Validation of Crop Coefficients and Water Requirement of Maize Crop in the Temperate Climatic Region of India

Owais Ahmad Bhat, Mohd Akbar Lone, Rohitashw Kumar

Abstract: The field study was conducted on Lysimeter by employing the soil water balance method to compute the water requirement and Crop coefficient of Maize in the temperate climatic zone of India. Non-weighing type lysimeters (drainage type) of 2 × 1.5 × 2 m was installed to compute the irrigation requirement, actual crop evapotranspiration (ETc) and actual crop coefficient of maize by water balance method. The water requirement of maize was found 410.4 mm using lysimeter data. The mean daily reference evapotranspiration (ETo) of maize ranged from 0.91 mm/day in the starting growth period to 5.29 mm/day at midseason. The peak ETo of Maize was found 6.3 mm/day. The computed crop coefficient (Kc) values of Maize for different crop growth stages were 0.53 for initial, 0.93 for development, 1.05 for mid-season, and 0.78 for late season. A Correlation was also established between Penman-Monteith (P-M) and four other reference Evapotranspiration methods.

Index Terms: Leaf Area Index, Lysimeters, Reference Evapotranspiration, Water Requirement.

I. INTRODUCTION

Maize is grown throughout the world and have a great sustenance value for human and animals. The global production of maize is 1.016 million tonnes with more than 184 million hectares cultivated (FAO, 2013). The maize crop is grown in India grown in the ‘Kharif’ season (May-August) (Kumar, 2008). The area under maize and pulses in Jammu and Kashmir is 3.02 and 0.30 lakh hectares, respectively. Irrigated area under maize is only 7.23 per cent with 0.66 million tons of annual production and an average productivity which is very less i.e 2.14 tons per hectare while as national average is 2.6 tons per hectare (Economic Survey, 2010), indicating tremendous potential to increase yield by increasing the percentage of irrigated area through specific water Management along with effectual irrigation scheduling. studies on Maize water use have been done throughout the world, Stegman 1988 and Steele et al in 1996 computed water requirement of maize in the United States; Howell et al. Also did a lot of work in the field and developed Kc values for maize 2006. Researches like Li et al. 2003; Zhao et al. 2013; Zhang et al. 2013 reported single crop coefficients of maize-based on grass reference evapotranspiration in China. Many studies on Kc of maize in various countries such as Portugal, Brazil in recent times determined crop coefficient values of maize on basis of reference of grass using the SIM Dual Kc model (Rosa et al. 2012;Martins et al. 2013). Water production of maize was calculated in a field trial in the US, crop evapotranspiration (ETc) was found as 630 mm (Thomas J. Trout 2017). Water now getting scarce is being called as ‘blue gold’, and it is intended to be the most sensitive and critical issue of the 21st century, the productivity of irrigated agriculture has to be maintained and further increased to cope with ever-increasing food requirements globally. Irrigated agriculture has to become more fruitful with a diminished water supply. The Water requirement of crop varies considerably during the growing period mainly as crop canopy and climatic conditions keep varying. Various authors have stated that a precise and standard method to estimate ETo is required, to predict actual crop water requirements (Jabloun and Sahli, 2008). The Water requirement of crops keeps varying during growth period, mainly because of the difference in crops canopy and climatic conditions. It is believed that about 99% of the water drawn by plants from soil is lost in form of ET. To avoid the errors in the computation of crop water consumption, the information about exact amount of water lost through crop ET is necessary for development and water management in the temperate region. Allen et al. (1990) proposed that crop coefficient values should be derived empirically from local climatic and lysimeteric data for each crop. Crop coefficient values for various crops have been put forth by Doorenbos and Pruitt (1977) and are useful for areas where the local data is scarce or not available. lysimeter data based Crop coefficients have not been developed for Maize temperate climatic conditions of Kashmir region in India. Smith .et al. (1992) suggested that FAO Penman-Monteith method estimates ETo accurately and performed better than other ETo methods but data required inPenman-Monteith equation is not easily obtainable with ease, therefore, present study was done to acquire the link between the FAO P-Mon method and various ETc methods used in study. Crop water requirement (ETc)using lysimeter soil water balance method and to validate crop coefficients(Kc) for the study area.
II. MATERIAL AND METHODS

A. Site Description

The experiments on Lysimeter and field crop were conducted using Non -Weighing type lysimeter (drainage type) of 2× 1.5× 2 m size installed at the experimental field of Dry Land Agriculture Research Station, SKUAST-Kashmir. The field was uniform and level and typical for mid altitude maize cultivation. The location map is shown in Fig. 1.

B. Climate

The experimental location has well segregated season’s viz. hot summer and very cold winter. Average precipitation of 812 mm is received annually mostly during months of December to April in the form of snow and rain. The Rainfall distribution and max and min temperature of study area during the growth period at the site i.e Budgam is given in figure 2 and 3 respectively.

C. Weather Station

The different meteorological data such as maximum temperature (°C), Minimum temperature (°C), Relative humidity (%), Wind velocity at 2m height (m/s), Sunshine hours (hrs) and daily Pan Evaporation (mm) was obtained from automated weather station installed near the periphery of old airport Rangreth (Figure 4) in at Dryland Agriculture Research Station, SKUAST-Kashmir.

D. Lysimeter

The experimentation at the site i.e. Budgam was conducted using the Lysimeter Set-up (Fig.5). A Non-weighing (Drainage type ) lysimeter of 2×1.5×2 m size was installed in the open fields for simulating the actual field conditions to calculate the ETo at varying stages of the crop growth using soil water balance. The lysimeter was made up of Cast-iron. To drain-out the percolated water, 2.5cm diameter drain holes were provided at the bottom. A drainage equipment was installed, to accumulate the percolated water and to measure the volume of drained water. The holes for draining were attached with pipes having a small diameter and opening in a chamber about (2m deep) containing a receiver tank (drainage tank). Irrigation was applied in the measured quantity and distribution as required by the crops under study.

E. Soil Moisture Sensors

Soil tension sensors fabricated and manufactured by Water mark, Irrometer Company were placed at a vertical drop of 0.4m, 0.8 m, and 1.2 m in Lysimeter so that the soil water potential at different depths is measured. To calculate regular changes in the in-situ soil moisture, moisture content values at selected depths at distinct time durations were measured through gravimetry, soil water potential was observed between two irrigations at different growth periods and Van Genuchten equation was used to calculate water content from the metric potential reading of soil obtained from sensors.
F. Reference Evapotranspiration
Reference crop evapotranspiration (ETo) is defined as the rate of Evapotranspiration from a reference surface, saturated with water. In literature, many equations/models have been published for the estimation of ETo. In the present study, the most commonly used models (approaches) are illustrated in Table 1.

Table 1 Reference evapotranspiration methods

<table>
<thead>
<tr>
<th>No.</th>
<th>Method of ETo Estimation</th>
<th>Equation Used</th>
<th>Soil Reference</th>
<th>Required Meteorological Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Penman-Monteith (PM)</td>
<td>[ \text{ETo} = \frac{\text{P} - \Gamma D - R + \Delta S}{\Gamma + \Delta S} ]</td>
<td>Allen et al. (1998)</td>
<td>vapour pressure deficit, solar radiation, temperature and wind velocity</td>
</tr>
<tr>
<td>2</td>
<td>FAO56-Simplified (SSM)</td>
<td>[ \text{ETo} = \text{Kc} \times \text{ETp} ]</td>
<td>Penman-Monteith (1958)</td>
<td>daily temperature and relative humidity</td>
</tr>
<tr>
<td>3</td>
<td>FAO24-Simplified (SM2)</td>
<td>[ \text{ETo} = \text{Kc} \times \text{ETp} ]</td>
<td>Penman-Monteith (1958)</td>
<td>daily temperature and relative humidity</td>
</tr>
<tr>
<td>4</td>
<td>��照著簡化版 (SM2)</td>
<td>[ \text{ETo} = \text{Kc} \times \text{ETp} ]</td>
<td>Penman-Monteith (1958)</td>
<td>daily temperature and relative humidity</td>
</tr>
<tr>
<td>5</td>
<td>स्वयं रोशनी दर (S-R)</td>
<td>[ \text{ETo} = \text{Kc} \times \text{ETp} ]</td>
<td>Allen et al. (1998)</td>
<td>Penman-Monteith</td>
</tr>
</tbody>
</table>

H. Crop Coefficient

\[ K_c = \frac{\text{ETc}}{\text{ETo}} \] (3)

The Kc value is belived to assimilate crop attributes and averaged effect of evaporation from the soil. The four Kc values corresponding to average values of Kc at different stages i.e. Kcini (initial stage), Kcedev (development stage), Kcmid (mid stage) and Kcend (end stage). The Kc value given by equation given below

I. Soil Water Retention Curve

Soil water retention curve (SWRC) expresses the practical association between soil water content and the soil water potential. It is a vital property of soil material and SWRC is very essential while studying water flow in soil and its availability to plants. Water retention curve gives the relationship between the soil water content (θ) and soil water potential (ψ) it’s also called as soil moisture characteristic and is used to estimate soil water storage, field capacity, etc (van Genuchten, 1980). Soil water tension was measured through sensors which were installed at different depth in Lysimeter these are solid electrical resistance measuring device. The moisture content at these points was also computed gravimetrically at discrete times.

J. Crop Details

Maize seeds (Var. Shalimar Maize -6) were sown on the 28th of April and harvested on September 15th of 2016 crop had a crop period of 140 days as shown in Table 2. To simulate the lysimeter and its surroundings so that plants of the same height and planting densities are achieved both inside the lysimeter and its surroundings sowing was done on the same date and same recommended agronomic practices were followed. Crop factors i.e Leaf Area Index (LAI), Plant Height and Root length were recorded at distinct time periods throughout the crop period for both the crops grown in the experimental plot.

Table 2: Duration of different crop growth stage

<table>
<thead>
<tr>
<th>Crops</th>
<th>Crop growth stages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
</tr>
<tr>
<td>Maize</td>
<td>140</td>
</tr>
</tbody>
</table>

Table 3: Texture soil properties at different depth

<table>
<thead>
<tr>
<th>Soil Depth</th>
<th>Bulk density</th>
<th>Soil Texture</th>
<th>Particle Density</th>
<th>Field Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>1.21</td>
<td>25.6</td>
<td>55.3</td>
<td>18.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.32</td>
</tr>
</tbody>
</table>
II. RESULTS AND DISCUSSIONS

The field experiments on lysimeter were conducted to estimate water requirement, actual evapotranspiration and growth-stage specific crop coefficients for Maize in temperate region of Kashmir. The experiment details of results are discussed as under

A. Reference Evapotranspiration (ETo)

The ETo was computed from the daily weather parameters collected from weather stations, using five climate-based methods/models is summarized in Table 4. As illustrated in table 4 Maximum value of ETo was obtained from (H-S) method followed by (F B-C) these methods overestimated ETo as compared to ETC, while as (F c P-Mon) and(F E-Pan) were in close range with each other and (P-M) was in close range with actual crop Evapotranspiration ETc obtained from lysimeter data.

![Figure 8 Daily ETc (mm/day) values during growth period of maize crop](image)

**Table 4: Maximum ETc values using different model**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Method of ETc Estimation</th>
<th>Maximum value of ETc (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Penman Monteith (P-M)</td>
<td>407.1</td>
</tr>
<tr>
<td>2.</td>
<td>FAO-24 corrected Penman (c = 1), (F c P-Mon)</td>
<td>453.7</td>
</tr>
<tr>
<td>3.</td>
<td>FAO-24 Blaney-Criddle, (F B-C)</td>
<td>497.6</td>
</tr>
<tr>
<td>4.</td>
<td>Hargreaves-Samani (H-S)</td>
<td>534.1</td>
</tr>
<tr>
<td>5.</td>
<td>FAO Pan Evaporation (F E-Pan)</td>
<td>448.9</td>
</tr>
</tbody>
</table>

B. Statistical Analysis

Linear regression was done to evaluate the correlation between the Penman-Monteith (P-M) method and other ETo methods and the result of regression analysis is given in table 5 for the Maize crop.

**Table 5: Regression analysis between Penman-Monteith (P-M) and different methods of ETo during different growth stages of maize**

<table>
<thead>
<tr>
<th>Regression analysis parameters</th>
<th>Initial stage</th>
<th>Development stage</th>
<th>Mid Stage</th>
<th>Late Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F c P-Mon</td>
<td>H-S</td>
<td>F B-C</td>
<td>F E-Pan</td>
</tr>
<tr>
<td>Regression line intercept (a)</td>
<td>0.077</td>
<td>-0.138</td>
<td>1.622</td>
<td>2.217</td>
</tr>
<tr>
<td>Regression line slope (b)</td>
<td>0.994**</td>
<td>0.841**</td>
<td>0.439*</td>
<td>0.134*</td>
</tr>
<tr>
<td>Coefficient of determination (R^2)</td>
<td>0.977</td>
<td>0.534</td>
<td>0.72</td>
<td>0.036</td>
</tr>
</tbody>
</table>

** 1% level of significance  * 5% level of significance**

As shown in Table 5 In the initial growth stage of Maize F B-C and F c P-Mon methods were found to be in a strong linear relationship with (P-M) equation (i.e. R^2 >80) while in Development growth stage F c P-Mon was in a close linear relationship with (P-M) equation. At mid and late growth stage again F B-C and F c P-Mon were found to be in a strong linear relationship with Penman-Monteith(P-M) equation (i.e. R^2 >90)

C. Crop Evapotranspiration and Water Balance

The water balance as illustrated in Table 6 showed that the total crop ET for maize crop was 410.4 mm and more than 50% of the ET requirement of Maize has fulfilled by rainfall, which was 217 mm. A total of 6 irrigations were applied to supply 240 mm of water as shown in Fig.9. The water loss beyond the root zone i.e. deep percolation (drainage) was 32 mm. Maximum water requirement of the crop was in the mid growth stage (i.e. 66 DAS to 112 DAS) followed by in development stage(31 DAS to 65 DAS).

![Figure 6 showed that the total crop ET for maize crop was 410.4 mm and more than 50% of the ET requirement of Maize has fulfilled by rainfall, which was 217 mm. A total of 6 irrigations were applied to supply 240 mm of water as shown in Fig.9. The water loss beyond the root zone i.e. deep percolation (drainage) was 32 mm. Maximum water requirement of the crop was in the mid growth stage (i.e. 66 DAS to 112 DAS) followed by in development stage(31 DAS to 65 DAS).
D. Soil water Retention Curve

At 3 distinct depths near the crop root zone (0.4 m, 0.8 m, and 1.2 meters) moisture sensors were placed in the soil. Soil water potential data which was recorded from these sensors regularly during periods between two irrigations or two rainfall events.

The soil potential reading obtained from the sensors read zero after irrigation was applied or after a rainfall showing the soil was completely saturated and soil moisture is being held mainly by capillary forces, as the time progressed soil potential reading increased and θ decreased binding the water more strongly with soil (figs 9&10). Available water for a plant is considered as difference of water that is in the soil at field capacity and that remains in the soil when it reaches the permanent wilting point. A mathematical equation was derived linking water potential and water content of soil using Van–Genuchten 1980 function. Soil water content was found to increase rapidly after irrigation and then gradually decrease until the next irrigation showing an inverse relationship with soil potential. The moisture depleted randomly in upper layer as already reported by (Shankar et al. 2013) that about 65–70% of the water consumed by a crop is derived from the portions of root zone lying close to upper surface of soil. It was also observed that highest water potential reading was found in upper layer i.e. (sensor installed at 0.4 meter depth) as compared to deeper layers i.e. 0.8 and 1.2 meters as the plants cannot withdraw soil moisture under determined levels, which lie in middle of field capacity (F.C) and permanent wilting point (PWP).

Further, it was observed that during development and mid growth stage as the canopy and plant height increased soil suction reading increased quickly suggesting that moisture depletion during these growth periods was more owing to...
higher evapotranspiration needs of the crop (figs 11 -13). Higher variations in water content of soil was observed in soil layer of 0- 0.4 depth followed by 0.4 – 0.8 m soil layer, in Maize. Greater water uptake from deeper layer (0.4 – 0.8 m) for maize was observed as the crop growth progressed and development of deeper root penetration and distribution. Moisture content increased with the depth of the soil and in lower layers i.e. 0.8-1.2 meter, not much fluctuation was seen in soil moisture content in lysimeter soil.

E. Crop Coefficient (Kc)
The crop coefficients of maize are illustrated in table 7 and Figure 14 (crop coefficient curve). In the early stage (sowing to end of the 4th week after sowing (WAS) also known as knee height stage crop coefficients (Kcint) varied from 0.39 to 0.57, 0.39 by (F E-Pan), 0.41 H-S, 0.57 by P-M and 0.53 by Fc P-Mon method respectively. The crop coefficient (Kc dev) increased from 0.78 to 1.02 during the crop development stage/flowering stage i.e. (5-9th WAS), 0.78 by (F E-Pan), 0.81 H-S, 1.02 by and P-M 0.93 by Fc P-Mon method, respectively. In the Mid growth stage also known as grain filling stage (10th WAS to 14th WAS) Kcmid (crop coefficient) was highest i.e. >1 except in H-S (0.96). During this stage, elevated values of crop coefficients were observed as the LAI was more than 4. The maturity phase lasted from the 14 to 15th weeks after sowing, crop coefficient (Kcend) values in this stage reduced up to 0.61, 0.78, and 0.82 by H-S, Fc P-Mon and P-M respectively this, was due to LAI decreasing up- to 1.93 in this stage.

Table 6: Crop coefficients of maize based on various ETo models

<table>
<thead>
<tr>
<th>ETa models</th>
<th>Kcint</th>
<th>Kcdev</th>
<th>Kcmid</th>
<th>Kcend</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOA Recommended</td>
<td>0.3-0.5</td>
<td>0.7-0.85</td>
<td>1.05-1.20</td>
<td>0.5-0.7</td>
</tr>
<tr>
<td>FAO-24 corrected Penman (c = 1), (Fc P-Mon)</td>
<td>0.53</td>
<td>0.93</td>
<td>1.06</td>
<td>0.78</td>
</tr>
<tr>
<td>Penman-Monteth (P-M)</td>
<td>0.57</td>
<td>1.02</td>
<td>1.19</td>
<td>0.82</td>
</tr>
<tr>
<td>FAO Pan Evaporation (F E-Pan)</td>
<td>0.39</td>
<td>0.78</td>
<td>1.186</td>
<td>1.0</td>
</tr>
<tr>
<td>Hargreaves-Samani (H-S)</td>
<td>0.41</td>
<td>0.81</td>
<td>0.96</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Fig 15: Crop coefficient curve based on various reference evapotranspiration methods and lysimeter data

III. CONCLUSION
Crop evapotranspiration and estimation of crop coefficient is not an easy task across a country like India which has such diverse agro-climatic conditions. The lysimeter water balance measurements were conducted on maize crop at the temperate region of Kashmir, India. The water requirement (ETc) was 410.4 mm and Kc values for study area during different growth stages were 0.57, 1.02, 1.19 and 0.82, respectively. The lysimeter field study could be useful for irrigation scheduling of maize under temperate climatic condition.

ACKNOWLEDGMENT
Authors are highly thankful to the Department of Civil Engineering NIT, Srinagar and All India Coordinated Research Project on Plasticulture Engineering and Technology, College of Agricultural Engineering and Technology, SKUAST-Kashmir, Srinagar for providing all facilities to conduct the study.

REFERENCES


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