non-plastic mulch conditions.

Crop and fertigation details

The Miss Okra-18 (F1 hybrid) variety was selected, and seeds were sown inside and outside of the lysimeter at a spacing of 0.45 × 0.3 m in the last week of February and harvested at 102 DAS in the second week of June during 2016 and 2017. Regular agronomic practices such as fertigation and plant protection measures were applied during the crop growing period. The fertilizer dose of 100 kg N and 50 kg P and K was supplied through ventury injection system to meet the nutritional requirements of the crop.

Crop biometric observations and green fruit yield

Plant height and days to 50% flowering were taken from 33 randomly selected plants in each treatment, including lysimeters at full bloom stage[6]. The leaf area index (LAI) measurement was done at seven weeks after sowing using a plant canopy analyser (Virtual Electronics, Roorkee, India), which gives an accurate estimate of LAI using a non-destructive method. Fresh pod yield of all treatments

Table 2. Water balance parameter inside lysimeter during okra-growing season under subsurface drip (SSD) irrigation with plastic mulch and non-mulch conditions during 2016 and 2017 (all units in mm)

DAS	R	I		DP		RO		Δs		ET_C		ET_0
		NM	M	NM	M	NM	M	NM	M	NM	M	
2016												
0–15	05.0	43.0	36.0	07.0	05.0	00.0	00.0	05.0	12.0	36.0	23.0	76.0
16–31	18.0	49.0	44.0	06.0	05.0	00.0	00.0	–02.0	20.0	64.0	38.0	88.0
32–47	06.0	86.0	73.0	03.0	04.0	00.0	00.0	–13.0	–4.0	103.0	79.0	108.0
48–63	00.0	134.0	97.0	01.0	02.0	00.0	00.0	02.0	–10.0	131.0	106.0	122.0
64–79	00.0	103.0	82.0	01.0	00.0	00.0	00.0	05.0	–01.0	97.0	83.0	114.0
80–95	00.0	73.0	57.0	01.0	00.0	00.0	00.0	12.0	02.0	61.0	56.0	98.0
96–102	00.0	30.0	21.0	00.0	00.0	00.0	00.0	09.0	02.0	21.0	18.0	46.0
Total	29.0	518.0	410.0	19.0	16.0	00.0	00.0	17.0	20.0	512.0	403.0	653.0
2017												
0–15	30.0	23.0	20.0	06.0	06.0	09.0	12.0	02.0	12.0	36.0	21.0	75.0
16–31	53.5	31.0	25.0	06.0	07.0	14.0	23.0	03.0	12.0	61.5	36.5	85.0
32–47	13.0	79.0	67.0	05.0	04.0	00.0	07.0	01.0	03.0	86.0	65.0	91.0
48–63	00.0	126.0	104.0	01.0	01.0	00.0	00.0	05.0	07.0	119.0	96.0	111.0
64–79	34.5	78.0	65.0	04.0	02.0	07.0	16.0	18.0	10.0	83.0	71.5	99.0
80–95	05.0	68.0	50.0	01.0	01.0	00.0	00.0	10.0	–01.0	62.5	55.0	99.0
96–102	02.0	22.0	18.0	00.0	00.0	00.0	00.0	04.0	02.0	20.0	18.0	46.0
Total	138.0	426.0	349.0	23.0	20.0	30.0	58.0	43.0	46.0	468.0	363.0	605.0

DAS, Days after sowing; R, Rainfall; I, Irrigation; DP, Deep drainage; RO, Run-off; Δs, Change in storage; ET_C, Crop evapotranspiration; ET_0, Reference evapotranspiration; NM, Subsurface drip with non-mulch treatment; M, Subsurface drip with plastic mulch treatment.

was taken from 33 plants grown in 6 m^2 area, including lysimeters at the centre of each plot to avoid border influence[14].

Water use efficiency

Water use efficiency (WUE; in kg ha^{-1} mm^{-1}), was estimated as follows[15].

$$WUE = \frac{Y}{ET_C}, \tag{6}$$

where Y is the green fruit yield (kg ha^{-1}) and ET_C is the crop evapotranspiration (mm).

Statistical analysis

Statistical analysis was done to test the effects of the treatment using IBM SPSS version 20.0. Analysis of variance (ANOVA) was done for plant height, days to 50% flowering, LAI and fresh pod yield okra.

Results and discussion

Water balance parameter and evapotranspiration

Table 2 shows the results of lysimetric studies for water balance analysis under mulch and non-mulch conditions during 2016 and 2017. Total ET_C under non-plastic mulch was 27% and 28.9% higher than that under plastic mulch in 2016 and 2017 respectively. It is due to increase in vapour diffusion resistance at the soil–air interface partially mulched by plastic film[16]. ET_C was higher in the first year trial compared to the second year under all treatments due to more dry spells connected to solar radiation and temperature in the first year trial. The average daily ET_0 for 2016 and 2017 during the okra growing season was 6.40 and 5.93 mm day^{-1} respectively. However, the highest ET_0 was observed (653 mm) for 2016, which was 7.93% higher than 2017 (Table 2). Total deep drainage loss of water in 2016 and 2017 was only 16 and 20 mm under plastic mulch, which was 15.7% and 15.0% less than non-plastic mulch respectively.

Surface run-off was 58 mm under plastic mulch, which was 93.3% higher than non-mulch treatment in 2017; this is due to the impermeable nature of plastic mulch[17]. Out of the total run-off in 2017, maximum (23 mm) was observed during 16–31 DAS (15 days period) due to high amount of rainfall (54 mm). In 2016, run-off generation was nil under both treatments due to less amount of rainfall.

Figures 4 and 5 show the relationship between daily mean ET_C under mulch and non-mulch conditions with ET_0 for 4 days interval period during 2016 and 2017 respectively. During both years, the initial stage ET_0 was higher than ET_C under mulch and non-mulch conditions. This can be mainly attributed to low canopy cover at the early stage of the crop in both the treatments. ET_C was slightly equal to ET_0 during 42–72 DAS because the crop

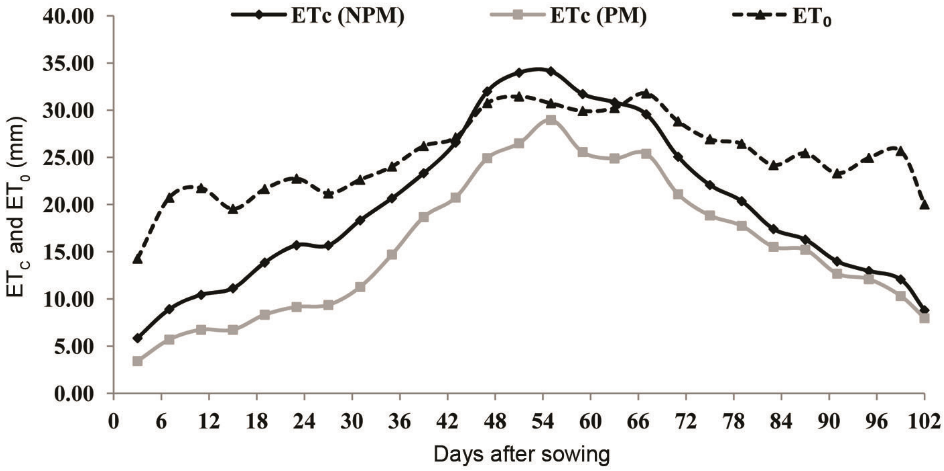


Figure 4. ET_0 and ET_C under plastic and non-plastic mulch conditions during okra growing period in 2016.

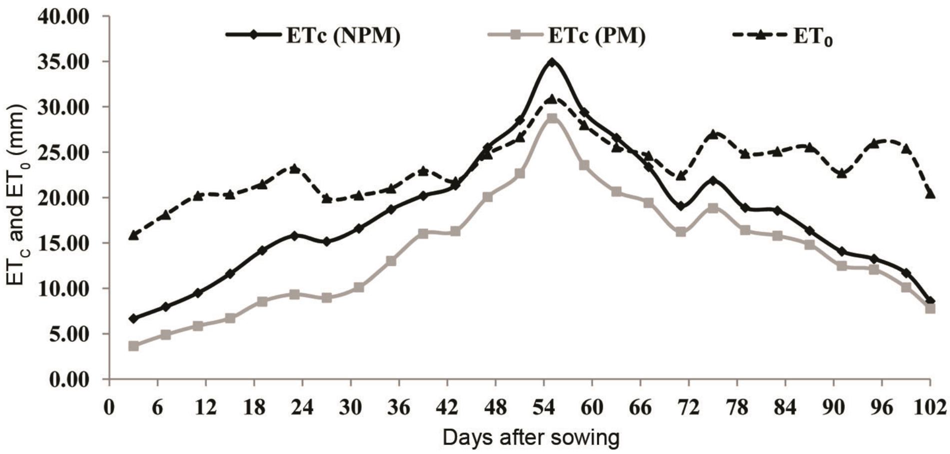


Figure 5. ET_0 and ET_C under plastic and non-plastic mulch conditions during okra growing period year 2017.

had attained the highest canopy cover and maximum rooting depth, which allowed it to use soil water in the root zone for its transpiration while minimizing evaporation[18]. However, ET_C was found lower in plastic mulch than non-mulch treatment during all the crop growth stages, due to lack of evaporation under plastic mulch treatment (Figures 4 and 5), and less amount of irrigation water application. In the late season stage, ET_C declined quickly whereas ET_0 declined slowly, but was relatively higher than ET_C under both treatments during 2016 and 2017.

Lysimetric studies for crop coefficient development

Fourth-order polynomial regression equations ($R^2 = 0.98$, eq. (7) for SSD without mulch, and $R^2 = 0.97$, eq. (8) for SSD with plastic mulch) were fitted to calculate the average K_C for the two seasons as a function of DAS (Figures 6 and 7)[7]. These equations will be useful for estimating crop water requirement of okra under SSD without and with plastic mulch.

$$K_C = 9 \times 10^{-8}x^4 - 2 \times 10^{-5}x^3 + 0.001x^2 + 0.0034x + 0.422, \tag{7}$$

$$K_C = 9 \times 10^{-8}x^4 - 2 \times 10^{-5}x^3 + 0.0013x^2 + 0.0148x + 0.3027. \tag{8}$$

Table 3 shows the K_C value of okra with and without mulch for 2016 and 2017. K_C showed an increase in trend during the initial stage (0–36 DAS) and remained almost constant during the second stage of the crop (37–72 DAS); it declined at the late season stage (at 73 DAS) under both the treatments. Maximum K_C under SSD without plastic was 1.12 and SSD with plastic was 0.93 observed during fruiting stage. Average K_C under plastic mulch was 0.31, 0.42, 0.68, 0.77 and 0.48 during initial, vegetative, flowering, fruiting and harvesting stage, which was 39.2%, 41.6%, 26.0%, 17.20% and 9.43% lesser than non-mulch treatment (Table 3). However difference in K_C between mulch and non-mulch

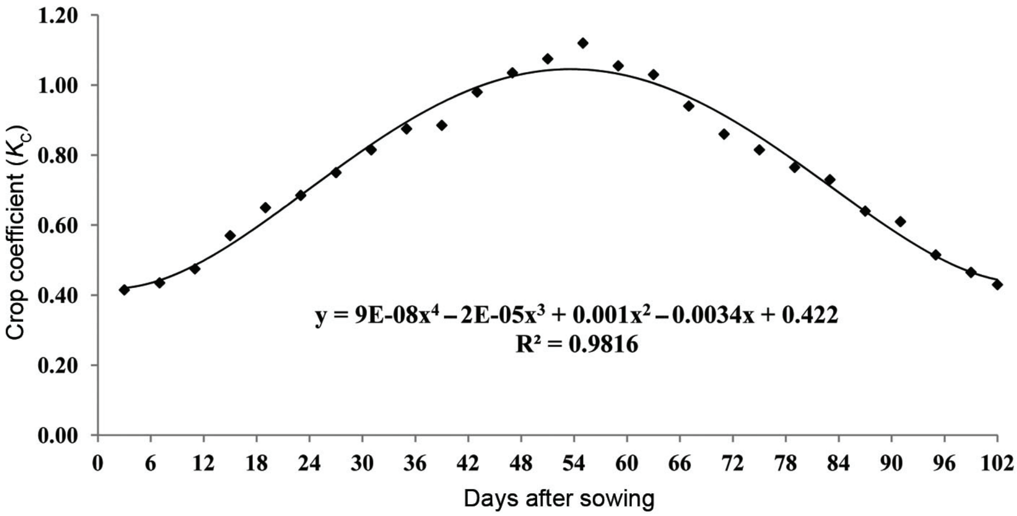


Figure 6. Average crop coefficient (K_C) versus days after sowing regression curve for 2016 and 2017 seasons under non-plastic mulch condition.

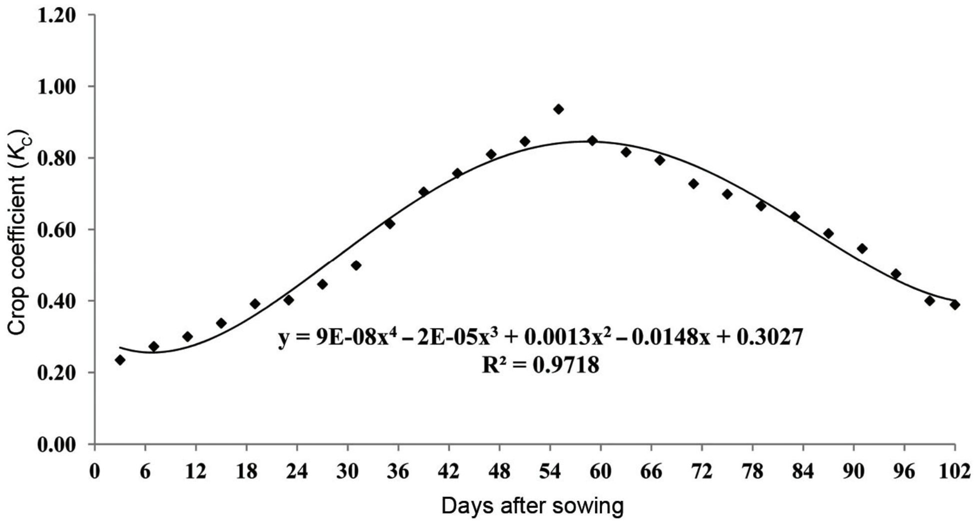


Figure 7. Average crop coefficient (K_C) versus days after sowing regression curve for 2016 and 2017 seasons under plastic mulch condition.

treatments during initial and vegetative stages was found to be higher than other stages. This is due to less evaporation and less transpiration at the initial and vegetative stages under plastic mulch, while less transpiration and higher evaporation under non-mulch condition. Further, variations in year-to-year K_C values could be attributed to error while quantifying water balance parameters[9,19]. Most of the variations in K_C are as a result of uneven rainfall and irrigation practices, resulting in soil moisture alteration.

Yield, biometric observation and water use efficiency

Table 4 shows the effect of SSD with plastic mulched and non-mulched surface on yield, LAI, days to 50% flowering and plant height. SSD with plastic and without mulch had significant impact on fresh pod yield of okra and plant height ($P > 0.05$) during 2016 and 2017. Average pod yield of two seasons under SSD with plastic mulch treatment was 16.92% higher than non-mulch treatment. Yield was higher under SSD with plastic mulch treatment for the two successive seasons. This was due to reduced evaporation with maximum transpiration, minimum direct entry of water and air causing distortion of bed surface, less weed growth and elevated soil temperature under plastic film[20]. The fresh pod yield of okra was 12.1 and 12.5 t ha^{-1} respectively, observed under SSD without plastic mulch in both the seasons. Despite the high amount of irrigation in 2016, pod yield under SSD without plastic mulch was found similar to that of 2017. This

Table 3. Comparison of crop coefficient (K_C) values developed under subsurface drip irrigation (SSD) with plastic mulch and non-mulch conditions

		SSD with non-mulch			SSD with plastic mulch		
Crop stage	DAS	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Initial stage	0–19	0.41	0.65	0.51	0.23	0.39	0.31
Vegetative stage	20–27	0.68	0.75	0.72	0.40	0.44	0.42
Flowering stage	28–47	0.81	1.03	0.92	0.50	0.81	0.68
Fruiting stage	48–83	0.73	1.12	0.93	0.63	0.93	0.77
Harvesting stage	84–102	0.43	0.64	0.53	0.39	0.59	0.48

Table 4. Biometric response and green fruit yield of okra crop during 2016 and 2017

Treatment	Plant height (cm)		Days to 50% flowering		Leaf area index		Green fruit yield (tonnes ha^{-1})	
Year	2016	2017	2016	2017	2016	2017	2016	2017
SSD with plastic mulch	89.96	89.77	40.60	41.66	4.43	4.16	14.60	14.62
SSD with non-mulch	86.49	87.17	42.66	42.33	3.06	2.96	12.11	12.25
CD (0.05)	2.18	2.07	NS	NS	NS	NS	1.3	1.033

CD, Critical difference at 5% level of significance; NS, Non-significant.

was due to undefined fresh pod harvesting time and high amount of weed in 2016. Similarly, average maximum plant height (89.86 cm), maximum LAI (4.29) and minimum days to 50% flowering (41.13) were observed under SSD with plastic mulch treatment during 2016 and 2017. However, LAI and minimum days to 50% flowering under SSD with plastic mulch treatment were found non-significant with SSD with non-plastic mulch treatment throughout the experimental period. WUE varied from 23.65 to 40.27 kg ha^{-1} mm^{-1} in both the treatments during the two-year experimental period. Maximum WUE (40.27 kg ha^{-1} mm^{-1}) was found under plastic mulch treatment due to lesser amount of irrigation water application and high green fruit yield of okra.

Conclusion

Variation in all the water balance parameters and K_C values was observed at different growth stages of okra crop under SSD with and without plastic mulch. Low volume of irrigation water, minimum or nil evaporation and less amount of water transpired by weed caused minimum ET_C under SSD with plastic treatment during both the experimental years. Results of plastic and non-plastic mulch treatments with SSD demonstrate that the former treatment significantly affected green fruit yield of okra and produced higher amount of green fruit yield. This was due to suppression of weed growth, optimized amount of solar radiation absorbed by the crop, modified microclimatic parameters, leaf temperature, air humidity, soil moisture and plant transpiration rates. Lower irrigation requirements under plastic mulching typically increase WUE by reducing evaporation. Thus, the developed K_C values and respective regression equations in this study might be useful for precise irrigation water management of okra grown under SSD with and without plastic mulch treatment at similar sub-humid agro-climatic conditions of Kharagpur area.

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