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Water and heat unit requirement in different growth stages of Soybean (*Glycine max* L. Merrill) at Bhopal

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सार – इस षोध–पत्र में 1991 से 1995 के दौरान भोपाल में सोयाबीन की फसल के उपलब्ध ई. टी. आँकड़ों का उपयोग किया गया है। इस फसल के लिए जल की आवष्यकता को ध्यान में रखते हुए सोयाबीन की फसल तैयार होने की अंतिम अवस्था तक की अवधि को पाँच महत्वपूर्ण अवस्थाओं में बाँटा गया है जैसे कि पौध लगाना, फसल बोने के दो सप्ताह तक (डब्ल्यू. ए. एस.), फसल की बढ़ोतरी की अवस्था (3 – 8 डब्ल्यू. ए. एस.), पौधे में फूल आना (9 – 10 डब्ल्यू. ए. एस.), फली का लगना (11 – 13 डब्ल्यू. ए. एस.), तथा फसल का पकना (14 – 15 डब्ल्यू. ए. एस.)। इस फसल के तैयार होने की विभिन्न अवस्थाओं के लिए आवष्यक जल का उपयोग (ई. टी.), जल उपयोग क्षमता (डब्ल्यू. यू. ई.), उष्मा एकक (एच. यू.), उष्मा उपयोग क्षमता (एच. यू. ई.), और फसल गुणांक (के. सी.) का आकलन और विवेचन इस शोध–पत्र में प्रस्तुत किया गया है।

इस अध्ययन से यह पता चला है कि सोयाबीन की फसल के लिए औसतन 450 मि. मी. जल की खपत होती है। औसतन जल उपयोग क्षमता (डब्ल्यू. यू. ई.), 3.23 कि. ग्रा./हैक्टा/मि. मी. पाई गई है। यह भी देखा गया है कि जल उपयोग क्षमता केवल फसल द्वारा खपत हुए जल की कुल राषि पर निर्भर नहीं होती है बल्कि फसल की बढ़ोतरी की विभिन्न अवस्थाओं के दौरान इसके वितरण की आवष्कयता की ओर संकेत करती है। औसतन फसल की पौध लगने, फसल की बढ़ोतरी की अवस्था, पौधें में फूल आने, फली लगने तथा फसल के पकने के दौरान क्रमषः लगभग 7%, 36%, 24%, 25% और 8% जल की आवष्यता होती है। फसल की बढ़ोतरी की अवस्था के दौरान फसल को अधिकतम जल की आवष्यकता होती है। हालाँकि पौधें में फूल आने की अवस्था लगभग (52 मि. मी.) के दौरान औसत साप्ताहिक ई. टी. दर अधिकतम पाई गई है। सोयाबीन के लिए उष्मा यनिट की औसत आवष्यकता 1694 डिग्री – दिनों की पाई गई है। फसल की बढ़ोतरी की अवस्था (638 डिग्री–दिन) एवं उसके बाद पौधे में फली लगने (358 डिग्री–दिन) के दौरान उष्मा यूनिट की अधिकतम आवष्यता होती है। उष्मा उपयोग क्षमता औसतन 0.86 कि. ग्रा/हैक्टा/डिग्री दिनों की देखी गई है। पौध लगने, फसल की बढ़ोतरी, पौध में फूल आने, फली लगने और फसल के पक कर तैयार होने की अवस्थाओं के दौरान फसल गुणांक (के. सी.) मान क्रमषः 0.30 – 0.45, 0.55 – 0.90, 1.00 – 1.15, 0.85 – 0.70 और 0.55 – 0.40 तक परिवर्तित पाए गए हैं। पौधे में फूल लगने के दौरान फसल गुणांक मान अपने चरम पर पाए गए हैं।

ABSTRACT. In this study, ET data available on Soybean crop for Bhopal during 1991-95 have been utilized. With regard to water need of the crop, the life span of soybean has been divided into five important growth stages *viz*., seedling up to 2 weeks after sowing (WAS), vegetative (3-8 WAS), flowering (9-10 WAS), pod development (11-13 WAS), and maturity (14-15 WAS). In this paper, consumptive use of water (ET), Water Use Efficiency (WUE), Heat Units (HU), Heat Use Efficiency (HUE) and crop coefficient (Kc) for different growth stages of the crop have been computed and discussed.

The study revealed that on an average, Soybean crop consumed about 450 mm of water. The average WUE was found to be 3.23 kg /ha/mm. It was also observed that WUE does not depend only on the total amount of water consumed by the crop but also indicates the importance of its distribution during various growth stages. On an average, the crop consumed nearly 7%, 36%, 24%, 25% and 8% of water during seedling, vegetative, flowering, pod development and maturity stage respectively. The crop consumed maximum amount of water during vegetative stage. However, the average weekly ET rate was found to be highest during flowering stage (nearly 52 mm). Average heat unit requirement of soybean was found to be 1694 degree-days. Maximum heat units were required during vegetative stage (638 degree days) followed by pod development stage (358 degree days). The average HUE was found to be 0.86 kg/ha/degree days. Crop coefficient (Kc) values varied in the range 0.30 – 0.45, 0.55 – 0.90, 1.00 – 1.15, 0.85 – 0.70 and 0.55 – 0.40 during seedling, vegetative, flowering, pod development and maturity stage respectively. The crop coefficient values attained the peak during the flowering stage.

Key words – Consumptive use of water, Water use efficiency, Heat units, Heat use efficiency, Crop coefficient.

1. Introduction

Soybean (*Glycine max* L. Merrill), belongs to the family Leguminosae and sub-family Pappilionaea. Soybean possesses a very high nutritional value as it contains nearly 20 percent oil and 40 % protein. As such, soybeans are mainly used as a protein and oil source (Hunsigi and Krishna, 1998). In India, the crop is grown over and area of about 6 million hectare with a total production of about 6.8 million tonnes (Singh *et al*. 2003). It is extensively grown in Madhya Pradesh, Uttar Pradesh, Maharashtra and Rajasthan. The crop is also grown on small acreage in Andhra Pradesh, Karnataka, Gujarat and Nagaland.

The crop growth is considered optimum in the temperature range 26.5 to 30° C, but growth ceases at temperature below 10° C. Agrometeorological conditions cause wide fluctuations in growth, development and yield of soybean crop. Brown (1960) proposed the "soybean development unit" based on temperature which could be used to predict soybean maturity. Whigham and Minor (1978) have studied the influence of temperature at different growth stages of Soybean. Reduced moisture availability affects several physiological functions of Soybean plants. Insufficiency of water during the pod development can limit the yield severely. Providing support irrigation at flowering and pod development has been useful in attaining better yield (Wang *et al*. 1980). Jeyaraman *et al*. (1990) studied the influence of weather parameters prevailing during critical growth stages and whole cropping period on seed yield of soybean. Samui *et al*. (2002) have studied inter relationship of various energy balance components during the growth of soybean.

In this paper, water and heat unit requirement in different growth stages of Soybean at Bhopal (Madhya Pradesh) have been studied and discussed.

2. Data and methodology

In this study, the ET data available on soybean crop for Bhopal (23° 16′ N, 77° 25′ E) during 1991-95 have been utilized. The location falls in sub humid agro climatic region. The crop was grown during kharif season. The normal rainfall in kharif season (June – September) at Bhopal is 1055 mm (IMD, 1999). The ET data was measured through gravimetric lysimeter located in the crop field by staff posted at the ET station, whereas data on meteorological parameters was recorded at the agrometeorological observatory located near the crop field. The evapotranspiration (ET), crop yield and other agrometeorological data (temperature, relative humidity, wind speed, rainfall etc.) have been obtained from the records of National Data Center, India Meteorological Department. The growth duration, crop variety and other agrometeorological parameters are given in Table 1. With regard to water need of the crop, the life span of soybean has been divided into five important growth stages *viz.*, seedling (up to 2 weeks after sowing (WAS), vegetative (3-8 WAS), flowering (9-10 WAS), pod development (11-13 WAS), and maturity (14-15 WAS). The weekly potential evapotranspiration (PET) has been calculated using Penmann's modified formulae (Doorenbos and Pruitt, 1977).

In this paper, consumptive use of water (ET), Water Use Efficiency (WUE), heat units or growing degree days (GDD), Heat Use Efficiency (HUE) and crop coefficient (Kc) for different growth stages of the crop have been computed and discussed. Consumptive use of water is defined as beneficial utilization of water by the crop during the crop life span. For all practical purposes, it is same as actual evapotranspiration. Crop coefficient (Kc) is defined as the ratio of actual evapotranspiration to the potential evapotranspiration and calculated by using following equation;

$$Kc = ET / PET \quad (1)$$

Growing Degree Days (GDD) or heat units is an index used in relating crop growth to air temperature (Vittum *et al*., 1965) and computed using the following formula:

$$GDD = \sum_{i=1}^{n} \left[(T_{max} + T_{min})/2 \right] - T_b \quad (2)$$

T_b is the base / threshold temperature below which no crop growth occurs. In the present study, T_b = 10° C has been used (Major *et al*., 1975, Kakde 1985).

3. Results and discussion

3.1. *Consumptive use of water (ET) and water use efficiency (WUE)*

Agrometeorological parameters and crop yield of soybean at Bhopal is shown in Table 1. The growth duration of Soybean at Bhopal was 14-15 weeks. The crop yield obtained varied from 1150 to 1860 kg/ha. The average yield obtained was about 1450 kg/ha. The amount of water consumed varied from 414 to 484 mm. On an average, the crop consumed about 450 mm of water. The ratio of crop yield to evapotranspiration, known as water use efficiency (WUE), serves as a very useful tool in crop and variety selection for maximum yield per unit of water consumed. WUE varied from a low value of 2.51 kg/ha/mm to a high value of 3.84 kg/ha/mm. The

TABLE 1

Agrometeorological parameters and crop yield of Soybean at Bhopal

Station	Year	Crop variety	Crop duration (Weeks)	Crop yield (kg/ha)	ET* (mm)	WUE* (kg/ha/mm)	Heat units (degree days)	HUE* (kg/ha/degree days)
Bhopal	1991	PK472	14	1200	414	2.90	1490	0.81
Bhopal	1992	Punjab 1	14	1450	442	3.28	1509	0.96
Bhopal	1993	Punjab 1	15	1860	484	3.84	1639	1.13
Bhopal	1994	Punjab 1	14	1575	438	3.60	2150	0.73
Bhopal	1995	Punjab 1	15	1150	458	2.51	1680	0.68
Mean	-	-	-	1447	447	3.23	1694	0.86

* ET – Evapotranspiration * WUE – Water use efficiency * HUE – Heat use efficiency

TABLE 2

Phase wise water requirement (ET, percent ET* and weekly ET) and growing degree days (HU, HU percent* and weekly HU) of Soybean crop at Bhopal

Seedling		Vegetative		Flowering		Pod development		Maturity	
ET (mm)	Weekly ET (mm)	ET (mm)	Weekly ET (mm)	ET (mm)	Weekly ET (mm)	ET (mm)	Weekly ET (mm)	ET (mm)	Weekly ET (mm)
32 (7.2)	16	160 (35.8)	27	105 (23.5)	52	113 (25.2)	38	37 (8.3)	19
HU (degree days)	Weekly HU (degree days)	HU (degree days)	Weekly HU (degree days)	HU (degree days)	Weekly HU (degree days)	HU (degree days)	Weekly HU (degree days)	HU (degree days)	Weekly HU (degree days)
241 (14.2)	120	638 (37.7)	106	234 (13.8)	117	358 (21.1)	119	223 (13.2)	112

* ET –Evapotranspiration * HU – Heat units * Figures in parenthesis are percentages.

average WUE was found to be 3.23 kg/ha/mm. It may be seen that in the year 1994, the amount of water consumed (ET) is 438 mm, the yield is 1575 kg/ha and WUE is 3.60 kg/ha/mm. However, in the year 1995, the amount of water consumed (ET) is 458 mm (i.e. 20 mm more than in the year 1994), the yield is 1150 kg/ha (*i.e*. 425 kg/ha lower than in the year 1994) and WUE is 2.51 kg/ha/mm (*i.e.* 1.09 kg/ha/mm lower than in the year 1994). It clearly indicates that WUE does not depend only on the total amount of water consumed by the crop but also indicates the importance of its distribution during the various growth stages. Similar results have been obtained with other crops (Verma and Das, 2004).

Phase wise water requirement (ET, percent ET and weekly ET) of soybean is given in Table 2. In this table, it may be seen that maximum amount of water consumed was 160 mm (*i.e.* nearly 36%) during vegetative stage. Water consumed was also high 113 mm (*i.e.* nearly 25 %) during pod development stage and 105 mm (*i.e*. nearly 24 %) during flowering stage. The average weekly ET rates were found to be highest during flowering stage (*i.e*.

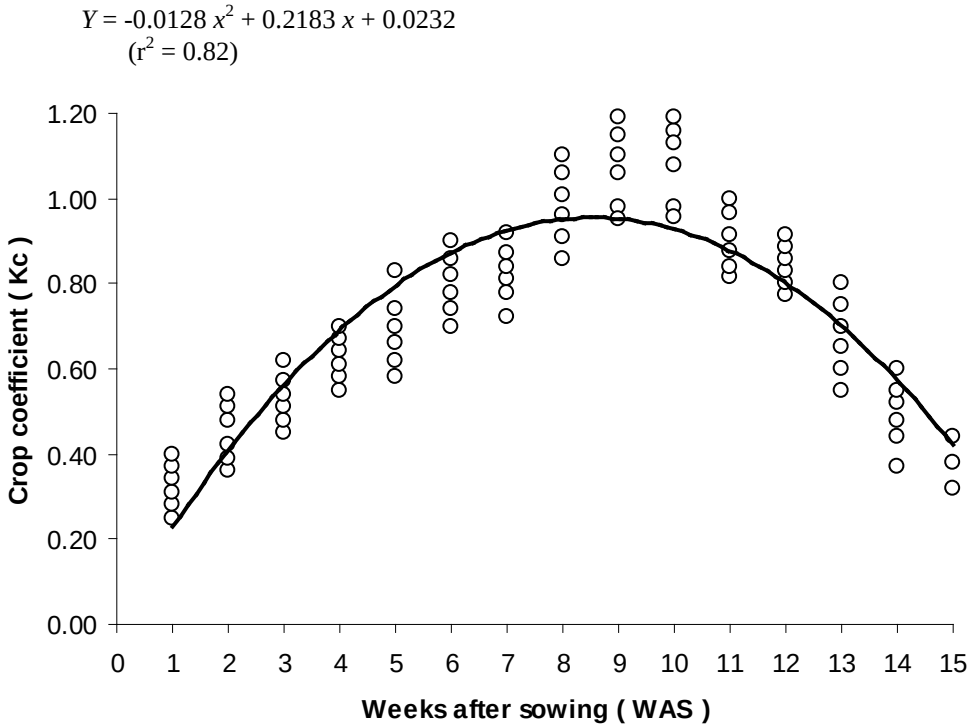

Fig. 1. Variation in crop coefficient (Kc) of Soybean with time (WAS) at Bhopal

nearly 52 mm) followed by pod development (*i.e*. nearly 38 mm) and vegetative stage (*i.e*. nearly 27 mm).

3.2. *Heat units (HU) and heat use efficiency (HUE)*

The total Heat Unit (HU) requirement or Growing Degree Days (GDD) for soybean crop throughout its life span at these locations varied between 1490 and 2150 degree-days (Table 1). On an average, the crop required 1694 degree-days. Heat Use Efficiency (HUE) of the crop was also computed to determine the number of heat units required to produce unit amount of economic grain yield (Table 1). HUE of the crop varied from a low value of 0.68 kg/ha/degree days to a high value of 1.13 kg/ha/degree days. The average HUE was found to be 0.86 kg/ha/degree days. It may be seen that, Heat Use Efficiency (HUE) of the crop increases with Heat Units (HU) up to a certain threshold high value (year 1993, HU = 1639 degree-days, HUE = 1.13 kg/ha/degree days). Heat use efficiency of the crop declines with heat units beyond the threshold high value (nearly 1640 degree-days).

Phase wise growing degree days (HU, HU percent and weekly HU) of Soybean at Bhopal is given in Table 2. In this table, it may be seen that maximum heat units are required 638 degree days (*i.e.* nearly 38 %) during vegetative stage followed by 358 degree days (*i.e*. nearly 21 %) during pod development stage. Heat unit requirement is less, between 223 to 241 degree days (*i.e*. nearly 14 %) during seedling, flowering and maturity stage.

The high and nearly equal values of average weekly heat unit requirement were found during seedling, flowering and pod development growth stages (*i.e.* nearly 120 degree days).

3.3. *Crop coefficient (Kc)*

Crop coefficient (Kc), defined as the ratio of actual evapotranspiration to the potential evapotranspiration, was computed using Eqn. 1. The knowledge of Kc is necessary to determine water requirements during different growth stages of the crop. Variation in crop coefficient (Kc) with Weeks After Sowing (WAS) of soybean is shown in

Fig. 1. It may be seen that Kc values are low (0.30 to 0.45) during the initial stage of the growth (seedling stage) and follow the rising trend (0.55 to 0.90) during vegetative stage. Kc values attain the peak (1.00 to 1.15) during the flowering stage. It means the climatic demand for water is high during flowering stage, when the crop is in good state of health. If the crop suffers from water stress during this critical growth period, it would not be able to evapotranspire at its optimum rate, and in turn, adversely affect the crop yield considerably. Thereafter, Kc values decline gradually during pod development (0.85 to 0.70) and maturity stage (0.55 to 0.40). The trend observed in Kc values of soybean during different stages of growth were compared for those given by Doorenboss and Kasam (1979), agreed fairly well. When Kc values were fitted to time, the following non linear relationship is obtained;

$$Kc = -0.013\,(WAS)^2 + 0.2183\,(WAS) + 0.0232 \qquad (r^2 = 0.82)$$

Using this equation, it is possible to estimate crop coefficient (Kc) values, at any time (WAS) or stage during crop growth. Das *et al*. (1995), Verma *et al*. (2004) have also observed such non linear relationship of crop coefficient.

4. Conclusions

(*i*) The average yield of soybean was found to be about 1450 kg/ha.

(*ii*) On an average, soybean crop consumed nearly 450 mm of water.

(*iii*) The average WUE was found to be 3.23 kg/ha/mm. It was also observed that WUE does not depend only on the total amount of water consumed by the crop but also indicates the importance of its distribution during various growth stages.

(*iv*) On an average, the crop consumed nearly 7%, 36%, 24%, 25% and 8% of water during seedling, vegetative, flowering, pod development and maturity stage respectively. The crop consumed maximum amount of water during vegetative stage. However, the average weekly ET rate was found to be highest during flowering stage (nearly 52 mm).

(*v*) The average heat unit requirement of soybean was found to be 1694 degree-days. Maximum heat units were required during vegetative stage (638 degree days) followed by pod development stage (358 degree days). The average HUE was found to be 0.86 kg/ha/degree days.

(*vi*) Crop coefficient (Kc) values varied in the range 0.30 – 0.45, 0.55 – 0.90, 1.00 – 1.15, 0.85 – 0.70 and 0.55 – 0.40 during seedling, vegetative, flowering, pod development and maturity stage respectively. The crop coefficient values attained the peak during the flowering stage.

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