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A study of water requirement of sugarcane (*Saccharum officinarum L.*) in gangetic plains

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सार – इस शोध–पत्र में लखनऊ में गन्ने (सी.ओ.–1148 किस्म) के कृषि मौसम वैज्ञानिक पहलुओं का अध्ययन किया गया है। इस कार्य के लिए 10 वर्षों का आँकड़ा समूह वर्ष 1980 से 1996 के बीच जब जब यह किस्म उगाई गई, उपयोगी पाया गया। फसल की ऋतु जैविकी को चार अवस्थाओं जैसे अंकुरण, दौजी, फसल संवर्द्धन और परिपक्वता में बाँटा गया है। फसल गुणांक, सिंचाई के अंतरालों के अलावा वाष्पन–वाष्पोत्सर्जन की आवश्यकताएं ज्ञात की गई और उनका विवेचन किया गया तथा फसल के लिए आवश्यक जल की अतिरिक्त राशि का परिकलन भी किया गया।

इस अध्ययन से यह पता चला है कि जब वाष्पन–वाष्पोत्सर्जन की आवश्यकता अधिकतम होती है उस समय फसल के संवर्धन की अवस्था सबसे महत्वपूर्ण होती है। इसी अवस्था के समय जल उपयोग की क्षमता भी अपने चरम मान पर होती है। फसल के अंकुरण के दौरान 7 दिनों के अंतराल से लगभग 35 मि.मी. तक जल और शेष अवधि में पद्रंह दिनों के अंतराल से 70 मि.मी. तक का जल गन्ने की अच्छी वृद्धि और अधिक उत्पादन के लिए आवश्यक होता है।

ABSTRACT. Agro meteorological aspects of sugarcane (variety CO-1148) at Lucknow has been studied in this paper. A data set of 10 years, whenever this variety was grown between 1980-1996 was availed for this purpose. The crop phenology was divided into four phases *i.e.*, germination, tillering, vegetative growth and maturity. Evapotranspirative demands were obtained and discussed, besides the crop coefficients, irrigation intervals and the amount of additional water needed by the crop were also computed.

The study revealed that vegetative growth stage is the most important phase, when evapotranspirative demand is maximum. The water use efficiency also attains the peak value in this phase. An interval of 7-days with about 35mm of water during germination and a fortnight interval with nearly 70mm of water in the rest of the period is needed by sugarcane for good growth and high yields.

Key words – Evapotranspiration, Water use efficiency, Crop coefficient, Irrigation scheduling.

1. Introduction

Indo-Gangetic plains has been recognised as the home of sugarcane *(Saccharum officinarum L)* in the world. Sugarcane is one of the important commercial crop in India as the sugar industry is the second largest agro based industry. India ranks first among the sugar producing countries of the world in terms of area and production. The productivity, however, is less than that in many important sugarcane growing countries (Sundara, 1998). Over most parts of sugarcane growing regions in India, it is grown with assured irrigation. Nevertheless, weather does influence on this tropical plant particularly in enhancing the saccharin contents (sucrose) and sugar accumulation within the plant. Thus, there is need for study of crop-weather relationship in sugarcane, if the productivity need to be increased.

With this objective in view, several attempts have been made in the past to unfold different aspects of weather in relation to sugarcane growth and yield. Raheja (1951) studied sugarcane yield in relation to maximum and minimum temperature. Gangopadhyaya and Sarker (1964) also examined effect of temperature and rainfall on the sugarcane yield at Pune. Yield response of sugarcane to weather variations in north-east Andhra Pardesh was studied by Rupa Kumar (1984). An attempt at estimating sugarcane yield at Padegaon (Maharashtra) from weather parameters was also made by Gupta and Singh (1988).

While most of the studies in India have been on the effect of temperature on the sugarcane crop, the water need of crop in different growth stages has not attracted the attention. The present study aims at investigating into (*i*) water need of sugarcane, (*ii*) water use efficiency, (*iii*) variations of water requirement in different phytophases of its life cycle, (*iv*) determining irrigation interval and amount of irrigation water for maximising the yield.

2. Material and methods

The present study is based on the sugarcane crop (variety CO-1148) grown at Central Sugarcane Research Institute, Lucknow (26° 52′ N, 80° 56′ E). Whenever this variety was grown between 1980 to 1996, data has been utilized. The growth duration of the crop was 52 weeks (*i.e.*, eksali). The soil at the experimental farm was sandy loam, medium deep, with field capacity (FC) of 25.5%, permanent wilting point (WP) of 6.3% and bulk density of 1.4g/cc. The average water requirement of the crop varies from 1000mm to 2500mm (WMO 1988). With annual normal rainfall of about 1020mm (India Met. Dept. 1999) the crop needs at least 8 irrigations during its growth cycle.

The water loss of the crop *i.e.*, evapotranspiration (ET), was measured from the lysimeter fixed within the crop, whereas data on meteorological parameters refer to the observatory located near the experimental farm. The weekly potential evapotranspiration (PET) has been calculated using Penman's modified formulae (Doorenbos and Pruitt 1977). Though difficult to differentiate and delineate distinctly, the sugarcane growth period in this paper has been divided into four growth phases *viz*.;

(*i*) Germination (G) : upto 6 weeks after sowing (WAS),

(*ii*) Tillering (T) : 7-17 WAS,

(*iii*) Grand growth period (GGP) : 18-38 WAS, and

(*iv*) Ripening or Maturity(R) : 39-52 WAS.

Crop Coefficient (K_c) was calculated on a weekly basis as well as for each growth stage using the equation ;

$$K_c = \frac{AET}{PET} \tag{1}$$

The irrigation interval (I) in days has been calculated as ;

$$I = \frac{S_a \times p \times d}{ET} \tag{2}$$

where

S_a = available soil water (mm/m),

p = fraction of the available water,

d = depth of the effective root zone (cm), and

ET = peak value of evapotranspiration (mm/day),

S_a is the range of moisture content, between field capacity (FC) and permanent wilting point (WP). In this study the value of S_a = 270 mm/m has been obtained, the fraction p has been assumed equal to 0.5. In most sugarcane growing soils the bulk of the roots lies in top 50 cm layer. Hence d = 50 cm has been used in the study for all growth stages except germination when d = 25 cm has been used. During the stress period, undoubtedly, the crop has to be provided supplementary water at regular intervals. However, besides the irrigation interval, what is equally important is the amount of water to be supplied. This is dependent on the soil moisture already available in the root zone of the crop. The present study also determines the quantum of irrigation water to be supplied in each phase. If Q is the irrigation water required to bring the soil moisture level in the root zone to field capacity (Michael, 1990) then,

$$Q = \sum_{i=1}^{1=n} \frac{(M_f - M_i) \times B_i \times D_i}{100} \tag{3}$$

where,

M_f = field capacity (%).

M_i = moisture content (%) before irrigation in the i^{th} layer of the soil.

B_i = bulk density of the soil in the i^{th} layer.

D_i = depth of the i^{th} soil layer, in cm.

n = number of soil layers in the root zone.

In this study we have considered root zone upto 50 cm soil depth *i.e.*, two soil layers each of which is 25 cm and hence n = 2. The bulk density is assumed to be uniform in both layers and M_i is half the difference between field capacity and permanent wilting point.

TABLE 1

Crop yield and distribution of agroclimatic factor

Year	Yield (kg/ha)	Rainfall (R)(mm)	Irrigation (I) (mm)	R + I	ET (mm)	ET/(R+I)	WUE (kg/ha/mm)
1980-81	39091	2094	568	2662	1567	0.59	24.95
1981-82	41818	1088	556	1644	1384	0.84	30.21
1982-83	32830	1089	615	1704	1344	0.79	24.43
1983-84	36364	1090	247	1337	1231	0.92	29.54
1984-85	38929	972	696	1668	1408	0.84	27.64
1985-86	34156	1337	547	1884	1141	0.61	29.93
1987-88	13577	564	407	971	967	1.00	14.04
1988-89	21109	1065	409	1474	1332	0.90	15.85
1989-90	16813	844	324	1168	1164	1.00	14.44
1995-96	54255	560	514	1074	1212	1.13	44.76
Average	32894	1070	488	1558	1275	0.86	25.5

3. Results and discussion

3.1. *Consumptive use of water*

Variations in the amount of water utilized (ET) by the sugarcane in different years are given in Table 1. The ET varied widely from a low of nearly 970 mm in 1987-88 to as high as 1570 mm in 1980-81. In the first case, not only rainfall was rather low but also the irrigation water supplied, in sharp contrast to that observed in the later instance. On an average the eksali sugarcane crop at Lucknow needs about 1275 mm of moisture to complete its phenological phases. Since Lucknow receives about 1020 mm of normal rainfall in a year, the rest of the amount must come from supplementary irrigation.

When seasonal ET was partitioned in different growth stages it was observed that crop consumes 6.4, 26.8, 53.6 and 13.2 percent water during G, T, GGP and R stages respectively. It means that maximum amount of water, is consumed during GGP stage, which covers the longest period of 21 weeks. This is also the period when water demand is more, as there is increase in crop canopy.

Each growth period considered in the analysis varied in length from 6 weeks in germination (G) to 21 weeks in grand growth period (GGP). Naturally the amount of total water consumed will vary from stage to stage and the figures given above may not truly reflect the rate of ET utilized. To overcome this, weekly water consumed in each stage was worked out. The average weekly ET values were found to be 13.7, 32.0, 32.3, 11.5 mm during the growth stages G, T, GGP and R respectively.

TABLE 2

ET/(R+I) during different stages of crop growth

Year	Germination	Tillering	Grand growth period	Ripening
1980-81	0.89	0.46	0.58	2.28
1981-82	1.38	0.77	0.88	0.60
1982-83	1.29	0.80	0.60	3.56
1983-84	1.65	0.56	1.02	2.19
1984-85	1.15	0.60	0.91	3.89
1985-86	2.13	0.79	0.47	1.33
1987-88	2.66	1.24	0.74	2.09
1988-89	3.17	0.94	0.74	1.25
1989-90	1.59	1.04	0.77	1.41
1995-96	0.63	0.86	1.61	0.37
Average	1.65	0.80	0.83	1.89

It is obvious that the lowest amount per week is consumed in the last phase (*i.e.*, ripening) when the demand is less. The average weekly water utilized by sugarcane during T and GGP are the highest and nearly equal *i.e.*, nearly 32 mm.

3.2. *Evapotranspiration and total water supplied*

Rainfall (R) and the amount of irrigation water (I) supplied together has been assumed as the total water being provided to the sugarcane. The ratio ET/(R+I) for different years is also given in Table 1. The ratio is found

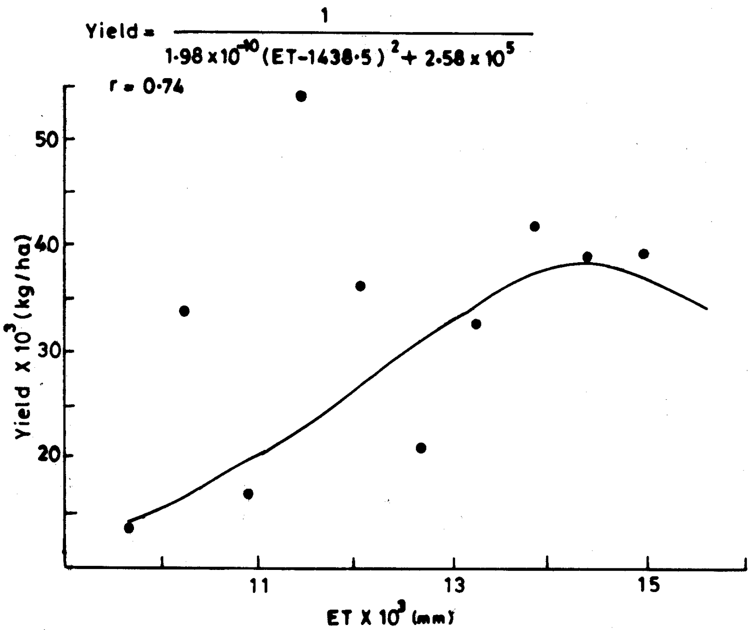

Fig. 1. ET- yield relationship

to vary from year to year, with lowest values (nearly 0.60) in 1980-81 and 1985-86 crop season. High values characterized other years particularly 1995-96 when it exceeded 1.0. Analysis of the ratio ET/(R+I) for different growth phases revealed some interesting features. Large variations in the different years can be seen in the Table 2. On an average it is observed that the ratio was 1.65 during germination (G), 0.80 at tillering (T), 0.83 at grand growth period (GGP) stage and 1.89 during ripening (R). A value of more than 1.0 in the first and last stage of sugarcane growth suggested that ET exceeded the total water supplied. A value of less than 1.0 in tillering and grand growth period stages means that the total water supplied exceeded ET. Large variations in water supply and demand, during different stages of growth, may in turn cause wide fluctuations in yield. Thus, there is need for management of water to be supplied to the sugarcane crop.

3.3. *Irrigation scheduling*

Optimum yields of sugarcane are obtained by maintaining high moisture level, above 50% of the available soil water, in the root zone during the entire growing season except 4-6 weeks before harvest (Michael, 1990). Rainfall in tropics being highly variable, to achieve this, sugarcane must be irrigated regularly without allowing the moisture level to deplete below 50% of the available soil water. In this study, irrigation interval was calculated by using the Eqn. (4). The average irrigation interval was found to be 7 days during germination and 13 days for each of the remaining growth stages. Thus, unless replenished by rainfall, during the early part of growth, sugarcane needs frequent irrigations. On the other hand, a fortnightly interval of irrigation could support the crop in healthy growth in later phenological phases.

Besides the interval, it is equally important how much water should be given to the crop. This of course, depends on the existing soil moisture in the root zone. The irrigation amount (Q) was calculated using Eqn. (5). In calculating Q, 25 cm soil depth during germination and 50 cm soil depth for rest of the growth season was assumed (Michael, 1990). In these calculations 50 percent of the available soil water was assumed as the allowable depletion limit. In other words, this means that the soil moisture in the root zone is not allowed to fall below 50 percent of the available soil water during the entire growing season. Under these assumptions, the crop is not likely to suffer from water stress at any stage. The values of irrigation amount (Q) were found as 34 mm during germination and 68 mm for the rest of the season.

The water needs of the crop falls drastically during the last phase of its growth. If the irrigation were withheld to a maximum of six weeks before harvest then as per our calculations, sugarcane would require a total of 1564 mm of water for its entire growth. Since, the normal annual rainfall for Lucknow is about 1020 mm, 544 mm of additional water would be needed through irrigation. As we know the rainfall during the crop season is not uniformly distributed, care would have to be taken to subtract the rainfall amount from the irrigation amount (Q) for that particular irrigation interval.

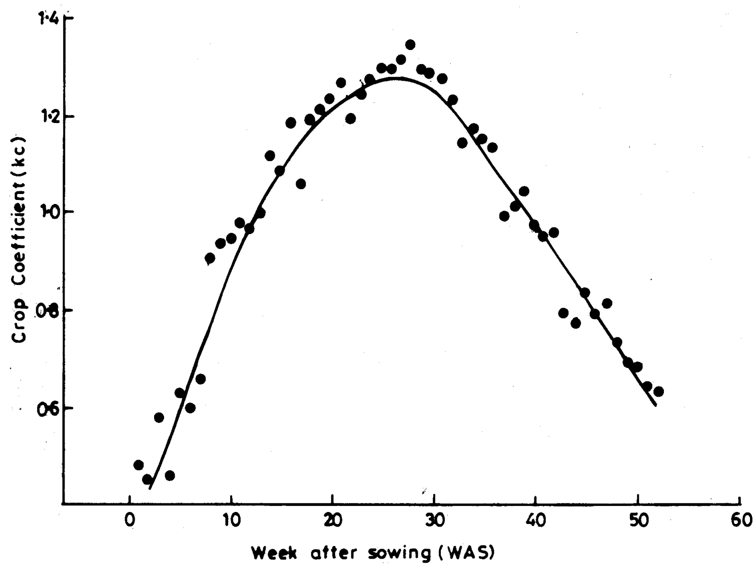

Fig. 2. Variation in crop coefficient of sugarcane with time

3.4. *ET –yield relationship*

Like ET, the yield fluctuates from year to year (Table 1) with a maximum value of 54255 kg/ha in 1995-96, when water used was incidently not the maximum, to a minimum value of 13577 kg/ha in 1987-88, with a low quantum of total water utilized by the crop. One may, therefore, be tempted to conclude that yield is linearly correlated to ET. Though the data sample was rather small to draw any tangible conclusion, the type of relationship between the two was found as ;

$$Y = [(ET-1438.5)^2 \times 1.98\times10^{-5} + 2.58]^{-1} \times 10^5 \quad (4)$$

r = 0.74

In the crop-weather relationship studies such non-linear relationships is not uncommon (Sarker *et al.* 1962).

Fig. 1 shows the non-linear relationship between ET and yield. It may be seen that for ET in the range of 1000 mm to 1425 mm, the yield increases nearly uniformly. The maximum crop yields of about 39000 kg/ha can be obtained when ET is nearly 1425 mm. Beyond this, the yield diminishes with increase in water lost by the sugarcane crop.

In order to determine if the water consumed in a particular stage of the growth have significant influence on yield, the yield was multiple-regressed with ET in all the four stages of growth. It was noticed that only in grand growth period (vegetative) stage and ripening (maturity) stage ET exert statistically significant relationship on yield. The following equation could be obtained:

$$Y = 28900 + 38.3\, X_3 - 136\, X_4 \quad (5)$$

r = 0.97

where,

Y = sugarcane yield (kg/ha),

X_3 = ET (mm) during grand growth period, and

X_4 = ET (mm) during ripening stage.

The high and nearly 1.0 correlation suggest usefulness of the equation in predicting yield with a very high degree of confidence.

3.5. *Water use efficiency (WUE)*

WUE which is defined as the ratio of yield to per unit of water consumed by the crop. The same for different years is also given in Table 1. The table shows wide variations in WUE from year to year. The lowest value of 14.0 kg/ha-mm was observed in the year 1987-88, while highest value of 44.8 kg/ha-mm in the year 1995-96. It can be seen that when WUE was maximum, the total amount of water (R+I) received by the crop or water lost by it was not maximum. When (R+I) was maximum (*i.e.*, 2660 mm) in the year 1980-81, WUE was not the maximum. On the other hand, the lowest rainfall of 560 mm plus not so high irrigation water (nearly 500 mm) gave the best WUE in 1995-96. It clearly indicates that the maximum WUE does not depend only on the total amount of (R+I) received by the crop, but also on its distribution during the various growth stages of the crop.

3.6. *Crop coefficient (K_c)*

The crop coefficient (K_c) represents what fraction of climatic water demand is met in a growing crop. As the crop canopy increases, K_c is bound to increase, while during maturity or senescence, the value diminishes due to decreased water demand. Variations in crop coefficient (K_c) with time is shown in Fig. 2. K_c values are found low (between 0.4-0.6) during the G stage. K_c values follow a rising trend increasing to 0.9-1.0 during T *i.e.*, upto 20 WAS. The values attain peak of 1.2 - 1.3 during 20-30 WAS *i.e.*, during the GGP stage of the crop. K_c values, thereafter have a falling trend until ripening. The values during this stage are however not low but continue in the range of 0.6-0.8. These values of K_c for sugarcane were compared to those given by Doorenbos and Kassam (1979) and agree fairly well for different growth stages. When K_c values were fitted to a regression with time, the regression equation obtained is ;

$$K_c = 0.364 + 0.066\,(WAS) - 0.001 \times (WAS)^2 \quad (6)$$

$$r = 0.93.$$

This equation confirms the parabolic form of relationship between K_c with time, observed in Fig. 2. Das *et al*. (1995) have also observed such nonlinear relationship between K_c and time for Sorghum at Solapur.

4. Conclusions

The following conclusions have been drawn in the present study:

(*i*) On an average sugarcane crop needs 1275 mm of water to complete its phenological growth stages. Maximum amount, nearly 54%, of water is consumed during grand growth period.

(*ii*) For a maximum yield of about 39000 kg/ha the evapotranspiration of 1425 mm is needed.

(*iii*) The crop coefficient attains peak of 1.2 - 1.3 during the vegetative phase of the crop.

(*iv*) The water use efficiency does not depend, only on the total amount of water (R+I) received by the crop, but also on its distribution during various growth stages.

(*v*) Irrigation interval was found nearly a week during germination and fortnight in the remaining growth stages.

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