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Estimation of evapotranspiration from pan-evaporation values : A study over the maize field in Bangalore

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सार — बंगलौर में बोई जाने वाली मक्का की फसल (दक्खिन संकर जाति) के लिए कड़ाह-वाष्पन के उपलब्ध मानों से वाष्पोत्सर्जन मानों के आकलन के लिए यहां एक सूत्र (फार्मूला) दिया गया है। यह सूत्र पौधों के क्षेत्रफल पर वाष्पोत्सर्जन व वाष्पन के अनुपात की निर्भरता की मात्रा बतलाता है। पौधों के क्षेत्रफल में वृद्धि का वाष्पोत्सर्जन वाष्पन के मान पर दोहरा प्रभाव होता है। प्रथम, वाष्पोत्सर्जन का मान बढ़ाकर वाष्पोत्सर्जन/वाष्पन का मान बढ़ाना तथा द्वितीय/स्थानीय मौसम संबंधी परिस्थितियों को इस तरह सुधारना कि खुले स्थान में विद्यमान परिस्थितियों के मुकाबले वाष्पन प्रक्रिया को रोका जा सके और इस प्रकार वाष्पो०/वाष्पन मान को कम किया जा सके। इस प्रकार वाष्पो०/वाष्पन का परिणामगत मान इन दो तत्वों के बीच एक समझौता है। इस समझौते से उत्पन्न आवश्यक शुद्धि तत्व, जो प्रत्येक फेनोलोजिकल अवस्था के अनुकूल है, इस सूत्र में निर्धारित व सन्निहित किए गए हैं।

ABSTRACT. A formula to estimate the values of evapotranspiration (E_T) from the available values of pan-evaporation (E_P), for the maize crops (Deccan Hybrid variety) grown in Bangalore is given. The formula brings out the degree of dependance of the ratio E_T/E_P on the area of the plants. The effect of increase of area of plants on the value E_T/E_P is two-fold : (1) to increase the value of E_T and thereby that of E_T/E_P and (2) to modify the local meteorological conditions in such a way as to inhibit evaporation processes compared with the conditions in an open space and thereby reduce E_T/E_P. The resulting value of E_T/E_P is thus a compromise between these two factors. The necessary correction factors arising out of this compromise, appropriate to each phenological stage are determined and incorporated in the formula presented.

1. Introduction

Along with the rainfall input, evapotranspiration, a process through which water is lost in a crop-field, is an important factor for the proper planning of irrigation schedules. This amount of evapotranspiration can be determined best by using Gravimetric Lysimeters. But they are very expensive to install and maintain. On the other hand, pan evaporimeters are far less expensive to install and far less difficult to maintain. Therefore, it is very desirable to know how an estimate of E_T can be obtained from the known values of pan-evaporation (E_P). With this end in view as a first step, the present study of estimating E_T values from E_P values has been undertaken for the maize field in Bangalore.

2. Materials and methods

This study has been conducted in the agricultural field of Gandhi Krishi Vigyan Kendra (G.K.V.K.) farm, University of Agricultural Sciences, Bangalore. The data used, cover three successive kharif seasons of 1982, 1983 and 1984.

Every day the lysimeter readings were taken and E_T values were computed and recorded. The readings taken from pan-evaporimeter (Class A-American type) maintained by the G.K.V.K. Observatory in a field closeby, at about the same time, were taken and noted.

Rainfall amounts were similarly obtained from G.K.V.K. Observatory. Irrigation amounts were determined from lysimeter readings by weighing just before and after irrigation.

The days of appearance of boot leaf, of flowering, milky stage and of maturity were noted. They are presented in Table 1. The number of leaves of all the plants grown in lysimeter, the average number of plants in surrounding field, the average area of each leaf of the representative plants of the field were regularly determined and noted every week. From this, it is easy to calculate the total area of all the leaves of all the plants grown over the lysimeter (Table 2 gives the total area of all the leaves of all the plants over the lysimeter). This was computed on the basis of assumption of linearity of growth between the days on which the actual areas were determined experimentally. The ratio E_T/E_P corresponding to each day was determined from the observed values.

3. Discussions and results

In a lysimetric study (Venkatraman 1981) at Ludhiana in respect of kharif maize (variety Vijay) for the years

TABLE 1

Crop stage	*Day of the year		
	1982	1983	1984
Appearance of boot leaf	44	40	47
Day of flowering	51	49	53
Milky stage (beginning)	68	74	87
Day of maturity (beginning)	90	87	96
Harvest	122	114	116

*Sowing day is taken as the first day (15 June of each year)

TABLE 2

Day	Lysimeter plant area (sq. mm) ($\times 10^2$)
1982	
19	1573
33	8260
47	30393
61	73632
75	74444
89	50964
103	21682
1983	
21	505
35	10791
49	14549
63	79463
77	70809
91	53830
1984	
21	1250
35	3604
49	22672
63	56032
77	42622
91	18440

1976 and 1977 though the E_T/E_P ratios were presented the reasons for the changes in the values of E_T/E_P were not discussed.

Battawar *et al.* (1983) presented similar values for Sonalika wheat (HD 1553), grown in Jabalpur. They also did not discuss the reasons for the changes in the values of E_T/E_P with different stages of the growth.

The present study is an attempt to obtain a simple quantitative relationship between the values of E_T/E_P and the characteristic feature of the growth of plants at different stages, namely, the area of the leaves of the plants.

E_P is determined from the amount of water loss through the area of the pan. This area is fixed. On the other hand, E_T is determined as

$$E_T = \frac{\text{The mass of water lost through the soil} + \text{through the plants grown over the soil of the lysimeter}}{\text{The area of the lysimeter}} \quad (1)$$

If the numerator is expressed in kg and denominator in square metres, E_T can be expressed in mm by a suitable choice of a constant depending on the area of the lysimeter. E_T is a function of (a) meteorological conditions, (b) soil moisture conditions and (c) plant area, whereas E_P is a function of meteorological conditions only. Therefore, E_T/E_P is a function of soil moisture conditions and plant area. If it is assumed the same meteorological conditions prevail over lysimeter and the pan, the Eqn. (1) can be recast as

$$E_T = \frac{(E \times \text{Soil area}) + (E \times \text{Plant area})}{\text{Area of lysimeter}} \quad (2)$$

where E is the evaporation taking place per unit area. The exact depedance of E on the soil moisture conditions is rather complex but in general it may be taken to be that

$$E = \frac{W}{W_F} \times E_P$$

where W is the actual soil moisture percentage and W_F is the soil moisture percentage at the field capacity of soil (*see* for instance, Munn 1966).

Therefore, Eqn. (2) can be recast as

$$E_T = \frac{W}{W_F} \times E_P \times \left(\frac{\text{Soil area} + \text{Plant area}}{\text{Area of lysimeter}} \right) \quad (3)$$

$$\therefore \quad \frac{E_T}{E_P} = \frac{W}{W_F} \; \frac{(\text{Soil area}) \left(1 + \dfrac{\text{Plant area}}{\text{Soil area}} \right)}{\text{Area of lysimeter}} \quad (4)$$

It is easily seen that the area of lysimeter can be taken to be soil area. The area of soil is fixed because the changes in soil area to be taken into account on account of stem growth, etc are practically negligible.

$$\therefore \quad \frac{E_T}{E_P} = \frac{W}{W_F} (1+P) \quad (5)$$

where P is the ratio of plant area/soil area, W is the actual soil moisture. We take

$$W = W_b + W_a \quad (6)$$

Where, W_b is the soil moisture percentage assumed to be always present in the soil and W_a is addition of soil

TABLE 3

Year/Day	Stage	MI (mm)	$MI/225$	$X=(0.5+MI/225)$	$Y=1+P$	Calculated values E_T/E_P (range) $E_T/E_P=(X)(Y)CF$*	Actual value of E_T/E_P
1982-32	Sowing to boot leaf	0	0	0.5	1.45	0.5 to 0.73	0.70
1984-35	Sowing to boot leaf	0	0	0.5	1.21	0.4 to 0.60	0.60
1982-45	Boot leaf to flowering	0	0	0.5	2.42	0.72 to 0.96	0.90
1983-55	Flowering to milky stage	4.2	0.02	0.52	3.35	0.52 to 0.82	0.80
1983-82	Milky stage to maturity	0	0	0.5	4.54	0.45 to 0.91	0.70

*Please see Table 4 for values of C.F.

TABLE 4

Stage	Correction Factor (CF) employed in $E_T/E_P=(X)(Y)CF$	The % of occasions when the calculated value of E_T/E_P is within + or −0.2 of actual value
20th day to the day of appearance of boot leaf	0.8 to 1.0	74%
Boot leaf to flowering	0.6 to 0.8	63%
Flowering to milky stage	0.3 to 0.5	83%
Milky stage to maturity stage	0.2 to 0.4	84%

moisture percentage due to an input of irrigation and/or rainfall. We take

$W_a=K'\ MI$ where K' is a constant of proportionality and MI is rainfall and/or irrigation in mm,

$$\therefore \quad W=W_b+K'\ MI \tag{7}$$

$$\therefore \quad \frac{E_T}{E_P}=\frac{W_b+K'\ MI}{W_F}\ (1+P) \tag{8}$$

$$\therefore \quad \frac{E_T}{E_P}=(X'+KMI)\ Y \tag{9}$$

where $X'=W_b/W_F$ and K=constant$=K'/W_F$ and $Y=(1+P)$,

This can be further written as

$$\frac{E_T}{E_P}=XY \tag{10}$$

where, $X=X'+KMI$

From the experimentally determined values of P every week, on the assumption of linearity of growth in the area of leaves known between the periods when areas are determined. The values of P can be determined each day. X' is taken to be 0.5. This value of 0.5 is assumed on the basis of the average of soil moisture values which were obtained during the period under study. K is taken to be 1/225, because the field capacity of the soil was determined to be 225 mm and MI is rainfall and/or irrigation input in mm. Now X, MI, P are known for every day. Therefore, from Eqn. (8) E_T/E_P can be calculated. For each day we can also determine E_T/E_P experimentally. A few examples are given in Table 3.

On an examination of the comparison of the calculated values of E_T/E_P on the basis of Eqn. (10) with actual value of E_T/E_P, it was noticed that the agreement is not very satisfactory. That is obviously the change in E_T and, therefore, change in E_T/E_P is not commensurate with change in plant area and, therefore, with P. On an analysis it was found as given in Table 4 that, the multiplication of $1+P$ (*i.e.*, Y) with suitable correction factor, determined empirically as appropriate to each stage can give the E_T/E_P values close to the actual values. The percentage of occasions when the formula with appropriate correction factors was successful is given in Table 4.

These correction factors were determined empirically. As can be seen in Table 4, the correction factors are found to reduce the value of Y as the plant passes through different phenological stages. The effect of increasing P can, therefore, be said to be two-fold : (a) to increase the E_T due to the increase of area of exposure of plant leaf, (b) to modify the local meteorological conditions (which had hitherto been assumed to be the same as those prevailing over the pan) by restricting incident radiation, reducing the temperature, increasing the relative humidity and affecting the free movement of air-masses, all inhibitory to evaporation processes. The resultant evaporation is a compromise between these two effects.

The present study has given the formula for calculating E_T/E_P over the maize field in Bangalore for the given set of cultural practices. The formula is

$$XY\ (CF)=E_T/E_P \tag{11}$$

where CF is the correction factor appropriate to each stage as given in Table 4.

4. Conclusion

The value of E_T/E_P is essentially a function of plant areas. The present study shows that, while plant area increases E_T by increasing the area of exposure for water loss, E_T/E_P by no means increases in step with increase in plant area. This is because plant canopy modifies the local meteorological conditions in such a way as to inhibit the increase in evaporation. In the present study suitable correction factors appropriate to each stage have been determined empirically and a formula to determine E_T/E_P appropriate to each stage is given. They are found to yield values close to actual values on about 76 per cent of total occasions. The advantage of this method is that given the values of E_P an estimate of E_T can be obtained with reasonable success.

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