Estimation of water requirement of Banana crop under drip irrigation with and without plastic mulch using dual crop coefficient approach

D T Santosh1 and K N Tiwari1,2
1Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur, 721 302, West Bengal, India
E-mail: kamlesh@agfe.iitkgp.ac.in

Abstract. Field experiments were conducted on the lateritic sandy loam soil and sub-humid climate of Kharagpur, West Bengal, India during 2014-2018 for two consecutive crop seasons to determine the optimum water requirement of the Banana crop under drip irrigation with and without plastic mulch. Reference evapotranspiration for the Banana crop was estimated using FAO-56 Penman-Monteith approach. The dual crop coefficient approach was used to improve the estimates of the crop coefficient ($K_c$) values for the irrigation treatments with black plastic mulch and without mulch. Plants treated with black plastic mulch consume about 12% less water for the main crop and about 22% less water for ratoon crop compared to non-mulch plants. The effect of black plastic mulch was studied to determine the soil moisture distribution in different soil depths (0-20, 20-40, 40-60, and 60-90 cm), and also loss of water through deep drainage. Net irrigation requirement under black plastic mulch was found to be lesser than without mulch. The deep percolation was found 50.4 % more under black plastic mulch in comparison to non-mulch treatment.

1. Introduction
Banana (Musa paradisica L.) is one of the oldest fruit known to humanity, which is a rich source of carbohydrates, vitamins, and minerals essential for the human diet. In 2014, worldwide, banana production was about 16.5 million tones [1]. India ranks first in the banana producing countries followed by China, Philippines, Ecuador, Brazil, and Indonesia. Drip irrigation has the potential of precise application of water both in amount and uniform application throughout a field [2]. Plastic mulch influences the microclimate near plants, temperature, net radiation, relative humidity [3], and affects crop water requirement and water productivity of plants [4]. The improved estimates of crop coefficients are needed for accurate irrigation scheduling for high valued crops daily. The FAO-56 dual crop coefficient method separately estimates transpiration and evaporation, which can be used for irrigating crops [5].

Researchers have investigated dual crop coefficients under drip irrigation with mulching [6,7]. However, research on dual crop coefficient for banana under mulched drip irrigation has not been reported in the literature. Hence, the present study aims to i) estimate banana crop water requirement using the dual crop coefficient approach and ii) to evaluate water balance parameters under black plastic mulch and non-mulch conditions.
2. Materials and methods
Field experiments were conducted for two crop seasons (2014-2018) at the Experimental Farm of Precision Farming Development Centre, Indian Institute of Technology, Kharagpur, India to estimate crop water requirement of banana under drip irrigation system and black plastic mulch. The experimental site is at 22°18.5’ N latitude, 87°19’ E longitude and at an altitude of 48 m above mean sea level. Annual rainfall varies from 1200 to 1500 mm and about 80% of this rainfall occurs during June to October. The monthly average of daily minimum air temperature is 6°C in January, whereas the monthly average of daily maximum air temperature is 43.5°C in May.

The daily meteorological data recorded from 2014 to 2018 were utilized to compute reference evapotranspiration (ET₀) using the modified Penman-Monteith method, as suggested by [8]. The dual crop coefficient is a summation of a basal crop coefficient (Kcb) and soil evaporation coefficient (Kc).

This approach estimates the plant and soil components of the crop coefficient separately and quantifies both the components independently and allows to make a comparison between them [9].

\[
ET_c = (K_{cb} + K_e) \times ET_o
\]

(1)

The basal crop coefficient (Kcb) is the ratio of crop evapotranspiration and the reference evapotranspiration (ET₀/ETo) while the soil surface is dry, but transpiration occurs at a potential rate in a plant. The soil evaporation coefficient (Kc) is the evaporation component of ETc. Where the top soil is wet, following rain or irrigation, Kc is maximal. Where the soil surface is dry, Kc is small and even zero when no water remains near the soil surface for evaporation.

The net irrigation requirement can be computed as follows

\[
I_w = (ET_c - R_e) \times Ap
\]

(2)
Where Iw - Net volume of irrigation (L); Ap – Effective area per plant considering wetting fraction (m²); Re – Effective rainfall (mm).

The field experiment was carried out for two successive crop seasons to estimate the daily crop water requirement under drip irrigation and plastic mulch. Tissue culture banana plants were transplanted in the field at a spacing of 2 m × 2 m in a plot size of 240 m² with drip system and a bed covered with 50-micron black plastic mulch. Sixty plants each under black plastic mulch (BPM) and without mulch (NM) were selected for the study.

The water balance study carried out using the following soil water balance equation

\[
P + I - ET_c - DP - R = \Delta S
\]

(3)

where P - rainfall,(mm); I- irrigation water supplied with drip system,(mm); ETc - crop evapotranspiration, (mm); \(\Delta S\) - change in soil water storage in the soil profile, (mm); DP - water lost due to deep percolation; R- surface water runoff, (mm).

Soil moisture content was measured at different soil depths (0-20, 20-40, 40-60, 60-90 cm) using FDR (frequency domain reflectometry) sensor for the period of the second crop season. During the experimental period, the deep drainage loss was computed using unsaturated hydraulic conductivity as a function of the prevailing moisture content and time period. The unsaturated hydraulic conductivity was estimated using van Genuchten equation

\[
K(S_e) = K_s S_e^\frac{l}{1 - (1 - S_e^{1/m})^m}^2
\]

(4)

Where Se is the relative saturation given by

\[
S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}
\]

(5)

Where Ks = Saturated hydraulic conductivity (mm day⁻¹), \(\theta =\) Volumetric soil water content (mm³ mm⁻³), \(\theta_s =\) Saturated volumetric water content (mm³ mm⁻³), \(\theta_r =\) Residual volumetric water content (mm³ mm⁻³), l = Pore connectivity/tortuosity parameter and m = van Genuchten parameter. These were obtained from the soil moisture characteristic curve, field measurements, and hydraulic
parameter optimization using software RETC (RETension Curve). Parameters values obtained by RTEC software were \( \theta_r = 0.0447 \), \( \theta_s = 0.3581 \), \( K_s = 0.34 \) and \( l = 0.5 \). The deep percolation loss (DP) was estimated by equation (6).

\[
DP = q\Delta t = K(S_e)\Delta t
\]  

(6)

Where, \( q \) = Mean volumetric flux density (mm day\(^{-1}\)); \( \Delta t \) = Time period (days).

For periods without rainfall, runoff value is zero and during wet periods runoff was estimated by curve number (CN) method [5].

3. Results and discussion

3.1. Determination of crop coefficient
The daily meteorological data recorded during two crop seasons of 2014 - 2016 and 2016-2018 were used to estimate \( \text{ET}_0 \) (figure 1). It can be seen from figure 1 that average \( \text{ET}_0 \) values from February to September are comparatively greater than other months. The \( \text{ET}_0 \) value gradually increases with the increase in sunshine hours and the intensity of radiation. The average peak value of the \( \text{ET}_0 \) was 5.1 mm and 5.36 mm occurred in May during 2014-16 and 2016-2018, respectively. From June onward average daily \( \text{ET}_0 \) values were observed to be reduced due to the incidence of rainfall, low solar radiation, and high humidity, especially during monsoon months (June to September). Further due to the lowering of temperature from October onward till March, daily \( \text{ET}_0 \) values gradually reduced and reached to lowest in December.

![Figure 1. Average monthly daily reference evapotranspiration (ET\(_0\)) of the banana crop cycle (2014-16 and 2016-18).](image)

According to FAO-56 recommendation, the values of basal crop coefficient (\( K_{cb} \)) for initial, development, and end of the growing season (\( K_{cbini} \), \( K_{cbmid} \), and \( K_{cbend} \)), for the banana crop were 0.15, 1.05 and 0.9, respectively. Initial \( K_{cb} \) value was comparatively lower due to lesser leaf area and value increases with an increase in leaf area. According to Shrestha and Shukla [7], the \( K_{cb} \) increased considerably due to increased transpiration as crop went through rapid plant growth phase to reach effective full cover.
Figure 2. Soil evaporation coefficient for mulch (\(K_{e(mulch)}\)), non mulch (\(K_{e(open)}\)), Crop coefficients for mulch (\(K_{c(mulch)}\)) and non mulch (\(K_{c(open)}\)) of banana crop (A) first crop season (2014-16), (B) second crop season (2016-18).

Figure 2 shows the soil evaporation coefficient (\(K_e\)) curve of the banana crop soil surface covered with plastic mulch (\(K_{e(mulch)}\)) and without plastic mulch, i.e., open soil surface (\(K_{e(open)}\)) of main and ratoon crop for two consecutive crop seasons (2014-16 and 2016-18). The \(K_{e(mulch)}\) curve shows evaporation occurred from the soil surface below plastic mulch is meager (0.4 to 1.6) and almost constant throughout the crop season. The fraction of soil surface covered with black plastic mulch reduced surface evaporation from 3 to 9%. The evaporation decreases with increase in the age of the plant, due to growth in canopy thereby increase in shade factor; hence, the energy available for soil evaporation decreases. \(K_{e(open)}\) values were found to be maximum during the establishment stage when the ground cover factor is small. Later, as the vegetative cover increases, the \(K_{e(open)}\) values decrease steadily. \(K_{e(open)}\) values decreased to the minimum during the banana crop developmental stage, when \(K_e\) values reached to its maximum. Soil surface area exposed for evaporation was relatively large for the first four months (transplanting to development stage), which resulted in consistently high \(K_{e(open)}\). After that, the \(K_{e(open)}\) values remained relatively low until the end of the season. The decrease in \(K_{e(open)}\) during the ratoon crop season, there is a considerable decrease in temperature and solar radiation during this period. The same trend was reported by Shrestha and Shukla [7] for the vine crop experiment.

Summation of \(K_{cb}\) with \(K_{e(mulch)}\) and \(K_{e(open)}\) is crop coefficient for banana crop covered with plastic mulch (\(K_{cb(mulch)}\)) and open soil surface (\(K_{cb(open)}\)), respectively. During the growth season, values of \(K_{cb(open)}\) increases from a minimum value (0.55) in relation to changes in canopy development until a maximum \(K_{cb(open)}\) (1.12) is attained at full canopy cover. The crop coefficient values are mainly dependent upon the plant height, crop growth, leaf area, and cover [8]. Estimated \(K_{cb(open)}\) values and changes observed in values along the growth of banana crop were found to be matched with the values reported (0.5 to 1.2) in FAO 56 [8]. Crop coefficient of the banana under plastic mulch (\(K_{c(mulch)}\)) was estimated to be 8 – 55.3 % lesser compared to the crop coefficient (\(K_{c(open)}\)) for different growth stages in main and ratoon crops of two crop seasons. The effect of plastic mulch cover on soil evaporation is significant, which reduced the crop coefficient values of the banana crop during the initial stage to the development stage. The same trend was observed for both \(K_{c(open)}\) and \(K_{c(mulch)}\) curves in figures 2A and 2B. These results are in agreement with those of Vickers [10] and Mata et al [11].

Based on the results reported in table 1, \(ET_c\) values of BPM treated plants were obtained to be lower than that of NM plants at the initial stage of main and ratoon crops due to more soil surface
available for evaporation which was reduced by the BPM. The rapid growth of plants can be observed in mulch treated treatments during the mid-season period of both main and ratoon crop leading to the higher ET\textsubscript{c} in comparison to non-mulch condition. Overall, total ET\textsubscript{c} for the non-mulch treatment was greater than the mulched treatment during the whole period of main and ratoon crop. Many studies have reported that the ET\textsubscript{c} is strongly correlated to the available energy supplying for the dense crop canopy [12,13]. In this study, plastic film decreased available energy supplying the latent heat flux, and thus reduced ET\textsubscript{c}.

### Table 1. Monthly average of daily values of ET\textsubscript{b}, K\textsubscript{cb}, estimated K\textsubscript{e}, K\textsubscript{c} and ET\textsubscript{c} (Pooled values of two crop seasons, i.e. 2014-16 and 2016-18).

| Months | ET\textsubscript{b}, mm | K\textsubscript{cb} | Black plastic mulch | Non-mulch |
|--------|-------------------|----------------|---------------------|-----------|
|        | K\textsubscript{e} | K\textsubscript{c} | ET\textsubscript{c}, mm | K\textsubscript{e} | K\textsubscript{c} | ET\textsubscript{c}, mm |
| Oct    | 3.15  | 0.23  | 0.016 | 0.25 | 0.77 | 0.32  | 0.55 | 1.73 |
| Nov    | 2.89  | 0.39  | 0.013 | 0.41 | 1.18 | 0.29  | 0.68 | 1.98 |
| Dec    | 2.24  | 0.55  | 0.010 | 0.56 | 1.26 | 0.26  | 0.81 | 1.82 |
| Jan    | 2.41  | 0.72  | 0.010 | 0.73 | 1.76 | 0.23  | 0.95 | 2.28 |
| Feb    | 3.15  | 0.87  | 0.009 | 0.88 | 2.78 | 0.19  | 1.06 | 3.35 |
| Mar    | 4.19  | 1.01  | 0.005 | 1.02 | 4.27 | 0.10  | 1.11 | 4.66 |
| Apr    | 4.84  | 1.02  | 0.005 | 1.02 | 4.95 | 0.10  | 1.12 | 5.40 |
| May    | 5.11  | 0.98  | 0.006 | 0.98 | 5.03 | 0.13  | 1.11 | 5.67 |
| June   | 4.63  | 0.94  | 0.008 | 0.95 | 4.40 | 0.17  | 1.11 | 5.14 |
| July   | 4.19  | 0.91  | 0.012 | 0.92 | 3.85 | 0.19  | 1.09 | 4.58 |
| Aug    | 3.91  | 0.90  | 0.012 | 0.91 | 3.57 | 0.20  | 1.10 | 4.29 |
| Sept   | 3.61  | 0.90  | 0.011 | 0.91 | 3.29 | 0.20  | 1.10 | 3.96 |
| Oct    | 3.47  | 0.69  | 0.012 | 0.70 | 2.44 | 0.25  | 0.94 | 3.25 |
| Nov    | 3.22  | 0.72  | 0.011 | 0.73 | 2.34 | 0.25  | 0.97 | 3.11 |
| Dec    | 2.34  | 0.74  | 0.010 | 0.75 | 1.75 | 0.25  | 0.99 | 2.31 |
| Jan    | 2.32  | 0.76  | 0.009 | 0.77 | 1.79 | 0.25  | 1.01 | 2.34 |
| Feb    | 3.03  | 0.79  | 0.010 | 0.80 | 2.41 | 0.24  | 1.02 | 3.11 |
| Mar    | 4.17  | 0.81  | 0.010 | 0.82 | 3.42 | 0.22  | 1.03 | 4.31 |
| Apr    | 4.76  | 0.83  | 0.011 | 0.85 | 4.02 | 0.22  | 1.05 | 5.02 |

\* K\textsubscript{e} = (K\textsubscript{cb} + K\textsubscript{e}) + ET\textsubscript{c} = ET\textsubscript{b} \times K\textsubscript{c}

### 3.2. Water balance studies

Water balance components with BPM and NM treatments for two banana crop period 2014-2016 and 2016-2018 are presented in Table 2. During the first crop season, i.e., 2014 - 2016, the total precipitation amount was 949 mm and 337 mm for the main and ratoon crop period, respectively. In second crop season (2016 - 2018) total precipitation occurred about 1109 mm and 207 mm during main and ratoon crop, respectively. Soil evaporation (E) is the product of soil evaporation component (K\textsubscript{e}) and reference evapotranspiration (ET\textsubscript{0}). Transpiration (T) is the product of the basal crop coefficient (K\textsubscript{cb}) and reference crop evapotranspiration (ET\textsubscript{0}). Reduced soil evaporation values recorded in BPM treatments in comparison to NM treatments for both first and second crop seasons. Earlier studies also reported the reduction in soil evaporation by 40-70% in Squash [14], 46-60% in potato [15], 40-70% in cucumber [16] and 40-70% in okra [17] due to the application of plastic mulch.

### Table 2. Water balance parameters estimated/monitored for both the crop seasons (2014-2018).
Cumulative transpiration values show contrast trend compare to total soil evaporation. There is an increase in total transpiration amount by 14.1% and 11% in main and ratoon banana crops respectively during the first crop cycle. The increase in transpiration amount up to 35% in potato [15], by 15% - 30% in cucumber [16] and 10% - 30% on okra [17] have been reported due to the application of BPM along with drip irrigation.

Total crop evapotranspiration (ETc) is the product of daily ET0 and daily Kc values of main and ratoon crop for two consecutive crop cycles. It is also the summation of total evaporation and total transpiration during the crop cycle. There was no significant difference found between ETc of BPM treatments, ETc of NM irrigation treatments in first crop cycle (2014 - 2016). Application of black plastic mulch reduces the soil water evaporation significantly, but BPM treated plants experiences rapid growth in comparison to that NM treated plants, which lead to an increase in transpiration amount. Because of the reduced evaporation and increased transpiration, no significant variation was found in total ETc of BPM treatments in comparison to NM treatments. These results are also in agreement with those of Jenni et al. [18] and Orzolek [19].

The deep percolation loss varied considerably due to irrigation, rainfall, and plastic mulch application during the crop cycle. Table 2 shows deep percolated water below the root depth in BPM treatment was 23.1% more for main crop and 24.8% more for ratoon crop in comparison to corresponding NM treatments in the first crop season. The increment in deep percolation loss at root depth of banana crop was 50.4% for the main crop, and 30.4% for ratoon crop in BPM treated irrigation treatments in comparison to NM treatments in the second crop season. The surface runoff was estimated for both main and ratoon crops during the first and second crop season. No significant difference in surface runoff magnitude was obtained during the irrigation period in BPM and NM treatments; this may be due to a water supply through the drip system as it does not generate surface runoff. However, a runoff was obtained during the rainy season both in BPM and NM treatments.

4. Conclusion
This research study established a dual crop coefficient for the banana crop. The maximum evapotranspiration of banana crop is obtained 5.67 mm in May, and the minimum value is 1.73 mm in October (which is the initial growth stage). The crop evapotranspiration estimated can be used to determine the amount of irrigation water to be supplied to the banana crop in different months. Application of plastic mulch reduces crop evapotranspiration by 14% and increases the deep percolation by 50.4% in comparison to non-plastic mulch.

Acknowledgments
Authors are thankful to the National Committee on Plasticulture Applications in Horticulture
(NCPAH), Ministry of Agriculture and Farmers Welfare, Government of India for providing funds to conduct this field research experiment. Authors are also thankful to IIT Kharagpur for providing the research facilities.

References

[1] FAO S 2014 *FAOSTAT Database* (Rome, Italy: Food and Agriculture Organization of the United Nations)

[2] Hanson B and May D 2007 The effect of drip line placement on yield and quality of drip-irrigated processing Tomatoes *Irr. and Drain. System* **21** 109-18

[3] Diaz-Pérez J 2009 Root zone temperature, plant growth and yield of broccoli [Brassica oleracea (Plenc) var. italica] as affected by plastic film mulches *Scientia Hortic.* **123** 156-63

[4] Qin S, Zhang J, Dai H, Wang D and Li D 2014 Effect of ridge–furrow and plastic-mulching planting patterns on yield formation and water movement of potato in a semi-arid area. *Agric. Water Manag.* **131** 87-94

[5] Allen R G 2000 Using the FAO-56 dual crop coefficient method over an irrigated region as art of an evapotranspiration intercomparison study *J. Hydrol.* **229** 27-41

[6] Amayreh J and Al-Abed N 2005 Developing crop coefficients for field-grown tomato under drip irrigation with black plastic mulch *Agric. Water Manag.* **73** 247-54

[7] Shrestha N K and Shukla S 2014 Basal crop coefficients for vine and erect crops with plastic mulch in a sub-tropical region *Agric. Water Manag.* **143** 29-37

[8] Allen R G, Pereira L S, Raes D and Smith M 1998 Crop evapotranspiration. Guidelines for computing crop water requirements *Irrigation and Drainage Paper 56* (Rome, Italy: Food and Agric, Organization of the United Nations) p 300

[9] Paço T A, Pôças I, Cunha M, Silvestre J C, Santos F L, Paredes P and Pereira L S 2014 Evapotranspiration and crop coefficients for a super intensive olive orchard. An application of SIMDualKc and METRIC models using ground and satellite observations *J. Hydrol.* **519** 2067-80

[10] Vickers A 2001 *Water use Conservation* (Amherst, MA: Water Plow Press) pp 215-380

[11] Mata V H, Nunez E R and Sanchez G P 2002 Soil temperature and soil moisture in Serrano pepper (Capsicum annuum L.) with fertigation and mulching *Proc. of the 16th Int. Pepper Conference* (Tamaulipas, Mexico)

[12] Burba G G and Verma S B 2005 Seasonal and interannual variability in evapotranspiration of native tallgrass and cultivated wheat ecosystems *Agric. and Forest Meteo.* **135** 190-201

[13] Ding R, Kang S, Li F, Zhang Y and Tong L 2013 Evapotranspiration measurement and estimation using modified Priestley–Taylor model in an irrigated maize field with mulching. *Agric. and Forest Meteo.* **168** 140-148

[14] Safadi A S 1991 Squash and cucumber yield and water use models (Doctoral dissertation, University of Wisconsin--Madison) pp. 1-132

[15] Wang F X, Kang Y and Liu S P 2006 Effects of drip irrigation frequency on soil wetting pattern and potato growth in North China Plain. *Agric. Water Manag.* **79** 248-64

[16] Yaghi T, Arslan A and Naoum F 2013 Cucumber (Cucumis sativus, L.) water use efficiency (WUE) under plastic mulch and drip irrigation. *Agric. Water Manag.* **128** 149-57

[17] Patil A and Tiwari K N 2018 Quantification of transpiration and evaporation of okra under subsurface drip irrigation using SIMDualKc model during vegetative development *Int. J. Veg. Sci.* **25**(1) 27-39.

[18] Jenni S, Brault D and Stewart K A 2002 Degradable mulch as an alternative for weed control in lettuce produced on organic soils *XXVI International Horticultural Congress: Sustainability of Horticultural Systems in the 21st Century* **638** 111-8

[19] Orzolek M D 2000 *New Concepts in Plasticulture for Tomatoes and Peppers 814* (University Park, PA: The Pennsylvania State University) pp 863-1150