Comparative Study of Crop Water Requirement of Traditional and Hybrid Sorghum Varieties

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ABSTRACT
An experiment was conducted to compare the crop water requirement of traditional and hybrid sorghum varieties at University of Agriculture Peshawar research farm. Soil moisture samples were collected to calculate Actual evapotranspiration for each variety. Maximum actual evapotranspiration of hybrid variety at full irrigation was 52% more than traditional variety at rainfed conditions (with pre irrigation). The crop coefficient (K_c) for different stages of V_1I_o, V_2Io, V_1I_1, V_2I_1, V_1I_2 and V_2I_2 ranged from 0.24-0.55, 0.27-0.61, 0.49-0.86, 0.47-0.92, 0.37-0.88 and 0.39-1.00 to respective values of FAO ranging from 0.35-1.1. Both the local and hybrid varieties are not significantly different from each other in terms of water productivity at all irrigation levels. Highest crop water productivity (0.61 kg m^{-3}) was observed for V_2I_1 and lowest (0.43 kg m^{-3}) for V_1I_0. Yield of hybrid variety was 62% more than the lowest grain yield of traditional variety under rainfed condition. At the full irrigation for traditional variety this percentage reduces to 59%. The reduction is only due to change in variety. Maximum harvest index (21%) was recorded for V_2I_1 and minimum (11%) for V_1I_o.
Keywords: Crop water productivity, traditional and hybrid sorghum, soil moisture sampling, full Irrigation, evapotranspiration.

INTRODUCTION

Sorghum bicolor (L.) Moench belongs to the family Poaceae of tropical origin, and sensitive to light and temperature. Sorghums and sorghum-Sudangrass hybrids have extensive root systems that can penetrate up to 8 feet into the soil and extend more than 3 feet away from the stem (Shoemaker and Bransby, 2010) These aggressive root systems alleviate subsoil compaction. To encourage more significant root growth, sorghum stalks should be cut at least once during the growing season when they reach 3–4 feet tall (Clark, 2007).
The area under sorghum in Pakistan 0.248 mha with an annual production of 621 kg ha^{-1} and 6.7% change in production (GoP, 2009). Sorghums are quick growing grasses that have the potential to shade out and/or smother weed populations when planted at a high density. In addition, root exudates of sorghum have been shown to reduce the growth of weeds such as velvet leaf, thorn apple, redroot pigweed, crabgrass, yellow foxtail and barnyard grass (Stapleton et al., 2010).
Crop water requirement gives information to growers in selecting the crop to grow and also to determine the time and quantity of irrigation events. In non limited water supply and mineral nutrition, among the various C4 crops sweet sorghum showed best performance which was revealed by water use efficiency (WUE) and primary analysis of biomass use radiation (RUE) and revealed the superior performance of (Mastrorilli et al. 1995). Water use efficiency varies in sorghum varieties to different irrigation regimes (Curt et al., 1995)
Sorghum cultivars are studied intensively as potential bio fuel sources due to their high biomass yield and sugar production. The sugars sorghums produce give it an economical advantage over
Starch based crops for bio fuel use. Other desirable characteristics of sorghum that make it an attractive bio fuel crop for use on marginal lands include its wide range of adaptation, drought resistance, and salinity tolerance (Shoemaker and Bransby, 2010).
This study was to devise and plan the availability of water under different conditions against the growing stage of sorghum crop for traditional cultivar and its hybrid. For this purpose an operational study in the field at Malakandhir farm was launched to estimate the daily and seasonal crop water requirement for the fore seen crop under different irrigation strategies. Hence it is more justified to plan its use before assigning a portion of it to certain crop among cropping system at national level in the irrigated and non irrigated colourable command areas.

MATERIALS AND METHODS

The experiment was conducted at developmental research farm The University of Agriculture Peshawar. The selected Farm is situated at 34°1'15.52" – 34° 1'38.63" N and 71°28'17.30"-71°28'93.30" E**.** The experiment was laid out in Randomized Complete Block Design, consisting two factors irrigation (three levels) and varieties (two) having factors of irrigations and varieties with four replications.
The experiment comprises of the following factors.
Factor A (irrigation)
1_0: One, irrigation before sowing
I_1: Full irrigation

I_2: One, irrigation before flowering stage and one before sowing
Factor B (varieties)
V_1: Traditional
V_2: Hybrid

Crop Sowing

Sorghum varieties were sown with seed rate of 45 kg ha^{-1} by manual method. The plant to plant distance was 10-15 cm while row to row distance was 75 cm. The direction of each row was parallel to the width of the sub plots.

Irrigation

The full irrigation was applied at a soil moisture depletion of 65%. The irrigation was applied to the field when soil moisture reaches to 65% depletion level. Subsequent irrigations were applied to the respective plots according to the moisture stress level maintained for different treatments. These all on volume basis were applied making use of the following relation:

$$\mathbf{MAD} = \frac{\mathbf{RAW}}{\mathbf{AW}} \mathbf{x\,100} \qquad (1)$$

Where:

MAD = Maximum allowable deficit or depletion in percent
AW = Available water in cm,
RAW = readily available water in cm.

The available water (AW) and the readily available water (RAW) used in the above equation 1 are defined as under:

$$\mathbf{AW} = \mathbf{(Drz\,(FC - PWP)/100} \qquad (2)$$

Where:

Drz = Root zone depth in cm
FC = Field capacity by volume in percent, and
PWP = Permanent wilting point by volume in percent.

While:

$$\mathbf{RAW} = \frac{\mathbf{Drz\,(FC - \theta c)}}{\mathbf{100}} \qquad (3$$

Where:

θc = Critical soil moisture content by volume in percent.

Combining equation 1 and 3, then we get;

$$\theta\mathbf{c} = \mathbf{FC} - \frac{\mathbf{100\,(AW\,x\,MAD)}}{\mathbf{Drz}} \qquad (4)$$

From per-irrigation soil moisture relationship the irrigation depth to be applied to each plot wa

$$\mathbf{Dw} = \frac{\mathbf{Drz(FC - \theta i)}}{\mathbf{100}} \qquad (5)$$

Where:

dw = Depth of water to be applied in cm
Drz = Depth of root zone in cm
FC = Field capacity in percent by volume, and
θi = Soil moisture content before irrigation in percent by volume.

To get the desired depth of irrigation for each plot time required was calculated as suggested by Jensen (1980). The fixed interval irrigation was applied i.e. after 7 days. The irrigation application time t (hours) was computed from given equation:

$$\mathbf{t} = \frac{\mathbf{A \times dw}}{\mathbf{Q}} \qquad (6)$$

Where:

t = Time required to irrigate (s),
A = Subplot area (m^2),

dw = Water applied depth (mm), and
Q = Watercourse discharge (ls^{-1}).

Consumptive use of water (ET_a)

The consumptive use of water or actual evapotranspiration for sorghum was work out by soil moisture depletion method. ET_a was determined by adding water loss between successive soil sampling plus rainfall plus irrigation plus actual evapotranspiration estimated from interpolation of soil moisture depletion. In case of heavy rainfall, deep percolation was estimated by subtracting maximum water holding capacity of the soil before rainfall from effective rainfall. Dividing the total water used between two samplings by the number of days, the consumptive use per day was calculated as:

$$\mathbf{ETa = \frac{I + P - Drz(\theta f - \theta i)}{\Delta t}} \qquad (7)$$

Where:
ET_a = Actual evapotranspiration between two successive sampling periods
Drz = Depth of rootzone in cm
θi = Soil moisture content in percent by volume at the time of first sampling
θf = Soil moisture content in percent by volume at the time of second sampling
I = Depth of irrigation in cm
Δt = Time period in days

Calculating ET_o

Evaporation from United States weather Bureau class A open pan is a common place and easy method for scheduling irrigation for field, fruit and vegetable crops. Reference evapotranspiration was calculated from pan evaporation data. U.S class A pan was built at Pakistan forest institute (PFI) Peshawar, Pakistan. From the open water surface the pan evaporation method measures the evaporation, considered cumulative effect of humidity, temperature, radiation and wind. By measuring the change in water level the irrigation depth was calculated, correcting it for precipitation and determining the amount of water evaporated from pan. The rainfall data was recorded by installing the rain gauge. The relationship described by the Linacre in 1993 between ET_O and pan evaporation is as under:

$$\mathbf{ETo = Kp \times Epan} \qquad (8)$$

Where:

ET_O = Reference evapotranspiration (mm d^{-1})
Epan = Pan evaporation (mm d^{-1}), and
K_P = Pan Coefficient.

For the Class A evaporation pan, the K pan varies between 0.35 and 0.85. Average K pan = 0.70. For the more accuracy in determination of the K pan factor Table 2 (Annexure) was used.

Crop coefficient (K_c)

Crop coefficient which is the ratio of actual evapotranspiration occurring under a specific crop at a specific stage of growth to Reference evapotranspiration at that time is given by the following relationship:

$$\mathbf{Kc = \frac{ETa}{ETo}} \qquad (9)$$

Where:
K_c = Crop coefficient for a specific crop and for a particular growth stage
ET_a = Actual evapotranspiration for a specific crop and for a particular stage in cm : and
ET_o = Reference evapotranspiration for the same period using pan evaporation data in cm

Water productivity

The ratio of services and good produced over the volume of water required for their production; measures the efficient use of water. Crop water productivity (WP) expressed in kg m^{-3}. The water productivity was calculated by the given formula:

$$\mathrm{CWP}\ (\mathrm{kg\ m^{-3}}) = \frac{\text{Crop Yield (Kg)}}{\text{Water applied (m}^3\text{)}} \qquad (10)$$

Agronomic Parameters
Data was recorded on the following parameters

Grain Yield
Grain yield was recorded with the help of spring balance, selecting central rows from row length of twelve meter with 75cm row to row distance in each subplot and was then converted into Kg ha^{-1}.

Harvest index
Harvest index is the ratio of grain weight to the total plant weight. The harvest index was calculated by the given formula:

$$\mathrm{H.I} = \frac{\text{Economic yield (kg)}}{\text{Total dry matter produced (kg)}} \qquad (11)$$

Biological yield
Two central rows were harvested and kept in the sun for drying and then weighted and converted into kg ha^{-1}.

Statistical procedure
The data collected on different parameters was subjected to analysis of variance (ANOVA) technology to observe the difference, between different treatments as well as their interactions. In case where the difference was significant the mean was further assist for differences through least significant difference (LSD) test. Statistical computer software, MSTATC (Michigan state university, USA), was applied for computing both ANOVA and LSD. (Steel and Torrie, 1980).

RESULTS AND DISCUSSIONS

Actual Evapotranspiration (ET_a)
There was significant difference in ET_a among selected sorghum treatment. The ET_a of traditional sorghum variety in all treatments were found to be the lowest whereas in the hybrid sorghum variety these were found to be highest. Table 1 shows the comparison of seasonal ET_a of all treatments showed that V_2I_o, V_1I_2, V_2I_2, V_1I_1 and V_2I_1 had 9, 26, 32, 45 and 48 % higher values when compared to V_1I_o. Table 1 shows that the ET_a of full irrigation is significantly high when compared to the one irrigation before flowering and without any irrigation to the sorghum crop. Table 2 shows the stage wise comparison of gradual increase in ET_a from crop initial stage to mid stage and then steadily declined towards crop harvest for the case of full irrigation while for rainfed there was gradual decline in ET_a from the time of sowing till rainfall and then after rainfall there was an increase which then showed decline till crop harvest. Similarly, in case of treatments having one irrigation, ET_a pattern was similar to the rainfed conditions but at the time of flowering after performing an irrigation there was a sudden increase in ET_a which then adopted similar trend as full irrigation treatment till crop harvest it was similar with full irrigation treatment. These results are in agreement with those of Piccinni et al. (2009) who reported that accumulated seasonal crop water use ranged for sorghum between 491 and 533 mm.

Reference Evapotranspiration (ET_o)
Results are presented from the reference evapotranspiration (ET_O) using the method of Pan Evaporation in Figure 1. ET_o variation was great in sorghum crop growth period (June to October). It was found that the highest value of ET_o (9.7 mm d $^{-1}$) was during the second week of July and the lowest value of ET_o (4.6 mm d $^{-1}$) was in the last week of September. During the months of July and September ET_o was variable due to irregular rainfall events and abrupt changes in climate due to which the atmospheric temperature became low. The total ET_o during the growing period of sorgum crop was 780 mm.

Crop Coefficient (K_c)
Figure 2 shows that K_c values of different treatment varieties showed almost different trend with some huge fluctuation. Traditional variety had lower value of K_c as compared to hybrid variety. Different varieties of traditional sorghum had similar value of K_c, while different variety of hybrid sorghum had lot of variation among the values of K_c different. For V_1I_o, V_2I_o the maximum K_c values were 0.67 and 0.77 and for V_1I_2, V_2I_2 the values were 1.04 and 1.19 and for V_1I_1, V_2I_1 these were 1.06 and 1.13 as in order. During all growth stages K_c treatment of V_2I_1 was higher constantly and V_1I_o treatment had the lowest value. Treatment V_1I_1 and V_2I_1 had the same K_c

value during initial stages of crop because the cover of crop increased towards middle stage. Due to increase in evapotranspiration the K_c values of all varieties increased. K_c values of irrigated treatments were similar to one another during the mid season stages but were different to other treatments. Due to heavy rainfall and decline of crop cover K_c of all treatment showed the maximum value. Heavy rainfall decreases evapotranspiration which in turn decreases the K_c values.

K_c values can be used for wide range of climatic conditions as recommended by FAO. The values of K_c for traditional and hybrid sorghum variety are different from each other as can be seen in this study. Therefore, it is suggested that K_c values of all sorghum varieties should be determined locally.

Crop Water Productivity (kg m^{-3})

Mean data for crop water productivity is presented in table 4. The data shows that crop water productivity is significantly affected by different levels of irrigation however not significantly affected by varieties and its interaction. The maximum crop water productivity (0.60 kg m^{-3}) was recorded with an irrigation level of I_1 followed by (0.48 kg m^{-3}) with an irrigation level I_2 however minimum crop water productivity (0.44 kg m^{-3}) was recorded with an irrigation level I_0.

Agronomic Parameters

Grain Yield

The mean data regarding grain yield is given in Table 5. The data shows that grain yield of sorghum was significantly affected by different irrigation levels and different varieties. However no significant effect of their interaction was observed. The mean table shows that maximum grain yield (3332.1 kg ha^{-1}) was observed with irrigation level I_1 followed by a yield of (1748.0 kg ha^{-1}) with irrigation level I_2. While least grain yields (1374.4 kg ha^{-1}) was observed with irrigation level of I_0. Data regarding grain yield revealed that increased grain yield (2236.7 kg ha^{-1}) was recorded in hybrid variety whereas least grain yield (2066.3 kg ha^{-1}) was observed in local variety. These findings are in agreement of those of Akram et al. (2007) who reported that maximum biological and grain yield were 31.7 and 2.26 t ha^{-1}.

Harvest Index (%)

Table 6 shows effect of irrigation levels and different varieties of sorghum. The statistical calculation showed that irrigation levels and different varieties have significant effect over sorghum harvest index whereas their interaction is not significant. Maximum harvest index (20.50) was observed with irrigation level of I_1 followed by (14.00) with irrigation level I_2. While least harvest index (11.25) was observed with irrigation level I_0. Similarly, hybrid variety showed maximum harvest index (15.92) while least harvest index (14.58) was observed in local variety.

Biological Yield

Biological yield did not show any significant change regarding all the treatments. It is further added that there is not a paramount difference in the traditional and hybrid sorghum varieties. Mean biological yield for traditional varieties ranged from 12223 to 16250 kg ha^{-1}, while in case of hybrid variety it varied from 12222 to 16250 kg ha^{-1}. Irrigation treatment V_2I_1 had given significant difference with a maximum yield of 16250 kg ha^{-1} when compared to the treatment V_2I_o with 12222 kg ha^{-1}. These results are in contrast with those of Akram et al. (2007) who reported that maximum biological was 31.7 t ha^{-1}.

Conclusions

Conclusions of the study are as follows:

- The maximum actual evapotranspiration (ET_a) of hybrid variety at full irrigation was 52% more when compared maximum traditional variety at rainfed conditions (with pre irrigation). Hence it was concluded that one, irrigation before flowering is not sufficient.
- The crop coefficient (K_c) for different stages of V_1I_o, V_2Io, V_1I_1, V_2I_1, V_1I_2 and V_2I_2 were ranged from 0.24-0.55, 0.27-0.61, 0.49-0.86, 0.47-0.92, 0.37-0.88 and 0.39-1.00 to the respective values of FAO ranging from 0.35-1.1.
- Both the local and hybrid varieties are not significantly different from each in terms of water productivity at all irrigation levels. However all irrigation levels are significantly different from each other irrespective of the varieties. Highest crop water productivity (0.60 kg m^{-3}) was observed for V_1I_o and lowest (0.43 kg m^{-3}) for V_2I_1.
- The highest grain yield of hybrid variety at full irrigation was 62% more than the lowest grain yield of traditional variety under rainfed condition (with pre irrigation). However at the same irrigation for traditional variety this percentage reduces to 59%. The reduction is only due to change in variety. Maximum harvest index (21%) was recorded for V_2I_1 and minimum (11%) for V_1I_o

Recommendation

- Among all the treatments treatment with full irrigation the hybrid variety is recommended on the basis of best performance with respect to crop water productivity and harvest index.
- Similarly, traditional variety having full irrigation is only recommended as its grain yield and water productivity is concerned.
- K_c values can be used for wide range of climatic conditions as it is recommended by FAO. Therefore, it is suggested that K_c values of all sorghum varieties should be determined locally

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Table 1: Mean table for ET_a as affected by different levels of irrigations and cultivars of Sorghum

Irrigations	Varieties		Mean
	Local	Hybrid	
I_0	296.50	322.50	309.50c
I_1	535.50	570.50	553.00a
I_2	401.25	436.75	419.00b
Mean	411.08b	443.25a	

LSD value for irrigation at 5% level of probability = 24.164
LSD value for varieties at 5% level of probability =19.730

Table 2: Stage wise actual evapotranspiration (mm d^{-1}) of all treatments

Varieties/Stages	Initial	Developmental	Mid Season	Late Season
V_1I_o	3.2	1.7	3.3	2.6
V_2I_o	3.3	1.9	3.6	2.8
V_1I_2	3.2	2.4	5.1	3.0
V_2I_2	3.3	2.6	5.8	3.2
V_1I_1	4.1	5.8	4.7	3.1
V_2I_1	3.9	6.3	5.4	3.2

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Table 3: Comparison of observed K_c of selected sorghum varieties with FAO reported values

Varieties/Stages	Initial	Developmental	Mid Season	Late Season
FAO	0.35	0.75	1.10	0.55
V_1I_o	0.38	0.24	0.55	0.49
V_2I_o	0.40	0.27	0.61	0.53
V_1I_2	0.37	0.37	0.88	0.56
V_2I_2	0.39	0.39	1.00	0.61
V_1I_1	0.49	0.86	0.81	0.58
V_2I_1	0.47	0.92	0.92	0.60

Table 4: Mean table for Water Productivity as affected by different levels of irrigations and varieties of Sorghum

Irrigations	Varieties		Mean
	Local	Hybrid	
I_0	0.43	0.46	0.44b
I_1	0.60	0.61	0.60a
I_2	0.46	0.50	0.408c
Mean	0.49a	0.52a	

LSD value for irrigation at 5% level of probability = 0.0551

Table 5: Mean table for Grain Yield as affected by different levels of irrigations and cultivars of Sorghum

Irrigations	Varieties		Mean
	Local	Hybrid	
I_0	1323.0	1425.8	1374.4c
I_1	3212.3	3452.0	3332.1a
I_2	1663.8	1832.3	1748.0b
Mean	2066.3b	2236.7a	

LSD value for irrigation at 5% level of probability = 158.11
LSD value for varieties at 5% level of probability = 129.10

Table 6: Mean table for Harvest Index as affected by different levels of irrigations and cultivars of Sorghum

Irrigations	Varieties		Mean
	Local	Hybrid	
I_0	11.00	11.50	11.25c
I_1	19.75	21.25	20.50a
I_2	13.00	15.00	14.00b
Mean	14.58b	15.92a	

LSD value for irrigation at 5% level of probability =1.3292
LSD value for varieties at 5% level of probability=1.0853

Table 7: Mean table for Biological Yield as affected by different levels of irrigations and cultivars of Sorghum

Irrigations	Varieties		Mean
	Local	Hybrid	
I_0	12223	12222	12222c
I_1	16250	16250	16250a
I_2	12917	12472	12694b
Mean	13796	13648	

LSD value for irrigation at 5% level of probability = 1338.4

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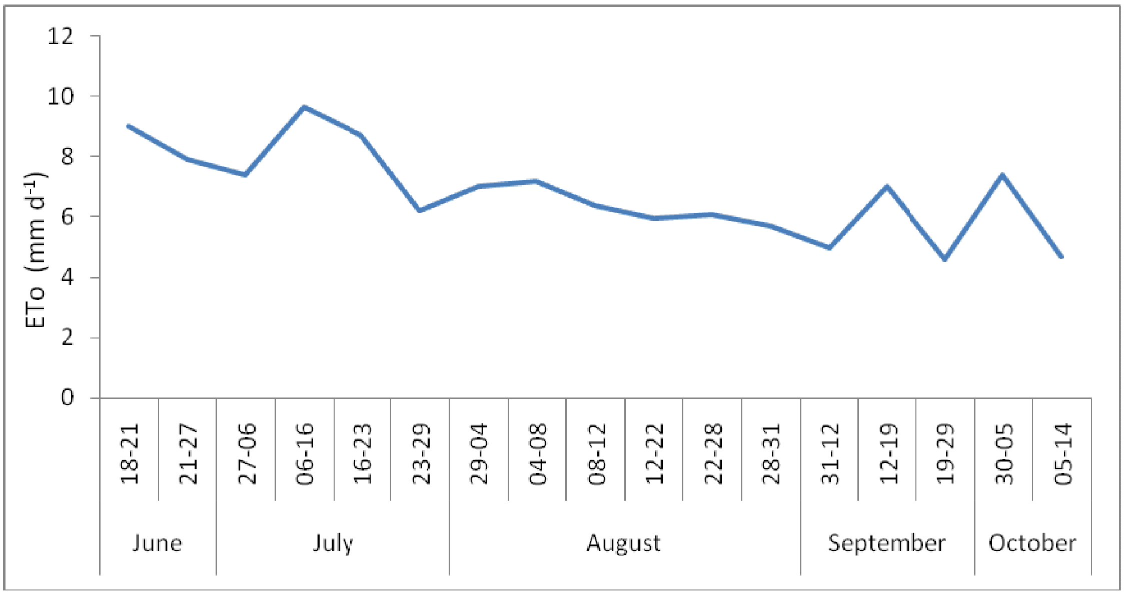

Figure 1: Reference evapotranspiration (mm d^{-1}) for growing season of sorghum

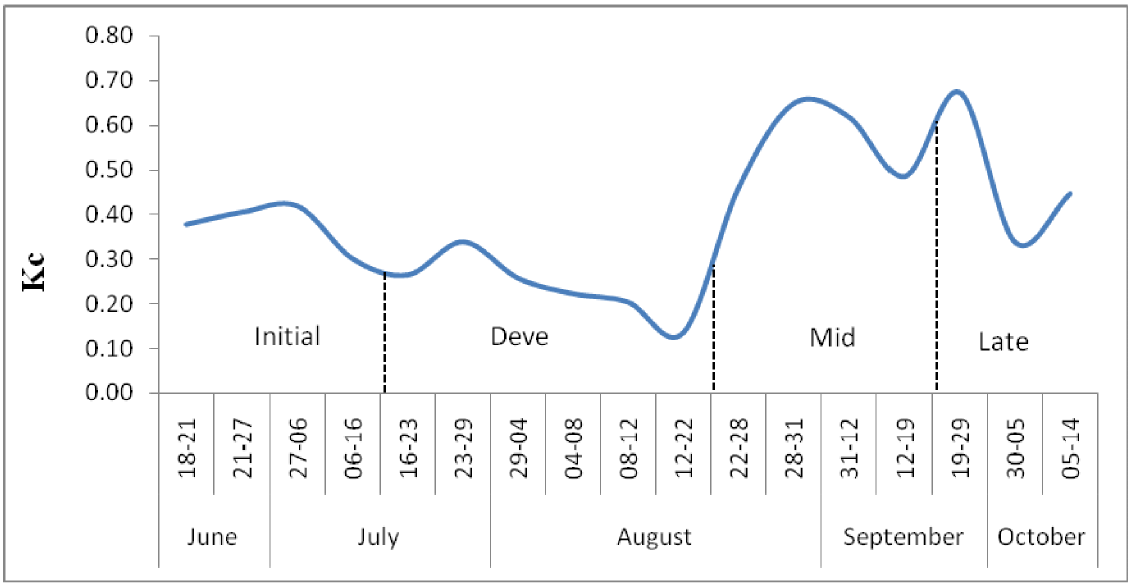

Figure 2: Crop coefficient (K_c) of all treatments