Tea Q. 49 (1) 25-33, 1980. Printed in Sri Lanka.

QUANTIFICATION OF WEATHER PARAMETERS TO PREDICT TEA YIELDS

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A weather term, $f_t\ R_w\ S_p$, derived from daily recordings of air temperature, rainfall and sunshine for each month from April to December, in the wet zone hill-country of Sri Lanka, was shown to be strongly correlated with yields of the following month, with a high predictive value, thus enabling prediction of monthly yields at the beginning of each month.

INTRODUCTION

The productivity of a crop depends ultimately on the degree of success of the variety to adapt itself to the seasonal regimes of solar radiation, temperature, water relations and other inputs. After optimising variables such as genetic make-up, soil fertility, and the control of pests and diseases, a limit to productivity may be attained when further increases would become dependent on the proper understanding of the relationship between the uncontrollable variable, weather and plant growth.

In tea, the crop at each harvest is a readily available index of growth in the plant. Many attempts have been made to relate yields with one or more weather parameters (Carr, 1972). Among these the rainfall-evapotranspiration term E_{tw} of Laycock (1964), which is in effect an estimate of water lost by the crop derived from potential evaporation E_o, calculated using Penman's formula, and the rainfall-sunshine-hours product term RS of Devanathan (1975a), gave very significant correlation with yields in Malawi and have scope for further improvement.

In the computation of E_{tw}, when the total rainfall during a ten day period was equal to or exceeded the corresponding total estimate of potential evapotranspiration E_t, ($=0.85E_o$), the total E_t value for each ten day period was used, but when total rainfall was less than total E_t, total rainfall was used. The E_{tw} for the year being the sum total of values computed in the above manner for ten day intervals. Annual yield of constant treatment plots was shown to bear significant correlation to E_{tw}.

E_{tw} is an estimate of the availability of rainfall to the plant. Since it is derived only from rainfall and evapotranspiration with no consideration of available soil water, it is likely to under-estimate rainfall available to the plant, especially when most of the rainfall is at the tailend of the ten day interval, and well above the computed total E_t value. Even if allowance is made for the water holding capacity of the soil, E_{tw} would only be a measure of the water transpired by the plant. Growth in the plant is dependent on photosynthesis and not transpiration, although the latter is a necessary condition it is not a sufficient condition on its own. In this respect the inclusion of hours of sunshine in the weather term is essential. This requirement is partly met in the rainfall sunshine product term RS.

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Using the same Malawi yield data Devanathan showed that monthly yield was strongly correlated with the product rainfall per month (R) and average daily sunshine hours (as given by a Campbell-Stockes recorder) (S) for the previous month. Devanathan (1975b) recently included a temperature term f_t, relating to Q10 of photosynthesis of isolated chloroplasts, derived from the data of Baldry *et al.*, and found the product f_tRS improved the correlation further.

For weather-plant correlation to be meaningful, the weather term must integrate the major climatic factors — temperature, rainfall and sunshine, all of which influence plant growth. Besides, in land plants the fact that they are fixed to the soil, necessitates the consideration of edaphic factors also. Of the weather parameters Et_{tw}, RS and f_tRS considered above, the latter satisfies the first condition, besides it has predictive value also — estimates of f_tRS for any month being correlated to yield in the following month. However, Devanathan indicated the limitations of his weather term in that it is applicable only to tea growing in ideal soil conditions, where all the rainfall is assumed to be available to the plant. Furthermore, no allowance was made for photosynthesis in non-recorded sunshine hours of the day though he assumed that this would be compensated by respiration.

Since soil factors would operate through soil water, modification of R related to soil type and plant needs appears essential; similarly if photosynthesis in the non-recorded sunshine hours of the day is appreciable S should be modified to account for this. This paper reports the derivation of such a formula which is tested with yields from an experiment at St Coombs, in the wet-zone hill country of Sri Lanka.

MATERIALS AND METHODS

An unshaded plot of tea at St Coombs having 770 plants of clone TRI 2024 planted on the contour, spaced 60 cm in rows and 120 cm between rows, was used for obtaining the yield data. The slope of the terrain could be considered typical of tea fields in the hill country of Sri Lanka. The clone is a high yielding 'Assam jat' planted in 1961 whose root system rarely extends below 1 m. A well developed feeder root system (unsuberized roots) is characteristic of this clone, and around 90 per cent of this is confined to the top 45 cm of the soil. The tea was four years after pruning. Crop was recorded on 44 occasions over a period of 12 months from April 1974 to March 1975. During this period a composite fertilizer mixture, T 560 (388 lb sulphate of ammonia, 72 lb saphos phosphate and 100 lb muriate of potash) was applied in August, November and February at the rate of 280 lb per acre. Pest and diseases were kept under control.

The meterological data were obtained from the Tea Research Institute Meteorological Station at St Coombs (longitude 81°E, latitude 7°N, elevation 1500 m and was 150 m from the experimental plot).

RESULTS

The existence of a time-lag in yield response to weather in tea has been reported (Portsmouth, 1957; Sen 1959; Hassan *et al.*, 1965). Devanathan (1975 a & b) found that monthly yield was strongly correlated with the weather parameters RS and f_tRS calculated for the previous month. The time-lag for yield response to weather in our studies too agreed with this observation. The crop of a month will therefore be related to the weather parameter of the previous month.

The monthly yield from the experimental plot was compared with the weather parameters E_{tw}, RS and f_tRS of the previous month and was found to show poor correlation. Examination of the meteorological data from which the weather parameters were derived indicated that of the three weather terms considered the disparity between $f_t RS$ and yield in the period extending from April to December, which constitutes the wet season in the wet zone hill country of Sri Lanka, was mainly due to very high values of R which overestimated the rainfall available to the plant or very low values of S which underestimated the sunshine available for photosynthesis. Based on $f_t RS$ we derived a weather teım that could satisfactorily overcome these shortcomings.

DERIVATION OF THE WEATHER TERM

(a) Temperature Term (f_t) :

The temperature coefficient (f_t) of Devanathan (1975 b) was retained in our weather term. Since it is directly related to rate of photosynthesis in the chloroplast it would satisfactorily account for the effect of temperature on photosynthetic rates in the tea leaf. Values of f_t for temperature ranging from 0° to 35°C are given in Table I where f_t at 25° C is taken as 1. It should however be noted that in full sunshine, leaf temperature may be upto 10° to 15°C above the air temperature, and when air temperature exceeds 25°C rate of photosynthesis in tea leaf falls rapidly (Hadfield, 1968), and thus f_t values computed from Baldry's data may be disproportionately high for temperatures above 25°C, especially in the large leafed 'Assam jat' of tea. Though air temperatures at St Coombs seldom exceed 25°C, in the low country air temperatures as high as 35°C have been recorded.

TABLE 1 – *Rates of Photosynthesis at various temperatures relative to 25° C*
(Devanathan 1975 b)

0° 0.034	1° 0.045	2° 0.059	3° 0.076	4° 0.099	5° 0.123
6° 0.152	7° 0.189	8° 0.226	9° 0.267	10° 0.311	11° 0.352
12° 0.398	13° 0.443	14° 0.484	15° 0.530	16° 0.575	17° 0.662
18° 0.667	19° 0.712	20° 0.756	21° 0.804	22° 0.851	23° 0.901
24° 0.949	25° 1.000	26° 1.050	27° 1.101	28° 1.155	29° 1.209
30° 1,268	31° 1.329	32° 1.389	33° 1,450	34° 1.512	35° 1.570

(b) Rainfall Term (R_w) :

In the computation of the rainfall term we considered that rainfall available to the plant is that available for transpiration. Following the Veihmeyer concept (Penman, 1956) this is taken as the amount of soil water between field capacity and permanent wilting point. For clone TRI 2024 whose effective rooting depth is around 45 cm this is equivalent to 76 mm (3 inches) of rainfall in our tea soil (S. Sandanam, personal communication). Most of the rain that passes through the uniform canopy of tea leaves, 15–20 cm thickness, is assumed to infiltrate the soil and surface run-off for average showers is considered negligible.

The rainfall term, denoted here by R_w, is the value of either daily evapotranspiration E_t or rainfall, whichev er is less (*ie* whichever is limiting water uptake by the plant) and is computed in the same manner Laycock dealt with aggregate values of E_t and rainfall for ten day intervals. The essential difference in our approach is that we account for excess rainfall that would be available in the soil in days when rainfall exceed E_t. Knowing that the freely available water in the root régime of clone TRI 2024 in our soil is 76 mm, rainfall exceeding evapotranspiration ($R-E_t$) to a maximum of 76 mm is carried over to the following day to be added to the rainfall value. This does not permit the use of means of aggregate values of E_t or R for computing the rainfall term R_w, which will have to be calculated daily. Since the maximum value for R_w will not exceed E_t the ratio R_w/E_t on any day will have values from 1 to 0, and could be considered to be an index of availability of water for transpiration and the value is considered here as the '*transpiration index*' (which would be inversely related to soil 'water stress', 'aridity' or 'droughtiness', on the basis of which the year is divided into wet and dry seasons (Kandiah, 1980). It must be conceded that though this is a convenient working hypothesis for determining available water it is in fact only an approximation to water taken up by the plant, as the factors that control water use by the plants, especially under stress can be more complex.

Calculation of E_o :

Potential evaporation E_o used in the estimation of evapotranspiration E_t can be calculated using Penman's equation and the tables given by McCulloch (1965) for rapid computation. If the meteorological data required for computation of Penman's estimate are not available pan evaporation values can be used instead. However, few estates in Sri Lanka maintain records of the relevant meteorological data for calculating E_o. In many estates the only meteorological record available is rainfall. Some record (or have facilities to record) air temperature and sunshine hours. Using the latter we may calculate E_o at our latitude assuming that direct solar radiation is the only significant source of energy for evaporation of water.

Net solar radiation is around 55 per cent of total solar radiation and varies only little with season (Monteith, 1965). $E_o = R_n/L$ (where R_n is the net radiation and L is the latent heat of evaporation = 590 calories per g). R_n can be calculated from total radiation at the top of the atmosphere (R_a), given in the Smithsonian Meteorological Tables using the Glover and (McCulloch (1958) equation which reads as:-

$$R_n = R_a \left[0.29 \cos \lambda + 0.52 \frac{n}{N}\right]$$

Hence E_o may be written as

$$0.55\, R_a \left[0.29 \cos \lambda + 0.52 \frac{n}{N}\right]/L$$

$$\text{Therefore } E_o = \frac{R_n}{L} = 0.55\, R_a \left[\frac{0.29 \cos \lambda + 0.52 \frac{n}{N}}{590}\right] \text{cm}$$

Where n = Actual sunshine hours recorded
N = Maximum possible sunshine hours (= day length)
λ = Latitude ($0.29 \cos 7° = 0.2878$)

Monthly values of R_a (cal cm^{-2} day^{-1}) and N (hr) for Sri Lanka latitude 7°N) and the equation for the daily estimation of E_t (= $0.85E_o$) from recordings of sunshine hours are given in Table 2.

TABLE 2 — *Monthly values of solar radiation at the top of the atmosphere (Ra) in cal cm^{-2} day^{-1}, maximum possible sunshine hours (N) for Sri Lanka (latitude 7°N) and the corresponding equation for estimating daily water requirement of the crop (=.85E_o mm) from hours of sunshine (n) recorded by Campbell-Stokes recorder*

	*Ra**	*N**	*Equation for .85E_o***
January	788	11.75	1.7966 + .2763 n
February	841	11.89	1.9178 + .2914 n
March	881	12.10	2.0090 + .3000 n
April	888	12.24	2.0250 + .2989 n
May	868	12.45	1.9794 + .2873 n
June	850	12.52	1.9383 + .2797 n
July	856	12.45	1.9520 + .2833 n
August	872	12.38	1.9885 + .2902 n
September	876	12.17	1.9976 + .2966 n
October	850	11.96	1.9383 + .2928 n
November	800	11.82	1.8243 + .2789 n
December	770	11.75	1.7559 + .2700 n

* From McCulloch, 1965

** $.85E_o = .0022804\ Ra + (.0041203\ Ra/N)n = Et$ mm

(c) Sunshine Hours Term (S_p) :

Sunshine hours as recorded by the Campbell-Stokes recorder records only bright sunshine. Experimental evidence indicated that photosynthesis in tea leaves was appreciable even on cloudy days with unrecorded sunshine hours. Hence, a fraction of the unrecorded hours of the day (= N–n) should be added to the recorded hours (= n), to get the effective sunshine hours for photosynthesis represented here by S_p. Using values ranging from 0.1 to 0.6 (N–n) in the computation of S_p we found $S_p = n + 0.3$ (N–n) gave the best correlation for the weather term with yield. Thus the sunshine hours term used is the total or recorded hours of the day and 30 per cent of the unrecorded hours of the day.

The weather term for yield determination is the product of the three terms derived from daily recordings of air temperature, rainfall and sunshine and is denoted $f_tR_wS_p$, which is considered here as the '*photosynthetic potential*' of the environment. In the computation of $f_tR_wS_p$, for any period mean values are not used. The product of mean values of f_t, R_w and S_p will be different from the total of daily $f_tR_wS_p$. Hence the product of $f_tR_wS_p$ is estimated daily, as exemplified in Table 3 by selecting a few days in July, October and February, and added to give the weather term for any period.

TABLE 3 — *Methods of computing the weather term $f_tR_wS_p$ from daily recordings of air temperature, rainfall and sunshine hours, exemplified by selecting a few days in 1974/75 differing in soil water content*

Meteorological Data	*July (Very Wet)*		*October (Wet)*		*February (Dry)*	
	16th	*27th*	*22nd*	*23rd*	*18th*	*26th*
a — Maximum temperature (°C)	18.3	18.9	23.9	24.4	26.0	24.8
b — Minimum temperature (°C)	15.1	15.8	11.4	8.9	6.8	9.1
c — Rainfall (mm) ...	335.2	75.4	0.0	0.0	0.0	0.5
d — Sunshine (hours from Campbell Stokes recorder) ...	0.0	0.0	10.8	11.2	11.2	8.4
e — Day length (N hours from Table 2) ...	12.45	12.45	11.96	11.96	11.89	11.89
Derivation of f_t, R_w and S_p						
Temperature coefficient (f_t)						
f — Mean temperature [=(a + b)/2]°C ...	16.7	17.4	17.7	16.7	16.4	16.9
g — f_t = value in Table 1 corresponding to temperature in f ...	0.608	0.640	0.654	0.608	0.594	0.617
Rainfall term (R_w)						
h — Evapotranspiration (=E_t mm calculated using Table 2 & d) ...	1.95	1.95	5.10	5.22	5.18	4.37
i — Available water in soil carried over from previous rainfall (=j — h)* mm to a maximum of 76 mm)	76.00	76.00	11.00	5.90	0.0	0.0
j — Rainfall used for computing R_w = (c + i) mm ...	411.00	151.00	11.00	5.90	0.0	0.5
k — R_w = h or j whichever is less ...	1.95	1.95	5.10	5.22	0.0	0.5
Sunshine term (S_p)						
l — S_p = d + 0.3 (e — d) ...	3.7	3.7	11.1	11.4	11.4	9.4
Weather term						
= $f_tR_wS_p$ = g x k x l ...	4.39	4.62	37.02	36.18	0.0	2.90

* Values of j & h refer to those of the previous day where negative values of (j—h) are considered 0.

Correlation of $f_tR_wS_p$ with yield

Monthly yield from the experimental plot during the period April to December, and weather parameters for the previous month are tabulated in Table 4 (column A). The correlation coefficient of $f_tR_wS_p$, tested against those of the other weather terms was significantly better (P = 0.05).

TABLE 4 — *Correlation between monthly yields (kg/ha), from April to December, and weather terms $f_tR_wS_p$, f_tRS, RS and E_{tw} for the preceding month.* (A) *data from experimental plot.* (B) *data from St Coombs Estate —mean of five years from 1971 to 1975*

Month	*Yield*		*Weather terms for the preceding month*							
	Experimental plot	*Estate*	$f_tR_wS_p$		f_tRS		*RS*		E_{tw}	
	(A)	*(B)*	*(A)*	*(B)*	*(A)*	*(B)*	*(A)*	*(B)*	*(A)*	*(B)*
April	272	149	683	483	748	409	1056	648	79	46
May	329	242	803	686	856	864	1173	1087	129	99
June	192	133	370	559	603	673	827	937	76	89
July	160	128	382	330	634	457	926	671	88	76
August	140	133	262	432	1232	749	1834	1110	72	81
September	237	136	602	432	1049	673	1512	1016	114	79
October	131	163	307	432	638	668	971	996	87	71
Novemner	265	156	720	508	538	625	822	856	50	84
December	151	178	608	559	490	635	735	955	88	94
Correlation coefficient			0.87	0.80	0.06	0.56	0.02	0.38	0.33	.46

During the dry season, which extends from January to March, the weather term failed to quantify the yield potential of the weather.

The values for R_w and S_p in the weather term will vary with soil type and 'jat' or clone of tea considered. However, in a well managed estate with a mixed plant population growing in the same land area, edaphic, genetic or morphogenetic effects that are likely to influence R_w and S_p are liable to be constant. But, $f_tR_wS_p$ vs crop correlation is bound to fail if management practices are not geared to reap the cropping potential of the weather. Comparing the mean monthly yield from St. Coombs Estate for five years from 1971 to 1975, with mean $f_tR_wS_p$, it is found that of the four weather terms tested, $f_tR_wS_p$, gave the best correlation to yield from April to December. The mean values for yield and the corresponding weather terms are presented in Table 4 (column B).

The significant correlation between monthly yield and $f_tR_wS_p$ of the previous month from April to December makes the prediction of monthly yield possible at the beginning of these months.

Calculation of the regression equation for the experimental data from April to December gave $Y = 3.065\ f_tR_wS_p + 47.464$. The 5 per cent confidence limits to the regression line contain the line passing through the origin, which could be represented by $Y = 3.968\ f_tR_wS_p$ [S.E. (b) = + 0.673].

DISCUSSION

In spite of many investigations on the response of tea to climate, a weather term integrating the various components of weather is lacking (Carr, 1972; Pereira, 1973). In the derivation of $f_tR_wS_p$ it is hoped that some progress has been made in this direction, and a promising line of approach to weather/crop interaction indicated. However, the approach is empirical and may need modifications to be applicable to climatic conditions differing markedly from up-country conditions in Sri Lanka.

Since transpiration index (R_w/E_t) is unity or near unity from April to December, it would appear that water is unlikely to limit growth and simpler weather parameters such as f_t, S_p or f_tS_p would correlate with yield during the rainy season, but this was not so because, by derivation R_w is an index of water transpired by the plant, which can be different for periods with the same transpiration index. However, it must be noted that values of R_w were estimated assuming that water is equally available for transpiration up to a pre-determined value (= 76 mm). Transpiration would take place even after $R_w = 0$, the extent and duration of which is not known. This could be one of the reasons for f_t,R_wS_p failing in the dry months, which are characterised by a transpiration index less than 1, more often 0 (Kandiah, 1980).

Testing $f_tR_wS_p$ with yield from low-country districts of Sri Lanka indicated that it was not as good a predictive term as for the upcountry. Probably as already indicated, the temperature coefficient, and perhaps, R_w, may have to be modified to suit the higher temperatures recorded at lower elevations. Besides water stress experienced by the plant in the dry season in the hillcountry, and also in the comparatively warmer climate at lower elevations, could alter growth metabolism modifying partitioning of assimilates and thereby altering the cropping response to weather and a modified weather term will have to be derived to suit these conditions. Nevertheless, a third of the tea in Sri Lanka is grown in the wet zone hillcountry where $f_tR_wS_p$ could serve as a predictive term for yield from April to December, when 75 per cent of the crop is harvested.

In tea where yield consists of entirely vegetative growth, yield prediction is synonymous with prediction of growth potential of the plant. Thus, in $f_tR_wS_p$ the tea planter has a means of assessing the growth potential of the plant during the part of the year when many of the cultural operations such as pruning, manuring, spraying etc., are implemented. The implications of $f_tR_wS_p$/crop relationship in the management of tea plantations are dealt with in a subsequent paper (Kandiah, 1980).

ACKNOWLEDGEMENTS

The encouragement given by the late Dr. M. A. V. Devanathan, past Director, Tea Research Institute of Sri Lanka, and the assistance rendered by Mr. S. Wimaladharma, Miss R. Subramaniam and Miss S. Puvanamalar, during the course of this study are acknowledged. We are indebted to Professor W. W. Schwabe for reading the manuscript and making helpful suggestions, and to Professor J. P. Hudson for critical evaluation of the paper which led to useful modifications in presentation.

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