Models to elucidate crop-weather association in turmeric (Curcuma longa L.)

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Models to elucidate crop-weather association in turmeric (*Curcuma longa* L.)

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Abstract: *Weather is a non-monetary and highly variable input in crop production. In this paper attempt was made to study the influence of weather elements on turmeric yield. The data on turmeric dry yield (kg ha^{-1}) and weather parameters viz., maximum temperature (TMAX) and minimum temperature (TMIN), rainfall (RAIN), maximum relative humidity (RHMAX) and minimum relative humidity (RHMIN), solar radiation (RADN), bright sunshine hours (SUNS), wind speed (WIND) and evaporation (EVPN) were collected from official records for 1979–80 to 1999–2000. The second-degree polynomial regression was fitted between yield and weekly weather variables. Weather changes gradually during life span of turmeric and accordingly response also varies for different weather elements. The response was negative for TMAX, SUNS, WIND and EVPN throughout the growing period. The response for TMIN, RAIN and RADN was negative during establishment and vegetative phases and positive during later part of crop growth i.e., maturity phase. RHMAX and RHMIN have showed a linear association with negative influence at establishment and positive effect at vegetative and maturity phases. The study gave a tentative estimation of parameters for greatly simplified functional relationships postulated in equations and it is possible to explain variations of turmeric yield on the basis of change in weather.*
Keywords: *crop-weather model,* Curcuma longa, *spice, turmeric.*

Riassunto: *Il tempo atmosferico è un input non monetario ed altamente variabile per la produzione agricola. In questo lavoro si è tentato di valutare l'influenza delle variabili atmosferiche sulla resa della curcuma. Per fare ciò per il periodo dal 1979-1980 al 1999-2000 si sono raccolti dai registri ufficiali i dati di produzione di curcuma espressa in sostanza secca (kg ha-1) e le variabili meteorologiche relative, costituite da temperatura massima e minima (Tmax, Tmin), pioggia (RAIN), umidità relativa massima e minima (RHMAX, RHMIN), radiazione solare globale (RADN), ore di pieno sole (SUNS), velocità del vento (WIND) ed evaporazione (EVPN). Fra i dati di resa e le variabili meteorologiche settimanali si è eseguita una regressione polinomiale di secondo grado con l'obiettivo di modellare il fatto che il tempo atmosferico varia gradualmente durante l'arco di vita della coltura e di conseguenza varia anche la risposta alle diverse variabili meteorologiche considerate. Nello specifico si è individuata una risposta produttiva negativa per TMAX, SUNS, WIND e EVPN durante tutto il periodo di crescita. La risposta produttiva a TMIN, RAIN e RADN è stata invece negativa durante le fasi di primo sviluppo e per tutte le fasi vegetative, per divenire poi positiva nelle fasi più tardive prossime alla maturazione. RHMAX e RHMIN hanno mostrato un'associazione lineare con influenza negativa nella fase di primo sviluppo seguita da un persistente effetto positivo durante le fasi vegetative e quelle riproduttive, fino alla maturità. In complesso lo studio ha offerto una stima sperimentale dei parametri di relazioni funzionali che pur nella loro estrema semplicità consentono di spiegare le variazioni di rendimento della curcuma in base alla variabilità meteorologica.*
Parole chiave: *modelli di produzione,* Curcuma longa, *spezie.*

1. INTRODUCTION

Turmeric (*Curcuma longa* L.) is one of the commercially important tropical rhizomatous spices, belongs to *Zingiberaceae*. The habitat of the crop ranges from subtropical dry to wet through tropical dry to wet forests life zones. It is cultivated extensively in tropical regions of the world, grown in Bangladesh, India, Iran, Pakistan, China, Japan, Sri Lanka, Indonesia, Taiwan, Peru, Haiti, Jamaica, Liberia, Nigeria, Sudan and Vietnam. India is the largest producer and exporter. The yellow coloring of turmeric is due to the presence of 'curcumin' which is a natural color, gaining wider use in food industry, pharmaceuticals and preservatives and in health and body care. Climates, changing spatially and secularly, have enormous influence on crop growth and development, resulting in large year-to-year and location-to-location variation in crop yield. The knowledge of role of climate is an essential precondition for sustainable production of crops (Sivakumar *et al.*, 2000). Detailed information of the influence of weather and climate on turmeric is of vital importance for scientist, research manager and development agencies which are lacking for spices including turmeric (Venkatraman and Krishnan, 1992). Watson (1963), Arnon (1972), Monteith (1981), Rechcigl (1982) and van Keulen (1987) discussed the influence of climate on

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crop production. The aim of crop weather relationship (CWR) studies are (i) to understand the crop response to climate/environment, (ii) to forecast crop yield before harvest based on weather for policy planning and management. The reviews of Baier (1973 and 1977), Baier *et al.*, (1976), Frere and Popov (1979), WMO (1982), Wisiol (1987), NCMRWF (1990) and Horie *et al.*, (1992) on CWR and yield forecast based on weather are important documents.

Least-squares regression has formed one of the principle methods in CWR studies (Jones, 1982). Physiological (Causal) and statistical (Correlative) approaches are two main methods to study CWR (McQuigg 1982). Baier (1979) has classified CWR studies into three, (i) mechanistic–type crop growth simulation models, (ii) statistically–based crop–weather analysis models (CWAM) and (iii) multiple–regression yield models. Sakamoto (1981) divided the technology of CWR studies into three stages depending upon availability of data and sophistication of hardware. The crude implement stage use basic observations (e.g. temperature and precipitation), as indices; the machine stage involving simple models (e.g. regression) which short-circuits the causal approach; the third stage, the process-oriented modeling approach involves a system approach to the problem. The process-oriented simulation models are better research tools to understand CWR, but many tropical crops including turmeric seldom have such mechanistic type models.

Relatively simpler data requirements of CWAM are a practical research tool for the analysis of crop responses to weather and climate. The CWAM defined as the simplified functional relationship between a particular plant response (e.g. yield) and the variations in selected weather variables at different plant developmental stages. Fisher (1924) studied the gradual change of the effect of weather variables on crop yield development during the growing season with special statistical technique. He assumed that the effects of change in weather variables in successive weeks would not be an abrupt or erratic change but an order one that follows some mathematical law. Gangopadhyaya and Sarker (1965), Ramamurthy and Banerjee (1966), Lomas (1972), Sreenivasan (1972), Lomas and Shashoua (1973) and Saha and Banerjee (1975) have studied the CWR by using Fisher's technique. Hendricks and Scholl (1943) has modified the Fisher's 'orthogonal polynomial technique'. They assumed that a second-degree polynomial in a week number was sufficiently flexible to express the relationship. Stacy *et al.*, (1957), Runge (1968), Huda *et al.*, (1975 and 1976) have adopted this method to find CWR. In this study attempts have been made to understand how the intensity and distribution of different climatic variables during growth affect the turmeric dry yield.

2. MATERIALS AND METHODS

2.1. Dataset

The Erode district in Tamil Nadu State of India is an efficient turmeric producer, where a relative spread and yield are very high (Kandiannan *et al.*, 2000) and selected for the study. The continuous reliable daily weather data of maximum temperature (TMAX), minimum temperature (TMIN), rainfall (RAIN), evaporation (EVPN) and sunshine hours (SUNS), wind speed (WIND), maximum relative humidity (RHMAX), minimum relative humidity (RHMIN) and solar radiation (RADN) for 22 years (1979 to 2000) were collected from the Agricultural Research Station of Tamil Nadu Agricultural University, Bhavanisagar (11°.29'N, 77°.08'E and 256 m msl) in Erode district and weekly mean/total were calculated from daily data. The data on turmeric dry yield (kg ha^{-1}) for this district was collected from Season and Crop Report, Government of Tamil Nadu, Chennai for 1979-80 to 1999-2000 and these data were used for the study.

2.2. Modeling

Turmeric is an annual crop with duration of 43 weeks. Normally planted during 19^{th} week (May 7-13) and harvested in subsequent year 9^{th} week (Feb 26-Mrach 4). Model fitted between dry turmeric yield and weekly weather variables is of the form:

$$\mathbf{Y} = \mathbf{A_0} + \mathbf{a_1} \sum_{i=1}^{n} \mathbf{t_i^o} \mathbf{X_i} + \mathbf{a_2} \sum_{i=1}^{n} \mathbf{t_i^1} \mathbf{X_i} + \mathbf{a_3} \sum_{i=1}^{n} \mathbf{t_i^2} \mathbf{X_i} + \mathbf{DT}$$

where,

Y = crop yield (dry turmeric) (kg ha^{-1});

x_i = any climatic variable within any given seven day period

t_i = the number of each of seven day periods (it is 1 for the period from May 7 – 13 (19^{th} Standard week) and 43 for the period from subsequent February 26 to March 4 (9^{th} Standard week)

n = 43 seven day periods in a given crop season.

T = year number

A_0, a_1, a_2, a_3 and D = constants

The year number for the beginning was assigned with one and it increases progressively and ends at last year. The year number was included to correct upward or downward trend.

3. RESULTS

The distribution of weekly climatic variables from 1st week to 43rd week is presented in Fig. 1 (1a to 4a) and 2 (5a to 9a). The multiple regression equations obtained for different climatic parameters and yield (Tab. 1) are utilized to estimate net change in yield for a unit increase or decrease in average weather variables was estimated.

3.1. Effect of temperature

The average maximum daily temperature during the turmeric-growing season varied from 29.8° to 37.6°C. The distribution of average maximum daily temperature for each seven-day period during the turmeric-growing period showed a decreasing trend up to January 7 and it increased in the subsequent weeks and continued up to harvest. The average weekly maximum temperature during the establishment, vegetative and maturity phases was 35.2°, 32.4° and 31.0°C, respectively. The net change in turmeric yield for different weeks of the growing season when the temperature was 1°C above the average maximum daily temperature is presented in Fig. 1 (1b). During the first week, the average maximum daily temperature was 37.6°C. An increase of 1°C above this value reduced the turmeric yield by 84.83 kg ha^{-1}. If the temperature was 1°C less than the average, an increase in yield of the same magnitude was observed. The harmful effect decreased progressively and reached near zero during 26th week (Oct. 29 - Nov. 4). Again, from 27th week onwards an adverse effect gradually increased up to maturity. The trend could be reverse for unit decrease in maximum daily temperature below average in each seven-day period.

The average minimum daily temperature during the turmeric-growing season varied from 19.6° to 27.3°C. The distribution showed a decreasing trend from the first week (26.5°C) to 38th week (19.6°C). It was 20.4°C in 39th week and gradually increased up to harvest (21.9°C). The average weekly minimum during establishment, vegetative and maturity phase was 26.2°, 24.5° and 20.8°C, respectively. The net change in turmeric yield during different weeks of growing season for an increase of 1°C above the average minimum daily temperature is shown in Fig. 1 (2b). During the first week, the average minimum daily temperature was 26.5°C. An increase of 1°C above this value produced an

Sl No	Weather parameter	Second degree Multiple Regression Equation	R^2
1	TMAX	$Y = 38950.42 - 92.0206\sum_{i=1}^{43} t_i^0 X_i + 7.336789\sum_{i=1}^{43} t_i^1 X_i - 0.14.623\sum_{i=1}^{43} t_i^2 X_i + 343.6956T$	0.29
2	TMIN	$Y = 26149.39 - 94.2946\sum_{i=1}^{43} t_i^0 X_i + 0.062095\sum_{i=1}^{43} t_i^1 X_i + 0.123434\sum_{i=1}^{43} t_i^2 X_i + 147.6398T$	0.61
3	RAIN	$Y = 6035.937 - 14.7287\sum_{i=1}^{43} t_i^0 X_i - 0.31192\sum_{i=1}^{43} t_i^1 X_i + 0.032807\sum_{i=1}^{43} t_i^2 X_i + 363.3467T$	0.73
4	RHMAX	$Y = -15697.693 - 9.3477894\sum_{i=1}^{43} t_i^0 X_i + 0.5865894\sum_{i=1}^{43} t_i^1 X_i + 0.0040\sum_{i=1}^{43} t_i^2 X_i - 444.00063T$	0.91
5	RHMIN	$Y = -352.7524 - 3.612115\sum_{i=1}^{43} t_i^0 X_i + 0.472885\sum_{i=1}^{43} t_i^1 X_i - 0.005208\sum_{i=1}^{43} t_i^2 X_i - 181.9419T$	0.99
6	EVPN	$Y = 14678.39 - 12.4578\sum_{i=1}^{43} t_i^0 X_i + 0.943434\sum_{i=1}^{43} t_i^1 X_i - 0.08427\sum_{i=1}^{43} t_i^2 X_i + 302.1245T$	0.37
7	RADN	$Y = -10512.401 + 38.634818\sum_{i=1}^{43} t_i^0 X_i - 11.90796\sum_{i=1}^{43} t_i^1 X_i + 0.3399538\sum_{i=1}^{43} t_i^2 X_i - 257.06113T$	0.99
8	SUNS	$Y = 16112.67 + 89.6422\sum_{i=1}^{43} t_i^0 X_i + 4.421037\sum_{i=1}^{43} t_i^1 X_i - 0.07801 t_i^2 X_i + 407.1435T$	0.44
9	WIND	$Y = 7651.7238 - 9.2227733\sum_{i=1}^{43} t_i^0 X_i - 0.010610\sum_{i=1}^{43} t_i^1 X_i - 0.0011561\sum_{i=1}^{43} t_i^2 X_i - 19.837291T$	0.45

Tab. 1 - Models for dry turmeric yield and weekly weather with regression co-efficient (R^2).
Tab. 1 - Modelli produttivi che correlano la produzione di curcuma secca ed i valori settimanali delle variabili meteorologiche, con i relativi coefficienti di regressione.

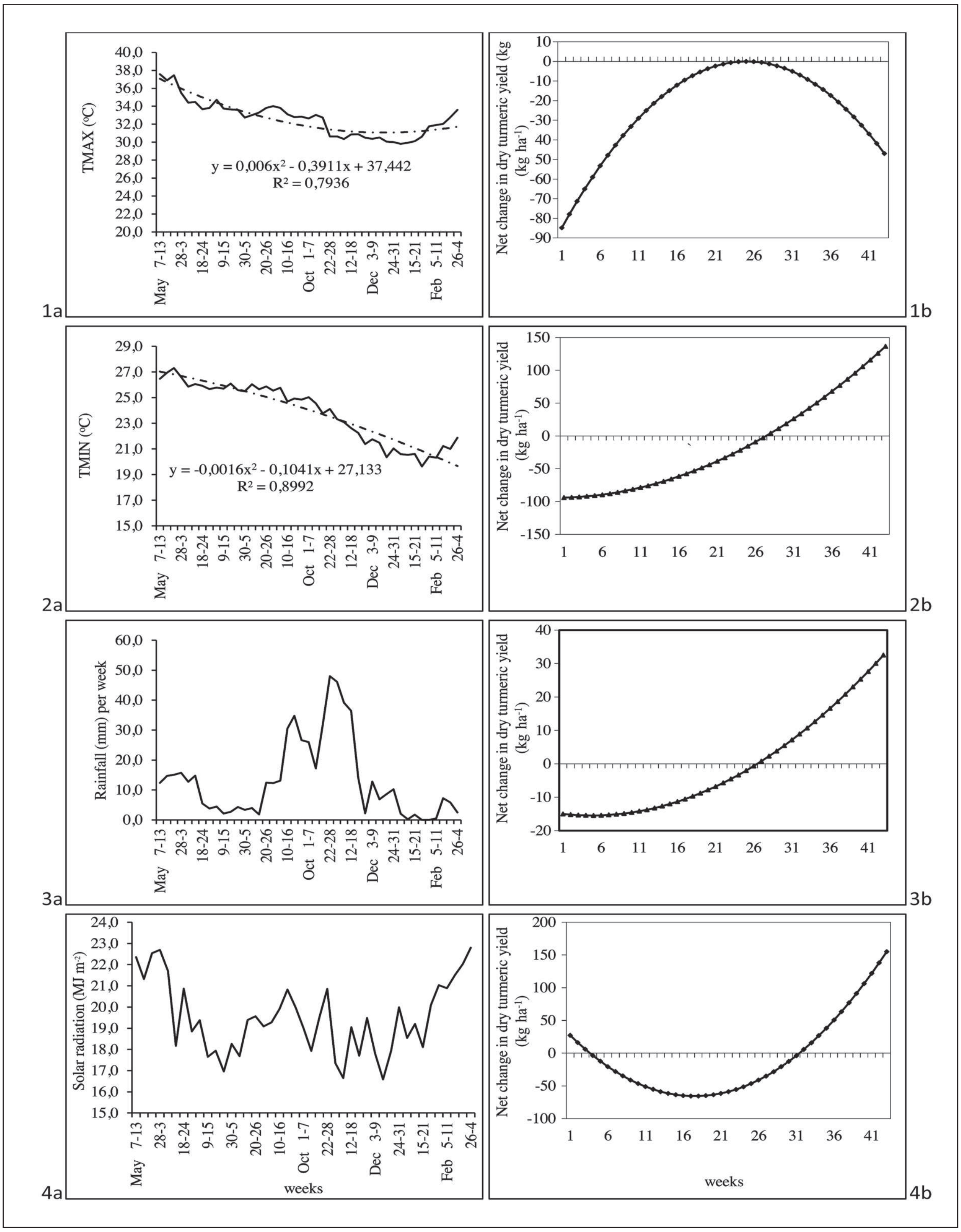

Fig. 1 - 1a to 4a are distribution of weekly TMAX, TMIN, RAIN & RADN; 1b to 4b are net change in dry turmeric yield (kg ha^{-1}) due to a unit change in weekly weather than average.

Fig. 1 - Le immagini sulla sinistra (da 1a a 4a) illustrano la distribuzione dei valori settimanali di TMAX, TMIN, RAIN e RADN mentre quelle sulla destra (da 1b a 4b) illustrano la variazione netta nella resa in sostanza secca (kg ha^{-1}) cui dà luogo una variazione unitaria rispetto alla media nei valori medi settimanali delle variabili meteorologiche.

adverse effect on yield by 94.10 kg ha^{-1}. The adverse effect continued up to 27th week (2.63 kg ha^{-1}). Had there been a decrease in this average temperature by 1°C, a beneficial effect of the same order would have been obtained. From 28th week onwards the beneficial effect was observed for 1°C increase in minimum daily temperature above the average. The same trend was continued up to harvest. Had there been a decrease in minimum daily temperature by 1°C below the average during the 28th to 43rd week, a harmful effect on yield of the same order would have been observed.

3.2. Effect of rainfall

The total rainfall during turmeric growing season in a study period of 10 years ranged from 343.5 mm (1982-83) to 1039.3 mm (1987-88) with a mean of 566.0 mm. The average weekly total rainfall received was 12.4 mm during the first week and it increased up to sixth week (July 11-17). From 7th week onwards there was decreased trend in rainfall (5.4 mm) and extended up to 15th week (1.8 mm) (Aug. 13-19). Again there was increased trend of rainfall from 16th week (12.5 mm) (Aug. 20-26) on wards and it further extended in the subsequent weeks, and reached the maximum of 48.0 mm at 25th week (Oct. 22-28). Then onwards the rainfall showed decreased trend towards maturity. The net change in yield on different weeks of growing season for rainfall of 1 mm above the average weekly total was calculated. The results (Fig. 1 - 3b) clearly indicated that the variation in rainfall during different growth stages had different effects on yield. If there was an increase of 1 mm rainfall over the average during the first week, an adverse effect of yield reduction by 15.01 kg ha^{-1} was observed. This adverse effect increased in the following weeks and reached higher (15.47 kg ha^{-1}) during 5th week (June 4-10). From 6th week onwards the adverse effect declined and reached the lowest at 26th week (0.66 kg ha^{-1}). A beneficial effect of the same order might have been seen if the rainfall was 1 mm less than the average from 1st week to 25th week. An increase of 1 mm rainfall over the average during 27th week was beneficial for the crop yield, to the tune of 0.77 kg ha^{-1}. The beneficial effect of rainfall in the following weeks were also observed with the maximum advantage of 32.52 kg ha^{-1} when rainfall was 1 mm above the average at the end of maturity phase. An adverse effect of the same magnitude would have been obtained if the weekly total rainfall were 1 mm less than the average during 27th - 43rd week.

3.3. Effect of solar radiation

The average daily solar radiation during the turmeric-growing season varied from 16.9 to 22.50 MJ m^{-2} day^{-1}. It was 18.67, 18.82 and 19.7 MJ m^{-2} day^{-1} during the establishment, vegetative and maturity phases, respectively. The net change in dry turmeric yield for different weeks for one unit increase in the average daily solar radiation is given in Fig. 1 (4b). During the first week, the average daily solar radiation was 22.36 MJ m^{-2}. An increase in one unit above this average was beneficial by 27.1 kg ha^{-1}. It reduced in the following weeks. From 4th week onwards, harmful effect was noticed for unit increase of solar radiation above the average. This adverse effect reached the maximum (65.6 kg ha^{-1}) during 17th and 18th week and gradually decreased up to 31st week. Again from 32nd week onwards, the beneficial effect was observed and it reached the maximum at harvest (155.2 kg ha^{-1}). If the average daily solar radiation decreased by one MJ m^{-2} day^{-1} below the average during turmeric-growing season, then the trend would have been reversed in the same order.

3.4. Effect of relative humidity

The average maximum daily relative humidity during the turmeric-growing period ranged from 72 to 90 per cent. It was 74.9, 82.0 and 86.5 per cent during the establishment, vegetative and maturity phases, respectively. The net change in turmeric yield for different weeks of growing season for one per cent increase in the maximum daily relative humidity is given in Fig. 2 (5b). During the first week, the average maximum daily relative humidity was 80 per cent. An increase of one per cent above this value decreased the yield by 8.76 kg ha^{-1}. This adverse effect steadily decreased up to 14th week. Subsequently, from 15th week onwards the beneficial effect was observed for a unit increase in average daily maximum relative humidity. The trend continued up to harvest. If the average maximum relative humidity decreased below the average, the trend would have been reverse with same magnitude.
The average minimum daily relative humidity during the turmeric-growing season varied from 37 to 58 per cent. It was 44.3, 49.8 and 46.2 during the establishment, vegetative and maturity phases, respectively. The net change in turmeric yield for different weeks of growing season for one per cent increase in the minimum daily relative humidity is given in Fig. 2-6b. During the first week, the average minimum daily relative humidity was 45 per cent. An increase of one per cent above this value decreased

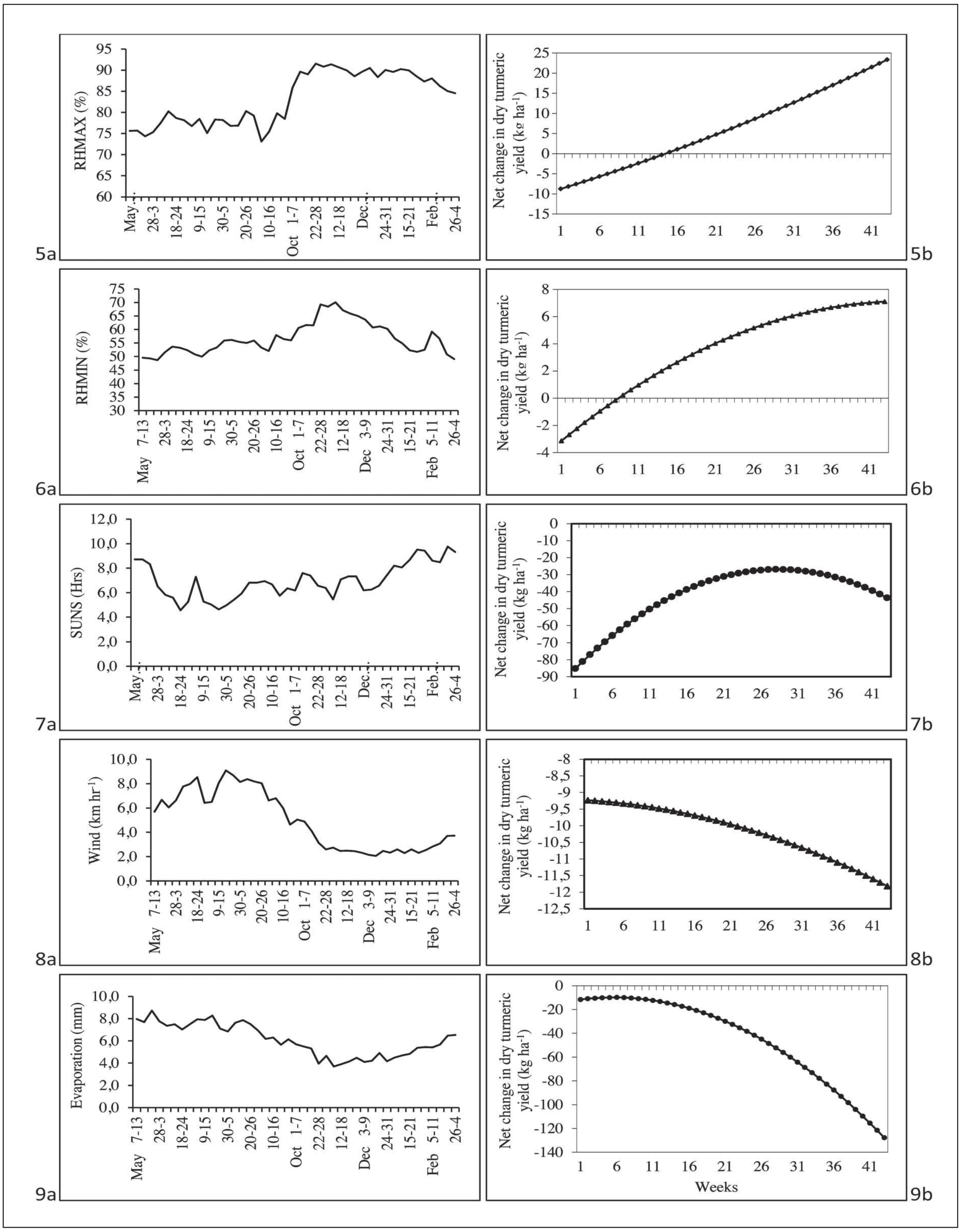

Fig. 2 - 5a to 9a are distribution of weekly RHMAX, RHMIN, SUNS, WIND & EVPN; 5b to 9b - net change in dry turmeric yield (kg ha^{-1}) for unit change in weekly weather than average

Fig. 2 - Le immagini sulla sinistra (da 5a a 9a) illustrano la distribuzione dei valori settimanali di RHMAX, RHMIN, SUNS, WIND & EVPN; mentre quelle sulla destra (da 5b a 9b) illustrano la variazione netta nella resa in sostanza secca (kg ha^{-1}) cui dà luogo una variazione unitaria rispetto alla media nei valori medi settimanali delle variabili meteorologiche.

the yield by 3.14 kg ha^{-1}. This harmful effect steadily declined in the following weeks and from 9th week onwards an increasing trend was observed (Fig. 2 - 6b). The trend could be reverse if the minimum daily relative humidity decreased by one per cent above this average.

3.5. Effect of sunshine

The average daily sunshine during the turmeric-growing period varied from 3.7 to 9.8 hrs day^{-1} with a mean of 7.0 hrs day^{-1}. It was high during the first week and decreased in the following weeks up to 12th week (July 23-29). Subsequently, from 13th week onwards it increased gradually and reached the maximum at harvest. The average weekly sunshine during the establishment, vegetative and maturity phases was 6.6, 6.3 and 8.2 hrs day^{-1}, respectively. The net change in turmeric yield due to an hour increase of sunshine day^{-1} was calculated and presented in Fig. 2 (7b). During the first week, the average daily sunshine was 8.7 hrs day^{-1}. An increase of one hour had an adverse effect in terms of yield reduction by 85.30 kg ha^{-1}. This harmful effect decreased in the following weeks and reached the minimum (270.71 kg ha^{-1}) during 28th week. Beyond this week (Nov. 12-18), the yield was declined progressively till the harvest. Had there been a decrease of sunshine by one-hour day^{-1} from average the beneficial effect of the same order would have been realised.

3.6. Effect of wind

The average daily wind speed at eight feet height during the turmeric-growing period ranged from 0 to 18.4 km hr^{-1}. It was 7.0, 5.3 and 2.7 km hr^{-1} during the establishment, vegetative and maturity phases, respectively. The net change in turmeric dry yield at different weeks for an increase of wind speed one km hr^{-1} over the average is given in Fig. 2 (8b). During the first week, the daily average wind speed was 5.7 km hr^{-1}. If it increased above this average, a harmful effect (9.2 kg $ha^{-1}$of yield reduction) was observed. This adverse effect continued throughout the growing season with gradual increase up to harvest. If the wind speed decreased below the average daily value during each seven-day period of growing season, the beneficial effect of same magnitude would have been observed.

3.7. Effect of evaporation

The average daily evaporation during the turmeric-growing season ranged from 3.7 to 8.7 mm with a mean of 6.1 mm day^{-1}. In general, the distribution of evaporation in each seven-day period during the turmeric-growing season showed a decreasing trend up to 31st week (Dec. 3-9). Subsequently, it increased gradually during the following weeks and continued up to the end of the season. The average weekly evaporation during the establishment, vegetative and maturity phases was 7.7, 5.9 and 5.1 mm, respectively. The net change in turmeric yield for different weeks of the growing season for 1 mm increase in the average evaporation was calculated and presented in Fig. 2 (9b). During the first week, the average daily evaporation was 8.0 mm. An increase of 1 mm, above this value brought an adverse effect on yield to the tune of 11.60 kg ha^{-1}. This harmful effect decreased in the following weeks up to 6th week (9.83 kg ha^{-1}). From 7th week onwards the yield declined steadily up to harvest for an increase of 1 mm evaporation above average in each week. If the average evaporation decreased by 1 mm, then the beneficial effect of the same magnitude would have been observed.

4. DISCUSSION

Mathematical model will give first hand information in understanding CWR. The response characteristics are not known and are not pre-determined. It was assumed that second degree polynomial would be sufficiently flexible to express the relation. Crop response changes gradually during the life span and it was negative for TMAX, EVPN, SUNS and WIND throughout growing period. We have also obtained similar results when monthly weather was correlated with dry turmeric yield at another district (Kandiannan *et al.*, 2002a,b).These variables are highly related to each other and might influence the microclimate around the plant. Thus is can be assumed that the combination of these variables affect the energy use and partitioning of dry matter. Plant leaves normally show an increasing rate of photosynthesis with increasing light intensity above the compensation point. Shade plants are light saturated at lower intensities (Moss, 1965). Turmeric might have adopted to shade as that of other tropical tuber and root crops (Johnston and Onwueme, 1998). The temperature range of turmeric cultivation at Kerala State, India was 28° C – 35°C (Puseglove *et al.*, 1981), whereas, Duke and de Cellier (1993) have compiled the data from 12 locations and given the range of 18.2°C – 27.4°C with a mean of 24.6°C. The optimum temperature range for different phases was noted as 30 °C -35°C, 25°C - 30°C, 20°C - 25°C and 18°C - 20°C during germination, tillering, rhizome initiation and rhizome bulking, respectively, at Orissa State, India (Panigrahi *et al.*, 1987). In the present study, TMAX and TMIN ranges 29.8 °C to 37.6 °C and 19.6 °C to 27.3 °C, respectively. The mean of TMAX and TMIN during establishment, vegetative and maturity were 35.2 °C, 32.4 °C, 31.0 °C and 26.2 °C, 24.5 °C, 20.8 °C, respectively. Hackett and Carolane (1982) have quoted that the base temperature requirement was 13°C and upper limit was 32°C/27°C (day/night) with a favorable range of 19 to 28°C for ginger (belongs to same family of turmeric and having similar habitat). The air temperature above 32°C caused sunburn of ginger leaf at Australia (Whiley, 1974) and overhead sprinkler irrigation reduced the sunburn. It is evident from the past observations and present study that higher air temperature at early part of growth and low temperature at later part turmeric is essential. TMIN had a favorable influence at maturity phase (Fig. 1 - 2b). Generally in all root and tuber crops, as the underground storage organs increase in size, there is a gradual decrease in the growth of parts above the soil (Kawakami, 1978). Milthrope and Terry (1967) and Boerboom (1978) have observed that low temperature favors the allocation of dry matter towards storage organs in tuber crops.

The harmful effect of rainfall during establishment and early part of vegetative growth was noticed (Fig. 1 - 3b) in this study. In contrary, under rainfed condition Ramana (1935) has noted the beneficial effect of rain during establishment phase. The daily maximum and minimum relative humidity had produced a linear response starting with negative effect at establishment phase and shifting to positive in subsequent phases (Fig. 2 - 5b & 6b). The humidity was low during the establishment phase compared to the vegetative and maturity phases (Fig. 2 - 5a & 6a). Generally, higher humidity resulted in vigorous vegetative growth, which resulted in better yield due to higher stem elongation, increased leaf area and higher shoot-root ratio (Hoffman *et al*., 1971). Hoffman *et al*. (1971) and O'Leary and Knecht (1971) have recorded lower yield at lower humidity. The positive influence of both maximum and minimum relative humidity during vegetative and maturity was observed in the present study. Went (1957) has affirmed that the beneficial effects ascribed to high relative humidity might be due to the equable temperature regime and the consequent reduction of heat load associated with them, which might have reduced the respiration loss.

Turmeric generally takes three weeks time for emergence and RADN was beneficial during this period (Fig. 1 - 4b). The effect of RADN was negative after emergence and its intensity increased progressively upto 18th week, then declines gradually and from 31st week onwards the response was positive until harvest. Probably, RADN at maturity phase was beneficial for downward translocation of assimilate to rhizome from leaves and pseudo-stem. Higher solar energy input was the pre-requisite during the bulking period of rhizome for higher dry matter turnover in the turmeric rhizome (Satheesan and Ramadasan, 1982).

Many tropical crops particularly spices and medicinal plants play an important role in international trade, but, not much attention was received from scientific community on production experiments which might augment their yield. The present study of crop-weather relation of turmeric gave a tentative estimation of parameters for greatly simplified functional relationships postulated in equations. It is apparent from the study that a large percentage of the variations in turmeric yield could be explained on the basis of changes in weather.

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