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Phenophase wise study of parameters controlling water requirement of soybean crop [*Glycine max* (L.) Merr.] at various agroclimatic zones

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सार – सोयाबीन मध्य प्रदेश, उत्तर प्रदेश, गुजरात, पंजाब और हरियाणा, महाराष्ट्र, राजस्थान, आन्ध्र प्रदेश और छत्तीसगढ़ के क्षेत्रों की प्रमुख खरीफ ऋतु की फसल है। विभिन्न कृषि जलवायविक क्षेत्रों में सोयाबीन की खेती वाले 8 ई. टी. स्टेशनों (अर्थात अकोला, बंगलुरू, बंशवाड़ा, धारवाड़, नई दिल्ली, पारभनी, आई. सी. आर. आई. एस. ए. टी. और राहुरी) में विभिन्न घटनाक्रमों में फसल की जल आवश्यकता को नियंत्रित करने वाले प्राचालों का अध्ययन किया गया है। इसमें फसल के आठ घटनाक्रमों (अर्थात अंकुरण, बीजन, फसल के उगने की अवस्था, पौधे की बढ़ोतरी, फल आने, फली के बनने, फली के पक कर तैयार हो जाने और फसल के काटने) का पता लगाया गया है। नवीनतम उपलब्ध 3 से 5 वर्षों के आँकड़े एकत्रित किए गए और माध्य मानों का विश्लेषण किया गया। सोयाबीन की फसल पर किए गए अध्ययन से पता चलता है कि सोयाबीन की खेती किए जाने वाले विभिन्न ई. टी. स्टेशनों में फसल की माध्य कुल जल की आवश्यकता की मांग में 294.7 से लेकर 559.2 मि. मी. की भिन्नता पाई गई है। अधिकांशतः पौधे की बढ़ोतरी की अवस्था (जो विभिन्न स्थानों पर कुल ई. टी. मांग का 19.0 से 25.6 प्रतिशत थी) में ई. टी. की मांग सबसे ज्यादा होती है। घटनाक्रमों में किसी भी समय आकलित की गई सर्वोत्तम ई. टी. कर्व किसी विशिष्ट क्षेत्र के लिए फसल की ई. टी. मांग को उपलब्ध कराते है। इस अध्ययन की अवधि के दौरान हुई वर्षा, सोयाबीन फसल के विभिन्न घटनाक्रमों पर विशिष्ट ई. टी. मांग को पूरा करने के लिए विशेष रूप से पर्याप्त थी। मृदा में नमी की प्रचुर मात्रा से पौधे की पैदावार अच्छी हुई। विभिन्न स्टेशनों में किए गए अध्ययन में माध्य Kc मान में 0.61 से लेकर 0.98 तक की काफी अधिक भिन्नता रही और ये लगभग पौधे की बढ़ोतरी से लेकर फूल आने की अवस्था तक सबसे अधिक पाए गए जहाँ पर ये मान तीन स्टेशनों को छोड़कर अधिकांशतः उन घटनाक्रमों में एक की अपेक्षा अधिक थी। माध्य सोयाबीन फसल की पैदावार और उत्पादकता में कृषि जलवायविक क्षेत्रवार भिन्नता पाई गई। सोयाबीन की उपज में 981.0 कि. ग्रा./हैक्टेयर से लेकर 2530.6 कि. ग्रा./हैक्टेयर तक की भिन्नता थी जबकि प्रत्येक दिन की उत्पादकता में 9.0 कि. ग्रा./हैक्टेयर/दिन से लेकर 23.2 कि. ग्रा./हैक्टेयर/दिन तक की भिन्नता थी। फसल की डब्ल्यू. यू. ई. विभिन्न स्थानों पर 2.1 कि. ग्रा./हैक्टेयर/मि. मी. से लेकर 6.0 कि. ग्रा./हैक्टेयर/मि. मी. थी।

ABSTRACT. Soybean is a major kharif season crop in parts of M.P., U.P., Gujarat, Punjab and Haryana, Maharashtra, Rajasthan, A.P. and Chattisgarh. The present work was undertaken to study the parameters controlling water requirement of the crop at various phenophases in soybean growing 8 ET- stations (*viz*., Akola, Bangalore, Banswara, Dharwar, New Delhi, Parbhani, ICRISAT and Rahuri) in various agroclimatic zones. Eight phenophases of the crop (*viz*., germination, seedling, vegetative, active vegetative, flowering, pod formation, pod maturity and harvesting) were identified. The data were collected for latest available 3 to 5 years and the mean values were analysed. The study on soybean crop revealed that the mean total water requirement demand of the crop varied from 294.7 to 559.2 mm in different soybean growing ET stations. The ET demand reached the peak mostly at active vegetative stage (which was 19.0 to 25.6 % of the total ET demand, at various locations). The computed best – fit ET curves provide ET demand of the crop at any point of the phenophases for the specific location. The rainfall during study period was mostly sufficient to meet the crop specific ET demand at various phenophaes of soybean crop. Abundant soil moisture supported good vegetation cover. The mean Kc value varied widely from 0.61 to 0.98 among different stations studied, which reached their peak mostly at active vegetative to flowering stages, where the values were even more than 1 in most of those phenophases except 3 stations. The mean soybean crop yield and productivity varied widely agroclimatic zone wise. The soybean yield varied from 981.0 kg/ha to 2530.6 kg/ha, while productivity per day varied from 9.0 kg/ha/day to 23.2 kg/ha/day. The WUE of the crop laid between 2.1 kg/ha/mm to 6.0 kg/ha /mm at various locations.

Key words – Phenophase, Water requirement, Soybean, Agroclimatic zones, ET (Evapotranspiration), PET (Potential evapotranspiration), Kc (Crop coefficient), WUE (Water use efficiency), Yield, Productivity.

1. Introduction

Soybean is an important crop known as golden bean, which originated in eastern Asia and useful both as source of protein as well as fat. It has unmatched composition of 40% protein and 20% oil. Soybean is a kharif season crop, the cultivation of which is spread in various States, *viz*., Madhya Pradesh, Uttar Pradesh, Gujarat, Punjab and

TABLE 1

Details of selected ET- stations at different agroclimatic zones

Items	ET- Stations							
	Akola	Bangalore	Banswara	Dharwar	New Delhi	Parbhani	ICRISAT	Rahuri
Agroclimatic zones	AZ 97	AZ 103	AZ 24	AZ 99	AZ 16	AZ 95	AZ 118	AZ 96
Soil types	Medium black	Sandy loam clay	Medium black	Medium black	Sandy loam	Medium black	Black clayey loam	Clay
Location	20° 42′ N	13° 00′ N	23° 33′ N	15° 26′ N	28° 40′ N	19° 16′ N	17° 32′ N	19° 24′N
(Lat./Long.)	77° 02′ E	77° 37′ E	74° 27′ E	75° 07′ E	77° 10′ E	76° 00′ E	78° 16′ E	74° 39′E
Variety	PKV-1	*Variable	JS-335	JS-335	P-22	MAUS-71	PK-472	JS-335
MSD	5 Jul	31 Jul	1 Jul	7 Jul	24 Jul	6 Jul	25 Jun	27 Jun
MHD	21 Oct	12 Nov	13 Oct	11 Oct	9 Nov	21 Oct	15 Oct	13 Oct
Duration (days)	109	105	105	97	109	108	113	109

MSD = Mean sowing date, MHD = Mean harvesting date.
*Variable: varieties were Hardee, MAUS-2 and KD-79 in different years.

Haryana, Maharashtra, Rajasthan, Andhra Pradesh, Karnataka and Chattisgarh. It grows well in all types of soils preferably in fertile loam soil and adapted to varied agroclimatic conditions. High temperature associated with high humidity with sufficient rain in July and August is suitable for soybean production. Venkataraman and Krishnan (1992) reported that sprouting of soybean seeds is not proper in presence of too much or too little soil moisture. Singh and Saxena (1969) reported that soybean can withstand short period of drought as well as short period of water logged soils relatively better than maize crop. The rooting habit, both horizontally and vertically (Mitchell and Russell 1971, Mota 1978) of this plant in many soils allows the crop to extract water exceedingly well. In the recent time soybean cultivation in the country has increased manifold as compared to any other oilseed crop and stands next only to groundnut. The area and production of the crop during 2007-08 stands 88.50 lakh hectares and 94.73 lakh tonnes, respectively, of which 53 and 34 per cent production share is from Madhya Pradesh and Maharashtra, respectively (as stated by Soybean Processors Association of India).

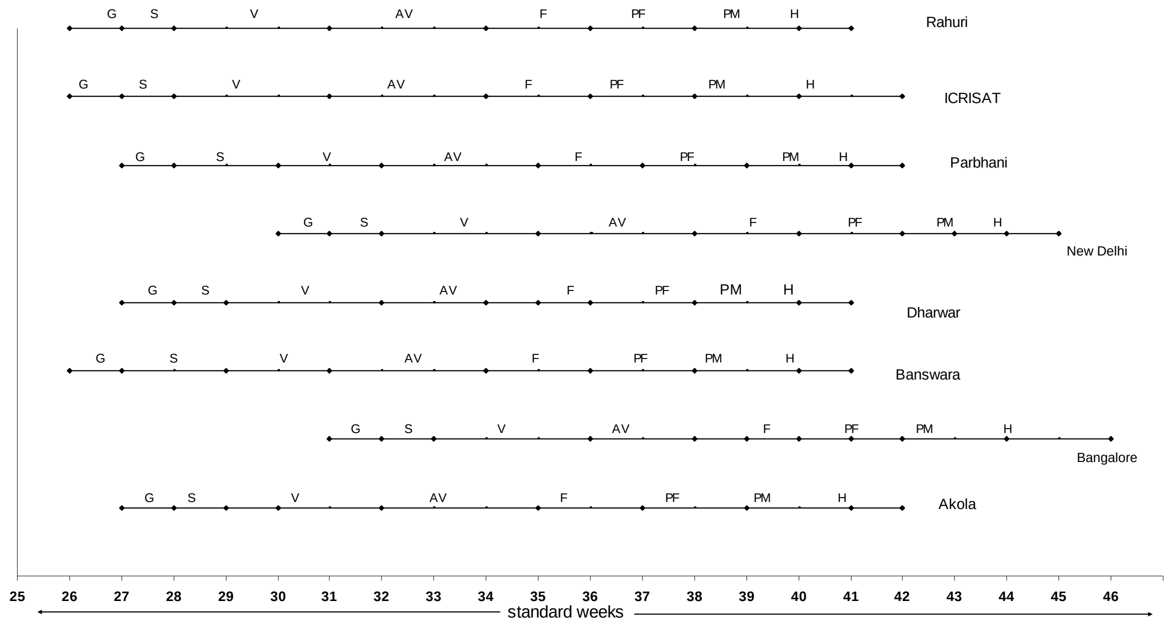
The crop duration varies from 97 to 113 days during kharif season in various parts of the country. Based on available data eight phenophases (crtical growth stages) of the crop were identified *viz*., germination, seedling, vegetative, active vegetative, flowering, pod formation, pod maturity and harvesting, which were found critical in terms of their specific water demand. The phenophase wise duration varies marginally according to the variety, soil type and prevalent weather parameters. Nearly all soybean cultivation is rainfed. However, flooding immediately after sowing, reduces 28% of plant population (Shanmugsundaram 1980). Field observations (Lawn and Byth 1979) and laboratory studies (Stanely *et al*. 1980) suggested that soybean compared with other legumes is relatively tolerant to temporary water – logging. The result of All India Coordinated Research Project on Soybean indicated that the crop in rainfed kharif season has excellent potential in various agroclimatic zones (Trikha 1986).

In India, water requirement of soybean crop varies with agroclimatic conditions, management practices and crop life span. Moisture deficiency during vegetative growth stages reduces rate of plant growth. Profile stored soil moisture also plays important role towards water requirement of crop. The parameters controlling water requirement of soybean crop are: rainfall (P), actual evapotranspiration (ET), potential evapotranspiration (PET), soil moisture (SM), crop coefficient (Kc) and water use efficiency (WUE) as reported earlier for wheat (Kashyapi and Dubey 1996) and rice (Kashyapi *et al*., 2009) crops. The present work was undertaken to study the parameters controlling water requirement of soybean crop at various phenophases in different soybean growing ET – stations in different agroclimatic zones. For this study 8 soybean growing ET – stations were selected from 8 different agroclimatic zones.

2. Data and methodology

2.1. *Selection of soybean growing zones*

ET- stations where soybean grows (Table 1) in the recent years from different agroclimatic zones (as classified under NARP, *i.e*., National Agricultural



G- Germination, S- Seedling, V- Vegetative, AV- Active vegetative, F- Flowering, PF- Pod formation, PM- Pod maturity, H-Harvesting

Fig. 1. Duration - wise phenophases of soybean crop in different locations

Research Project) *viz*., Central Vidarbha zone, Eastern dry zone of Karnataka, Southern humid plain zone of Rajasthan, North-east transition zone of Karnataka, Western semi-arid zone, Scarcity zone of Maharashtra, Southern Telengana and Central Maharashtra plateau were selected for the study. The selected ET – stations were: Akola, Bangalore, Banswara, Dharwar, New Delhi, Parbhani, ICRISAT and Rahuri, respectively. The agroclimatic zone numbers, soil types, location (lat./long.), varieties grown in each of the stations, mean sowing date (MSD), mean harvesting date (MHD) and duration (days) for each of the ET – stations studied are presented in Table 1. The soil type varied from medium black, sandy loam clay to clay soils.

2.2. *Collection of crop data and other agrometeorological parameters*

2.2.1. *Collection of crop data*

The crop data were collected for latest available three years (as soybean crop was grown in very limited years only) from all the ET stations, except Dharwar, where latest five years of data were available. (Table 3). The mean for the three years (five years for Dharwar) were computed. The duration wise phenophases of soybean crop at different ET – stations are presented in Fig.1. The mean crop yield and the mean crop productivity are presented in Table 3.

2.2.2. *Collection of data on parameters controlling water requirement of soybean crop*

The parameters studied were rainfall, actual evapotranspiration, potential evapotranspiration and computed water use efficiency. Eight phenophases of the soybean crop identified during the full crop span were: germination (G), seedling (S), vegetative (V), active vegetative (AV), flowering (F), pod formation (PF), pod maturity (PM) and harvesting (H), which are presented phenophase wise for different ET – stations (Fig. 1).

Rainfall data were collected from all the ET – stations studied and the mean values were obtained phenophase wise for the entire study period. The mean values for each of the stations are presented in Table 2.

Daily rate of actual evapotranspiration (ET) is directly measured by use of gravimetric lysimeter. For soybean crop available soil moisture is limited by depth and density of root system. Simultaneously, in lysimeter both the factors are limited alongwith advection (due to limitation of lysimeter depth). Considering these constraints the lysimeter data from each of the stations were collected for the study period. For each of the years, phenophase wise cumulation was made to obtain ET at different growth stages and the mean ET – values are presented in Table 2. Yearly computed ET values,

TABLE 2

Mean rainfall – P, Potential evapotranspiration – ET (all in mm of Water) and crop coefficient (Kc) at various growth stages in different agroclimatic zones during Soyabean growing season

	ET - Stations									ET - Stations							
CGS	P	PET	ET	Kc	P	PET	ET	Kc	CGS	P	PET	ET	Kc	P	PET	ET	Kc
	Akola				**Bangalore**					**Banswara**				**Dharwar**			
G	75.1	37.1	17.9	0.48	70.0	28.2	20.5	0.73	G	36.7	26.7	21.3	0.79	20.8	20.3	11.5	0.56
S	77.5	54.1	29.3	0.54	72.1	53.8	37.3	0.69	S	103.4	44.3	38.3	0.86	33.0	39.8	24.9	0.62
B	66.4	85.0	66.4	0.78	49.7	83.3	62.8	0.75	B	166.0	60.4	85.3	1.41	65.3	69.8	52.4	0.75
AV	83.3	90.5	110.8	1.22	69.8	90.4	91.5	1.19	AV	99.4	57.5	91.4	1.58	24.4	70.6	69.9	0.99
F	63.5	60.6	77.8	1.28	98.4	58.8	84.7	1.44	F	35.5	45.4	83.8	1.84	8.3	50.4	49.4	0.98
P_1	40.9	59.8	70.7	1.18	54.5	48.9	57.5	1.18	P_1	63.7	43.7	45.6	1.04	36.2	51.4	40.2	0.78
P_2	9.8	60.1	53.3	0.88	30.5	47.3	59.3	1.25	P_2	21.6	50.3	45.0	0.89	60.5	50.2	28.4	0.57
H	4.8	52.1	32.1	0.61	9.7	40.5	24.3	0.60	H	4.2	47.2	15.4	0.33	32.4	43.0	18.0	0.42
T	421.3	499.3	458.3	0.87	457.7	451.2	437.9	0.98	T	530.5	375.5	426.1	1.09	280.9	395.5	294.7	0.71
	New Delhi				**Parbhani**					**ICRISAT**				**Rahuri**			
G	32.5	38.5	21.2	0.55	51.4	38.2	19.4	0.51	G	26.2	42.0	17.9	0.43	3.7	33.5	13.9	0.38
S	52.1	51.4	55.2	1.07	64.8	58.0	32.2	0.56	S	130.4	72.8	35.4	0.49	34.5	49.5	28.8	0.58
B	142.9	88.9	102.7	1.15	266.8	92.9	56.0	0.60	B	141.8	111.6	75.6	0.68	74.8	78.2	56.1	0.72
AV	68.5	96.3	143.1	1.49	33.5	99.2	76.9	0.78	AV	128.5	108.8	94.8	0.87	50.9	78.6	80.0	1.02
F	1.5	65.6	99.9	1.52	52.9	66.0	52.0	0.79	F	54.5	91.8	65.2	0.71	70.7	55.7	73.8	1.32
P_1	8.5	52.5	69.1	1.32	84.9	61.4	43.8	0.71	P_1	41.6	66.7	42.2	0.68	98.6	54.5	67.6	1.24
P_2	0.0	51.3	50.4	0.98	21.1	59.5	40.1	0.67	P_2	66.6	62.4	39.1	0.62	113.2	54.6	63.2	1.16
H	0.3	37.1	17.6	0.47	51.2	49.9	27.9	0.56	H	51.3	52.7	23.1	0.44	34.5	50.4	37.0	0.73
T	306.3	481.6	559.2	1.07	626.6	525.1	348.3	0.65	T	624.9	608.8	410.2	0.61	480.9	455.0	420.4	0.89

CGS – Crop growth stages; G – Germination; S- Seedling; V – Vegetative; Av – Active Vegetative; F – Flowering; P_1 – Pod formation; P_2– Pod maturity; H – Harvesting; T – Total for P; PET, ET and mean for Kc

phenophase - wise, were used to obtain best – fit ET – demand curves/equations (Fig. 2).

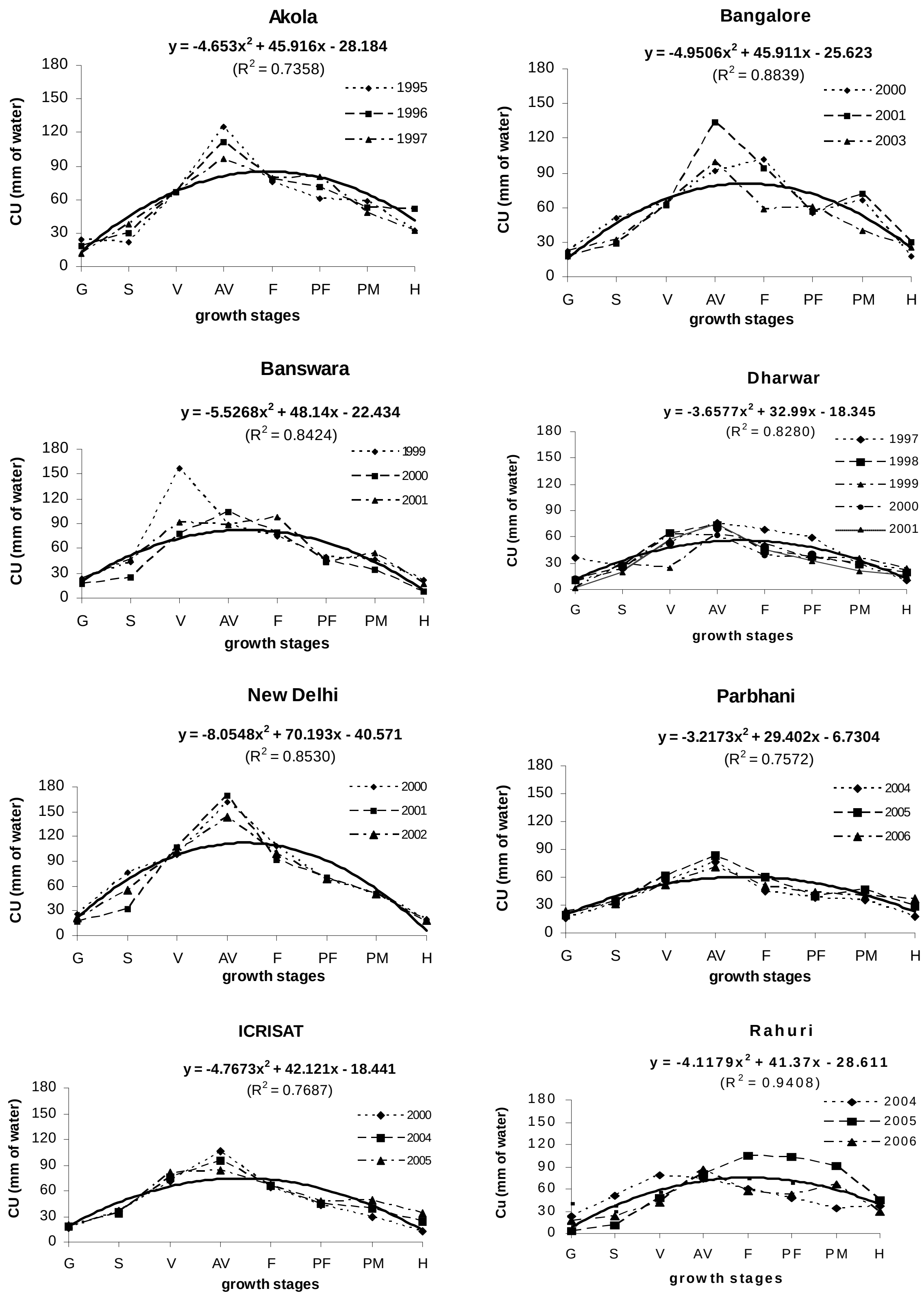
Mean daily potential evapotranspiration (PET) values, weekly for 52 weeks using weekly meteorological normals of IMD through modified Penman method as obtained by Khambete and Biswas (1992) were used and phenophase wise PET were derived and are presented in Table 2.

In absence of phenophase wise actual soil moisture data from different ET – stations, field capacity (FC) of the available soil and ET, PET values at various crop phenophases were used to compute soil moisture (SM) at various growth stages of soybean crop as given below (Mavi 1994):

$$SM = ET \times FC/PET \quad (1)$$

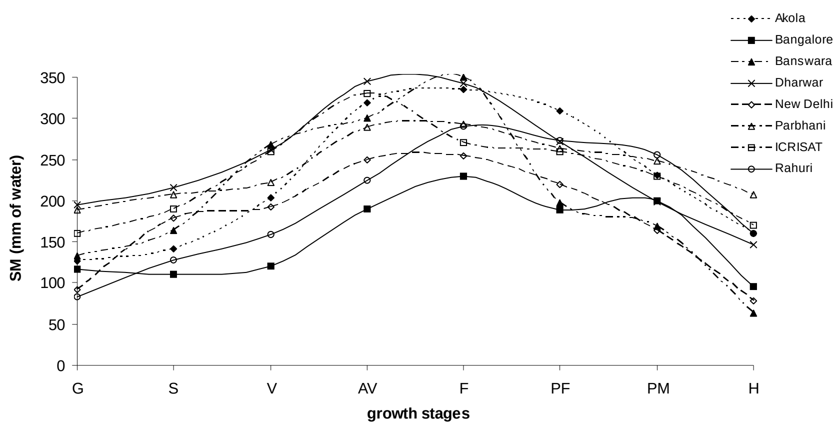
The assumption as suggested by Thornthwaite for equation (1) are that the equation functions between two points: (*i*) SM = 0, when ET = 0 and (*ii*) SM = FC, when ET = PET; in between the equation performs linearly.

The computed soil moisture (mm) at various phenophases of the crop for different stations are presented in Fig. 3.



G-Germination, S-Seedling, V-Vegetative, AV-Active vegetative, F-Flowering, PF- Pod formation, PM-Pod maturity, H- Harvesting

Fig. 2. Computed best-fit ET- demand curves/equations at various phenophases of soybean crop in different locations



G-Germination, S-Seedling, V-Vegetative, AV-Active vegetative, F-Flowering, PF-Pod formation, PM-Pod maturity, H-Harvesting

Fig. 3. Actual soil moisture at various phenophases of soybean crop in different locations

The ratio of actual ET to potential evapotranspiration is represented by the following formula:

$$Kc = ET/PET \quad (2)$$

Where, Kc is the crop coefficient. The crop coefficient for all the study period were obtained phenophase wise and the mean Kc values, growth stage wise for each of stations are presented in Table 2.

The water use efficiency (WUE) was computed by the formula:

$$WUE = Yield/Total\ ET \quad (3)$$

WUE (kg/ha/mm) for each station for each of the study period were obtained and the mean values are presented in Table 3.

3. Results and discussion

3.1. *Rainfall (P in mm)*

The mean rainfall during the study period as presented in Table 2 showed wide variation between 280.9 mm (at Dharwar) to 640.9 mm (at ICRISAT). Among the stations studied the crop was rainfed in Banswara, Dharwar, Parbhani and ICRISAT; minor protective irrigation (21.5 mm of water) was applied at Bangalore, while two times minor irrigations were applied at Akola (18.5 mm, 20.5 mm), New Delhi (35.0 mm, 36.0 mm) and Rahuri (38.5 mm, 34.1 mm). The rainfall distribution was higher than the water demand at most of the phenophases in Parbhani and ICRISAT, closely followed by Banswara and Rahuri. The rainfall distribution at Akola and Bangalore almost met the crop water demand. However, the rainfall quanta were low at Dharwar and New Delhi, though rainfall amount was far below water demand at New Delhi. The peak period of rainfall was mainly coinciding with vegetative, active vegetative stages of crops at most of the locations, while it extended upto flowering stage at Bangalore, Parbhani, ICRISAT and Rahuri.

3.2. *Potential evapotranspiration (PET in mm)*

The PET values for all the stations are presented in Table 2. The values varied from 375.5 mm at Banswara to 608.8 mm at ICRISAT, Among the growth stages, the peak PET demand was observed mostly at active vegetative stage, followed by vegetative stage; though high values were maintained at flowering to pod formation (at Akola, Parbhani and ICRISAT). The evaporative power of air as determined by radiation, humidity and wind controls the rate of PET (Mukammal and Bruce 1960); Also it is governed by soil type, its structure, moisture content and colour of soil as varied in different agroclimatic zones (Vitkevich 1968). Computation of those PET values phenophase wise helped in further computation of crop coefficient.

3.3. *Actual evapotranspiration (ET)*

The actual evapotranspiration (ET) of soybean crop at various phenophases at different ET- stations are presented in Table 2. The mean total ET demand was between 294.7 mm (at Dharwar) to 559.2 mm (at New Delhi); For most of the stations the total ET demand was between 410 to 455 mm, while Parbhani recorded low total ET demand. The phenophase wise distribution of ET showed that the demand was initially low at early growth stages, which reached the peak mostly at active vegetative stage and then again the demand reduced. The ET demand at active vegetative stage ranged between 19.0% (at Rahuri) to 25.6% (at New Delhi) of total crop ET demand

TABLE 3

Yield (kg/ha), productivity (kg/ha/day), water use efficiency (WUE in kg/ha/mm) and period of data studied of soybean at various locations in different agroclimatic zones

Parameters	ET-Stations							
	Akola	Bangalore	Banswara	Dharwar	New Delhi	Parbhani	ICRISAT	Rahuri
Yield(kg/ha)	981.0	1380.9	1843.3	1559.4	1698.5	2019.6	1536.3	2530.6
Productivity (kg/ha/day)	9.0	13.1	17.5	16.1	15.6	18.7	13.6	23.2
Total actual ET (mm)	458.3	437.9	426.1	294.7	559.2	348.3	410.2	420.4
WUE (kg/ha/mm	2.1	3.2	4.3	5.3	3.0	5.8	3.7	6.0
Data studied (Years)	1995 to 1997	2000, 2001 2003	1999 to 2001	1997 to 2001	2000 to 2002	2004 to 2006	2000, 2004 2005	2004 to 2006

(during its life span). The ET demand was high enough at vegetative and flowering stages also. The demand reduced after pod maturity stage. The computed best – fit ET demand curves as well as equations at various phenophases of soybean in different locations are presented in Fig. 2, which at any point of the phenophases can compute ET demand *(i.e.*, almost equal to CU or consumptive use of water) of the crop for the specific location and thus can act as powerful tool in location specific agromet product generation. In case of rice crop, same trend (though quanta of demand varied) was observed (Kashyapi *et al*., 2009). It is noticed that when the ET falls short of PET, the actual yield will also be less than the maximum; however relationship between ET and yield may not be linear (Chang 1968). In the present study, except Dharwar, Akola and New Delhi rainfall for all the stations was more than ET. In Dharwar and Akola the balance between P and ET was only marginal, while at New Delhi P was far below ET. The stored soil moisture along with rainfall was enough to meet soybean crop ET demand at any of the phenophases during the crop life span.

3.4. *Actual soil moisture at various phenophases*

The mean actual soil moisture pattern as computed at various phenophases are depicted in Fig. 3 for eight different locations. The values (in mm of water) increased upto active vegetative/flowering stages and then decreased gradually upto harvest. Sufficient soil moisture throughout the crop growth period supported good vegetation cover.

3.5. *Mean crop coefficient (Kc) of soybean crop*

The computed mean crop coefficient at various phenophases of soybean crop at different locations are presented in Table 2, which followed usual trend for soybean crop as obtained by Kashyapi *et al*. (2009) for rice crop, though the values showed wide fluctuations among various phenophases as well as among different locations. On an average Kc value was the highest at Bangalore (0.98); while the lowest value was recorded at ICRISAT (0.61) followed by Parbhani. For all the stations studied, Kc values were initially low, which reached their peak mostly at active vegetative to flowering stages, where Kc values in most of those phenophases were more than one (except Dharwar, Parbhani and ICRISAT), which indicated that ET was more than PET during those phenophases. These Kc values for comparing relationship between water and crop yield obtained at various locations can act as an useful tool (Chang *et al*. 1963). Kakde (1985) and Kashyapi and Dubey (1996) opined that at some advanced crop phenophases under favourable moisture conditions, ET rate was even greater than PET due to good canopy cover.

3.6. *Other crop related parameters (viz., yield, productivity and WUE of soybean crop)*

The mean yield (kg/ha), productivity (kg/ha/day) and water use efficiency (WUE in kg/ha/mm) for all the ET stations are summarized in Table 3. The yield data varied widely from 981.0 kg/ha (at Akola) to 2530.6 kg/ha (at Rahuri). Per day productivity of soybean crop also followed almost the same pattern with the highest per day productivity at Rahuri (23.2 kg/ha/day). Akola recorded the lowest productivity followed by Bangalore and ICRISAT, while productivity at other locations were reasonably good enough. However, WUE was the highest at Rahuri (6.0 kg/ha/mm), closely followed by that observed at Parbhani and Dharwar. WUE was the lowest at Akola (only 2.1 kg/ha/mm), closely followed by Bangalore and New Delhi. Michael (1990) opined that WUE increased with increase in crop yield as occurred in case of Rahuri and Parbhani; while decrease in consumptive use (*i.e*., almost equal to ET) of water demand at that location (Kashyapi and Dubey 1996) also has same effect as observed in Dharwar and Parbhani.

4. Conclusions

The present work revealed the following conclusions:

(*i*) The mean total ET demand varied between 294.7 mm (at Dharwar) to 559.2 mm (at New Delhi). The ET demand was initially low, which reached the peak mostly at active vegetative stage (19.0 to 25.6 % of total ET demand, at various locations) of soybean crop with high ET demand at vegetative and flowering stages.

(*ii*) The computed best – fit ET demand curves and equations in different locations, provide ET demand of the crop at any point of the phenophases for the specific location.

(*iii*) The rainfall during crop growth period was mostly sufficient to meet the crop specific ET demand at various phenophases of soybean crop. Also, sufficient soil moisture throughout the crop growth period supported good vegetation cover.

(*iv*) The mean Kc value varied widely, from 0.61 (at ICRISAT) to 0.98 (at Bangalore). Kc values reached their peak mostly at active vegetative to flowering stages.

(*v*) The mean soybean yield as well as productivity varied widely from station to station. The highest productivity was observed at Rahuri (23.2 kg/ha/day) closely followed by Parbhani.

(*vi*) The WUE varied widely from 2.1 kg/ha/mm (at Akola) to 6.0 kg/ha/mm (at Rahuri). WUE increased with the increase in crop yield (as observed in Rahuri and Parbhani) or due to less ET demand in the station (as observed in Dharwar and Parbhani).

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