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Soil moisture prediction, evapotranspiration, yield and water use efficiency of soybean (*Glycine max* L.) crop under variable weather conditions in a semi-arid environment

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सार – भारतीय कृषि अनुसंधान संस्थान, नई दिल्ली क्षेत्र के रेतीली दोमट मृदा में खरीफ 2009 व 2010 के दौरान सोयाबीन की तीन किस्मों V1: JS 335, V2: Pusa 9712 और (D1) Pusa 9814) की सामान्य बुवाई (D2) तिथि व देर से बुवाई करके तथा इसके प्रभाव की मृदा नमी, इवापोट्रांसपाइरेशन (ई टी), जल उपयोग क्षमता व सोयाबीन उपज पर अध्ययन हेतु परीक्षण किया गया। सोयाबीन फीनोलोजी दर्शाती है कि देरी से बुवाई होने पर फसल के जीवन चक्र का पूरा होने में कम समय लगा। कृषि मौसम विज्ञान जल संतुलन मॉडल से आर एम एस ई (%) 6.27 से 12.06 प्रतिशत व सहसंबंध गुणांक 0.828 से 0.982 के बीच प्राप्त होने पर यहाँ मॉडल संतोषजनक ढंग से मिट्टी की नमी की मात्रा का पूर्वानुमान लगाने में उपयोगी है। सोयाबीन किस्मों के कारण ई टी में अधिकतम मान प्राप्त हुए। सोयाबीन की सामान्य तिथि में बुवाई करने पर अधिक पैदावार प्राप्त हुई। तीनों किस्मों की तुलना करने पर किस्म JS 335 की उपज एवं जल उपयोग क्षमता कम प्राप्त हुई। इस शोध पत्र में किए गए अध्ययन के आधार पर कहा जा सकता है कि दिल्ली क्षेत्र के अर्द्धशुष्क पर्यावरण में किस्म Pusa 9712 व Pusa 9814 की अधिक पैदावार के लिए उसकी बुवाई जुलाई महीने के दूसरे सप्ताह (सामान्य बुवाई तिथि) में करने से ही प्राप्त की जा सकती है।

ABSTRACT. A field experiment was conducted during *kharif* season of 2009 and 2010 in a sandy loam soil of New Delhi to study the effect of weather, achieved by sowing at normal (D1) and late (D2), on soil moisture prediction, evapotranspiration (ET), yield and water use efficiency (WUE) of three varieties (V1: JS 335, V2: Pusa 9712 and Pusa 9814) of soybean. Study of soybean phenology showed that there was reduction in the number of days taken for the crop to complete life cycle with delayed sowing. The agrometeorological water balance model could satisfactorily predict soil moisture content during soybean crop growth period with RMSE (%) varying between 6.27 to 12.06 and correlation coefficient between 0.828 to 0.982. The ET decreased significantly with delay in sowing; however there was no significant variation among the varieties. Among the stages of the soybean crop, mid season stage had highest ET followed by development stage, late season stage and initial stage. Normal sowing resulted in higher yield but lower WUE than the late sowing. Among the cultivars, JS 335 resulted in lower yield and WUE than Pusa 9712 and Pusa 9814. It may be recommended that, Pusa 9712 or Pusa 9814 may be sown during first and second week of July (normal sowing) to achieve higher yield in the semi-arid environment of Delhi region.

Key words – Soil moisture, Evapotranspiration, Water use efficiency, Soybean.

1. Introduction

Soybean (*Glycine max* L.) is one of the important oilseed legume crops of India, cultivated in *kharif* season under rainfed conditions. Soybean is a thermo-sensitive crop and its growth rate and blooming date are often affected by temperature and soil moisture and the emergence of soybean is seldom observed below 20% soil moisture (Das, 2003). With delayed sowing, which may occur due to delay in onset of monsoon, the growing cycle shortens which further leads to decrease in the amount of radiation intercepted during the growing season and thus, lowered total dry matter at harvest (Andrade, 1995).

Water use by the soybean crop, an important determinant of soybean growth and yield, is mainly determined by the weather and soil moisture availability. The ratio of evaporation (E) to evapotranspiration (ET) is largely affected by canopy coverage and surface soil moisture (Liu *et al.*, 2002) and therefore varies throughout crop growing season. At initial crop growth stages, canopy coverage is usually less and evaporation is the main component of field water use. With increasing canopy size, evaporation becomes less important and transpiration increases significantly (Eastham *et al.*, 1999; Liu *et al.*, 2002). Soybean cultivars differ with respect to canopy coverage, radiation interception and ET demand

and hence respond differently under different dates of sowing (Annual Report, 2009-10). Studies on ET and water use efficiency of soybean cultivars under early and late sowing situation with adequate and limited soil moisture condition are meager in India. There is a need to optimize the sowing dates and cultivars under different agroecological regions to achieve higher yield and water use efficiency of soybean.

With this backdrop, an experiment was conducted to study the effect of weather on phenology, actual evapotranspiration, water use efficiency and yield of soybean cultivars sown on different dates and predict soil moisture during crop growth period.

2. Materials and method

A field experiment was laid out in the research farm of Indian Agricultural Research Institute, New Delhi with soybean as test crop. The experimental site is located between 28°37' and 28°39' N latitude and 77°90' and 77°11' E longitude and at an altitude of 228.7 m above mean sea level in a semi-arid subtropical climatic belt. It is characterized by extreme temperatures, the annual maximum temperature goes as high as 45 °C in summer, whereas the minimum temperature dips to as low as 1 °C in winter. The monsoon sets during July to September and primarily contributes to the annual rainfall. The soil is sandy loam (Typic Haplustept) with medium to angular blocky structure, non-calcareous and slightly alkaline in reaction. The soil is low in organic carbon and available nitrogen and medium in available P and K content. The bulk density varied from 1.51 Mg m^{-3} in the 0-15 cm layer to 1.62 Mg m^{-3} in the 60-90 cm layer. The soil moisture content at 0.033 Mpa ranged from 24 to 26% (Field Capacity) and at 1.5 Mpa ranged from 8-10% (Permanent Wilting Point) in different layers of 0-90 cm soil depth.

The field experiment was laid out in Randomized Block Design (RBD) with 6 treatments and three replications incorporating factorial component (2×3) in years 2009 and 2010. The treatments included two dates of sowing, *i.e.*, D1: normal (7^{th} July in 2009 and 17^{th} July in 2010) and D2: late (22^{nd} July in 2009 and 29^{th} July in 2010) and three cultivars (V1: JS-335, V2: Pusa-9712 and V3: Pusa-9814). The plot size was 5×5 m. Soybean crop was sown at the seed rate of 80 kg ha^{-1} using tractor drawn seed-drill with a row spacing of 40 cm. All the fertilizers were applied as basal dose at the time of sowing. Nitrogen, phosphorous and potassium were applied as urea, single super phosphate and muriate of potash at the time of sowing @ 20 kg N/ha, 60 kg P_2O_5/ha and 40 kg K_2O/ha, respectively. The plots were kept weed free. The crop was allowed to grow naturally by allowing the incidence of pest and diseases without any control measures. During the year 2009 two irrigations of 6 cm depth were given to all the treatments, one at flowering stage and other at grain filling stage whereas during the year 2010 no irrigation was provided because of sufficient and well distributed rainfall received during this year.

Phenological stages were recorded by closely following crop growth on every alternate day. Phenological stages were used for fixing the crop coefficient for estimation of actual evapotranspiration (AET). The following phenological stages were identified as explained in FAO irrigation and drainage paper 33 (Doorenbos and Kasam, 1979): (a) the date of sowing (b) the length of the total growing season (c) the duration of initial stage *i.e.*, sowing to emergence (d) the duration of crop development stage, *i.e.*, from emergence to full bloom (e) the duration of mid-season stage, *i.e.*, from full bloom to start of ripening (f) the duration of late season stage, *i.e.*, from start of ripening to harvest.

Growing degree day (GDD) was calculated by subtracting base temperature from the daily mean temperature. The base temperature of soybean was taken as 10 °C (Kumar *et al.*, 2008). Cumulative GDD for a period was calculated by summing up the daily GDD of that period considered. The heliothermal (HTU) unit represents the product of GDD and the actual hours of bright sunshine for that day. Cumulative HTU for a definite period was calculated by summing up the daily HTU of the period considered.

Reference crop evapotranspiration (ET_0) was computed using Penman-Monteith method (Allen *et al.*, 1998) on daily basis. The required meteorological data were taken from the IARI meteorological station adjoining the experiment site. The ET_0 estimation is done as follows (Allen *et al.*, 1998):

$$\mathrm{ET}_0 = \frac{0.408\Delta(Rn - G) + \gamma\left(\dfrac{900}{T+273}\right)U_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34U_2\right)} \qquad (1)$$

where, Rn is the net radiation at the crop surface (MJ m^{-2} day^{-1}); G is the soil heat flux density (MJ m^{-2} day^{-1}); T is the mean daily air temperature at 2 m height (°C); U_2 is the wind speed at 2 m height (ms^{-1}); e_s is the saturation vapor pressure (kPa); e_a is the actual vapor pressure (kPa); (e_s-e_a) is the saturation vapor pressure deficit (kPa); Δ is the slope of vapor pressure curve (kPa°C^{-1}); and γ is the psychrometric constant (kPa°C^{-1}).

The crop coefficient values for the soybean crop for the crop duration were taken from the FAO drainage and irrigation paper 33 (Doorenbos and Kasam, 1979). The crop coefficient values were 0.40 for initial stage, 1.15 during mid season stage and 0.50 at harvest. The crop coefficient value linearly increased from 0.40 to 1.15 during crop development stage whereas in the late season stage, the crop coefficient value linearly decreased from 1.15 to harvest value of 0.5 (Allen *et al*., 1998).

Daily actual evapotranspiration (AET) was estimated by agrometeorological soil moisture balance model (Ray *et al.*, 1999) for each plot on daily basis.

The soil moisture balance model was also used to compute the soil moisture storage. The soil moisture predicted by the model was compared with the observed soil moisture. Soil moisture content of the profile (0-90 cm soil depth) was determined regularly at 15 cm increment during crop growth period by gravimetric method. This data was utilized to find the soil moisture storage up to 90 cm soil depth.

Coefficient of residual mass (CRM) statistics gives the degree to which the prediction has over or under estimated the observed value. Positive value of CRM indicates that the model underestimates the observed value whereas, negative value of CRM indicates a tendency to overestimate the observed value. The CRM is expressed as follows

$$\text{CRM} = \frac{\sum (O_i - P_i)}{\sum O_i} \quad (2)$$

where, O_i is the observed value and P_i is the predicted value.

The root mean square error (RMSE, %) against the observed mean, was used to calculate the fitness between the predicted and observed results (Jamieson *et al*., 1991). RMSE (%) was calculated as follows:

$$\text{RMSE}\,(\%) = \sqrt{\frac{1}{N}\sum_{1}^{N}(O_i - P_i)^2} \times \frac{100}{M} \quad (3)$$

where, O_i is the observed value, P_i is the predicted value and M is the observed mean.

RMSE (%) shows the relative difference between the predicted and observed data. The prediction is considered excellent with the RMSE < 10%, good if 10-20%, fair if 20-30%, poor if > 30% (Jamieson *et al*., 1991).

The correlation coefficient (CC) gives an indication of the quality of trend conformity, with values of 1.0 indicating perfectly positively correlated.

TABLE 1

Weather conditions during the period of study

Particulars	Jul	Aug	Sep	Oct	Nov
2009					
Mean air temperature (°C)	31.2	30.4	28.3	21.1	19.3
Relative humidity (%)	68.2	69.3	72.8	60.8	70.3
Wind speed (km hr^{-1})	2.7	2.3	2.8	3.1	2.6
Rainfall (mm)	124.2	188.6	201.9	0.3	14.2
Pan evaporation (mm day^{-1})	7.8	5.8	4.6	4.6	2.8
Sunshine hours (hr)	6.1	5.8	7.1	7.6	5.1
2010					
Mean air temperature (°C)	30.7	29.0	27.2	25.4	20.0
Relative humidity (%)	74.9	83.3	85.8	67.6	70.5
Wind speed (km hr^{-1})	6.2	2.5	2.1	1.6	0.9
Rainfall (mm)	237.2	342.6	314.2	22.0	10.6
Pan evaporation (mm day^{-1})	5.7	3.9	3.8	4.3	2.8
Sunshine hours (hr)	4.1	3.1	3.8	6.2	3.3

Water use efficiency was computed as follows (Kashyapi and Bahot, 2012):

$$\text{WUE} = \frac{Y}{\text{AET}} \quad (4)$$

where, Y is soybean grain yield (kg ha^{-1}) and AET is the cumulative actual evapotranspiration (mm). The net sub-plot areas were harvested for grain yield.

The data for the crop and soil properties were analyzed by analysis of variance as outlined by Gomez and Gomez (1984). The significance of the treatment effect was determined using F-test and to determine the significance of the difference between the means of the two treatments, least significant differences (LSD) at 1% or 5% probability level and Duncan's multiple range test were used.

3. Results and discussion

3.1. *Weather*

Mean monthly air temperature, relative humidity, wind speed, total rainfall, pan evaporation and sunshine hours during the period of study are presented in Table 1. The growing period of soybean from July to September was cooler and wetter during 2010 in comparison to 2009. Well distributed and significantly higher amount of

TABLE 2

No of days required to reach different growth stages

Treatment	Initial* stage		Development stage		Mid season stage		Late season stage		Total duration	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
D1V1	8	6	52	53	25	25	18	19	103	103
D1V2	8	6	55	55	28	28	19	22	110	111
D1V3	8	6	56	56	28	28	19	22	111	112
D2V1	5	5	49	50	23	24	14	17	91	96
D2V2	5	5	53	53	27	27	20	21	105	106
D2V3	5	5	52	53	27	26	20	21	104	105

*Initial stage: Sowing to emergence; Development stage: Emergence to full bloom; Mid season stage: Full bloom to start of ripening and Late season stage: Start of ripening to harvest

TABLE 3

Growing degree days (GDD) and Heliothermal Units (HTU) requirement of three soybean cultivars at two dates of sowing

Treatment	GDD (Base temperature is 10 °C)						HTU					
	Vegetative phase (°C days)		Reproductive phase (°C days)		Total crop duration (°C days)		Vegetative phase		Reproductive phase		Total crop duration	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
D1V1	1065	824	815	967	2057	1792	6495	2485	6250	4629	13915	7105
D1V2	1141	844	803	1006	2080	1850	6912	2559	6124	4919	14109	7478
D1V3	1064	882	877	968	2136	1850	6620	2689	6747	4788	14555	7478
D2V1	923	703	744	898	1728	1601	5661	2255	5703	4566	11778	6818
D2V2	905	721	841	891	1807	1612	5619	2270	5939	4609	11972	6880
D2V3	923	739	823	896	1807	1637	5661	2274	5897	4662	11972	6999

rainfall was observed in *kharif* 2010 compared to *kharif* 2009. The *kharif* rainfall (July, August and September) of 2010 was 62% above normal (566.9 mm) where as the *kharif* rainfall of 2009 was 9% lower than the normal. Well distributed rainfall throughout the crop growth period of 2010 resulted in higher relative humidity compared to 2009 as seen in the Table 1. Significantly higher pan evaporation ($P<0.01$) in *kharif* 2009 resulted from high mean air temperature and sunshine hours as compared to 2010. As a whole, *kharif* 2009 experienced drought and necessitated application of irrigation in order to meet the plant water stress.

3.2. *Phenological stages*

The occurrence of different phenological stages and the number of days required to reach the different stages such as initial stage (sowing to emergence), crop development stage (emergence to full bloom), mid season stage (full bloom to start of ripening) and late season stage (start of ripening to harvest) were carefully noted and are presented in Table 2. Among the three cultivars, JS 335 reached development, mid season and late season stages, 3-5 days early compared to Pusa 9712 and Pusa 9814 cultivars in both the seasons. However, all the three cultivars required same number of days for emergence in both the years. In the season of 2009, all the three cultivars required more number of days for emergence as compared to 2010. This may be due to less availability of soil moisture for germination which resulted from delay in monsoon setting and prevalence of drought like situation in the first fortnight of July. While comparing the date of sowing in both the years for occurrence of phenological events, it was observed that late showing hastened the growth processes hence early occurrence of phenological events in late sowing than the normal sowing. Though drought like situation prevailed in *kharif* season of 2009 compared to *kharif* season of 2010, almost same number

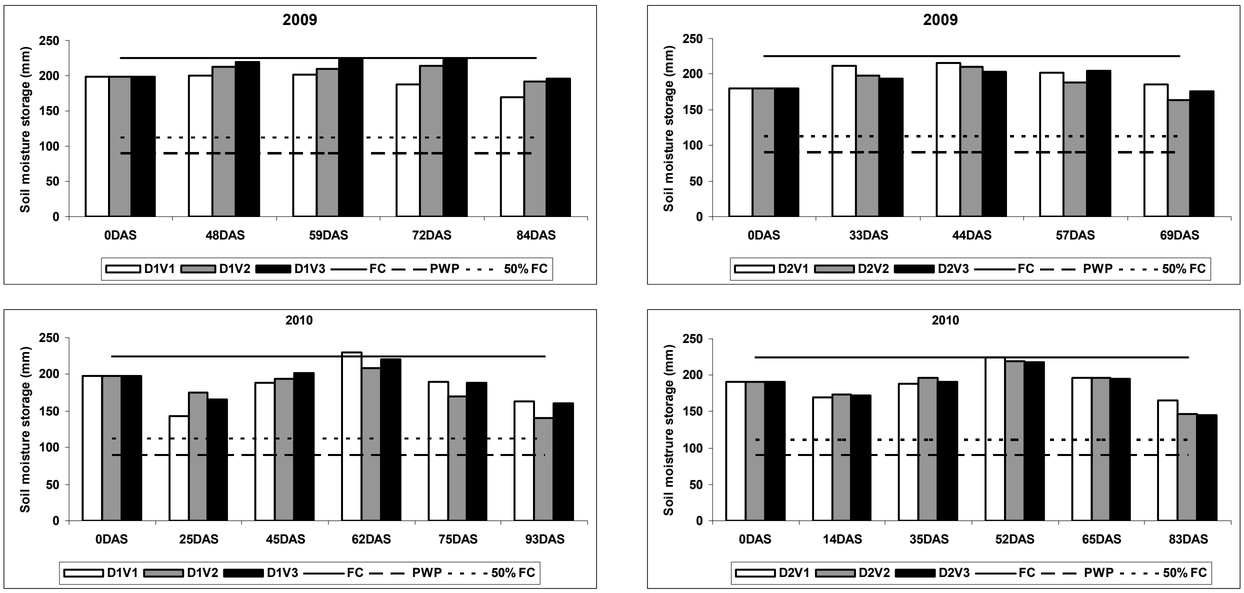

Fig. 1. Temporal variation in soil moisture storage in the profile (0-90 cm) during the soybean growth (2009 and 2010); FC: Field capacity; PWP : Permanent wilting point; 50% FC: 50% of Field capacity

of days was required to reach the phenological stages for all the cultivars and the date of sowing except the initial stage. This may be due to the application of irrigation to soybean crop as and when required in *kharif* season of 2009 in order to avoid water stress.

The total duration of crops for both the season showed that cultivar JS 335 matured earlier than the cultivars Pusa 9712 and Pusa 9814. The cultivars Pusa 9712 and Pusa 9814 did not show much variation in duration for completing their life cycle for both the seasons studied. In all the cultivars, irrespective of year, there was reduction in the number of days taken for the crop to complete life cycle with the delay in sowing. Changes in sowing dates lead to change in thermal environment of the crop with respect to different growth and development stages and hence variation with respect to completion of life cycle (Pradhan *et al.*, 2014). The number of growing degree days required to reach vegetative and reproductive stage was significantly higher in case of early sowing (D1) than late sowing (D2) in both the years of study (Table 3). The heliothermal unit (HTU) also followed the similar trend as the cumulative GDD.

3.3. *Soil moisture content*

Soil moisture storage during soybean growth was monitored to a soil depth of 90 cm at regular intervals by gravimetric method for both the years of study (Fig. 1). The soil moisture storage in all the treatments for both the years remained well within the Field Capacity (FC) and Permanent Wilting Point (PWP), more specifically between FC and 50% of FC (the upper limit of classical concept of soil water availability) through out the growth period. Application of two irrigations of 60 mm each to the crop during the year 2009 was needed to avoid water stress and hence in both the years, the soil moisture storage remained within the optimum range of soil water availability.

The cultivar JS 335 showed lower soil moisture storage as compared to the other two cultivars at first date of sowing but not at second date of sowing for the year 2009 (Fig. 1). Poor stand of JS 335 cultivar due to incidence of yellow mosaic virus (YMV) resulted exposure of soil surface and hence there was higher evaporation and soil moisture loss as compared to other two varieties. Bandyopadhyay *et al.* (2003) also observed higher soil moisture loss through evaporation under low canopy coverage of soybean crop due to no fertilizer supply. However, delaying the sowing of the same variety escaped infestation of YMV and there was better crop stand as compared to the normal sowing, which is evident from the higher LAI and yield (LAI data not given) under the delayed sowing. Better crop coverage of the cultivar JS 335 in late sowing reduced exposure of soil surface to solar radiation resulting in lower evaporation and soil moisture loss as compared to other two cultivars. However in the year 2010, the cultivar JS 335 showed lower soil moisture storage at initial growth stages for both date of sowing (up to 45 days after sowing) compared to the cultivars Pusa 9712 and Pusa 9814 because of poor soil

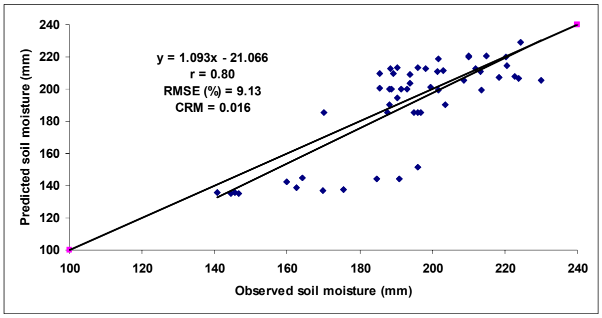

Fig. 2. Comparison of observed and simulated soil moisture for both the years

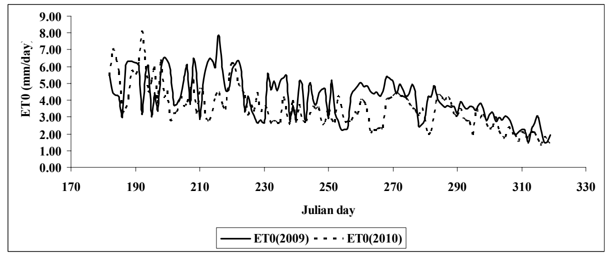

Fig. 3. Reference evapotranspiration (ET_0) of soybean crop growth period for the year 2009 and 2010 as determined by Penman-Monteith method

coverage and hence higher water loss through evaporation. However at peak and later growth stages cultivar Pusa 9712 and Pusa 9814 had lower soil moisture storage as compared to the cultivar JS 335 at both date of sowing probably because of better crop and root growth and hence higher uptake of water by the crop. Similar type of result were observed by Pradhan *et al.* (2013) for maize crop in an Inceptisol for 0 kg N/ha compared to 120 and 180 kg N/ha treatment because of poor crop growth and poor evapotranspiration demand in the 0 kg N/ha treatments.

3.4. *Soil moisture computation*

The simple one-layer soil water balance model (Ray *et al*., 1999) was developed and coded in EXCEL for calculating radiation balance components, potential evapotranspiration (ET_0) and actual evapotranspiration of crop using weather, crop and soil parameter on a daily time scale and also outputs the soil moisture storage at the end of day. The measured soil moisture storage at different intervals was used for validation purposes for all the treatments. The graphical representation indicates close agreement between the predicted and observed soil moisture storage except towards the end of crop growth period for all the treatments. It could be due to the drying of surface soil which restricts the soil moisture loss through evaporation appreciably as expected. The statistical evaluation (CC, RMSE (%) and CRM) was also done between observed and predicted soil moisture storage for all the treatments and is found to be in appropriate agreement. The comparison of predicted and observed soil moisture for all the treatments of both the years are presented in Fig. 2. It showed a significant ($P \leq 0.01$) correlation ($r = 0.80$) between the observed and predicted soil moisture. It also showed an RMSE (%) value of 9.13 which is rated as an excellent agreement between the observed and predicted value as per Jamieson *et al.* (1991). A CRM value of +0.016 indicates underestimation of the observed soil moisture.

3.5. *Reference evapotranspiration (ET_0)*

Reference Evapotranspiration (ET_0) by Penman-Monteith method has been found out on daily basis for the soybean crop growth period and is presented in Fig. 3. The daily value of ET_0 was higher during initial growth period which decreased with advancement of crop growth and was minimum towards the harvesting stage. The mean ET_0 of soybean crop growth period of 2009 (4.16 mm/day) was significantly higher ($P<0.001$, two tailed) than the corresponding mean ET_0 of 2010 (3.52 mm/day). The ET_0 of 2009 and 2010 crop growth period found out by Penman-Monteith method was significantly correlated ($P \leq 0.01$) with the ET_0 measured by pan evaporation (Doorenbos and Kasam, 1979); correlation coefficient of 0.62 for 2009 and 0.71 for 2010, indicating the suitability of Penman-Monteith method for further calculation of actual evapotranspiration (AET) using ET_0 and crop coefficient.

3.6. *Actual evapotranspiration (AET)*

AET was estimated for each treatment on a daily basis as described in materials and methods. The daily AET increased steadily from sowing stage onward in all the treatments reaching its peak somewhere between flowering to pod development stage and then decreased gradually from maturity to harvest for all the treatments (data not presented).

The seasonal AET of soybean was found out by adding daily estimated AET of the crop growth period. The seasonal AET did not show much variation among the cultivars. Averaged over date of sowing and years, cultivar Pusa 9712 and Pusa 9814 showed only 4% higher seasonal AET compared to the cultivar JS 335. Though the cultivar JS 335 had poor crop stand in both the years because of YMV infection, the evaporation from the soil was significant, which contributed to seasonal AET. Hence much variation was not observed among the soybean cultivars. Averaged over the cultivars and years,

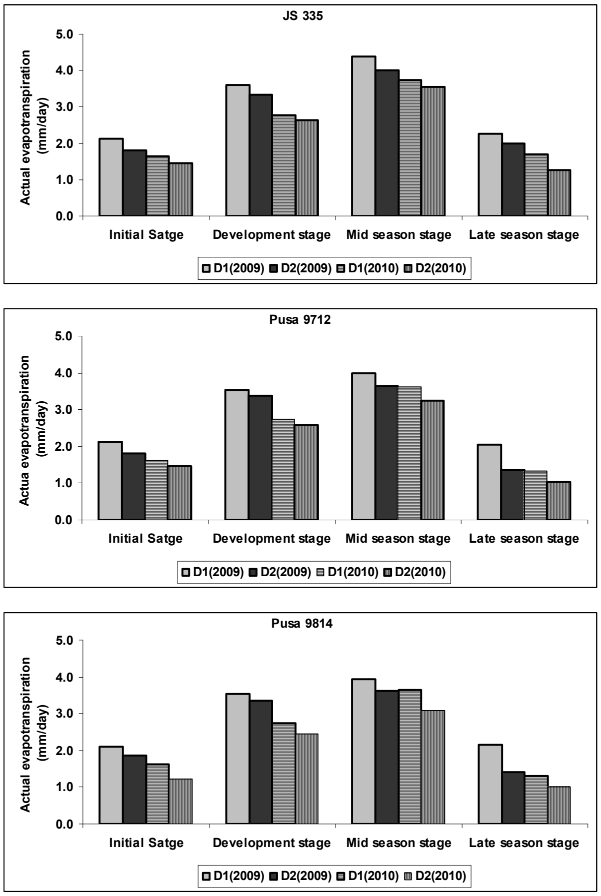

Fig. 4. Actual evapotranspiration (mm/day) of soybean cultivars at different growth stages

normal sowing had 16 per cent higher seasonal AET compared to the late sowing. Normal sowing exposed soybean crop to higher evaporative demand resulting in higher seasonal AET in normal sowing compared to late sowing. Kumar *et al.* (2008) also experienced higher evaporative demand in normal sowing of soybean cultivars and higher water use. The seasonal AET of 2009 was 24 per cent higher than that of 2010. Soybean crop growth period of year 2009 experienced higher mean air temperature, sunshine hours and lower relative humidity and hence higher evaporative demand (Table 1 and Fig. 3) compared to the year 2010. Though the rainfall was less during 2009 soybean, adequate soil moisture was maintained through irrigation to meet the evaporative demand. So the seasonal AET of the year 2009 was higher compared to the year 2010.

Average daily AET for different growth stages (initial, development, mid season and late season stage) were found out by dividing cumulative AET of that stage by the no. of days involved in that particular stage and presented graphically in Fig. 4 for different treatments.

TABLE 4

Yield (kg ha^{-1}) and WUE (kg ha^{-1} mm^{-1}) of soybean 2009 and soybean 2010 crop

Treatment	Yield (kg ha^{-1})			WUE (kg ha^{-1} mm^{-1})		
	2009	2010	Pooled	2009	2010	Pooled
D1	1208b*	1676a	1442a	3.33b	5.77a	4.55b
D2	1333a	1351b	1342b	4.32a	5.39b	4.86a
V1	542c	1180c	861b	1.76b	4.50c	3.13c
V2	1729a	1587b	1658a	5.12a	5.80b	5.46a
V3	1542b	1773a	1658a	4.59a	6.46a	5.53a
D1V1	250c	1160c	705d	0.71c	4.11d	2.41c
D1V2	1792a	1840a	1816a	4.93a	6.32a	5.63a
D1V3	1583a	2026a	1805a	4.34a	6.89a	5.62a
D2V1	833b	1200c	1017c	2.81b	4.88cd	3.84b
D2V2	1667a	1333bc	1500b	5.31a	5.27bc	5.29a
D2V3	1500a	1520b	1510b	4.84a	6.03ab	5.44a

*Columns followed by same letter are not significantly different ($P \leq 0.05$) as per DMRT

Highest AET per day was observed in mid season stage followed by development stage and initial stage for all the varieties at all dates of sowing which indicates that the peak growth stage requires better input of water for better crop growth and yield. Das (2003) also observed higher mean daily ET during the flowering stage, which corresponds to the mid season stage. The lowest AET/day was observed during late season stage. Averaged over dates of sowing for the years showed that the cultivar JS 335 had highest AET/day at all growth stages compared to the cultivars Pusa 9712 and Pusa 9814, which indicated water loss through evaporation plays an important role in determining the seasonal AET when crop stand is poor and water is not limiting. Similar results have been reported by Liu *et al.* (2002) for wheat and maize in China. Averaged over years, varieties and growth stages, normal sowing showed higher AET/day (2.68 mm/day) compared to late sowing (2.35 mm/day). During the year 2009, soybean showed higher AET/day (2.81 mm/day) compared to year 2010 (2.22 mm/day), because of higher evaporative demand in the former.

3.7. *Soybean seed yield and water use efficiency*

The pooled data of soybean yield showed significant ($P<0.05$) decrease in yield with delay in sowing (Table 4). Similar results have been observed by Pradhan *et al.* (2014) for mustard and by Kumar *et al.* (2008) for soybean. The late sown crop is subjected to relatively less time span available for plant growth and development and less cumulative GDD. Due to less time availability for transport of photosynthate to sink, yield reduction occurs in late sown crops as compared to early and normal sown crop (Pradhan *et al.* 2014). Among the three cultivars, the seed yield of the cultivar JS 335 was significantly (P<0.01) lower compared to the other two cultivars. The lower yield in the cultivar JS 335 as compared to other two cultivars can be attributed to the incidence of YMV disease. The cultivar JS 335 is highly susceptible to YMV infection compared to other two cultivars, more specifically, at normal sowing. The cultivars Pusa 9712 and Pusa 9814 were statistically at par with respect to seed yield. There was significant interaction between dates of sowing and cultivars with respect to seed yield of soybean. Normal sowing of the cultivar Pusa 9712 or Pusa 9814 gave highest yield compared to other combinations of dates of sowing and cultivars.

Water use efficiency of late sown soybean crop was significantly (P<0.05) higher than the normal sown crop (Table 4). This was mainly attributed to higher AET under normal sowing than the late sowing situation. Among the three soybean crop cultivars, the cultivar JS 335 has significantly (P<0.01) lower WUE than the cultivars Pusa 9712 and Pusa 9814. However, the cultivars Pusa 9712 and Pusa 9814 were statistically at par (P<0.05) with respect to WUE. Infestation of YMV disease on the cultivar JS 335 reduced yield significantly (Table 4) without any appreciable change in seasonal AET, which resulted in significantly lower WUE in the JS 335 cultivar as compared to other two cultivars. Like seed yield, the WUE of soybean showed significant interaction between date of sowing and cultivars. Cultivar Pusa 9712 or Pusa 9814 at normal or late sowing produced significantly higher WUE compared to the normal or late sowing of the cultivar JS 335.

4. Conclusions

From this study it may be concluded that, (*i*) the agrometeorological water balance model could satisfactorily predict soil moisture content during soybean crop growth period, (*ii*) there was reduction in the number of days taken for the crop to complete life cycle with delayed sowing, (*iii*) Normal sowing resulted in higher yield but lower WUE than late sowing, (*iv*) during water scarce years it is advisable to go for late sowing of soybean to achieve higher yield and WUE and (*v*) The cultivar JS 335 resulted in lower yield and WUE than Pusa 9712 and Pusa 9814. It is suggested that Pusa 9712 or Pusa 9814 may be sown during first and second week of July (normal sowing) to achieve higher yield and improved water use efficiency in the semi-arid environment of Delhi region.

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