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Water consumption of cotton in the semi arid tracts of India

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सार - इस शोध पत्र में कपास की फसल के लिए काम में आने वाली चीजों तथा इससे सबंधित अन्य पहलुओं को समझने के लिए अकोला, बेलारी और कोविलपट्टी नामक तीन विभिन्न स्थानों के वाष्पन-वाष्पोत्सर्जन तथा अन्य कृषि मौसम विज्ञान के आँकड़ों का उपयोग किया गया है। अध्ययन से यह पता चला है कि पौधों की बढ़ोतरी के समय वाष्पन - वाष्पोत्सर्जन से सम्भाव्य वाष्पन - वाष्पोत्सर्जन (ई.टी./पी.ई.टी.) और वाष्पन - वाष्पोत्सर्जन से सकल लघुतरंग विकिरण (ई.टी./आर.एस.) के अनुपातों में शनैःशनैः वृद्धि होती है जबकि इनमें एक ही स्थान पर अलग-अलग वर्षों में भिन्नता पाई जाती है। इन सभी तीनों केन्द्रों के लिए ऊर्जा संकलन इंडेक्स तैयार किए गए हैं जिससे यह पता चलता है कि फसल की कुल पैदावार ऊर्जा संकलन इंडेक्स की अपेक्षा फसल में प्रयुक्त किए गए वाष्पन - वाष्पोत्सर्जन जल पर अधिक निर्भर है। समय और स्थान के अनुसार कपास की फसल की जल उपभोग क्षमता (डब्ल्यू. यू. ई.) में भी व्यापक भिन्नताओं का पता चलता है।

ABSTRACT. In the present study, evapotranspiration and other agrometeorological data for three different locations, *viz*., Akola. Bellary and Kovilpatti have been utilized to understand consumptive use and related aspects of cotton. Ratios of evapotranspiration to potential evapotranspiration (ET/PET) and evapotranspiration to total shortwave radiation (ET/Rs) increase gradually as the vegetative cover develops and shows year to year variation at same location. The energy summation indices have been worked out for all the three stations which indicate that the total yields are more dependent on consumptive water use by crop rather than energy summation indices.. The water use efficiency (WUE) of cotton crop also reveals wide variations in time and space.

Key words – Consumptive use, Water use efficiency (WUE), Shortwave radiation (Rs), Evapotranspiration (ET), Evaporation (EP).

1. Introduction

Cotton is one of the most important commercial crops playing a key role in economic, political and social affairs of the world. Cotton is best adapted to sub-tropical climates. The minimum rainfall limit for growing cotton crop is 50 to 65 cms during 154 days of its growing period of which 42 days (boll opening to harvest) rainfree weather is needed (Sahu and Sastry 1992a and 1992b). Cotton in India is largely cultivated under rainfed conditions during the tropical monsoon season or in the southern parts of the country (Karnataka / Tamil Nadu) during the late / post monsoon season.

In respect of cotton crop, water is needed for vigorous growth, good budding, fruiting and formation of healthy bolls. Excessive water restricts root growth and crop development. Abrupt changes in water supply may lead to flower and boll shedding. Heavy rainfall during sowing and the early stage is undesirable. In cotton crop, no clear cut demarcation could be made in crop growth periods since there is an overlap between vegetative growth and development of phenophases. Vegetative growth continues during both flowering and boll formation. Flowering continues during boll formation. Doorenbos and Kassam (1979) suggested the different growth stages and crop coefficients for estimation Of evapotranspiration and water requirements of cotton crop. Sahu and Sastry (1992 a) used phase wise crop-coefficients for working out water requirement of cotton for north western regions of India.

In the present study, an attempt has been made to determine variability in water use pattern by cotton crop under three different locations of semi arid tracts of India, *viz*., Alcola, Bellary and Kovilpatti. Evapotranspiration rates for cotton were determined by various workers by indirect or direct methods, *e.g*., lysimetric techniques, profile soil water depletion or field water balance etc. (Stanhill and Fuchs, 1968; Hutchinson *et al*., 1958; Eagleman 1967; Kowal and Falkner 1975 and Rijks 1976).

TABLE 1

Agrometeorological informations & energy unit indices of cotton

Station & variety	Year (Crop duration)	Total in growth period: Consumptive Water use (ET) (mm)	EP (mm)	PET (mm)	PAR (mm)	Heat Unit (°C)	Lint + seed Yield (kg/ha)	Total rainfall from sowing to harvesting (mm)	Total number of irrigations from sowing to harvesting (days)	Water Use Efficiency WUE (kg/ha/mm)
AKOLA AHH-468	1991-92 (190 days)	549.5	991.2	809.2	653.6	2400.9	567.9	191.9	7	1.03
	1992-93 (246 days)	617.4	1192.8	1149.8	882.3	3010.5	667.7	780.5	3	1.08
	1993-94 (265 days)	572.6	1222.2	11 81.6	937.6	3213.1	624.1	757.0	1	1.09
BELIARY DCH - 32	1992-93 (285 days)	673.0	2104.0	1583.4	1095.0	3845.1	908.5	404.5	7	1.34
	1994-95 (278 days)	778.0	1844.6	1478.2	1095.8	3772.0	956.9	300.0	9	1.22
	1995-96 (273 days)	858.2	1917.6	1542.3	1098.4	3949.8	986.9	297.8	7	1.15
KOVILPATTI MCU - 10	1991-92 (204 days)	353.7	943.9	1022.3	777.1	3038.8	N.A	263.2	N.A.	N.A.
	1993-94 (258 days)	355.0	1133.9	1397.4	977.5	4191.3	436.6	569.6	Nil	1.23
	1995-96 (305 days)	356.8	1356.6	1603.2	1167.1	4511.3	361.9	353.5	Nil	1.01

N.A.- Not Available

2. Materials and methods

The evapotranspiration (ET) data of the cotton crop for three years were collected from gravimetric lysimeter at Akola (20° 42'N, 77° 02' E), Bellary (15° 09' N, 76° 51' E) and Kovilpatti (9° 12' N, 77° 53' E). The cotton crop season, variety and duration were different under these three different locations of semi arid tracts. The soils at Akola, Bellary and Kovilpatti are mainly vertisol. The evapotranspiration (ET) data were measured through gravimetric lysimeter located in the crop field and were used to determine water use efficiency by the cotton plant. The evaporation (EP) values refer to standard US open pan evaporimeter, while the potential evapotranspiration (PET) was calculated from usual meteorological elements by modified Penman's method. The EP, hours of sunshine and meteorological data needed for computing PET were obtained from the Agrometeorological observatory located near the crop field. The incoming solar radiation (Rs) was calculated indirectly from number of sunshine hours, using Angstrom formula:

$$Rs = (a+b.n/N)R_A \qquad (1)$$

Where R_A is the theoretical amount of radiation that would reach the earth's surface in the absence of the atmosphere, *n* is the actual duration of sunshine hours, *N* is the maximum possible duration of sunshine and *a* & *b* are constants. The sunshine hours were recorded by Campbell-Stroke solarimeter.

Concept of heat units (HU) which is based on the assumption that the plants have particular range of temperature requirement for their growth, has been used in the study. The HU has been computed by subtracting the base temperature of 12° C from the mean daily temperature. A factor of 0.45 was used (Meek *et al*., 1984) to convert incoming radiation values into photosynthetically active radiation. The crop co-efficient (K_c) has been estimated using the relationship:

$$K_c = ET/PET \qquad (2)$$

The water use efficiency of cotton was calculated by utilizing available crop yield data.

3. Results and discussion

3.1. *Water use and crop coefficient during the growing period*

Agrometeorological information including the growing season, rainfall, total water use and energy summation indices etc. for cotton crops in three different

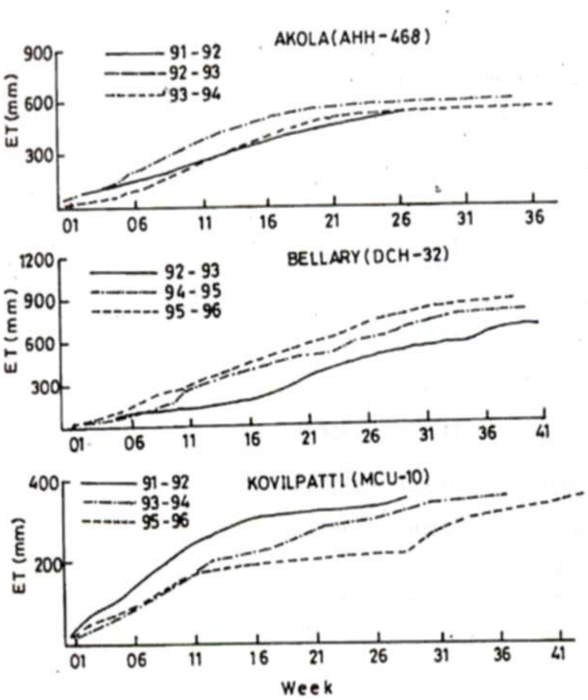

Fig. 1. Cumulative evapotranspiration (mm) by cotton

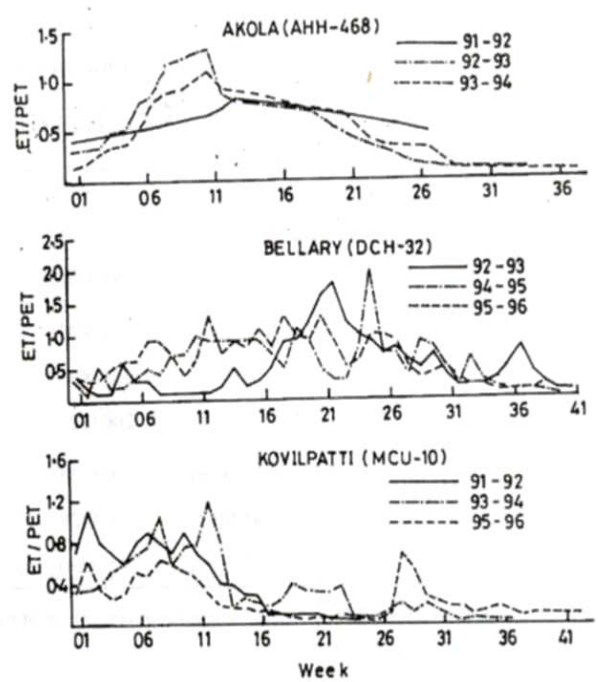

Fig. 2. Weekly evapotranspiration – Potential evapotranspiration ratio (ET/PET) for cotton

locations are given in Table 1. It is seen that total water use generally exceeds total rainfall during growing period of the crop. This indicates that plant extracted soil moisture from root zone depth supplied by irrigation. There is a wide variation of consumptive use of water from year to year at different locations (Fig. 1).

At Akola, the water use of cotton was maximum in 1992-93 (617.4 mm) followed by the crop grown in 199394 (572.6 mm) and 1991-92 (549.5 mm). This may be attributed to increased rainfall and longer duration of the crop growing season. The almost similar relationship between rainrall and water use was found at Kovilpatti where the value ranged from 353.7 mm in 1991-92 to 356.8 mm in 1995-96. The almost similar values of consumptive use of hybrid cotton were observed in Maharashtra where the value was reported to be 774 mm (Khade *et al*., 1988) and at Coimbatore in south India, the value being 616 mm (Gopalaswamy *et al*.,1991). Sahu and Sastry 0992b) also reported that water requirements of kharif cotton was 603 rom in north western region of India.

Table 2 contains phasewise water use and mean weekly ET of cotton at three locations during various years. Differences in ET of all the phenological stages are evident at every location which is due to dissimilar weather experienced during different crop season and variation due to soil factors and cultivars used. At Akola during 1992-93, the water use for establishment and vegetative stage is 105.7 mm and 215.6 mm which is higher than that at other locations among all the years presumably because of high amount of stored moisture at the beginning of crop season. The water use between flowering to boll formation has varied markedly due to wide variation in duration of growth period, microclimatic conditions and soil differences. In general, the plant uses the largest, *i.e*., nearly 40% of its total water use for flowering stage, followed by 29% in vegetative stage. It is observed that DCH - 32 grown at Bellary uses 19 mm of water per week followed by AHH468 (18 mm) at Akola and MCU - 10 at Kovilpatti uses 10 mm per week. It is also observed that the average daily water use varies from 1.4 mmlday at Kovilpatti to 2.7 mm / day each at Akola and Bellary.

The values of weekly K_c during the growing season at three locations are shown in Fig. 2. It is seen that the K_c gradually increases from establishment stage as the plant development progresses, attaining the highest value of 1.32 at 11 weeks after sowing (WAS) during 1992-93 at Akola. At Akola, during all three years, effect of plant senescence is also seen by gradual decline in the K_c values during the maturity stage when the value falls below 0.7 at 19 WAS.

There is a wide variation of K_c value from year to year at Bellary and Kovilpatti. The highest K_c value of 2.0 is seen at Bellary during 1994-95 at 25 WAS and 1.18 at

TABLE 2

Phase wise water use (mm) and mean weekly ET (mm) of cotton

Station & variety	Year	Establishment	Vegetative	Flowering	Boll formation	Ripening/ Maturity	Total ET (mm)	Mean weekly ET(mm)
Akola (AHH-468)	1991-92	83.5{15)	192.4(35)	210.3(38)	19.3(4)	44.0(8)	549.5	20.3
	1992-93	105:z(ri)	. .2!.6(5)	219.4(36)	20.3(3)	56.4(9)	617.4	17.6
	1993-94	89.7(16)	. 1-98.1(34)	209.9(37)	26.5(5)	48.4(8)	572.6	15.1
Bellary (DCH-32)	1992-93	.45.0(7)	154.0(23)	304.0(45)	148.0(22)	22.0(3)	673.0	16.4
	1994-95	46.0(6)	201.0(26)	341.0(44)	174.0(22)	16.0(2)	778.0	.19.9
	1995-96	73.1(9)	200.0(23)	387.0(45)	174.0(20)	24.1(3)	858.2	22.0
Kovilpatti (MCU-IO)	1991-92	63.0(18)	100.9(28)	134.8(38)	35.0(10)	20.0(6)	353.7	12.2
	1993-94	5.0(13)	100.0(28)	141.0(40)	47.0(13)	22.0(6)	355.0	9.6
	1995-96	.62.0(17)	92.0(26)	145.0(41)	33.0(9)	24.8(7)	356.8	8.1

Note: Figures in the parenthesis represent percentage of total water use

Kovilpatp during 1993-94 at 12 WAS. Mishra and Ahmed (1987) reported that the crop coefficient values for cotton were from 0.22 to 0.95 during vegetative stage, 0.96 to 1.33 during flowering and boiling period and 0.85 to 0.70 during the harvesting period. Gopalaswamy *et al.* (1991) also reported that at Coimbatore K_c values for cotton were 0.81 for vegetative, 1.10 for flowering and boll development and 0.57 for harvest maturity stage.

3.2. *Evapotranspiration (ET)-solar radiation (Rs) relationship*

The ratio ET/Rs is an indirect method of estimating ET when Rs is known and can be used to predict irrigation needs (Carrekar, 1963). This ratio also reflects the combined effect of the energy balance components and can be utilized to compute the energy balance of crops during different phenological growth phases. The ET/Rs ratio of the three locations are shown in Fig. 3 for each year.

In the semi arid environment of all the stations, the ET/Rs values for cotton t:evealed dissimilar pattern. The maximum values of ET/Rs ranged from 0.1 to 0.9 each at Akola and Bellary and 0.1 to 0.6 at Kovilpatti. In general, maximum ET/Rs ratio reached at flowering stage and decreased afterwards because of senescence period of the crop. The ET/Rs ratio increases as the vegetative cover develops. The low ratio in the early stage of the crop is a result of the presence of a large proportion of bare ground that cannot be kept wet all the time by ordinary irrigation practices. Because of irregular availability of moisture to cotton and being a long duration crop, the pattern of each of the year in three locations revealed much diversification from week to week till the commencement of senescence. The rapid variation of ET/Rs ratio indicates lack of variable available moisture in the root zone. For sandy clay loam for cotton, Namken *et al.* (1968) found that maximum value of this ratio was 0.73.

3.3. *Energy summation indices*

The rate of crop development can be considered as a function of the energy receipts and temperature conditions prevailing in a season. Sastry and Chakravarthy (1982) and Das *et al.* (1995) expressed that energy summation indices representing radiation, thermal units and pan evaporation and potential evapotranspiration could be used for identification of phenological events and maturity dates in crop. A base temperature of 10.2° C was used by McMahon and Low (1972) for calculating growing degree days of cotton. Maim and Kerby (1981) used a base temperature of 12.8° C and Munro (1971) indicated a base temperature of 14° C for the same purpose. According to WMO (1996), 12° C can be defined as a base temperature for working out degree days of cotton crop and was used in the present study. Heitholt, *et al.*, 1992 derived photosynthetically active radiation (PAR) of normal leaf pattern and narrow row cotton as a function of cumulative heat units which have practical application in crop growth modelling. In the study, the total value of the four indices namely heat units (HU), pan evaporation (EP), potential evapotranspiration (PET) and photosynthetically active radiation were estimated from sowing to harvesting (Table 1). Energy unit indices, in general, show considerable annual variability. At Akola, it is observed that inspite of comparative low values of energy

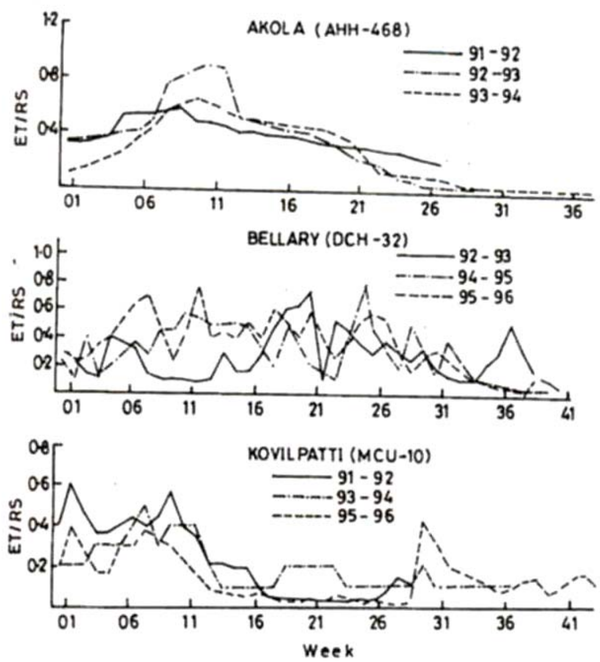

Fig. 3. Weekly evapotranspiration – Solar radiation ratio (ET/RS) for cotton

summation indices in 1992-93 as compared with those in 1993-94, total yield was found to be on the higher side in case of the former. Similarly at Bellary, yield was found to be higher in 1994-95 and 1995-96 inspite of comparatively low energy summation indices in these two years as compared with higher indices in 1992-93. Similar situation has also been noticed at Kovilpatti. The response of higher yield in those years may probably be due to higher water use by the crop rather than contribution by energy summation indices during crop growing period as may be seen in Table 1.

3.4. *Water use efficiency*

The relationship between the evapotranspiration and yield in the field mayor may not be linear as has been found between transpiration and dry matter production in experiments (De Wit, 1958). This is partly because the fraction of the evaporation that does not contribute to the plant growth varies throughout the crop life cycle. 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. The WUE is thus given by

$$WUE = YIET \tag{3}$$

Where Y = Yield of crop

ET = Cumulative evapotranspiration during growth period.

The yield (Y) and evapotranspiration, both are influenced independently or differentially, by crop management and environmental factors. The yield is greatly dependent on moisture regime, the more water available to the crop, the higher the yields. A greater water supply also leads to increase of evapotranspiration. The WUE of cotton for each location of three years are shown in Table 1. The WUE varies from year to year at same or different locations. At Akola, it is varied from minimum value of 1.03 kglha/mm in 1991-92 to maximum value of 1.09 kg/ha/mm in 1993-94 and at Bellary, it is varying from 1.15 kg/ha/mm in 1995-96 to 1.34 kg/ha/mm in 1992-93. The lowest value of 1.01 kg/ha/mm has been observed at Kovilpatti in 1995-96. The wide variations in WUE may be attributed to the plant species and varying environments in different years. Singh and Bhan (1993) found the WUE of 2.8 kg/ha/mm at central Uttar Pradesh and Path an *et al*. (1999) obtained the WUE of 3.10 kg/ha/mm at Rajasthan for high yielding varieties of cotton.

4. Conclusions

The following conclusions could be drawn :

(*i*) Application of more number of irrigations and fairly distributed rainfall resulted higher consumptive water (ET) use at Bellary than that of Akola and Kovilpatti.

(*ii*) The consumptive use of water increases with the development of vegetative cover of cotton reaching peak value during vegetative growth phase at 5 to 12 weeks after sowing.

(*iii*) ET/Rs increases gradually up to flowering stage as the vegetative cover develops and shows year to year variation at same location.

(*iv*) The crop coefficient values can be utilized suitably to schedule irrigation for the cotton crop.

(*v*) The water use efficiency of cotton crop reveals wide variations in time and space.

(*vi*) The energy summation indices of cotton crop also show high year to year variability.

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