International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-5, January 2020

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

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***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 6.3mm/day. The computed crop coefficient (Kc) values of Maize for diffrent crop growth stages were 0.53 for intial, 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 Doorenbose 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.

Manuscript received on January 02, 2020.
Revised Manuscript received on January 15, 2020.
Manuscript published on January 30, 2020.

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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 ET_0 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

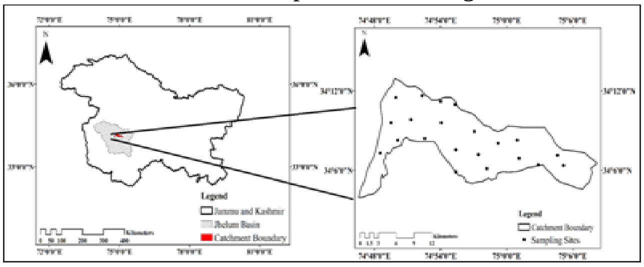

Figure 1 Study Area

B. Climate The experimental location has well segregated season's viz. hot summer and very cold winter. Average precipitation of 812 mm is received annual mostly during months of December to April in the form of snow and rain. The Rainfall distriution 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.

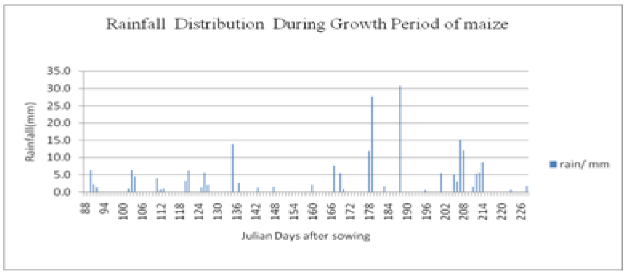

Figure 2 Precipitation at study area (Budgam) during growth period

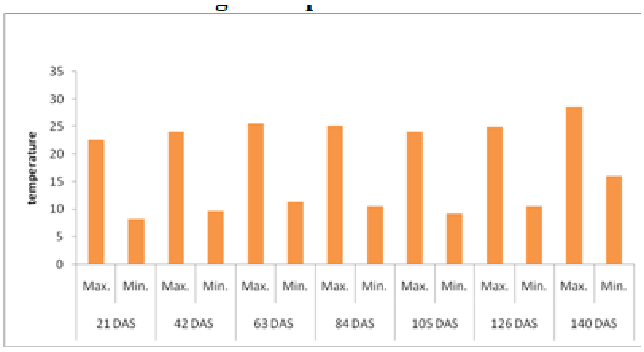

Figure 3 Max and min temperature °C during growth period of maize

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

Figure 4 Meteorology Station located in SKUAST-K (DARS Budgam, 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 ETc 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 equipmentt 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 0.4 m, 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

Figure 5 Design of Lysimeter Setup

Figure 6 Maize Crop in Initial Stage grown in lysimeter installed with soil moisture 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

No.	Method of ET_0 Estimation	Equations Used	Basic Reference	Required Meteorological Data
1	Penman Monteith (P-M)	$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1+0.34u_2)}$	Allen *et al.*, (1998)	Vapour pressure deficit, radiation flux, wind velocity, temperature and soil heat flux.
2.	FAO-24 corrected Penman (c = 1), (F c P-Mon)	$ET_0 = c\left[\frac{\Delta}{\Delta+\gamma}(R_n - G) + \frac{\gamma}{\Delta+\gamma} 2.7 W_f (e_s - e_d)\right]$	Doorenbos and Pruit, (1977)	Net radiation, vapour pressure deficit and wind velocity
3.	FAO-24 Blaney-Criddle, (F B-C)	$ET_0 = a + b[p(0.46\bar{T} + 8.13)]$	Doorenbos and Pruit, (1977)	Annual day time hours, temperature and wind velocity
4.	Hargreaves-Samani (H-S)	$ET_0 = 0.0135(KT)(R_a)(TD^{1/2})(TC+17.8)$ $KT = 0.00185(TD)^2 - 0.0433TD + 0.4023$	Hargreaves and Samani, (1982, 85)	Net radiation, min/max temperature
5.	FAO Pan Evaporation (F E-Pan)	$ET_0 = K_p E_{pan}$	Allen *et al.*, (1998)	Pan evaporation

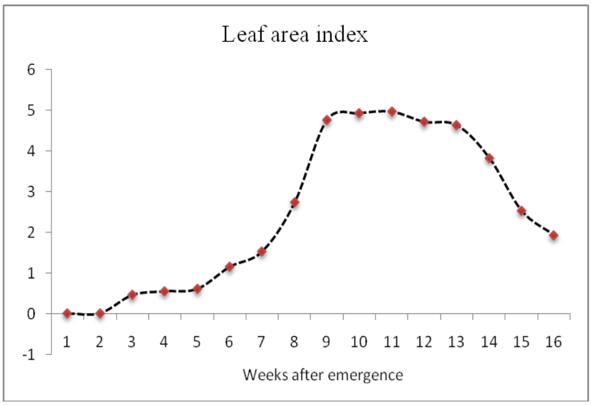

Figure 7 Leaf Area Index

As illustrated by Fig 7 during initial growth stage LAI was less than 0.6, LAI was maximum on 11th WAS (4.959) during this period crop water requirement was highest owing to increased evapotranspiration , LAI again decreased during maturity and reached a value below 2 showing that there is relationship between crop water requirement and leaf area index.

G. Crop evapotranspirtaion

Crop Evapotranspiration (ETc) was computed from Lysimeter data using soil water balance equation. Crop coefficients were estimated from the ratio ETc and ETo for each stage of crop. The ET_C can be quantified by equation:

$$ET_C = P + I - D - R - \Delta S \quad (1)$$

Where, ETc denotes Crop Evapotranspiration (mm), P = precipitation (mm), I = irrigation (mm), D = water drained (mm), R = runoff (mm) and ΔS = is the change in water storage of soil . Runoff (R) was stopped by constructing small ridge around the lysimeter and was considered to be negligible during the period and was neglected.

H. Crop Coefficient

$$K_c = \frac{ET_0}{ET_C} \quad (3)$$

The Kc value is belived to assimilate crop attributes and averaged effect of evaporation from the soil. The four Kcvalues corresponding to average values of Kc at different stages *i.e.* Kcini (initial stage), Kcdev(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 distint time periods i.e. Weekly for (LAI) and Plant Height and root length was measured fortnightly throughout the crop period for both the crops grown in the experimental plot.

Table 2: Duration of different crop growth stage

Crops	**Crop growth stages**				
	Crop growth cycle	Initial	Development	Mid	Late
Maize	140	30	35	47	38

Table 3: Texture soil properties at different depth

Soil Depth	**Bulk density**	**Soil Texture**			**Particle Density**	**Field Capacity**
		Sand (%)	Silt (%)	Clay (%)		
0-15	1.21	25.6	55.3	18.1	2.57	0.32

15-30	1.23	24.93	55.97	19.1	2.59	0.33
30- 45	1.3	26.82	56.09	17.09	2.61	0.35
45-60	1.35	24.72	57.65	17.63	2.64	0.35
60-75	1.45	24.85	55.9	19.25	2.64	0.36

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

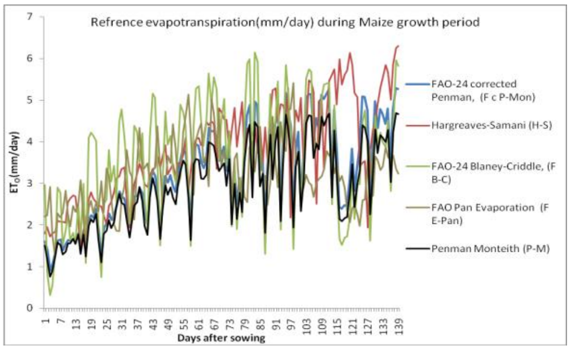

Figure 8 Daily ET_o (mm/day) values during growth periodof maize crop

Table 4: Maximum ET_o values using different model

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

B. Statistical Analysis

Linear regression was done to evaluate the correlation between the Penman-Monteith (P-M) method and other ET_0 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 ET_O during different growth stages of maize

Initial stage				
Regression analysis parameters	**F c P-Mon**	**H-S**	**(F B-C**	**F E-Pan)**
Regression line intercept (a)	-0.145	0.276	0.870	1.277
Regression line slop (b)	1.006*	0.592**	0.308*	0.130*
Coeffcient of determination (R^2)	0.971	0.393	0 .832	0.627
Development stage				
Regression line intercept (a)	-0.077	-0.138	1.622	2.217
Regression line slope (b)	0.994**	0.841**	0.439*	0.134*
Coefficient of determination (R^2)	0.977	0.534	0.72	0.036
Mid Stage				
Regression intercept(a)	-0.086	3.244	1.190	3.879
Regression line slope(b)	0.914**	0.054*	0.560**	-0.105*
Coefficient of determination(R^2)	0.994	0.003	0.875	0.009
Late Stage				
Regression intercept(a)	-0.20	3.865	1.194	1.892
Regression line slope(b)	0.881**	-0.066*	0.654**	0.522**
Coefficient of determination(R^2)	0.994	0.006	0.953	0.114

** 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)

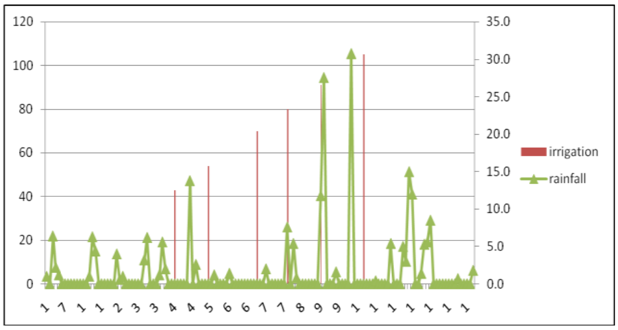

Fig. 9: Distribution of rainfall and irrigation during growth period of maize.

D. Soil water Retention Curve

At 3 distinct depths near the crop root zone (0.4 m, 0.8m, 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

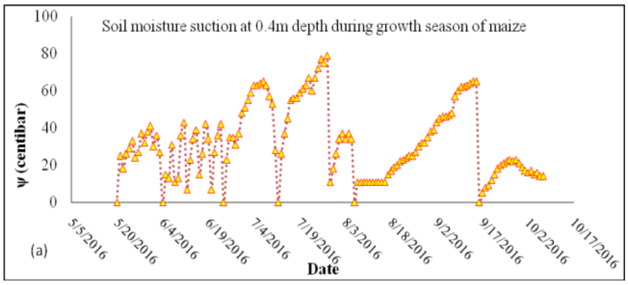

Fig 10: Soil water potential variation during crop period at 0.4 meter depth

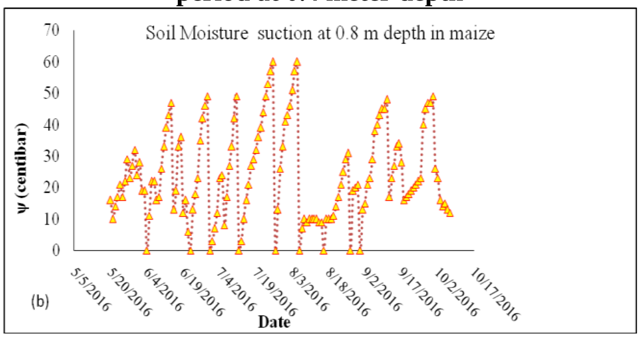

Fig. 11: Soil water potential variation during crop period at 0.8 meter depth

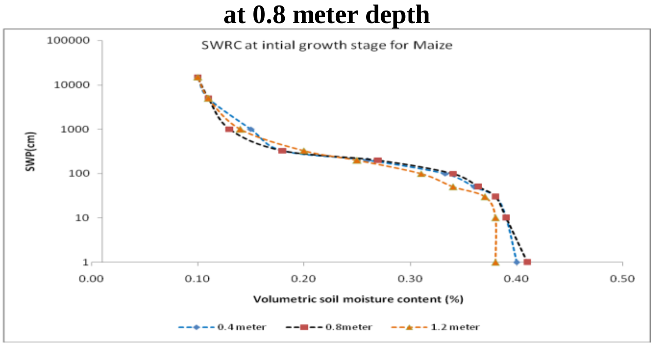

Fig 12: Relationship between soil water potential and volumetric moisture content (SWRC)

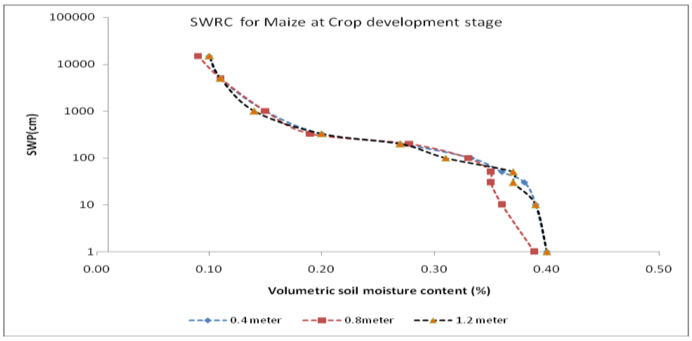

Fig 13: Soil water potential and volumetric moisture content (SWRC) at development stage

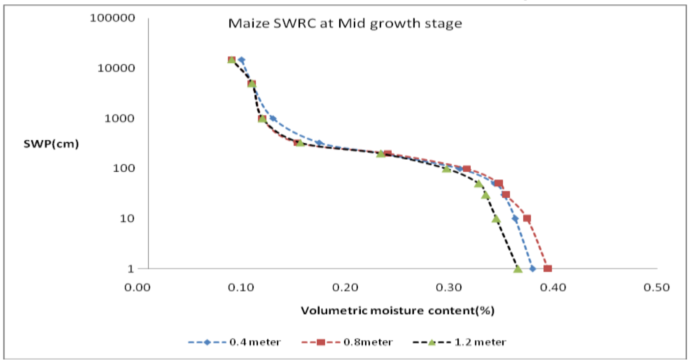

Fig 14: Soil water potential and volumetric moisture content (SWRC) at mid growth stage

. 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 –Genucthan 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(figs11 -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 (K_c)

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 know as knee height stage crop coefficients(Kc_{int}) 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 F c 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 F c P-Mon method, respectively. In the Mid crop growth stage also known as grain filling stage (10th WAS to 14th WAS) Kc_{mid} (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(Kc_{end}) values in this stage reduced up to 0.61, 0.78, and 0.82 by H-S, F c 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

ET_omodel	$K_{c\ int}$	$K_{c\ dev}$	$K_{c\ mid}$	$K_{c\ end}$
FOA Recommended	0.3-0.5	0.7-0.85	1.05-1.20	0.5-0.7
FAO-24 corrected Penman (c = 1), (F c P-Mon)	0.53	0.93	1.06	0.78
Penman -Monteith (P-M)	0.57	1.02	1.19	0.82
FAO Pan Evaporation (F E-Pan)	0.39	0.78	1.186	1.0
Hargreaves-Samani (H-S)	0.41	0.81	0.96	0.61

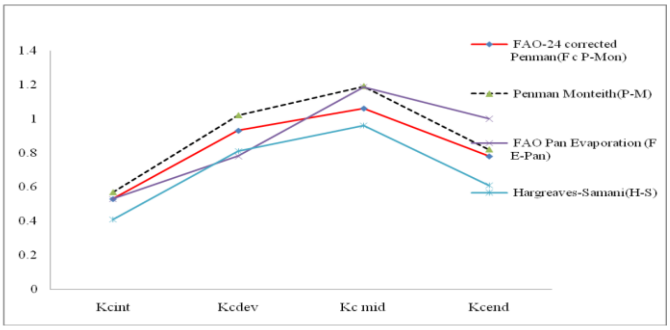

Fig 15: Crop coefficient curve based on various refrence evapotranspiration methods and lysimeter data

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.

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