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AN ANALYSIS OF THE EFFECT OF CLIMATE AND WEATHER ON COCONUT (*COCOS NUCIFERA*)

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SUMMARY

Studies on the effect of climatic factors such as rainfall, relative humidity, temperature, sunshine hours, pan evaporation, evapotranspiration, solar radiation, vapour pressure and wind velocity on the button shedding, premature nut fall, and final nut yield of coconut, and crop-weather models developed to predict nut yield, are reviewed. The type of data and statistical analyses techniques used and the areas of research poorly addressed under the different topics are highlighted.

Efectos de las condiciones climáticas y el tiempo en el coco

RESUMEN

Se revisan aquí los estudios sobre el efecto de los factores climáticos como las precipitaciones, la humedad relativa, la temperatura, las horas de sol, la evaporación de capas, la evapotranspiración, la radiación solar, la presión del vapor y la velocidad del viento en: la muda de los brotes, la caída prematura de los cocos y el rendimiento final del coco, y los modelos de cultivo-clima desarrollados para predecir el rendimiento del coco. Se han destacado el tipo de información y las técnicas de análisis estadístico utilizadas, además de los campos de investigación dentro de los distintos puntos tratados que se han abordado de modo poco eficaz.

INTRODUCTION

The coconut palm is one of the most economically important tree crops for the people of the humid tropical regions in the world. The main coconut growing countries, Indonesia, Philippines, India and Sri Lanka, account for 8375 million hectares. Coconut is a perennial tree, producing inflorescences at the rate of nearly one a month. Development from the flower primordium to the harvest stage of the mature nut (drupe) takes 44 months, of which the last 12 months represent the period taken from the opening of the spathe to harvest. Effects of weather are evident at all stages of development but the influence of weather depends on the stage of development. Rainfall, evapotranspiration, temperature, solar radiation, sunshine hours, relative humidity and wind velocity are the major climatic variables that influence the yield when other external factors such as fertility, management, pest and diseases are non-limiting.

Detailed information of the impact of weather and climate on coconut is of vital importance for scientists and research managers. The review by Prasada Rao

(1991) of some of the past agrometeorological studies of coconut does not provide comprehensive details and critical evaluation. This paper reviews previous work carried out on the influence of climatic variables on button nut shedding and mature nut yield, the impact of drought on mature nuts, and the crop-weather models developed for yield prediction. Areas which require research in future are also discussed.

INFLUENCE OF CLIMATIC VARIABLES ON BUTTON NUT SHEDDING

A coconut inflorescence carries on average 16–20 female flowers (potential nuts) when the spathe opens. Shedding of button nuts and immature nut fall are key factors in determining the final yield of the coconut palm. The physiological reasons for shedding of button nuts and for immature nut fall are discussed by Sudhakara (1991). Immature nut fall is insignificant compared with button nut shedding. The possible causes of nut shedding are fungus or pest attack, nutritional deficiencies, defective pollination and weather conditions. It is generally greater in dwarf than in tall palms, and varies from year to year within a variety.

Gadd (1923) reported that shedding of button nuts was high during the north-east monsoon rains from September to November in Sri Lanka. Patel (1938) observed that there was no relationship between nut shedding and rainfall, but that the shedding of button nuts was high during the dry months in August, September and November in India. Gangolly (1953) showed that shedding of button nuts occurred not only when there was a moisture deficit but also during the wettest times of the year in Kenya, Solomon Islands, Fiji and Papua New Guinea. The reports of Gadd and Patel are apparently contradictory, but both are supported by Gangolly's conclusion. Krishna Marar and Pandali (1957) showed that button nut shedding was high during the south-west monsoon from June to September and low during the cold weather period from December to February in the Pilicode area of India. However, more information is required before firm conclusions can be drawn about the relationship between button nut shedding and moisture conditions in Sri Lanka.

Gangolly (1953) indicated that the shedding of button nuts during the second and third week after receptivity was significantly higher than during other periods of development of the button nuts, while Abeywardena (1955) suggested that the climate from the fourth month after pollination only affected final yield through immature nut fall, and that the weather after eight months had no significant effect, though his data did not provide sufficient evidence to support this suggestion.

Nambiar *et al.* (1969) divided the nine month period after the spathe opened (fertilization) into three phases: a phase of slow growth up to three months after fertilization; a phase of active growth from four to seven months after fertilization; and a phase of rapid decline in growth from eight to nine months after fertilization. He claimed that the weather during the second phase adversely affected the rate of growth, size of the nuts, and their copra content, but his phases do not coincide with the development stages in the 12 month period from fertilization to maturity discussed by other authors. These divisions were not based on studies of the impact of climate and weather because the rate of button nut shedding is caused by the interaction of many climatic variables.

Rate of button nut shedding

Gangolly *et al.* (1956) showed that nearly 70% of potential nuts were lost within the first month after fertilization. In contrast, Abeywardena and Mathes (1971), working in Sri Lanka, showed that only about 24% of potential nuts were lost within the first two months after fertilization, but that 40% were lost during the third and fourth months and a further 2% during the fifth and six months after fertilization, leaving only about 33% of the initial nuts at the time of harvest. Prasada Rao and Nair (1988) reported that 83% of nuts from inflorescences that opened during the south-west monsoon (June–September) were shed but only 39% of those that opened during the winter (December–February). Peiris (1990) reported that the rate of button nut shedding was higher between 0800 and 1600 local time than between 1600 and 0800.

There is thus no general consensus concerning the time at which the shedding of button nuts is most rapid. Evidence from Sri Lanka seems to suggest that it is the first three months after fertilization while reports from India suggest the first month. It seems plausible that the timing is site specific. We plotted the number of female flowers surviving on 100 inflorescences of spathes which opened during bi-monthly intervals between December 1968 and November 1969 against time using the data from Abeywardena and Mathes (1971) and found that the pattern of female flower development was similar irrespective of the time when the spathe opened (Fig. 1). However, more data are needed to confirm this finding.

Prasada Rao *et al.* (1984) showed that the percentage of button nuts shed was significantly correlated with total rainfall and minimum air temperature, while Prasada Rao and Nair (1988) found that minimum air temperature and relative humidity in the forenoon during the 4–7 months after the opening of spathes had a significant effect on nut development. However, they made no attempt to investigate the climatic variables in a multiple regression setting.

INFLUENCE OF DROUGHT ON NUT YIELD

Park (1934) observed that the severe drought experienced in 1931 in the Puttalam district of Sri Lanka affected nut yield for about two years, with the maximum effect occurring about 13 months after the end of the drought. This was confirmed by Prasada Rao (1986a) who showed that the effect of drought on nut yield was greatest between the eight and twelfth month after the drought.

Information on the effect of drought on nut yield is scanty. Prasada Rao (1985) attempted to classify the effects of drought by calculating weekly 'aridity' indices,

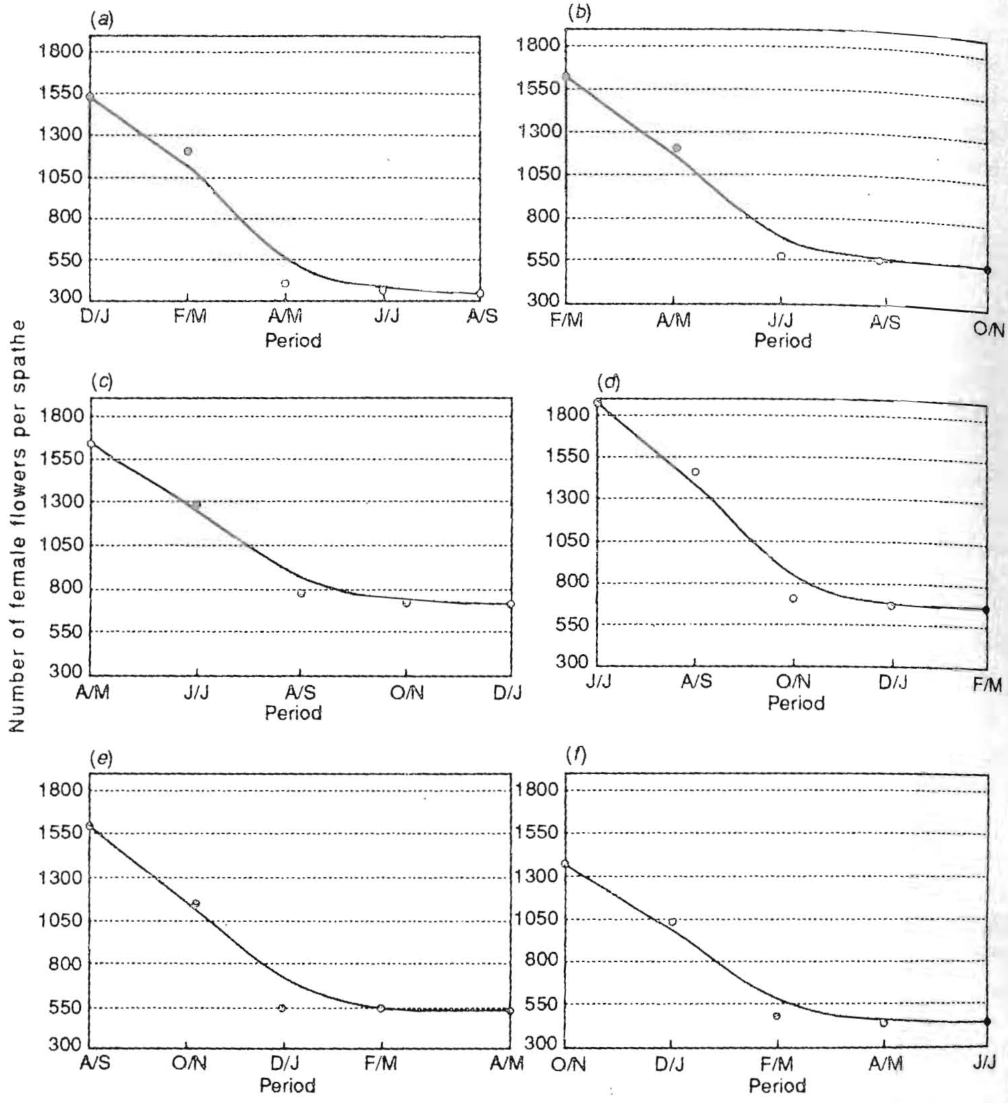

Fig. 1. Number of female flowers surviving on spathes opening in (a) December/January, (b) February/March, (c) April/May, (d) June/July, (e) August/September, and (f) October/November.

based on rainfall, pan evaporation and water balance data. In a later publication (Prasada Rao, 1988) he defined an 'index of moisture adequacy' (IMA), based on the ratio between the actual evaporation and potential evapotranspiration. He showed that nut yield exceeded 45 nuts palm^{-1} a^{-1} when the IMA in the previous year was greater than 30% but that yield was less than 30 nuts palm^{-1} a^{-1} when it was less than 15%. He assumed that the crop coefficient (k_c) for coconut is 0.7, though it depends on the stage of growth, prevailing evapotranspiration (ET_{crop}) and the reference crop evapotranspiration (ET_o) when the crop is grown in large fields under optimum growing conditions so that $ET_{crop} = k_c \times ET_o$ (Doorenbos and Pruitt, 1977). The classification of severity of drought in relation to coconut is very important and the work initiated by Prasada Rao should be further developed. The length of dry spells in relation to coconut yield should also be investigated. Mahindapala (1984) suggested that, in general, yields would be unsatisfactory if a dry spell exceeded 90 days for tall varieties or 75 days for dwarf varieties.

INFLUENCE OF WEATHER AND CLIMATIC VARIABLES ON MATURE NUTS

Coconut requires a well distributed annual rainfall of about 1500 mm to produce a satisfactory yield. A mean air temperature of 27°C and moderate relative humidity, of about 80–90%, are ideal provided that other external factors (such as fertilizer and cultural practices) are non-limiting.

The coconut palm produces one mature bunch more or less regularly every month. Thus at any particular time each palm has twelve (or more) bunches at different stages of development from which at least one mature bunch can be harvested monthly. The harvesting intervals, however, differ from country to country; in India and Thailand bunches are harvested monthly whereas on many estates in Sri Lanka they are harvested every two months. The influence of weather is not the same on each bunch (or each harvest) and there are marked differences in the quality and quantity of nuts from successive harvests. The highest yield at Kasaragoda in India is generally obtained in May, during the summer, and the lowest in October, during the north-east monsoon (Vasudevan and Satyabalan, 1959). At Lunuwila in Sri Lanka the highest yield is generally obtained in May and June (the third pick), during the south-west monsoon, and the lowest in November and December (the sixth pick), during the summer (Abeywardena and Fernando, 1963). The fluctuation between seasons is mainly due to the impact of climate on button nut shedding.

Patel and Anandan (1936) reported that the coconut yield in a given year was influenced by the cumulative rainfall during the first quarter of the two year period prior to harvest and during the first quarter of the year of harvest, while Abeywardena (1955) reported that the coconut yield in a given year was influenced by the cumulative rainfall during the previous year and during the first quarter of the harvest year. The influence of cumulative rainfall some time before the harvest arises because all the bunches to be harvested in a given year have passed their time of susceptibility to nutfall by March or April of the harvest year. However, for a perennial crop like coconut the distribution of rainfall is more important than the total quantity, although it is difficult to identify the parameters concerned.

Abeywardena (1962) used yield and monthly rainfall data from Bandirippuwa Estate in Lunuwila to calculate the effective rainfall for each month using the 'maximum effective rainfall limit' (MERL) assigned to that month. The MERL was based on the cumulative rainfall over the previous two months, though the methodology of assigning such values was not discussed. On the basis of the monthly MERLs for a year, an arbitrary index was defined to represent the annual rainfall distribution for that year. However, this index did not provide a satisfactory explanation of the yield variation among years. Later Abeywardena (1968) used the total rainfall and the number of rainy days in a year to represent the distribution of rainfall, but again this did not provide a satisfactory explanation of the yield variability between years. However, analysis of cumulative rainfall from January to April, May to August, and September to December of the year prior to harvest showed that the rainfall between May and August of the previous year was critical from the point of moisture sensitivity and had no depressing effect on total yield. Abeywardena also showed that up to 350 mm rainfall from September to December increased crop yield but that heavier rainfall depressed yield appreciably. Jacob Mathew *et al.* (1988) showed that yield variability was not related to the total rainfall received in the harvest year or in the preceding years, but that rainfall from March to May (summer) was positively correlated with the yield in the succeeding year. In these studies the effects of sub-periods were taken as independent.

Prasada Rao (1986b) studied 40 years' data on monthly water deficits and the time of the start of the monsoon rains in the Pilicode area of India and found that high rainfall during the months of June, July and August (the monsoon period) and dry spells during the post-monsoon and pre-monsoon periods decreased the coconut yield in the subsequent year. However, no statistical relationships were established to confirm this and the length of dry spell was not well defined. Furthermore, as the potential evaporation for a specific month was assumed to be constant throughout the entire 40 years, the same annual water balance was assumed for all the years.

Using Penman's method to calculate reference crop evapotranspiration, and a crop coefficient (k_c) of 0.75 for coconut plantations, Saseendran and Jayakumar (1988) studied the effective rainfall for coconut as a percentage of the total rainfall during January and February (winter), March to May (hot weather), June to September (south-west monsoon), and October to December (north-east monsoon). The study showed that the effective rainfall varies from location to location and from sub-period to sub-period but no statistical relationships were derived between the effective rainfall and nut yield.

Most of these studies were based on single correlation coefficients worked out for the entire period of experimentation. Peiris (1993) defined a mean correlation coefficient (r_m) by considering seven groups of 15 consecutive years from 1969 to 1989. Such a grouping gave a better estimate of the correlation than consideration of the entire period. In this study r_m values were calculated between annual yields and the rainfall during successive two month periods (January/February, March/April, May/June, July/August, September/October, and November/December) prior to the harvesting year. This showed that the rainfall in the first two months of the previous year had the most influence on total annual yield while that in the period from July to August had the least influence. Excessive rainfall during May and June depressed yields; rainfall of about 450 mm was sufficient during this period. These results were based on simple linear models and the assumption that the effect of each sub-period is independent of others. Multiple regression models might have been more useful for the analysis of data when a year is divided into different sub-periods and problems of multi-collinearity have to be considered.

The studies indicate that the influence of rainfall parameters on nut yield are location specific and that yield is mainly dependent on the pattern of rainfall. However, it was not possible to identify the most relevant parameters or to identify a suitable index to represent the rainfall distribution required for coconut, even for a given location. This was mainly due to the unpredictable pattern of rainfall, though the variation of rainfall distribution was not studied in detail. Identification of the variation in distribution of rainfall would be helpful, and a study of the distribution of the water balance in coconut-growing areas to define a suitable index for rainfall distribution is required. This would also be useful for irrigation scheduling.

The relation between annual yield, rainfall, maximum and minimum air temperature and relative humidity were studied using simple correlations by Abraham and Kunju (1988). They considered three sub-periods, February to May (pre-monsoon), June to September (monsoon), and October to January (post-monson), and showed that low relative humidity during the pre-monsoon period and total rainfall during the monsoon had a beneficial effect on the annual yield in the same year. High maximum air temperature during the pre-monsoon and post-monsoon periods decreased the yield during the third subsequent year. Pankajakshan Nair and Unnithan (1988) calculated coefficients of correlation between season-wise weather variables and annual yield of coconut in three lag years' data from the Regional Station at Vittal of the Central Plantation Crops Research Institute (CPCRI) of India. They found that sunshine hours and relative humidity during the pre- and post-monsoon periods and evaporation during the monsoon season infuenced yields, confirming observations from the Coconut Research Institute of Sri Lanka by Salgado (1955). Similar results were obtained by Vijaya Kumar *et al.* (1988) using data from the CPCRI's station at Kasaragod in India and by Dootson *et al.* (1989) using data from the Chumphon Horticultural Experiment Station in Thailand. The effect of solar radiation on yield has not been reported though it could also be a major climatic variable influencing yield.

YIELD PREDICTIVE MODELS BASED ON CLIMATIC VARIABLES

Prediction of coconut yield is of vital importance for policy-makers, scientists, and growers and predictive models based on climatic variables are more meaningful than those developed without them by various authors such as Reynolds (1979), Silva de Sumith (1985) and Jacob Mathew *et al.* (1991).

Abeywardena (1968) developed a crop forecasting model based on 12 rainfall parameters using data from 1935 to 1966 and obtained yield predictions close to the observed values. However, the validity of the model for anticipating yields has not been tested. Abeywardena (1983) later developed an empirical statistical model to forecast yields in Sri Lanka. This was based on eight variables, defined as 'drought indices' for eight different agro-ecological regions, derived from the monthly rainfall figures from 1963 to 1976 and taking into consideration the minimum requirement of soil moisture for optimum production. The errors of the estimated values for some years were very large, but no alternative methods have been developed and the use of drought indices is more meaningful and useful than the use of actual cumulative rainfall. Improvements to this methodology are urgently required.

Saraswathi and Mathew (1988) used 15 years data on total monthly rainfall as 12 independent variables to predict yields in each of the ten districts in the state of Kerala. Though the coefficients of determination of these models were reasonably high, there were two degrees of freedom for error and few of the parameters were significant at the 5% level. Pillai *et al.* (1988) also attempted to forecast yield using a linear regression model, $Y = f(X_1, X_2)$, where X_1 is the total rainfall for the five month period from the sixteenth to the twentieth month and X_2 that from the fourth to the ninth month prior to harvest, but the coefficient of determination of this model was not sufficient to obtain useful predictions. Peiris (1991) developed a model ($R^2 = 0.89$) to predict yield on an estate a year ahead based on six variables derived from monthly rainfall distribution one year earlier. The validity of the model was tested for seven different 15-year yield groups. The model was flexible to use, but the percentage of error for the seven groups varied from 1.9 to 40.0. A predictive model ($R^2 = 0.91$) with six climatic variables (maximum relative humidity, sunshine duration, vapour pressure, and minimum air temperature at different periods) was developed by Vijaya Kumar *et al.* (1988). From this model, yield for a given year could be predicted by the middle of May in the year before harvest, but its use is limited by the paucity of such climatic data.

In many of the studies discussed, no attempt has been made to compare predictions with actual yields obtained. Furthermore, the models were not tested using independent sets of data. But the results obtained suggest that it is not possible to develop a single model for yield forecasting as the effect of climate varies from location to location.

CONCLUSIONS

The statistical modelling of the effect of climate on yield can provide a useful description of the system using routine techniques that do not require any physiological knowledge. These techniques can be used in the development of yield prediction models for an entire country (or an ecological zone) in spite of the difficulties discussed. The application of non-climatological models is questionable for such purposes since no regular pattern of annual yield has been reported and yield is determined by many climatic variables. Attempts should therefore be made to identify the distribution of climatic variables and the relation among them in order to gain a better understanding of their effect on the coconut crop.

Agroclimatologists have acquired considerable knowledge and expertise in the development of crop–weather assessment models for many crops. However, knowledge on the influence of weather and climate on coconut is insufficient to quantify the effect of one or more climatic variables at different stages of the nut development process and to explain the yield variability between and within years. Thus research into the development of practical crop–weather assessment models should be accorded priority in coconut research.

The work carried out in Sri Lanka was confined to the study of the effect of rainfall on coconut yield. Only limited use has been made of appropriate statistical theory in these studies so far and multivariate models which involve functions of various weather elements have not been attempted. The effect of environmental conditions on the coconut crop could be studied by the development of crop simulation models. This would require multi-disciplinary work, with plant physiologists, soil scientists and agroclimatologists, to obtain a detailed understanding of how the components of yield respond to each of the climatic variables.

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