EFFECT OF WEATHER ON COCOA AND IMPROVEMENT OF BEAN SIZE THROUGH SEASONAL CROP ORIENTATION

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Effect of weather on cocoa and improvement of bean size through seasonal crop orientation" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled " Effect of weather on cocoa and improvement of bean size through seasonal crop orientation" is a record of research work done independently by Smt. K.P.Prameela, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Introduction

INTRODUCTION

Cocoa, botanically called *Theobroma cacao L.* is one of the classical examples of major horticultural crops exclusively grown in developing countries in the tropics. Over 80 per cent of the commodity is coming from Ivory Coast, Brazil, Indonesia, Ghana, Malaysia, Nigeria, and Cameroon.

Commercial cultivation of cocoa commenced in India in 1960's. Its adaptability as an intercrop under the shade of other tree crops, the attractive price and extension support helped in the faster expansion of area under cocoa. Thus by 1978-'79 the area coverage reached around 15500 hectares and by 1980-'81, 29000 hectares. But the subsequent steep fall in prices and inadequate marketing facilities reversed the trend in the development of cocoa in the country and the area covered by the crop stands now at 12300 hectares with an output of 5400 tonnes per annum. Kerala accounts for 75 per cent of the area and Karnataka, 24 per cent.

Cocoa is a tropical crop with desirable climatic conditions of 1250-3000 mm of rainfall per annum and temperature varying between 30°C to 32°C as mean maximum and 18°C to 21°C as mean minimum. The crop flowers and fruits throughout the year, but significant variation is observed in monthly pattern of flowering, fruit set and bean size. During certain months there is profuse flowering while in some others, it will be nearly flower-free. Of the large number of flowers produced, only a small percentage will set and very few of the fruits set develop to ripe fruits. Bhat (1983) reported that a tree produces about 8000 to 10000 flowers per year but only 4% of them set fruits and only 16% of the set fruits matured.

Literature shows that the production of cocoa is very much affected by weather parameters like rainfall, temperature, relative humidity and sunshine hours. These parameters are interdependent to a certain degree and act together, either directly or indirectly in the growth and production of crop.

The present experiment was designed to understand the probable effects of weather elements on flower and fruit production and to arrive at a prediction model, if at all possible, for the estimation of flower and fruit production.

Another objective of the experiment was to orient the crop to a favourable season. Cocoa is peculiar in that it flowers and fruits throughout the year. But two peaks of harvest are apparent, one in April-May and the other in October-November. The

April-May crop develops through a period of water scarcity and bean size and weight of this season are low leading to poor acceptance. The scattered production in other months also imposes difficulties in harvesting and curing, especially in small farms. It was considered that if by some means, harvesting could be limited to a single season without affecting the total annual yield, it would save a lot of resources, especially in terms of labour requirement in addition to improving bean quality.

It was also considered that limiting cropping to a single season and allowing the plants to rest for a longer period will enhance the economic life of cocoa.

The present study was taken up to understand the above factors better and the broad objectives set were the following.

1. Study the relation between yield and weather and to arrive at a prediction model if possible.
2. Assess the effect of weather on flowering behaviour.
3. Study the effect of fruit load on flowering intensity.
4. Orient the crop to a season favourable for bean size through defloration.

Review of Literature

REVIEW OF LITERATURE

2.1 Climatic requirements of cocoa

The climatic conditions of cocoa growing areas vary from one location to another, still, they fall in the tropical range. Out of the different climatic factors affecting the crop, rainfall and temperature are the most important factors determining the distribution.

2.1.1 Rainfall

According to Cuatrecasas (1948, 1964) cocoa flourished where the rainfall ranged between 2000 mm and 8000 mm with more or less even distribution throughout the year. Adams and Mc Kelvie (1955) observed that most of the cocoa growing areas had a short, mild, dry season. In Ghana, cocoa was limited to those areas which receive more than 250 mm of rain in the dry period between November and March. Purseglove (1974) had estimated the rainfall in cocoa growing areas to be 1010 to 2540 mm. He stressed the importance of distribution of rainfall and stated that there should be rainfall of 101 mm or over per month and a marked dry season with less than 63.5 mm per month should be absent. Wood (1985) reported that the total annual rainfall in most cocoa growing countries is between 1250 and 2800 mm. In West Africa, this varied from 1200 to 3000 mm while in South America rainfall was more than 2000 mm per annum. Malaysia and Papua New Guinea of South-East Asia show a far more uniform climate with well distributed rainfall and with no dry months. He came to the conclusion that the distribution of rainfall is more important than the total annual rainfall. Brenes *et al.*(1988), defining areas with cocoa growing potential, reported that precipitation of 1600-3200 mm per year is highly suited for growing cocoa. Asopa and Narayanan (1990) described well distributed rainfall above 1200 mm a year as the most comducive for growth.

2.1.2 Temperature

The optimum temperature range for cocoa varies from 21.1°C to 32.2°C, with a mean monthly minimum of 15°C as the lower limit and an absolute minimum of 10°C as reported by Erneholm (1948). However, there is evidence that somewhat lower temperature can be tolerated. In the State of Sao Paulo cocoa has been planted in places where the mean monthly minimum in the coldest month is about 10°C and the absolute minimum drops to 4°C to 6°C (Alvim, 1977).

Lee (1974) reported that in Malawi (16°S) where the minimum temperature is 13°C to 14°C for three months, cocoa has been grown successfully giving yields up to 2000 kg per hectare , but when the temperature fell to 10°C for several consecutive days yields were reduced by about 50 per cent.

According to Wood (1985), a minimum range of 18°C to 21°C and a maximum of 30°C to 32°C limited the cocoa belt. Brenes *et al.*(1988) described mean temperature between 24°C and 29°C as the best temperature range for commercial cocoa growing areas. Asopa and Narayanan (1990) reported a shade temperature between 13°C and 35°C as the optimum range for growth.

2.1.3 Relative humidity

According to Wood (1985) relative humidity is uniformly high in cocoa growing areas, often 100% at night, falling to 70 to 80% by day, and sometimes lower during dry season. Asopa and Narayanan (1990) reported humidity above 85% as the optimum for growth.

2.2 Effect of weather elements on general growth of cocoa

2.2.1 Rainfall/ soil moisture

Greenwood and Posnette (1950) from their studies on cocoa reported that flushing was controlled by an endogenous system inherent in the plant, but at least after the tree had passed the juvenile stage, its onset was affected by environment. They also observed that growth of cocoa occurred in the dry month, while during wet season, when condition of rainfall and humidity were more stable, little growth occurred. Irrigation had not affected the frequency of flushing of individual trees. All the trees, irrespective of treatment differences, flushed at more or less regular intervals of eight to ten weeks. Container experiments involving different watering regimes have generally demonstrated the beneficial effects of wetter treatments on growth (Murray, 1966; Sale, 1970). Alvim (1959) reported that where rainfall was adequate and the dry season was not very severe or prolonged, irrigation seemed to have only a small effect on mature cocoa. Alvim (1960) showed that the stomata of container grown cocoa plants started to close when the available moisture fell to 70% and closed rapidly as available moisture fell from 50 to 25%. Murray (1961) working on older trees in Trinidad found irrigation to be beneficial in only one year out of five studied. Clearly, there will be variations in the severity of different dry seasons, but in the case of established trees, there may be a long period during which adaptation to a new soil moisture regime takes place. Smith (1964) studied the effects of irrigation on young cocoa in Ghana where he found favourable responses in terms of flower production and growth rate.

The effect of soil moisture on seedling growth was studied at the Cocoa Research Institute, Ghana (CRI, 1972). The experiment was conducted in a green house where plants were grown in top soil in five litre buckets. Between 11 weeks and 44 weeks, these plants were subjected to eight different soil moisture regimes, there being ten plants in each. The soil moisture content was allowed to fluctuate between field capacity and one of the following available soil moisture percentages - 100, 90, 80, 70, 60, 45, 30 and 15 per cent. The soil moisture was determined by weighing bucket + soil + plant as necessary and rewatering to field capacity when the appropriate degree of drying out has been reached. Under the conditions of the experiment, growth was best when the soil was allowed to dry out to about 60 per cent of the available moisture. There is little doubt that the plants growing in regimes wetter than this suffered from poor root aeration and probably reduced water and mineral uptake. The result emphasises that excess soil moisture is as harmful to the growth of cocoa seedlings as inadequate moisture. This is especially true where the soil is rich in organic matter and has a high water retaining capacity. Studies of the fine changes in stem diameters of seedlings using the dendrograph also suggest that stem growth is slower during the day following watering than during a day when the soil has begun to dry out.

Balasimha (1988) conducting studies on the behaviour of cocoa under drought conditions, found that the relative water content of leaves of rainfed cocoa plants was lower than that of irrigated plants. This was accompanied by a decrease in leaf water potential and osmotic potential. As drought progressed, nitrate reductase activity and chlorophyll contents declined while proline accumulated in the leaves. Leaf elongation rates were inhibited under drought and there was a significant decrease in total dry matter produced, canopy area, relative growth rate, and net assimilation rate. It was suggested that for cocoa the ability to tolerate drought resulted from stomatal regulation, which reduced transpirational water loss, and high tissue elasticity.

2.2.2 Humidity

The effect of humidity on cocoa plants was studied by Sale (1968). The most marked effect was on leaf area, plants growing at low humidity (50-60%) having larger leaves and greater leaf area than plants growing at medium (70-80%) and high (90-95%) humidities.

Gomes *et al.* (1987) reported that the stomata of three month old seedlings were more open at high relative humidity (76-89%) than at low relative humidity (39-62%). In both regimes, stomata closed gradually during the day, with the rate of closure accelerating in the late afternoon. Transpiration rate (TR) was correspondingly high early in the day and low late in the day. Average leaf diffusive resistance (rl) was 26% lower at high relative humidity. Nonetheless, TR was generally higher for plants in the low RH, because of the much greater vapour pressure gradient between the leaf and air. Abruptly lowering the RH at noon rapidly increased rl, and increasing RH decreased rl. In another experiment conducted in constant high or low RH regimes, rl was lower, the rate of net photosynthesis (Pn) was higher, leaf water potential (psi) was lower (more negative), and TR was lower in the high RH regime. Water use efficiency was higher at high than at low RH. The relationships between Pn and rl were identical at high and low RH. Thus, differences between TR and water use efficiencies at high and low RH were a direct result of variations in vapour pressure deficit between the two humidity regimes. Stomatal opening and closing reflected direct effects of humidity on guard cells rather than responses to changes in bulk leaf psi. In addition, root to leaf hydraulic conductivity was apparently greater at low than at high RH.

Harun and Hardwick (1988) studied the effect of different temperature and water vapour pressure deficits on photosynthesis and transpiration of cocoa leaves. Infrared analyzers were used to measure photosynthesis and respiration. Photosynthetic rate remained constant with low water vapour pressure deficit upto 10 mbar (corresponding to approximately 70% relative humidity at 28°C field conditions) after which it declined sharply with increases in water vapour pressure deficit. Transpiration rate increased with increases in water vapour pressure deficit to 10 m bar and thereafter (with increasing water vapour pressure deficit) remained constant. Stomatal resistance increased with any increase in water vapour pressure deficit.

2.2.3 Temperature

Murray and Spurling (1964) reported that in Trinidad a constant temperature of 31°C leads to loss of apical dominance, the axillary buds producing numerous flushes with small leaves. However, Wood (1985) noticed that such conditions do not occur in the field where there will be diurnal variation, and cocoa trees can withstand temperature well above 31°C for short periods during the day.

Leaf surface temperature of 46°C were commonly observed in Trinidad with a maximum of 52°C (Hoskin and Sale, 1969). Temperature as high as 50°C will eventually damage the leaves, but in the field it is unlikely that leaves will be subject to such temperature for long enough to cause damage.

Harun and Hardwick (1988) found that photosynthetic rates changed very little between 20°C and 30°C. Stomatal resistance, however, decreased with increases in leaf temperature.

2.3 Flowering and fruiting pattern of cocoa and weather factors affecting them

2.3.1 Flowering pattern

Hewison and Ababio (1929) conducted studies on the flowering pattern of cocoa in Ghana and reported that the period from March to July was the time of main flowering activity with the greatest number of flowers produced in April to June. Alvim (1965) reported that flowering in Bahia was most intense during the early part of the rainy season following the July-September drought. The non-flowering period was July to September (Alvim, 1966). At the beginning of the wet season, there was a burst of flowers which resulted in the main crop after five to six months.

The flowering pattern of cocoa in Cuba was described by Delpinalrivero and Acunagale (1967). Abundant flowering occurred from June to September and gradually decreased thereafter. Under severe drought conditions, however, flowering decreased earlier and abruptly. Rajamony (1981) and Madhu (1984) described the flowering pattern in Kerala as throughout the year. Madhu reported that maximum flowering per tree per year under Kerala conditions was in December, while the minimum was in September, the peak being from November to April.

Studying the flowering and fruit setting characters of upper Amazon cocoa, Uthaiah and Sulladmath (1984) observed that more than 75% flowers were produced between January and April with a peak in March (30.9%) in Bangalore.

Cocoa produces a large number of flowers. Murray (1975) reported that a full grown tree produced more than 10,000 flowers in a year. Under Dharward conditions, Bhat (1983) recorded 8000-10000 flowers per year per tree. He also observed that about 70% of the flowers were produced on the crown periphery, 22% on primary branches and 8% on the trunk. Madhu (1984) reported a mean of 7062 flowers per tree per year under Kerala conditions. In Vittal, Karnataka, the annual flower production per meter of stem varied from 168 to 2358 (CPCRI, 1977). Zacharias (1983) observed that the number of flowers per unit length of 50 cm on the trunk ranged from 93 to 904 with a mean of 258 in Thrissur, Kerala.

2.3.2 Fruiting pattern

Hewison and Ababio (1929) reported that only 0.2 to 1.5 per cent of the cocoa flowers developed into mature fruit. Purseglove (1974) also recorded that only 0.2 per cent of the flowers matured to fruit. According to Murray (1975), out of 10,000 flowers produced by a mature tree in a year, only 10 to 50 ie 0.1 to 0.5 per cent developed to mature fruits. From Dharward, Karnataka, Bhat (1983) reported that only 3.7% of the flowers set fruits and only 16% of the set fruits matured. Madhu (1984) from Kerala observed that the recovery of mature pods ranged from 21.6 to 44.7% of the pollinations made and 29.6 to 63% of the pods set.

Two peaks of cocoa harvest are observed in most of the cocoa growing countries - once during the rainy season and again during the dry season. In countries with marked wet and dry seasons, the main harvest occurred five to six months after the start of the wet season, as reported by Bridgland (1953) and Alvim (1967). Alvim (1974) studied the pattern of climate and cropping of cocoa in Bahia and West Africa. In Bahia where the rainfall was fairly well distributed, the cocoa harvest season was found to be rather long, usually starting in April and extending until mid January. The April to August crop was bigger than the September-January crop, depending on the rainfall pattern. During the years with well distributed rainfall, both the crops had almost the same volume. In West Africa, where a long dry season exists between October-November to March-April, about 80 to 90% of the crop was harvested in a relatively short period between September and December.

Purseglove (1974) observed that the cocoa plants produced pods throughout the year, but the main harvest usually began at the end of the wet season and continued for a period of three months. Accordingly in West Africa, the main harvest was during October to January and in Trinidad during February to March, followed by a minor harvest early in the rainy period. In Sri Lanka there were two well defined cropping seasons, one from May to August and the other from September to January (Shanmugavelu and Rao, 1977). Generally in South India, cocoa is found to have two main crops in a year, September to January and in April to June (CPCRI, 1978).

Fruiting pattern of irrigated cocoa in Nileswar, Kerala was studied by Hassan *et al.* in 1981. The peak cropping months were July, August, June and October, which together accounted for 78% of the total annual yield. The least production months were January, December, February and March in that order. The total yield during these months was 3%. In upper Amazon cacao, Uthaiah and Sulladmath (1984) found that more than 60% of the yield came from fruits set during January and February.

Wood (1985) also showed that there were one or two peak harvest periods and there was some cocoa to be harvested at all times of the year. He also reported that in Ghana, on an average, 25% of the crop was harvested in the peak month, November, which was about six months after the wet season began. In Malaya, where there was no true dry season, the peak of harvest was less pronounced with 20 to 25% of the crop in the peak, which falls between November and March.

Bopiah and Bhat (1989) recognised two peaks of harvest, April to July (71%) and November to December (17.8%). The wet season (June to August) accounted for 42.8 per cent and the remaining 57.3 per cent was harvested during dry period. In Karnataka, Jose (1996) compiled the yield data on quarterly basis. He found that on an average 40% of fruits were harvested during June to August, 30% between March to May, 16% between September to November and the remaining 14% between December to February.

2.3.3 Effect of weather elements on flowering and fruiting

2.3.3.1 Temperature

Effect on flowering

Alvim (1965, 1968, 1981) reported that temperature affects the flowering intensity and lower than average temperature contributed to reduced flowering. Flowering was inhibited when the monthly mean temperature was below 23°C (Alvim, 1966). Sale (1969) studied the flowering process of cocoa in relation to the temperature conditions in Trinidad, West Indies. He observed that as compared to plants growing in regions with a day temperature of 23.3°C, plants in the regions with a day temperature of 26.6°C to 30°C had more active flowering cushions per plant and more number of flowers per cushion per week. Couprie (1972) showed that flowering was greatest when daily temperature variation was least. Mossu and Lotode (1977) found low temperature to be favourable for pollination.

Madhu (1984) observed that the mean monthly minimum and maximum temperature one month previous to flowering affected the flower production. Wood (1985) also reported the effect of temperature on flowering.

He found that the number of flowers increased as the temperature increased.

Effect on yield

Couprie (1972) examined the growth, flowering and fruiting characters of cocoa and found that the fruit set was negatively influenced by the cumulative maximum temperature of the preceding two weeks. Boyer (1974) also reported a negative relation of fruit set to temperature. Alvim *et al.* (1972) studied pod development in relation to temperature and concluded that the rate of pod development increased with increase in temperature.

Regarding seasonal distribution of the crop, Alvim (1981) reported that temperature played an important role in regions like Bahia where there is marked seasonal difference in temperature. Alvim (1987) reported that in Bahia, the relatively low temperature during the month of June through August was responsible for the lack of a harvest during the period of January to March, *ie.*, seven months after the cool period (mean temperature lower than 23°C). Hassan *et al.* (1981) observed a significant positive correlation between the number of harvested pods and mean monthly maximum temperature five months before.

Studies conducted by Vijayakumar *et al.* (1991) to correlate the yield of cocoa with weather variables showed that maximum temperature of fourth and 21^{st} fortnight had significant effect on yield.

2.3.3.2 Rainfall

Effect on flowering

Smith (1964) conducted a study on the effect of three soil moisture regimes on young Amazon cocoa in Ghana. He found that irrigation increased growth rate and flower production, but did not affect the percentage of setting or wilting of cherelles. He found that irrigated trees flowered earlier and produced greater number of flowers than did the unirrigated trees, probably because of the increased size of irrigated trees and large number of cushions available for flower production. Alvim (1968) described excessive rainfall with water logging from September, 1967 to March, 1968, and lower than average temperature as the reasons for reduced flowering during the season. Sale (1970) obtained profuse flowering in potted cocoa plants whenever the soil was watered following a period of moisture stress and concluded that flower initiation has been enhanced during the dry period and only flower growth was inhibited by moisture deficiency. Based on the results of previous experiments, Alvim *et al.* (1972) also opined that periods of increased flowering were usually preceded by a relatively dry period followed by a wet period and that decreased flowering was associated either with a dry spell or with excessive soil moisture. Hutcheon *et al.* (1973) showed that irrigation increased flower production of both the unshaded as well as shaded cocoa but this effect was greater on unshaded trees. In 1974, Alvim again stressed the importance of rainfall on flowering. Hutcheon (1977) recorded maximum flowering and fruit setting after the beginning of the wet season, when both leaf area and photosynthetic rate were high.

Describing flowering and fruit setting patterns of cocoa trees at three localities in Costa Rica, Young (1984) reported a marked decline in flowering near the end of the rainy season when rainfall was very high. In Kerala, Madhu (1984) found that the mean monthly rainfall one month prior to flowering along with temperature and sunshine determined the flower production.

Effect on fruiting

Studying the flowering and fruiting characters of cocoa in relation to weather elements, Couprie (1972) reported that fruit set was strongly influenced by the rainfall which occurred four to twelve weeks earlier. Boyer (1974) also reported a positive relation of fruit set to rainfall. Mossu and Lotode (1977) reported that rain was unfavourable for pollination.

According to Alvim (1981), yield variability from year to year was more affected by rainfall distribution than by any other climatic factor. Studying the fruiting pattern of irrigated cocoa in Kerala, Hassan *et al.* (1981) observed a significant negative correlation between the number of harvested pods and number of rainy days.

2.3.3.3 Sunshine

Soria (1970) studied the annual flowering and pollination of cocoa at two localities of tropical rain forest climatic conditions in Costa Rica. He found that the annual flowering and pollination could be represented as a bimodal curve in direct proportion to the bimodal regime of solar energy. Couprie (1972) reported that sunshine had a negative but non-significant effect on fruit set and cherelle wilt. Boyer (1974) supported this theory. Madhu (1984) found that the mean monthly sunshine hours one month prior to flowering affected the flower production.

2.4 Effect of weather on bean characters

Seasonal differences in bean characters have been reported by many workers. Egbe and Owolabi (1972) found lowest bean weight, lowest butter fat and highest shell percentage for the February-May crop in Nigeria and highest bean weight, highest butter fat and lowest shell percentage for the October-January crop. Wood (1985) reported that bean size is affected by rainfall during the development of the crop. According to Manurung *et al.* (1988), the number of rainy days, evening temperature and wind speed occurring seven months earlier together contributed 66.9% of the variation in bean fresh weight. Bopiah and Bhat (1989) analysed the bean characters with regard to weather conditions and found higher pulp percentage and lower total soluble solids and bean weight in wet season as compared to dry season.

2.5 Effect of fruit load on flowering and fruiting

The fruit load of plants also affects flowering intensity, there being a decrease in flowering during intense fruit development period. Hewison and Ababio (1929) observed that in Ghana where less than one third of a tree's crop was set by the end of April, great flowering activity occurred during

June. Alvim *et al.* (1972) attributed this effect to the competition between fruits and flowers for a substance or substances (which could very well be carbohydrates) whose concentration is related to flowering intensity. Alvim in 1974 and 1981 again stressed the importance of fruit load on flowering. Mossu and Lotode (1977) reported that the presence of fruits had a negative influence on fruit set.

2.6 Prediction of yield

Reliable pre-harvest forecasts of crop yield are of great importance as a decision making basis for planners, policy makers and agriculturists. Weather elements, agricultural inputs, biometric characters or their combinations will serve as independent variables in such prediction models. Prediction models have been reported for many crops by several workers.

In an attempt to make a pre harvest forecasting of sugarcane yield, Alphi and Prabhakaran (1991) found that sugarcane yield could be predicted with sufficiently high degree of accuracy as early as the sixth month after planting with the aid of biometrical characters. Murua (1994) developed a yield model for Spanish almonds. This model allowed average almond yield to be predicted with some accuracy from historical yield and environmental data, together with current meteorological records and other measurable factors.

Biswas *et al.* (1996) reported a method for forecasting weekly crop of tea based on crop-weather relationship. The experiment showed that temperature difference and mean vapour pressure of second and fifth week and rainfall of fourth week prior to plucking generally contributed more significantly to weekly crop. A fair degree of agreement of these variables was observed irrespective of place and year.

Efforts have been made to forecast yield of cocoa also. In an attempt to forecast yield variables in bulk cocoa yield based on climatic components, Manurung *et al.* (1988) studied the influence of 16 climatic components on number of pods and bean fresh weight using step-wise multiple regression and three models of yield function. The number of rainy days, evening temperature, and wind speed occurring six months earlier together contributed 69.7% of the variation in the number of pods, and these three indices occurring seven months earlier contributed 66.9% of the variation in bean fresh weight. The climatic factors alone were not considered sufficient for predicting the yield potential of bulk cocoa.

2.7 Crop Orientation

Manipulation of crop growth behaviour so as to orient the yield to a favourable season is very much welcome for many crops. In North India, guavas produce two crops annually, one during the rainy season and the other during winter. The quality of the crop produced during the rainy season is poor. Agnihotri and Bhullar (1979) obtained a good winter crop by carrying out deblossoming during the rainy season on 12 year old Allahabad Safeda guava trees.

Efforts have been made in cocoa also to manipulate the timing of crop maturity. In Ecuador, pod diseases reduce potential cocoa production by 60 to 70 per cent. However, pods which develop and mature during the dry season escape heavy infestation. Edwards (1978) reported that manipulating the timing of crop maturity by supplementing natural pollination by hand pollination during the early dry season reduced losses from pod diseases and gave economic yield increases.

2.8 Use of chemicals for defloration/ fruit thinning.

The possibility of using chemicals to improve the growth and development of crop plants first arose in the 1930's with the discovery of auxins as natural plant hormones (Thomas, 1982).

The plant growth regulatory properties of maleic hydrazide were first described by Schoene and Hoffman in 1949 following the synthesis of the compound by the United States Rubber Company two years earlier. Ethephon (2-chlorethyl phosphonic acid) was first described by the Russian workers, Kabachnick and Rossiyskaya in 1946, but it was not until 1965 that Amchem Products Inc. reported and patented its plant growth regulatory properties.

Wittwer (1971) recommended 100 - 200 ppm of ethrel to induce flower abscission in tree crops like apple and peach. Luckwill (1976) also recommended NAA or ethephon for fruit thinning. They are applied to the crop within one month of full bloom to promote abscission of a proportion of the fruit. Wertheim *et al.* (1978) conducted flower thinning trials for several years using Ethrel-A (ethephon) at various concentrations, supplemented with hand thinning on four varieties of apple. The safer concentration varied from 0.025% to 0.3% depending on varieties. Application of carbaryl at 0.15% gave satisfactory results.

Bidwell (1974) reported 250 ppm Sevin (carbaryl) to induce flower and fruit thinning in apple so as to avoid alternate bearing. Noma (1976) conducted studies on fruit thinning of citrus using NAA. The chemical was applied at 150 and 300 ppm, five and 30 days after full bloom. He found that the heavier, later treatment gave the best thinning effect. Agnihotri and Bhullar (1979) tried deblossoming in guavas using sprays of NAA (100-150 ppm), carbaryl (250-400 ppm), MH (150-250 ppm) or ethephon (250-400 ppm) applied when about 10 to 20 per cent of the flowers had opened. All treatments gave significant fruit set reduction (74-86.6%) compared with the control.

Kilavuz and Eti (1993) thinned loquat cultivars with 25, 50, and 100 ppm NAA or Naphthalene acetamide (NAAm) and by hand. They found that thinning percentage increased with increasing concentration. However, the optimum level of thinning was obtained with 25 ppm. Reddy and Reddy (1993) obtained reduced number of inflorescence and flowers per shoot by a spray of NAA 200 ppm. In *Citrus reticulata,* Shiang and Hsintszu (1994) could achieve thinning with the help of NAA applied at concentrations 200 to 500 ppm. Degree of thinning increased with increasing concentration.

Chemical flower removal with Ethrel-48 (ethephon) at 0, 800, or 1600 ppm was compared with manual removal on mango cv. Keitt trees (Sauco *et al.*, 1993). Hand thinning or application of ethrel at 800 or 1600 ppm increased the number of terminals with normal fruits compared with controls and yield was increased from 1924 g per 10 panicles for controls to 3552 g and 4124 g by hand thinning and 800 ppm ethrel, respectively.

Chemical deblossoming was tried in Kinnow by Sidhu *et al.* in 1993. Flower thinning at full bloom stage with NAA (200, 300, 400 ppm), Ethephon (100, 200, 300 ppm), Sevin (1000, 2000, 3000 ppm) sprays and hand thinning were tried. Ethephon 300 ppm resulted in the highest percentage (91.8%) of flower abscission, but it also promoted leaf abscission. NAA (400 ppm) caused 80.3% flower abscission which resulted in reduced fruit set and increased leaf fruit ratio.

Material and Methods

MATERIALS AND METHODS

The present investigation was carried out in the field of *Cadbury*-KAU Cocoa Research Project, attached to the College of Horticulture, Vellanikkara, Thrissur, during 1992-96. The area is situated at 10°31' North latitude and 76°13' East longitude. The soil is lateritic sandy clay loam and the climate is warm, humid tropical . The total rainfall is around 3000 mm, about 75% of which is concentrated in about four months. There is a long dry spell with only occasional rains. The monthly weather data for five years from 1988 are given in Appendix 1. The experimental materials and methods used for the study are described hereunder.

3.1 Experimental materials

The experiment on the effect of weather on pod yield was carried out using 646 nine-year old bearing cocoa trees. Out of these, 374 were being grown under rainfed and 272 under partially irrigated conditions that provided one irrigation once in a fortnight to a month. Another part of the trial consisted of 170 plants of ten years of age, developed from a single clone. These were used for the study on crop orientation. The flowering intensity was studied in relation to weather and pod load using 30 plants of 10 years of age, all belonging to the same clone. In addition to these, plants from bulk plantings were used for the defloration study. All these plants belonged to the Forastero type of cocoa.

3.2 Experimental Methods

3.2.1 Field trials

3.2.1.1 Relation between weather, pod load and flowering

In this experiment, thirty genetically identical plants were used. Out of these, fifteen plants were maintained with pod load and fifteen without pod load. In the case of plants maintained without pod load, the fruits were removed as and when they were formed. Mechanical methods were resorted to for fruit removal. In the other set with pod load, fruits were allowed to form and develop without any disturbance.

Cocoa being an year-round bloomer with flowers all over the tree, a sampling procedure was adopted for taking daily flower counts. Two metre length of the tree trunk was marked from base and flowers produced on this area were considered for the study. Flower count was taken daily and the counted flowers were stripped off in the set without pod load. In the other, the counted flowers were paint marked to avoid recounting next day.

The estimation of pod load was done as suggested by Alvim *et al* (1972). Five hundred newly set fruits were marked first from which twenty developing fruits were plucked every month and dry weight determined till the fruits were ripened.

3.2.1.2 Relation between weather, pod load and yield

The data on number of pods produced by each of 374 cocoa trees grown under rainfed and 272 trees under irrigated conditions for the period from 1988 to 1992 were collected and tabulated on monthly basis. The potential production was considered *ie,* the number of damaged pods were also added to the properly ripened pods of each month

3.2.1.3 Orientation of crop season

3.2.1.3.a Effect of defloration on total yield and bean size

In this experiment, one set of fifty plants used as the treatment plants were stripped of all the flowers excepting for the period from April to July (eight months). Defloration was done at weekly intervals during periods of heavy flowering. It was done at fortnightly intervals in seasons with sparse flowering. Manual methods were resorted to for defloration.

In the year 1993-94, when the experiment was initially conducted, there was continuous rain during June-July and flower production was very sparse. The few flowers produced did not develop into fruits also. The previously produced fruits were severely affected by black pod and wilt so that there was nothing for a harvest.

The experiment was repeated in 1995-96 using another set of 70 plants. Thirty five plants were used as treatment plants which were stripped of all the flowers for eight months as done previously. Another set of thirty five plants were used as control. For the treatment plants harvesting was concentrated during October to December. During each harvest, pod number, bean fresh weight, bean size and bean dry weight were determined, for both treatment and control plants. Representative samples of five beans were taken for bean size determination. The length, width and breadth of the beans were measured using vernier calipers. Dry bean weight was determined using twenty beans.

3.2.1.3.b Effect of growth regulators/ chemicals on defloration

Different chemicals/ plant growth regulators were tried for their effect on defloration, as an alternative for mechanical methods.

1) Finding out lethal concentration

In order to arrive at the toxic levels of chemicals/ growth regulators, above which level the chemical should not be tried, one year old seedlings grown in pots as well as five-year old trees were sprayed with different concentrations of the chemical. The chemicals and the concentrations tried are shown below.

	Name of chemical	Concentration(ppm)			
1	Ethephon	200	400	600	800
2	Maleic hydrazide	250	500	750	1000
3	Naphthalene acetic acid	200	300	400	500
4	Carbaryl	250	500	750	1000

2) Effect of chemicals on defloration

Different concentrations of these five chemicals were tried for defloration on field-grown mature plants. The concentrations which were arrived at based on the observations on toxicity were the following:

Name of chemical	Concentration(ppm)					
1. Ethephon	50	100	150	200	250	300
2. Carbaryl	100	150	200	300	500	700
3. Maleic hydrazide	50	100	150	200	300	500
4. Naphthalene acetic acid	50	100	150	200	300	500

3) Effect of ethephon on defloration

Based on the results of previous experiments, further refinement of the concentration of ethephon was made by spraying it at concentrations of 20, 30, 40, 50, 60, 70, 100, 150 and 200 ppm on field-grown mature plants. From marked area flower count was taken at frequent intervals.

3.2.2 Statistical methods

3.2.2.1 Relation between weather and flower production of plants without pod load.

From the daily observations of flower production, mean weekly flower production of 15 trees on the marked area was determined. Such flower production values of 65 weeks were correlated with seven weather parameters of previous 12 weeks. The weather parameters considered were the following.

a. Maximum temperature
b. Minimum temperature
c. Morning relative humidity
d. Evening relative humidity
e. Bright sunshine hours
f. Total rainfall
g. Number of rainy days

3.2.2.1.a Maximum temperature

Flower production of 65 weeks was correlated with maximum temperature of previous one to twelve weeks.

3.2.2.1.b Minimum temperature

Simple correlation analysis was done for flower production and minimum temperature for the whole 65 weeks.

3.2.2.1.c Relative humidity and bright sunshine hours

As in the previous case, the morning and evening relative humidities and bright sunshine hours of the whole period were correlated with flower production.

3.2.2.1.d Total rainfall

Correlation analysis was done with weekly flower production and total weekly rainfall of previous one to twelve weeks of the summer rainy period. The analysis for the remaining period and the whole period were also done. The daily flower production was also correlated with the summer rains of previous ten to twenty four days.

3.2.2.1.e Number of rainy days

Flower production was correlated with weekly total rainy days one to twelve weeks prior to flowering.

3.2.2.1.f Water deficit and water surplus

In addition to weather variables, soil water deficit and soil water surplus were also used for the correlation study. These variables were found out using Thornthwaite and Mather (1955) method. In this method, potential evaporation was calculated from values of pan evaporation. The sum of the values by which precipitation was less than potential evaporation was taken as the accumulated potential water loss (APWL). The water holding capacity of the soil was taken to be 250 mm, as suggested by Thornthwaite and Mather (1955).

The value of soil storage corresponding to each value of APWL was collected from the Tables (Thornthwaite and Mather,1955). The precipitation plus the amount of water drawn from the soil moisture storage gave the actual evaporation. The amount by which the potential evapotranspiration and actual evaporation differed in any week was the water deficit in that week. Any excess precipitation after reaching the water holding capacity was counted as water surplus. The water deficit and water surplus were correlated with flower production in the same way as weather variables were correlated.

3.2.2.2 Relation between weather elements, pod load and flower production of plants with pod load

This experiment differed from the previous one in that there was no defloration and all the fruits were retained. All the statistical analyses done in the previous experiment were performed in this also. In addition to these, gain in pod weight of each week was correlated with flower production of succeeding one to twelve weeks.

Pod load was calculated as suggested by Alvim *et al* (1972). To start with, 500 newly set fruits were marked and 20 each were plucked when they were 4, 8, 13, 17 and 21 weeks old. By 21 weeks, the fruits were fully formed. The plucked fruits were oven dried and weighed. A curve was plotted with dry weight against age in weeks and from the curve, dry weight and percentage gain in weight of fruits corresponding to each week were determined. In order to find out the weekly gain in pod load, fruits harvested from each tree were marked separately and their fresh weight was found out. A representative sample of five fruits was then taken from the total harvested fruits and their fresh weight and oven dry weight were taken. The ratio of dry weight to fresh weight multiplied by the fresh weight of harvested pods gave the dry weight of harvested pods.

The dry weight thus obtained was split up into twenty one based on the percentage change in pod weight of the sample. Thus each harvest was split up and the total weight gain of each tree corresponding to each week was determined.

3.2.2.3 Relation of pod yield to weather and pod load

In this study, 374 rainfed and 272 irrigated plants were used. Pod number was taken as the yield and the pod yield of each tree in each harvest available from previous records was utilized. The monthly totals and means of each tree were worked out for the period from 1988 to 1992, for both rainfed and irrigated crops separately. Correlation analysis was done with mean pod number and important weather parameters, water deficit and water surplus of previous one to seven months. In addition to these, separate analyses for weather variables of summer and monsoon periods were also done. Here the monthly weather variables were correlated with mean pod number one to seven months after.

Pod production was also correlated with increase in pod load. For every month, the increase in pod load of previous one to five months was mainly dependent on that month's yield. So the contribution by that month was deducted from the total increase in load while calculating increase in pod load.

3.2.2.4 Crop orientation

Effect of defloration on total yield and bean size

In this experiment data on the total pod number and wet bean weight of control and treatment plants were collected. In the case of treatment plants, the yield was restricted to three months from October to December. In control, there were pods throughout the year. The per plant total yield of control and treatment plants were compared using Student's t-test (Panse and Sukhatme, 1985).

Results

RESULTS

4.1 Relation between weather and flower production of plants without pod load

The mean weekly flower production from the marked area of fifteen plants with and without pod load and the corresponding weather parameters during 65 weeks of 1993-'94 are given in Appendix 2. The water deficit and water surplus of these 65 weeks are presented in Appendix 3.

Table 1 presents the monthly flower production from April, 1993 to June, 1994. The results of simple correlation analysis between flower production and weather parameters one to 12 weeks before are presented in Table 2. Out of the seven variables, four were negatively and significantly related to flower production in many instances, while two showed positive and significant correlation. Maximum temperature and sunshine hours were the factors with positive correlation while morning and evening relative humidity, total rainfall and number of rainy days showed negative relationship. Minimum temperature showed both positive and negative relationship during different weeks.

Table 1 Monthly flower production of plants without pod load

Month	Tree number															Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Apr 93	95	113	93	145	4	29	142	262	101	133	20	87	35	59	141	1459
May 93	132	118	265	132	146	95	252	403	255	252	212	217	40	292	380	3191
Jun 93	162	94	97	78	79	33	156	219	148	86	120	107	35	93	154	1661
Jul 93	7	16	20	1	2	4	6	10	9	4	4	2	0	3	18	106
Aug 93	16	14	15	3	4	2	9	14	19	5	1	2	0	2	44	150
Sep 93	99	86	39	25	41	43	50	153	50	22	7	6	4	16	179	820
Oct 93	131	124	102	51	83	103	169	204	120	72	28	22	7	25	293	1534
Nov 93	187	250	103	88	71	82	143	200	114	36	23	27	2	33	236	1595
Dec 93	212	246	111	113	64	137	219	193	161	87	30	22	9	43	393	2040
Jan 94	72	143	140	28	30	15	190	293	122	95	43	29	19	25	322	1566
Feb 94	390	656	251	212	28	232	439	724	212	414	133	99	109	149	671	4719
Mar 94	65	345	355	457	171	97	123	137	134	118	66	11	112	100	293	2584
Apr 94	1268	1380	1386	1054	457	445	1222	1303	1186	1192	1082	716	301	1071	1753	15816
May 94	293	337	492	168	380	142	235	384	254	192	184	150	89	178	354	3832
Jun 94	245	260	148	150	189	185	189	262	82	195	96	164	62	142	285	2654

Table 2 Correlation between weekly flower production and weather elements of previous 1 - 12 weeks for plants without pod load

Weather elements	Correlation coefficient values for variables prior to											
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks	11 weeks	12 weeks
Maximum temp.	0.283*	0.317**	0.322**	0.318**	0.352**	0.396**	0.364**	0.313*	0.231	0.187	0.179	0.097
Minimum temp.	0.125	0.024	0.105	0.317**	0.277*	- 0.017	- 0.214	-0.216	- 0.101	0.013	- 0.129	- 0.298*
Total rainfall	- 0.099	- 0.084	- 0.128	-0.225	- 0.258*	- 0.240	- 0.223	-0.213	- 0.214	- 0.218	- 0.210	- 0.194
No .of rainy days	- 0.083	- 0.045	- 0.087	-0.240	-0.312**	- 0.287*	- 0.257*	-0.249*	- 0.229	- 0.251*	- 0.243	- 0.213
Morning R.H.	- 0.006	- 0.084	- 0.095	-0.079	- 0.063	- 0.216	-0.475**	-0.463**	- 0.142	- 0.073	- 0.160	- 0.294*
Evening R.H.	- 0.132	- 0.196	- 0.170	-0.151	- 0.229	-0.407**	-0.517**	-0.480**	- 0.278*	- 0.201	- 0.259*	-0.319**
Sunshine hours	0.178	0.198	0.242	0.286*	0.331	0.330**	0.346**	0.251*	0.153	0.140	0.223	0.263*

* Significant at 5% level ** Significant at 1% level

4.1.1 Maximum temperature

Maximum temperature always had a positive relationship with flower production. From the first to eighth week before flowering, maximum temperature had a significant correlation and the highest correlation coefficient value of 0.396 was noted in the sixth week.

4.1.2 Minimum temperature

Minimum temperature recorded positive influence four to five weeks before flowering and negative influence 12 weeks before. The highest correlation value of 0.317 was observed in the fourth week.

4.1.3 Relative humidity

Both morning and evening relative humidity showed a negative influence on flower production. In both the cases, maximum influence was noted seven weeks prior to flowering, the correlation values being - 0.475 and -0.517, respectively.

4.1.4 Bright sunshine hours

Duration of bright sunshine hours had a positive effect on flowering with maximum effect seven weeks before flowering.

4.1.5 Total rainfall

Table 2 shows that rainfall had an overall negative influence on flowering. But an evaluation of the raw data showed that there was often a bout of flowering following a rain during the dry season. In order to find out the probable seasonal differences, correlation study was conducted with flower production and rainfall of monsoon and summer periods separately. The period from June to November was taken as rainfall period and that from March to May of 1993 and December, 1993 to April, 1994 as summer. In Table 3, the relationship between flower production and rainfall separately of summer and monsoon periods is given. Influence of daily rainfall of summer period on daily flower production was also analysed and the results are furnished in Table 4.

When the whole period was considered, the highest correlation coefficient value was -0.258, corresponding to the rainfall five weeks prior to flowering. For summer rains, the influence was positive during the period from first to third week. The highest correlation coefficient value of 0.815 was noted during the third week. The correlation analysis of rainfall for periods other than summer

Table 3 Correlation between rainfall 1-12 weeks before flowering and mean weekly flower production for summer and period other than summer

Rainfall of	Correlation coefficient values for variables prior to											
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks	11 weeks	12 weeks
summer period.	0.609**	0.789**	0.815**	0.304	- 0.131	- 0.120	- 0.130	- 0.139	- 0.106	- 0.133	- 0.163	- 0.162
period other than summer	- 0.223	- 0.312	- 0.241	- 0.393*	- 0.417*	- 0.355*	- 0.284	- 0.248	- 0.297	- 0.309	- 0.270	- 0.223

* Significant at 5% level
** Significant at 1% level

Table 4 Correlation between daily flower production and daily rainfall of previous 10 to 21 days in summer rainy period

	Correlation coefficient for rainfall prior to											
	10 days	11 days	12 days	13 days	14 days	15 days	16 days	17 days	18 days	19 days	20 days	21 days
For plants without pod load	0.510**	0.569**	0.484**	0.459**	0.497**	0.489**	0.400**	0.311**	0.307**	0.217**	0.364**	0.367**
For plants with pod load	0.248*	0.308**	0.320**	0.341**	0.392**	0.481**	0.419**	0.427**	0.389**	0.315**	0.245*	0.234*

* Significant at 5% level
** Significant at 1% level

recorded negative values of correlation coefficients four to six weeks before flowering with maximum influence five weeks before flowering.

Correlation studies with daily flower production and daily rainfall of the summer period gave high values for rainfall of 10 to 21 days prior to flowering. There was a decrease in the values beyond this period. The highest correlation values, however, were noted for rainfall of 11^{th} day prior to flowering.

4.1.6 Number of rainy days

The influence of rainy days was also negative with the highest value of - 0.312 obtained for the fifth week prior to flowering (Table 2).

4.1.7 Water deficit and water surplus

The results of correlation analysis between weekly mean flower production and weekly water deficit and water surplus are given in Table 5. The results showed that water deficit of five to eight weeks before flowering had a positive influence on flowering with maximum effect in the seventh week. Water surplus did not show any significant influence on flowering.

Table 5 Correlation between mean weekly flower production and water deficit/ water surplus of previous 1-12 weeks

Variables	Correlation coefficient values for variables prior to											
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks	11 weeks	12 weeks
water deficit	- 0.053	- 0.043	- 0.065	0.163	0.304*	0.322**	0.363**	0.311*	0.156	0.134	0.178	0.223
water surplus	- 0.216	- 0.226	- 0.217	- 0.217	- 0.207	- 0.195	- 0.182	- 0.178	- 0.179	- 0.167	- 0.156	- 0.142

* Significant at 5% level
** Significant at 1% level

4.2 Relation of flowering with weather and pod load for plants retained with pod load

Table 6 shows the monthly total flower production of fifteen plants for the period from April, 1993 to June, 1994. The results of simple correlation analysis between flower production and weather variables are presented in Table 7. The results of correlation analysis with water deficit and water surplus and pod load are given in Table 8.

The correlation analysis with weather variables showed more or less the same trend as in plants grown without pod load. The main difference was that the correlation coefficient values were comparatively high in this case.

4.2.1 Maximum temperature

As in plants without pod load, the maximum influence of temperature was six weeks before flowering. The coefficient of correlation was 0.411. From first to eighth week, there was significant positive correlation.

4.2.2 Minimum temperature

Significant positive effect of minimum temperature on flowering was noticed after five weeks.

Table. 6 Monthly flower production of plants with pod load

Month	Tree number															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Apr 93	5	8	69	134	62	23	139	141	121	28	10	27	77	13	19	876
May 93	26	111	181	98	65	62	131	56	98	42	30	79	76	38	67	1160
Jun 93	44	40	83	28	31	18	33	60	54	39	22	57	39	74	62	684
Jul 93	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	3
Aug 93	0	0	0	0	8	0	0	2	4	0	0	6	0	2	0	22
Sep 93	10	3	3	0	13	2	59	23	13	4	5	10	20	10	8	183
Oct 93	92	27	10	3	20	11	83	108	30	31	21	37	64	16	38	591
Nov 93	65	30	10	2	22	7	99	78	33	30	6	42	106	21	40	597
Dec 93	60	45	23	6	44	21	101	144	54	62	22	48	162	39	57	888
Jan 94	22	18	18	12	22	24	37	44	25	43	21	25	86	22	8	427
Feb 94	27	49	54	34	135	102	86	83	39	28	23	72	213	75	17	1037
Mar 94	7	68	57	94	73	66	7	4	2	15	9	30	13	237	4	686
Apr 94	103	211	220	272	208	270	297	164	236	295	136	193	186	125	91	3007
May 94	38	89	133	99	64	57	92	40	100	71	51	103	91	80	33	1141
Jun 94	13	28	28	8	5	35	16	9	27	22	18	44	49	14	6	322

Table 7 Correlation between weekly flower production and weather elements of previous 1 - 12 weeks for plants with pod load

Weather elements	Correlation coefficient values for variables prior to											
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks	11 weeks	12 weeks
Maximum temp.	0.369**	0.390**	0.356**	0.383**	0.379**	0.411**	0.394**	0.336*	0.235	0.174	0.143	0.047
Minimum temp.	0.246*	0.089	-0.023	0.159	0.255*	-0.017	-0.239	-0.216	-0.101	-0.210	-0.217	-0.440**
Total rainfall	-0.188	-0.150	-0.157	-0.225	-0.310*	-0.309*	-0.286*	-0.256*	-0.250*	-0.218	-0.210	-0.234
No. of rainy days	-0.218	-0.157	-0.104	-0.240	-0.364**	-0.365**	-0.340**	-0.306*	-0.257*	-0.272*	-0.243	-0.243
Morning R.H.	-0.070	-0.163	-0.159	-0.137	-0.052	-0.231	-0.395**	-0.552**	-0.258*	-0.088	-0.226	-0.300*
Evening R.H.	-0.172	0.282*	-0.220	-0.204	-0.229	-0.396**	-0.531**	-0.592**	-0.376**	-0.201	-0.300*	-0.337**
Sunshine hours	0.266*	0.274*	0.276*	0.338**	0.331	0.395**	0.424**	0.338**	0.200	0.177	0.223	0.313*
Difference in temp.	0.266*	0.329**	0.366**	0.286*	0.241	0.392**	0.515**	0.438**	0.341**	0.229	0.227	0.274*

* Significant at 5% level
** Significant at 1% level

Table 8 Correlation between mean weekly flower production and water deficit/ water surplus of previous 1-12 weeks

Variables	Correlation coefficient values for variables prior to											
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks	11 weeks	12 weeks
Water deficit	0.104	0.120	- 0.044	0.192	0.348**	0.430**	0.456**	0.416**	0.226	0.156	0.212	0.224
Water surplus	- 0.265*	- 0.269*	- 0.263*	- 0.267*	- 0.256*	- 0.231	- 0.204	- 0.198	- 0.200	- 0.195	- 0.186	- 0.172
Pod load	- 0.204	- 0.245	- 0.258*	- 0.245	- 0.226	- 0.212	- 0.181	- 0.124	-0.062	- 0.027	- 0.000	0.023

* Significant at 5% level
** Significant at 1% level

In all other weeks the influence was either non significant or negative. In eighth, ninth and twelfth weeks, there was significant negative relationship (Table 7).

The differences between day and night temperatures were found out and correlated with flower production. The results are presented in Table 7. This shows that there was positive correlation between flower production and the difference in temperature throughout the period and it was significant during most of the period.

4.2.3 Relative humidity

Both morning and evening relative humidity values showed negative correlation with flower production, the highest correlation being recorded eight weeks prior to flowering. The coefficients of correlation for morning and evening humidity were -0.552 and -0.592, respectively.

4.2.4 Bright sunshine hours

Sunshine hours also affected flowering, the maximum influence being noted after seven weeks [Table 7).

4.2.5 Total rainfall and number of rainy days

The influence of total rainfall and number of rainy days was negative throughout the period, with maximum effect recorded after five to six weeks. Table 9 shows the relationship between flower production and rainfall of summer period and period other than summer.

For summer rains, the influence was positive, the highest value of correlation coefficient being 0.835 corresponding to the rainfall three weeks prior to flowering. The correlation analysis for periods other than summer gave the highest negative value of -0.395 corresponding to rainfall five weeks before flowering. Table 4 gives the results of correlation analysis between daily flower production and daily rainfall of the summer period.

4.2.6 Water deficit and water surplus

Water deficit recorded positive influence on flowering after five to eight weeks, as shown in Table 9. The highest value of coefficient of correlation was 0. 456, corresponding to water deficit seven weeks before flowering. Water surplus, on the other hand, showed negative relationship one to five weeks after.

Table 9 Correlation between rainfall 1-12 weeks before flowering and mean weekly flower production for summer and period other than summer

Rainfall of	Correlation coefficient values for variables prior to											
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	7 weeks	8 weeks	9 weeks	10 weeks	11 weeks	12 weeks
summer period	0.266	0.641**	0.835**	0.306	- 0.154	- 0.148	- 0.168	- 0.142	- 0.106	- 0.132	- 0.175	- 0.191
period other than summer	-0.216	-0.278	-0.203	- 0.346	- 0.395*	- 0.391*	- 0.325	- 0.253	- 0.272	- 0.268	- 0.253	- 0.221

* Significant at 5% level
** Significant at 1% level

4.2.7 Pod load

Table 8 gives the correlation of flower production with pod load. The relationship was inverse, the highest value of coefficient of correlation being -0.258, corresponding to the pod load three weeks before flowering.

4.3 Relation of pod yield of rainfed cocoa with weather parameters and pod load

The monthly mean pod production of 374 rainfed cocoa plants from 1988 to 1992 is presented in Table 10. The data show that there are mainly two peaks of pod production, one during April-May and the other during October-November, the exact period changing slightly from year to year.

4.3.1 Temperature, relative humidity and sunshine hours

Table 11 shows the results of correlation analysis of pod production with these variables. Significantly high correlation was noted for maximum temperature one to two months before harvest, for number of rainy days and sunshine hours two months before, for relative humidity three months prior to harvest and for minimum temperature four months before.

Table 10 Monthly mean pod production of 374 rainfed cocoa plants for the period from 1988 to 1992

Year	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	1.74	3.00	6.14	5.95	5.57	2.45	3.73	1.30	3.00	2.75	2.45	2.01
1989	1.96	1.24	3.48	3.76	4.65	2.77	2.28	1.16	0.99	8.92	5.29	1.64
1990	4.67	2.46	1.65	2.41	3.92	5.17	3.04	2.33	0.23	2.15	2.70	1.14
1991	1.52	2.09	2.52	4.55	8.45	3.56	2.64	1.43	0.74	2.20	1.23	1.72
1992	3.07	4.35	3.59	8.18	7.35	5.04	5.97	3.97	1.92	5.08	5.30	0.38
Mean	2.59	2.62	3.47	4.97	5.98	3.79	3.53	2.03	1.37	4.22	3.39	1.37

Table 11 Correlation between monthly pod production and weather parameters of the rainfed crop

Weather variable	Correlation coefficient for variables prior to						
	1 month	2 months	3 months	4 months	5 months	6 months	7 months
Maximum temp.	0.410**	0.449**	0.263*	0.026	- 0.012	- 0.067	- 0.094
Minimum temp.	0.284*	0.105	- 0.348**	- 0.504**	- 0.263*	- 0.029	0.041
Morning R.H.	- 0..031	- 0.203	- 0.307 *	- 0.294*	- 0.210	- 0.007	0.206
Evening R.H.	- 0.204	- 0.361**	- 0.422**	- 0.289*	- 0.170	0.048	0.180
No. of rainy days	- 0.173	- 0.360**	- 0.313*	- 0.231	- 0.262*	- 0.190	0.045
Bright sunshine hrs.	0.232	0.378**	0.346**	0.179	0.217	0.058	- 0.053

* Significant at 5% level
** Significant at 1% level

4.3.2 Rainfall and number of rainy days

The results of correlation analysis with rainfall and number of rainy days are given in Table 11 and Table 12. There was high negative correlation with these parameters during second, third and fifth months before harvest. When the monsoon and non-monsoon periods were taken (Table 12), significant negative relationship was noted with monsoon rainfall during most of the period. Non-monsoon rains were unfavourable two to four months after their occurrence. The most deleterious effect was observed four months after, the correlation coefficient being -0.376.

4.3.3 Water deficit and water surplus

Correlation analysis between pod production and water deficit of previous one to seven months (Table 13) show that there was positive relationship during two and three months before harvest.

Water surplus showed negative relationship with pod production after two and five months.

4.3.4 Pod load.

Correlation analysis of pod production recorded positive correlation with pod load one to

Table12 Correlation between mean pod production and rainfall of rainfed cocoa crop

	Correlation coefficients for rainfall prior to						
	1 month	2 months	3 months	4 months	5 months	6 months	7 months
Total rainfall	- 0.135	- 0.385**	- 0.252	- 0.117	- 0.250	- 0.204	- 0.003
Monsoon rains	- 0.001	- 0.236	- 0.051	0.105	- 0.081	- 0.381	- 0.382
Non - monsoon rains	0.024	- 0.198	- 0.315	- 0.376*	0.140	0.254	0.024

* Significant at 5% level
** Significant at 1% level

Table 13 Correlation between monthly mean pod production and water deficit, water surplus and pod load of rainfed cocoa

Variables	Correlation coefficients for variables prior to						
	1 month	2 months	3 months	4 months	5 months	6 months	7 months
Water deficit	0.204	0.426**	0411**	0.231	- 0.112	- 0.238	- 0.196
Water surplus	- 0.181	- 0.378**	- 0.18	- 0.098	- 0.290*	- 0.207	0.007
Pod load	0.331*	0.491**	0.445**	0.237	0.014	- 0.195	- 0.303*

* Significant at 5% level
** Significant at 1% level

three months prior to harvest (Table 13). Seven months before, pod load showed negative relationship.

4.4 Relation of pod yield of irrigated cocoa to weather parameters and pod load

The monthly mean pod production of irrigated crop during the period from 1988 to 1992 is presented in Table 14. Here the yield was more distributed. When compared to the rainfed crop, the irrigated crop recorded notable increase in the yield of August-September months. Very low yield was noted only in December. The two peaks of April- May and October-November were comparable. Table 15 gives the results of simple correlation analysis between pod yield, weather parameters and pod load.

4.4.1 Maximum temperature

Maximum temperature recorded positive relationship with pod production. The relationship was highest with pod yield five months after (Table 15).

Split up of the years to monsoon and non-monsoon periods and correlation analysis between pod yield and maximum temperatures of these periods separately, showed that during monsoon season significantly positive correlation existed between

Table 1.4 Monthly mean pod production of 272 irrigated cocoa plants for the period from 1988 to 1992

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	1.88	1.85	3.43	5.85	5.00	3.28	2.10	1.11	3.04	2.83	2.15	0.81
1989	1.97	0.81	3.16	6.15	5.12	2.93	1.66	2.65	3.98	10.99	2.60	0.40
1990	2.96	1.66	2.28	2.58	3.99	3.51	3.62	4..24	1.27	1.98	2.04	1.25
1991	1.68	2.39	2.16	4.80	5.54	2.69	2.25	2.25	1.25	4.35	1.81	1.14
1992	2.51	3.65	3.07	7.44	6.02	3.82	7.17	3.42	5.44	5.69	2.7	0.22
Mean	2.20	2.07	2.82	5.36	5.13	3.24	3.36	2.73	2.99	5.16	2.26	0.76

Table 15 Correlation between monthly pod production and weather parameters of the irrigated crop

Weather variable	Correlation coefficient for variables prior to						
	1 month	2 months	3 months	4 months	5 months	6 months	7 months
Maximum temp.	0.223	0.264	0.177	0.151	0.271	0.230	0.066
Minimum temp.	0.302	- 0.013	- 0.290	- 0.291	- 0.029	- 0.077	- 0.213
Morning R.H.	0.169	- 0.068	- 0.276	- 0.350**	- 0.276	- 0.144	0.004
Evening R.H.	- 0.051	- 0.239	- 0.325	- 0.302	- 0.303	- 0.200	- 0.095
No. of rainy days	0.006	- 0.109	- 0.180	- 0.256	- 0.460**	- 0.345	- 0.176
Bright sunshine hrs.	0.027	0.153	0.168	0.247	0.390**	0.264	0.117

* Significant at 5% level
** Significant at 1% level

temperature and pod yield after five to seven months (Table 16).

During November to May period the response was positive one to two months after, but negative five months after.

4.4.2. Minimum temperature.

Minimum temperature was inversely related to yield after three to four months. When the minimum temperature of monsoon and non-monsoon periods were separately correlated with pod yield, the same trend was noticed during non-monsoon period. However, during monsoon period there was no significant relation between pod yield and minimum temperature.

4.4.3 Relative humidity

Relative humidity showed negative relationship with pod production after three to five months. For morning humidity the influence was maximum after four months and for evening humidity the highest coefficient of correlation was recorded after three months.

Relative humidity of non-monsoon period showed negative influence one month after but beyond

Table 16 Correlation between monthly pod yield and weather parameters during monsoon and non-monsoon periods

Weather elements	Period	Correlation coefficients for variables prior to						
		1 month	2 months	3 months	4 months	5 months	6 months	7 months
Maximum temperature	Jun - Oct	0.023	- 0.336	- 0.258	- 0.040	0.607**	0.547**	0.670**
	Nov-May	0.701**	0.565**	0.136	- 0.247	- 0.396*	- 0.095	0.185
Minimum temperature	Jun - Oct	0.100	- 0.018	- 0.014	- 0.099	0.167	- 0.203	- 0.007
	Nov-May	0.440**	- 0.021	- 0.447**	- 0.417*	- 0.040	- 0.074	- 0.313
Morning relative humidity	Jun - Oct	- 0.080	- 0.487*	- 0.204	- 0.386	- 0.598**	- 0.081	0.339
	Nov-May	- 0.359*	- 0.226	- 0.221	- 0.048	0.240	0.365*	0.356*
Evening relative humidity	Jun - Oct	- 0.436*	- 0.381	- 0.311	- 0.359	- 0.601**	- 0.337	0.277
	Nov-May	- 0.402*	- 0.319	- 0.182	- 0.088	0.297	0.376*	0.238

* Significant at 5% level ** Significant at 1% level

five months, higher relative humidity was found to be beneficial (Table 16). Relative humidity of monsoon period had an adverse effect on pod production and the influence was maximum five months after. Positive relationship existed only in seventh month.

4.4.4 Bright sunshine hours

Duration of light was positively associated with fruit production and development. Sunlight hours of fifth to sixth months prior to harvest had significant correlation with pod yield.

4.4.5 Total rainfall and number of rainy days

Heavy rainfall and more number of rainy days were inversely related to yield. Rains five to six months prior to harvest had the maximum deleterious effect. Break-up of the correlation to monsoon and non-monsoon periods is shown in Table 17. During third and fourth months, monsoon rains showed positive relationship with yield. From fifth month onwards, the relationship became negative, the maximum influence being noted six months before harvest (-0.514). Non-monsoon rains had positive influence on yield five to six months before harvest. But during second, third, fourth and seventh months, the relationship was negative.

Table 17 Correlation between mean pod production and rainfall of irrigated cocoa

	Correlation coefficients for rainfall prior to						
	1 month	2 months	3 months	4 months	5 months	6 months	7 months
Total rainfall	- 0.006	- 0.118	- 0.014	- 0.113	- 0.454**	- 0.365**	- 0.121
Monsoon rains	- 0.069	- 0.007	0.337	0.411*	- 0.447*	- 0.514**	- 0.507**
Non - monsoon rains	0.081	- 0.235	- 0.366*	- 0.290	0.251	0.096	- 0.278

* Significant at 5% level
** Significant at 1% level

4.4.6 Water deficit and water surplus

Results of simple correlation analysis between pod production and water deficit is shown in Table 18. All the values of correlation coefficients were positive with significant values in second and third months.

The influence of water surplus was negative excepting during third month, with significant values five and six months before .

4.4.7 Pod load

Pod load of first four months before harvest recorded positive correlation with yield, while load of fifth to seventh months had negative influence (Table 18).

4.5 Crop orientation

4.5.1 Effect of defloration on total yield and bean size

Data on total monthly yield in terms of pod number and wet bean weight of both treatment and control plants are presented in Table 19. Table 20 gives data on bean characters.

The per plant total yield of control and treatment plants were compared using Student's t-test.

Table 18 Correlation between mean pod production and water deficit, water surplus and pod load of irrigated cocoa

	Correlation coefficients for variables prior to						
	1 month	2 months	3 months	4 months	5 months	6 months	7 months
Water deficit	0.130	0.343**	0.377**	0.251	0.047	0.075	0.099
Water surplus	- 0.039	- 0.095	0.021	- 0.152	- 0.490**	- 0.347**	- 0.071
Pod load	0.214	0.362**	0.302*	0.080	- 0.041	- 0.169	- 0.103

* Significant at 5% level
** Significant at 1% level

Table 19 Monthly total yield of treatment and control plants of the crop orientation experiment (1995-96)

Month and year	Pod no. of treatment plants	Pod no. of control plants	Wet bean weight of treatment plants	Wet bean weight of control plants
August, 1995	96	88	8140	7450
October, 1995	48	51	4555	4802
December, 1995	19	37	1610	3420
January, 1996	--	240	--	24203
February, 1996	--	50	--	5769
March, 1996	--	21	--	1680
April, 1996	--	38	--	2958
May, 1996	--	108	--	9290
June, 1996	--	58	--	4980
October, 1996	344	105	34666	10497
November, 1996	597	236	52911	24990
December, 1996	38	20	3045	1860
Total	1142	1052	104927	101899

Table 20 Monthly mean bean size of treatment and control plants of the crop orientation experiment (1995-96)

Month and year	Mean bean size of treatment plants (mm)			Mean bean size of control plants (mm)			Mean bean weight of	
	Length	Width	Thickness	Length	Width	Thickness	treatment plants (g)	control plants (g)
Aug, 1995	16.8	8.7	6.2	16.7	8.70	6.3	0.395	0.380
Oct, 1995	20.4	10.8	7.6	20.6	10.50	7.5	0.790	0.785
Dec, 1995	20.2	11.0	7.6	20.4	11.20	7.4	0.880	0.860
Jan, 1996	--	--	--	19.2	10.60	7.3	--	0.775
Feb, 1996	--	--	--	19.3	11.00	6.8	--	0.760
Mar, 1996	--	--	--	18.2	9.00	4.8	--	0.745
Apr, 1996	--	--	--	18.6	10.60	6.2	--	0.690
May, 1996	--	--	--	17.6	9.90	5.5	--	0.465
Jun, 1996	--	--	--	17.4	9.80	5.5	--	0.460
Oct, 1996	20.4	11.6	7.9	20.4	11.60	7.9	0.790	0.825
Nov, 1996	20.3	11.0	7.4	20.6	11.40	7.5	1.010	0.965
Dec, 1996	20.3	11.2	7.3	20.5	11.00	7.5	0.920	0.945
Mean of the oriented period	20.33	11.27	7.53	20.5	11.30	7.6	0.907	0.912

The results showed that there was no significant difference between the two in pod number and wet bean weight. Tables 21 and 22 give data of the 1993-'94 experiment when it was noted that the differences in yield were conspicuous and significant. Bean size of both treatment and control plants were comparable.

4.5.2 Effect of plant growth regulators/ chemicals on defloration

4.5.2.a Finding out lethal concentration

One year old seedlings treated with even the lower-most concentration of these chemicals were seriously affected. There was yellowing and defoliation of lower leaves with all chemicals except NAA. The terminal leaves were retained. With NAA, tender leaves were the first to be affected. Upper leaves dried and later the lower leaves were shed.

Mature plants were not affected by any of the chemicals at the concentrations tried.

4.5.2.b Effect of chemicals on defloration

The results of treating the plants with NAA, ethephon, carbaryl, and maleic hydrazide for defloration are given below.

Table 21 Monthly total yield of treatment and control plants of the crop orientation experiment (1993-94)

Month and year	Pod no. of treatment plants	Pod no. of control plants	Wet bean weight of treatment plants (g)	Wet bean weight of control plants (g)
August, 1993	657	742	40900	49422
September, 1993	143	176	9010	11075
October, 1993	16	1	1580	105
November, 1993	102	122	9652	11544
December, 1993	40	290	3985	27842
January, 1994	--	466	--	33276
February, 1994	--	218	--	15032
March, 1994	--	518	--	43260
April, 1994	--	438	--	30777
June, 1994	--	319	--	19415
July, 1994	--	44	--	2340
September, 1994	26	114	1663	14302
October, 1994	8	178	765	16427
Total	992	3714	67555	274817

Table 22 Monthly mean bean size of treatment and control plants of the crop orientation experiment (1993-94)

Month and year	Mean bean size of treatment plants (mm)			Mean bean size of control plants (mm)			Mean bean weight of	
	Length	Width	Thickness	Length	Width	Thickness	treatment plants (g)	control plants (g)
August , 1993	17.4	9.5	6.1	17.3	9.4	5.7	0.447	0.396
September, 1993	19.5	9.9	7.3	19.8	10.1	7.1	0.801	0.812
October, 1993	20.1	10.3	7.5	20.1	10.1	7.3	0.920	0.918
November, 1993	19.1	9.6	7.1	21.6	10.9	7.5	0.880	0.950
December, 1993	20.1	10.0	5.7	18.9	9.2	5.6	0.951	0.944
January, 1994	--	--	--	18.6	10.2	6.5	--	0.714
February, 1994	--	--	--	18.7	9.8	6.3	--	0.720
March, 1994	--	--	--	19.7	11.1	6.8	--	0.670
April, 1994	--	--	--	17.8	10.5	6.1	--	0.620
June, 1994	--	--	--	17.5	10.1	6.0	--	0.580
July, 1994	--	--	--	17.2	9.6	5.8	--	0.460
September, 1994	20.3	10.9	7.7	17.6	9.8	7.0	0.825	0.575
October, 1994	19.8	10.5	7.3	20.0	10.7	7.6	0.800	0.835
Mean of the oriented period	20.1	10.7	7.5	18.8	10.3	7.3	0.813	0.705

NAA

Concentrations from 50 to 500 ppm were tried. Lower concentrations did not show any effect on defloration. Concentrations above 500 ppm caused drying of a portion of flowers.

Maleic hydrazide

Concentrations upto 500 ppm were used. No defloration could be achieved with any of these concentrations.

Carbaryl

The concentrations tried varied from 100 to 700 ppm of carbaryl. These also did not show any effect on flower thinning.

Ethephon

Ethephon was tried from concentrations of 20 ppm to 200 ppm. At concentrations above 40 ppm there was thinning of flowers. The thinning occurred at the time of flower opening. At 100 ppm, almost all the opened flowers were shed. Concentrations above 150 ppm induced complete defloration within four days. New flowers opened five to six weeks after ethephon treatment. The results of the defloration trial with ethephon are shown in Table 23.

Table 23 Efffect of different concentrations of ethephon for defloration

Days after spraying	Mean flower number after treatment with different concentrations									
	20 ppm	30 ppm	40 ppm	50 ppm	60 ppm	70 ppm	100 ppm	150 ppm	200 ppm	Control
0	127	112	150	127	92	82	128	92	123	87
3	118	67	87	58	60	32	39	11	0	80
5	142	62	47	42	37	21	22	0	0	78
8	97	43	43	36	24	11	6	0	0	62
12	79	28	37	29	17	5	3	0	0	62
16	90	17	17	9	7	0	0	0	0	80

Discussion

DISCUSSION

5.1 Relation between weather and flower production

Tables 1 and 6 show that there is much variation in the monthly distribution of flowers. The percentage monthly distribution from April, 1993 to March, 1994 is shown in Fig.1 and 2. The week to week difference in flower production is also very conspicuous as revealed by Fig.3 and 4. This is an indication of the influence of weather on flower production since there is no other reason for this type of flower distribution. The results of correlation analysis between flower production and weather parameters (Table 2) also established the relationship. Out of the seven weather parameters tried, four were negatively and significantly correlated in many instances while two recorded positive and significant correlation. One factor showed both positive and negative relationship. Fig.5 to 8 give effect of weather parameters on flower production.

Maximum temperature showed positive relationship with flowering one to eight weeks after.

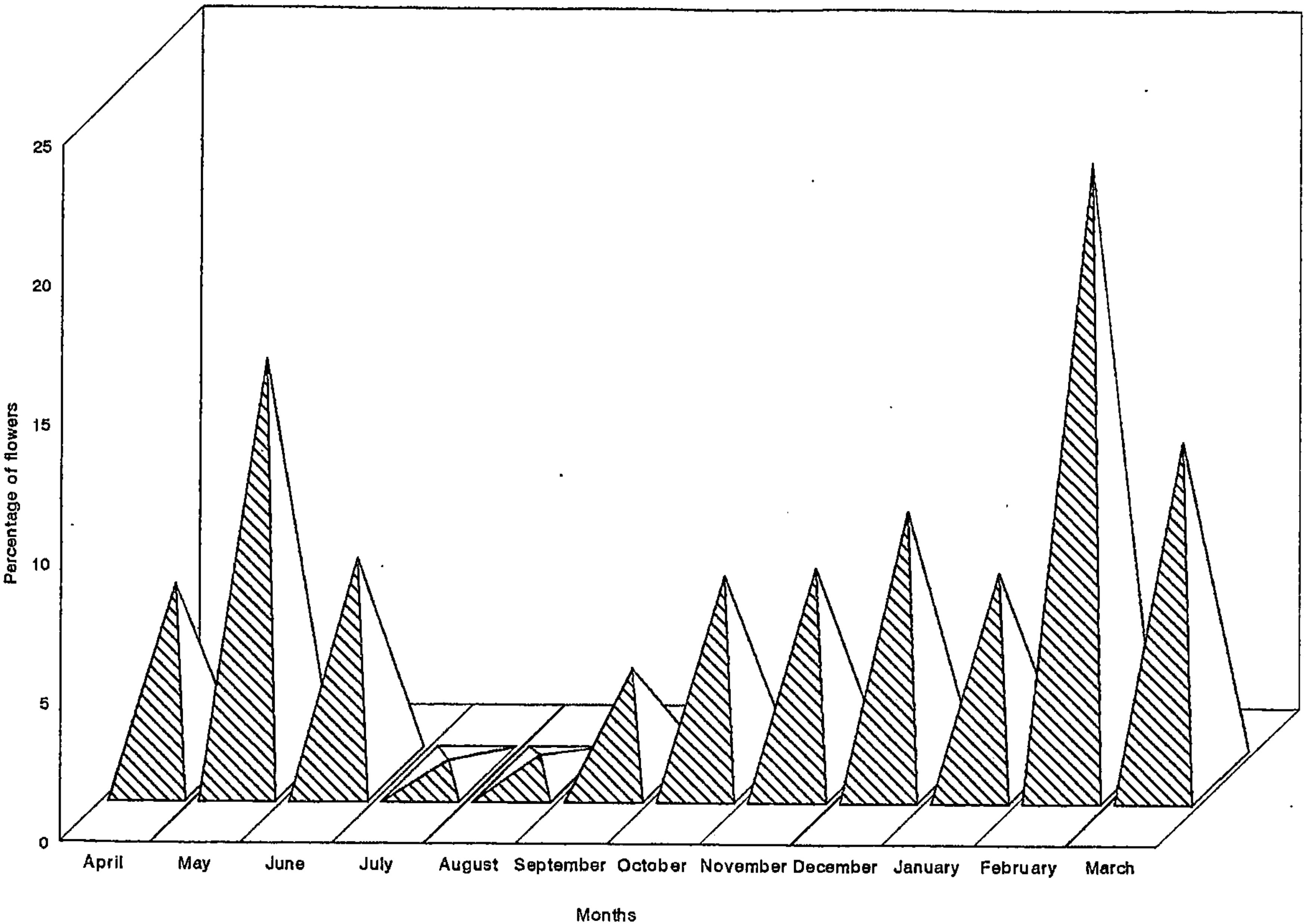


Fig.1 Percentage monthly flower distribution of plants without pod load

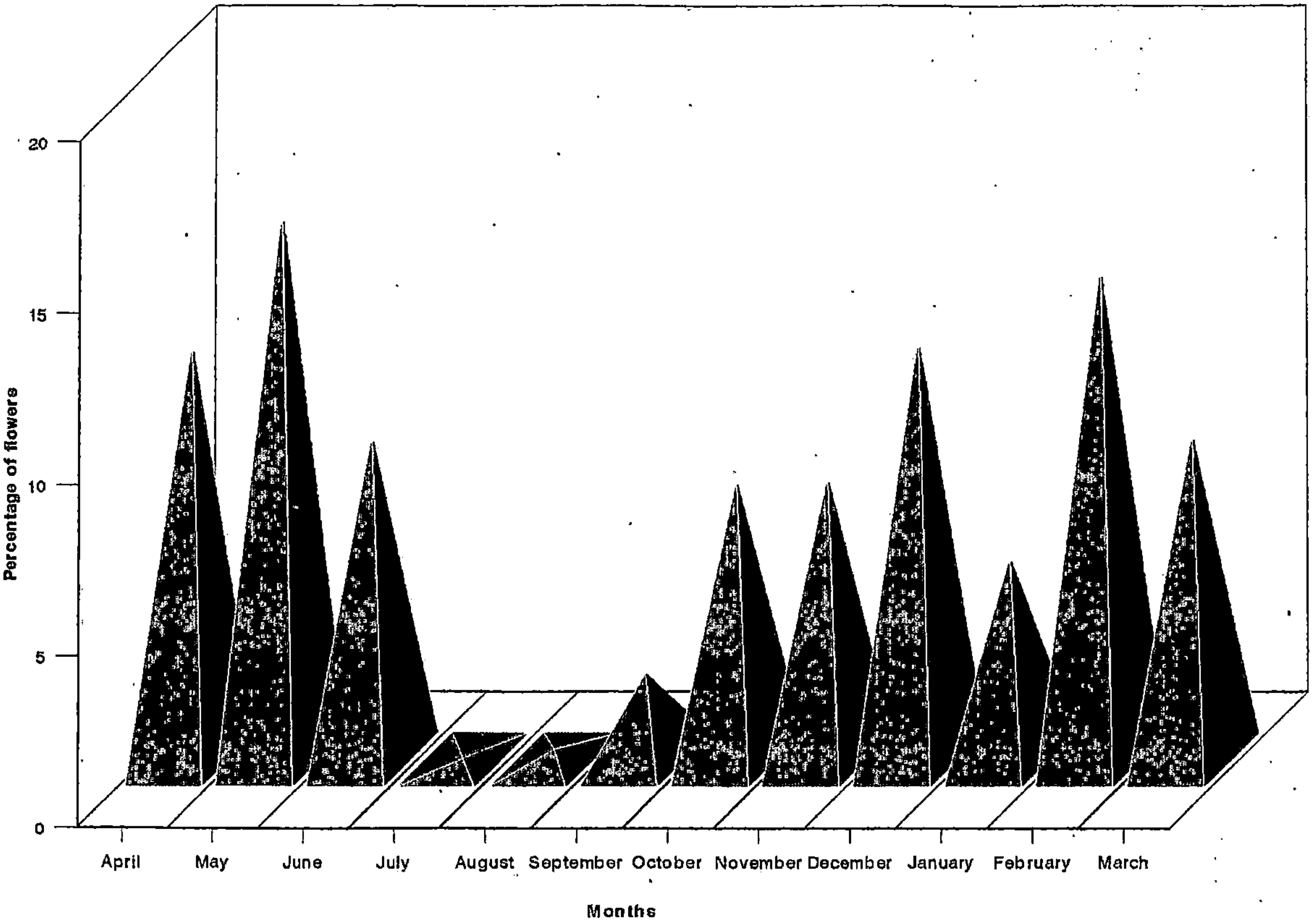


Fig. 2 Percentage monthly flower distribution of plants with pod load

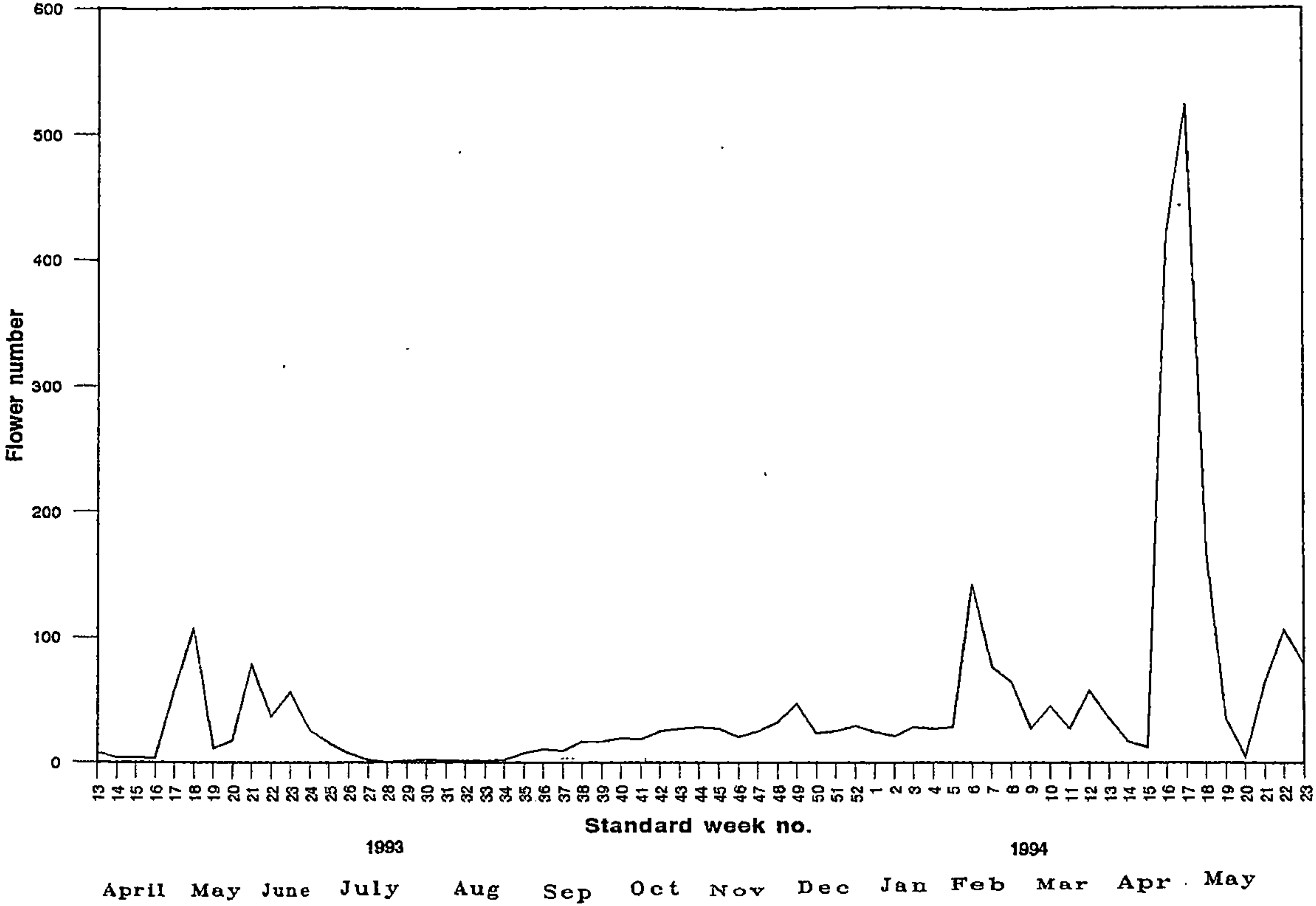


Fig.3 Weekly flower production of plants without pod load

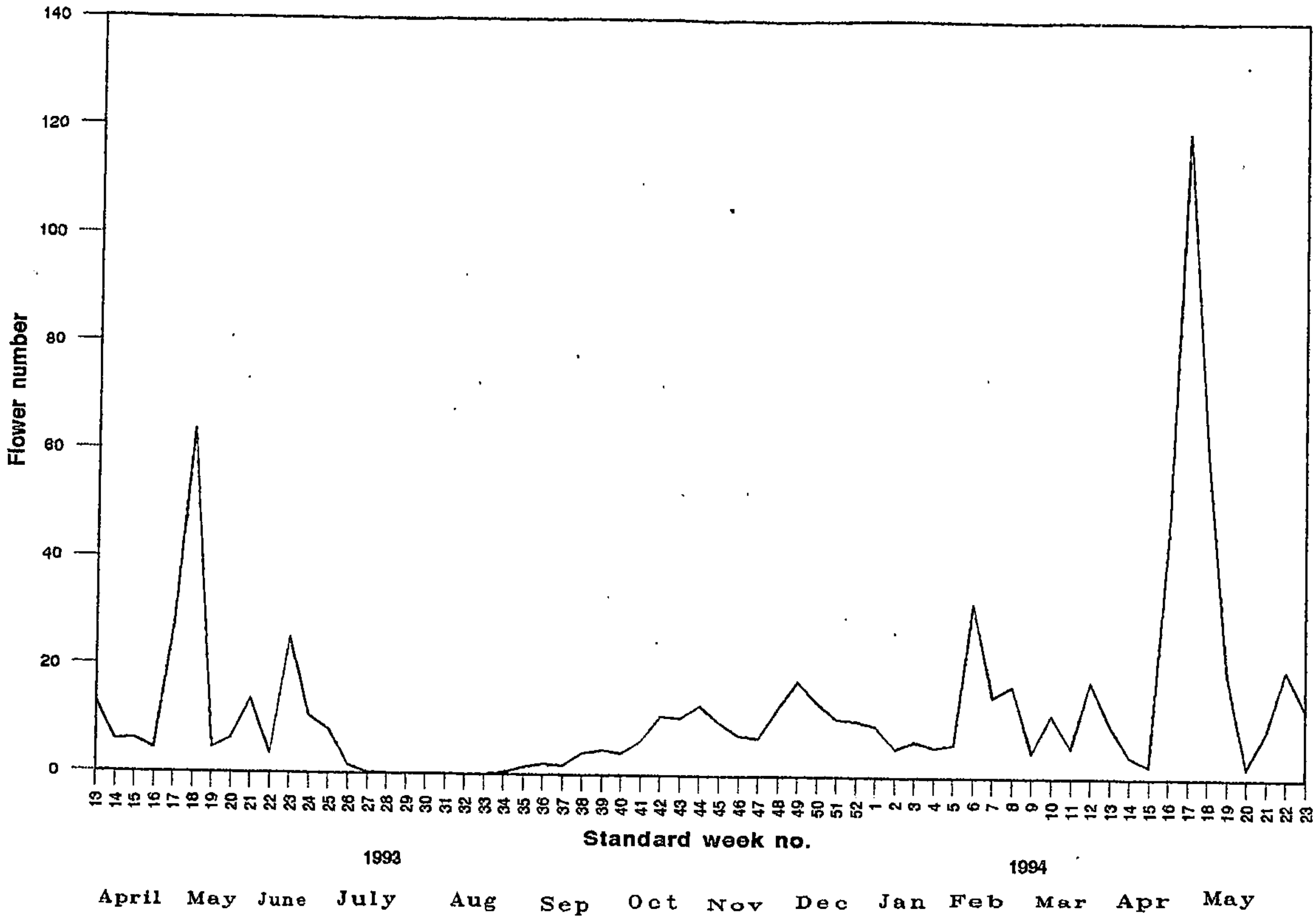


Fig.4 Weekly flower production of plants with pod load

The highest value of coefficient of correlation was noted six weeks before flowering which coincides with the flower initiation period.

Minimum temperature showed positive relationship with flower production of one to four weeks after. This means that both maximum and minimum temperature should be high for flower production one to four weeks after. This period coincides with the period of many biochemical activities.

Correlation analysis with daily difference in temperature showed positively significant correlation with flower production during most of the period.

An overall assessment of the effect of temperature on flowering of cocoa should be that high temperatures are beneficial for flower initiation. It, however, is to be noted that temperature can define flowering pattern of cocoa only partially as correlation coefficients are not very high in most instances.

Work by Madhu (1984) also showed that mean minimum and maximum temperature one month prior to flowering affected flower production.

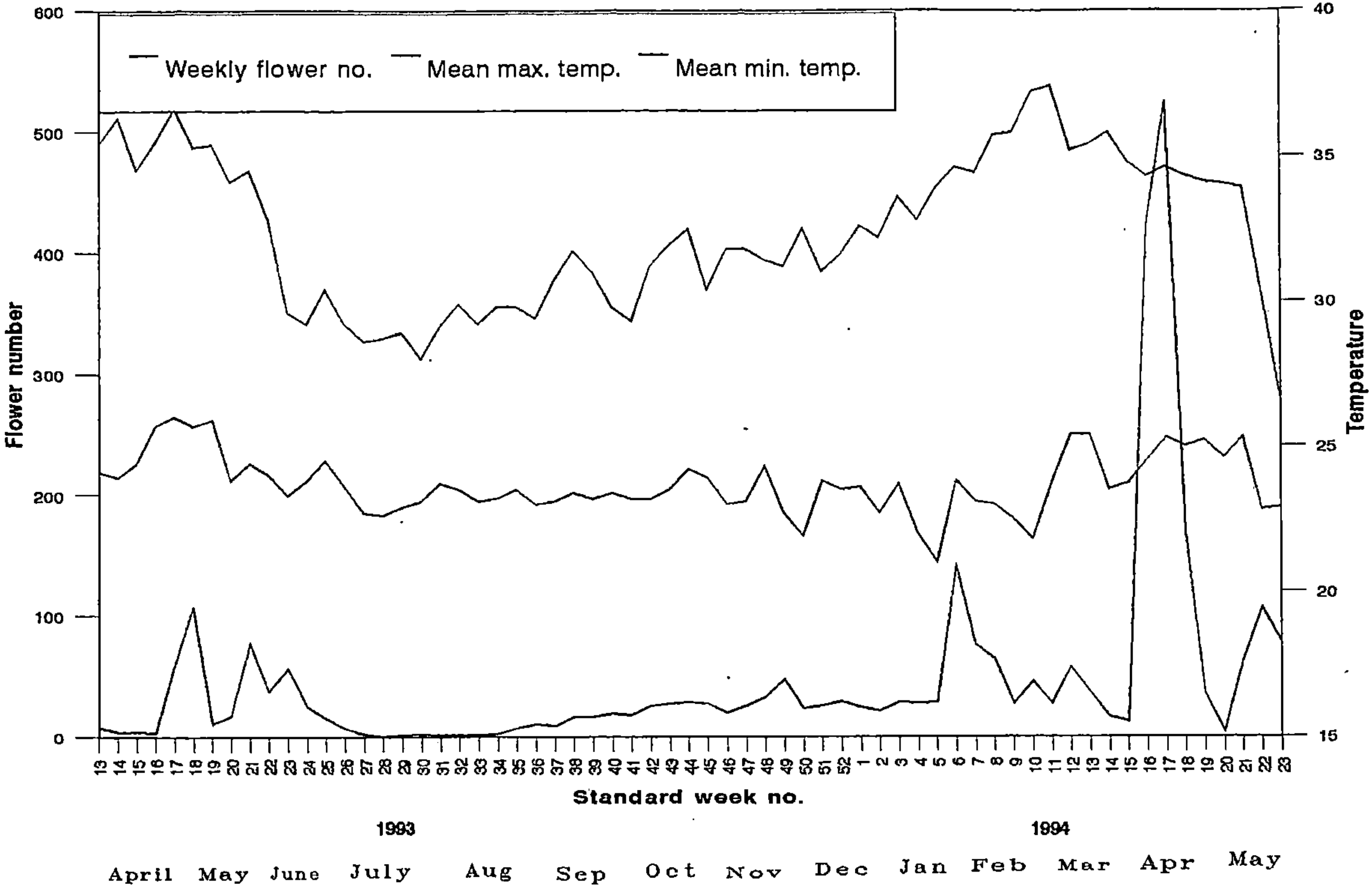


Fig.5 Weekly variation of flower production and temperature

The effect of humidity on flowering was negative and the maximum influence was seven weeks before flowering. The effect of rainfall on flowering also was nearly identical and it is probable that the influence of relative humidity is incidental and through the effect of rainfall.

The three characteristics of light which affect plant growth and development are duration, intensity and quality. Correlation analysis with flower number showed that duration of bright sunshine hours had a positive effect on flowering, with maximum effect four weeks before flowering. As in the case of relative humidity, part of the relationship is attributable to the indirect effect of rainfall. However, it is also to be noted that nearly all growth functions of cocoa are found favoured by higher illumination and there are reports of enhanced photosynthesis with increasing rates of solar radiation (Wood, 1985). Flowering also appears to be no exception to such a favourable influence. Madhu (1984) reported that the mean monthly sunshine hours one month prior to flowering affected flower production.

Simple correlation analysis showed that rainfall had a negative influence on flowering. When the whole period was considered, the highest correlation coefficient value was -0.258, corresponding

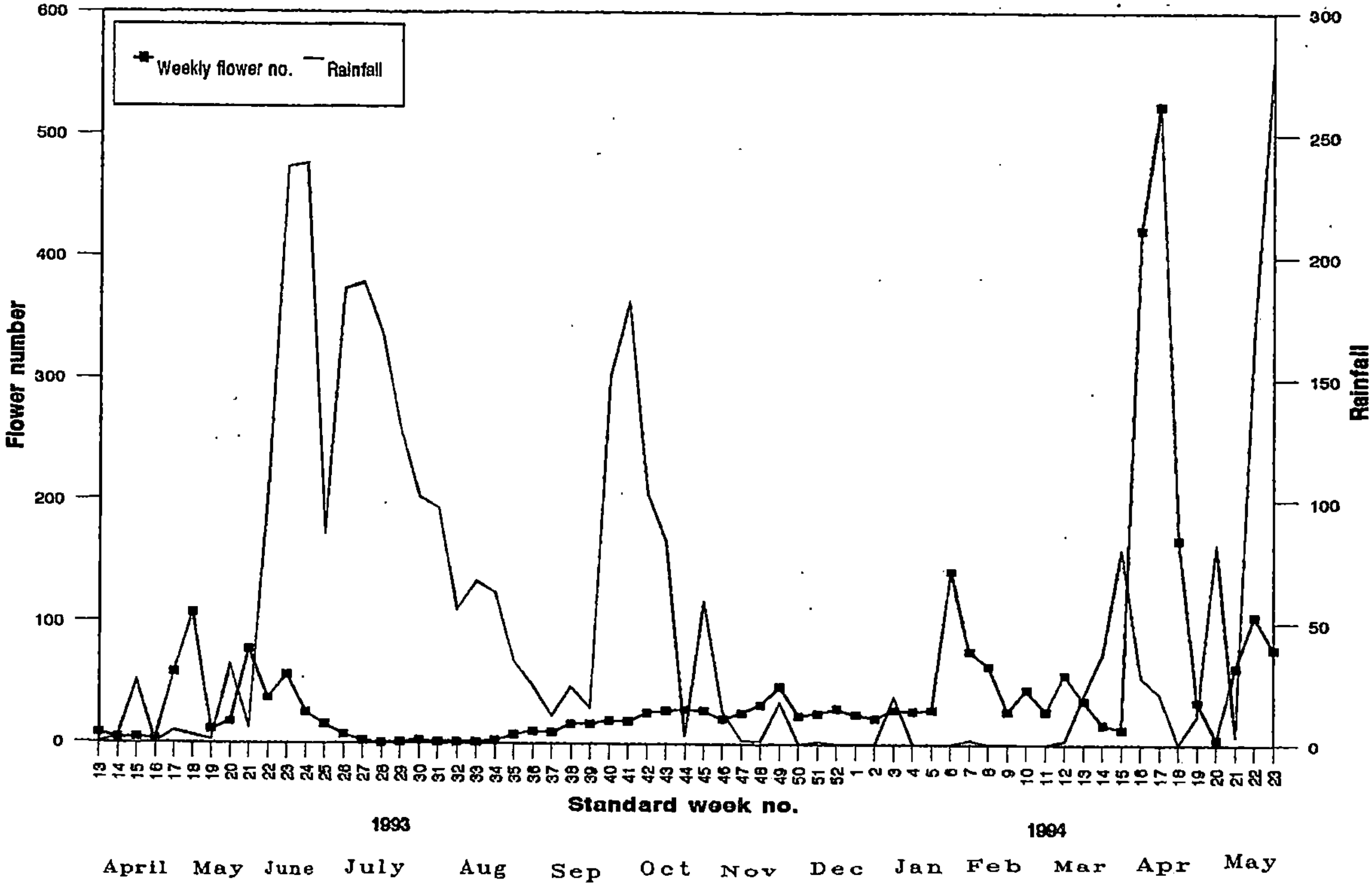


Fig.6 Weekly variation of flower production and rainfall

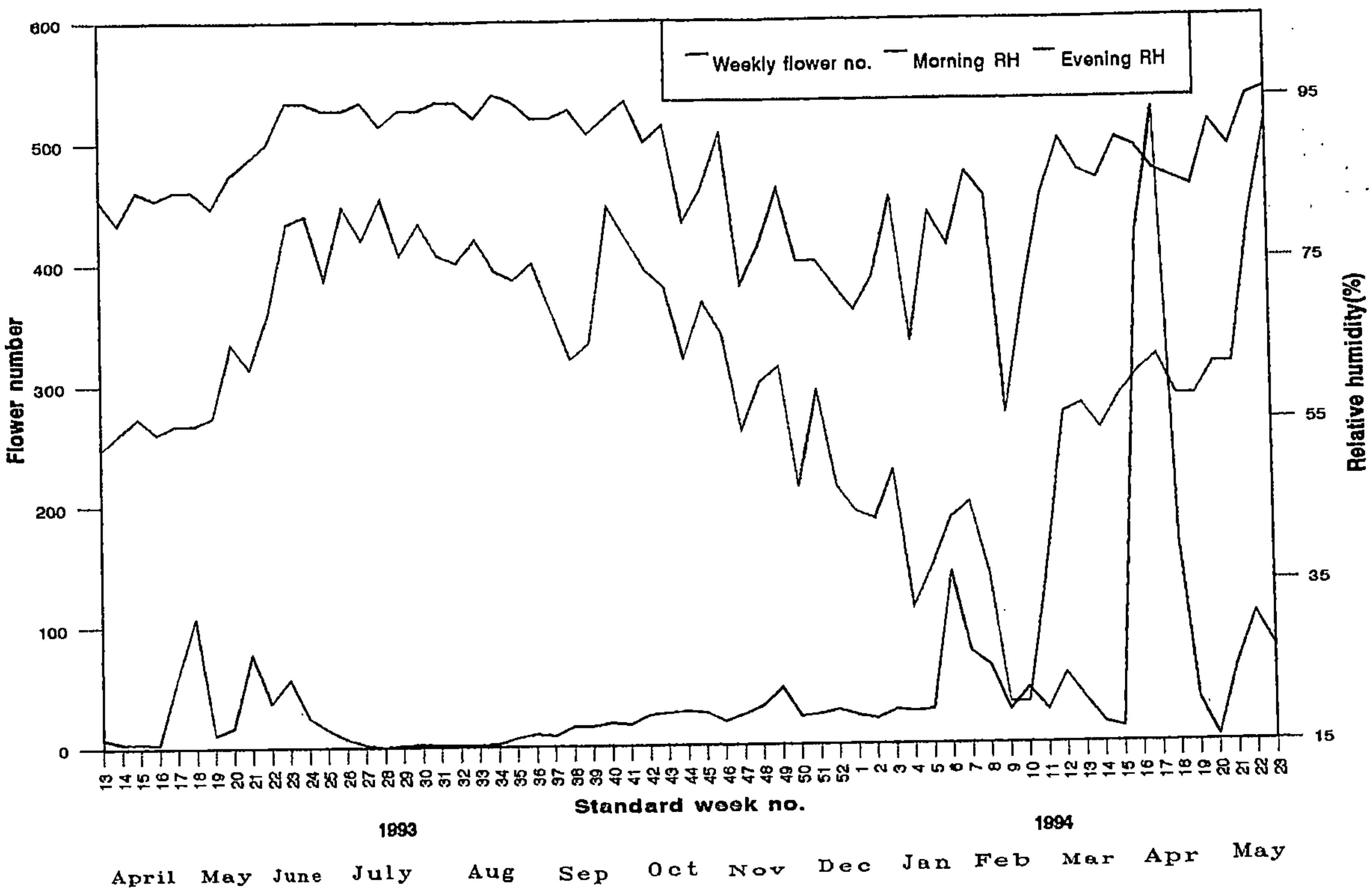


Fig.7 Weekly variation of flower production and relative humidity

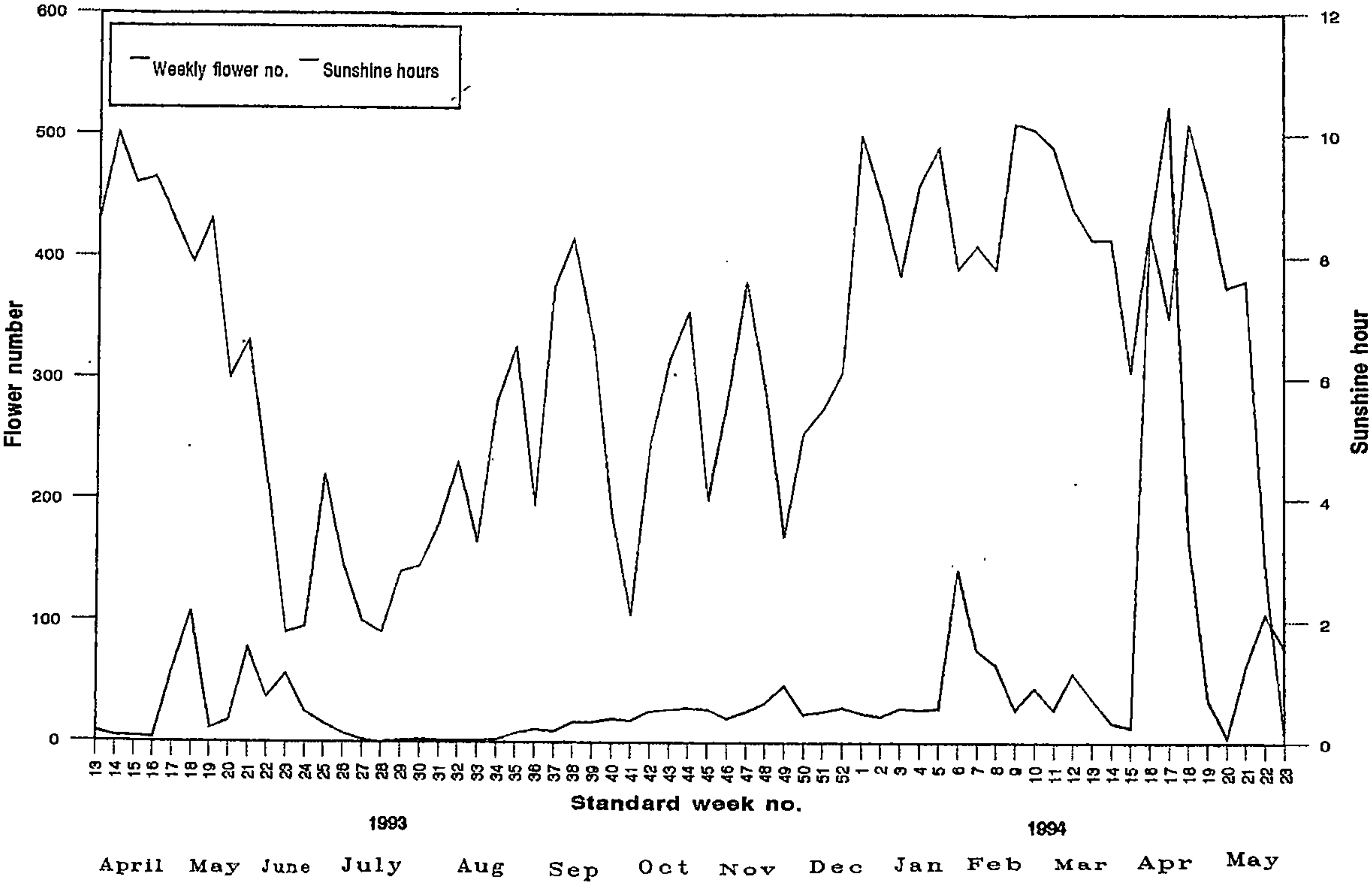


Fig.8 Weekly variation of flower production and bright sunshine hours

to the rainfall five weeks prior to flowering. The corresponding value for the rainfall period was -0.417. This points to the detrimental effects of heavy showers of monsoon period. Alvim (1966, 1968) and Young (1984) also reported that excessive rains reduced flowering. Heavy rains may interfere with flower production by lowering the temperature, reducing biochemical activities, causing mechanical injuries etc.

When the summer period alone was taken, there was highly positive correlation between flower production and rainfall one to three weeks before. Clearly, a break in the dry period was beneficial and there was a bout of flower production two to three weeks after. Madhu (1984) obtained high correlation for flowering and rainfall one month prior to flowering. The heavy rains were most lethal when received five weeks prior to flowering.

Correlation analysis between daily flower production and daily rainfall showed that rainfall 10 to 21 days prior to flowering was highly correlated with flowering. Number of rainy days had the same effect as total rainfall and a negative correlation was thus noted with this parameter during the period before flowering. This aspect was discussed in detail earlier.

Table 5 shows that soil water deficit is correlated with flower production. Excepting for the first three preceding weeks, there was positive correlation between flower production and water deficit. The highest correlation value corresponds to seventh week before flowering. Apparently, initiation of flower production is favoured by water deficit. Appearance of flowers, on the contrary, was favoured by the absence of this stress factor.

The effect of water surplus on flowering was negative throughout the period of observation. Alvim *et al.*(1972) had indicated continuous rainfall as a suppressing factor for flower production in cocoa of Brazil.

A comparison of the data under pod-free situation will indicate two major differences. The most conspicuous is the near halving of flower production in plants with pod load. The second is the stronger and consistent relation with climatic factors in the presence of pods. The former is explainable as due to suppression arising out of a high carbohydrate sink of developing pods. Pod load as a suppressing factor was reported by Alvim (1974, 1981) and Hutcheon *et al.* (1973). The stronger relation with climatic factors in the presence of developing pods was not expected, as it was considered that climatic influences will express themselves in the absence of other interfering factors. The justification for the observed trend may be that in the presence of developing pods photosynthetic accumulation will act as a limiting factor and that climatic parameters that have a direct bearing on photosynthetic accumulation may have more of influence on flowering.

The overall influence of weather on flower production can be summarised as follows:

Though some relationship exists between flower production and weather parameters of previous one to twelve weeks, the weather of five to eight weeks appears to be critical. During this period, conditions like high temperature, water deficit, bright sunshine hours, low rainfall and low relative humidity will induce flowering. As these conditions are not satisfied, flower production during July and August is low. Then temperature tends to increase, rainfall decreases and sunshine hours increase. There is induction of flowering and appearance of flowers from September onwards. High water deficit also appeared to inhibit flower production, but the effect was much less. In addition to this general climatic influence, there were sharp peaks observed at frequent intervals, especially during May, 1993 and February-March and May, 1994. The reasons for these flecks are attributable to receipt of rainfall three weeks before. Even where minute peaks in flower production were noted, there was rainfall before about three weeks . Such an effect of summer rains was consistent and was noted during the entire period of observation. Based on the studies on flowering Alvim *et al.* (1972) had reported that the major determinant in flower production of Brazilian cocoa was "relief from strains". High temperature, dry spell and continuous wet conditions were indicated as some factors contributing to "strain". Such a relief from strain resulting often from receipt or cessation of rains was reported to lead to flushing. Flowering would follow just as leaves hardened. Under Brazilian situations, the time lag would be about two months.

In the present study, the only important strain appears to be the continuous monsoonal rain. Another important observation in Indian cocoa is that the time lag between receipt of rain and flower appearance is only to the extent of about three weeks. Presumably, flushing of cocoa in our environment does not strictly follow cycles of "relief from strains". Another incidental observation is the strong relation of flower production with the climatic parameters - rainfall, sunshine hours, relative humidity, temperature and number of rainy days five to seven weeks before. The relationship was consistently positive with maximum temperature, rainfall of summer season and sunshine hours and inverse with relative humidity, number of rainy days and rainfall of monsoon period. Presumably under favourable climatic conditions five to seven weeks before, there is initiation of flowering, the full expression of which occurs following a shower during the rain-free period. Sale (1970) also reported that flower initiation had been enhanced during the dry period and only flower growth was inhibited by moisture deficiency.

5.2 Prediction of flower production

Step down regression analysis using SPAR1 package was carried out to develop a prediction model for flower production. The predictor variables used were maximum temperature of sixth week, sunshine hours of seventh week, rainfall of third and fifth weeks, pod load of third week and relative humidity of seventh week before flower production, all having significant correlation with flower production. The step down regression analysis revealed that bright sunshine hours and evening relative humidity could explain most of the variation in flower production that could be attributed to the weather characters considered. However, the R^2 value was only 0.33. Since the predictability using these variables for the whole period was low and as it was thought that the effect of climatic parameters will be different in the wet and dry periods, separate regression analysis was done for monsoon and summer periods.

For summer period, the step down analysis recorded an R^2 value of 0.87 for the variables maximum temperature (x_1), sunshine hours (x_2) and rainfall of third week (x_3). The estimated prediction model was

$$y = 33.64 + 2.252\ x_1 + 2.047\ x_2 - 0.567\ x_3$$

where y is the mean weekly flower production.

For the monsoon period the variables were maximum temperature (x_1), rainfall of third (x_3) and fifth weeks (x_4) pod load (x_5) and evening relative humidity (x_6). The R^2 value was 0.60. The prediction model worked out was

$$y = 129.03 - 2.014\ x_1 - 0.025\ x3 - 0.053\ x4 - 0.074\ x5 - 0.667\ x_6$$

5.3 Relation of pod yield to weather parameters and pod load

The monthly pattern of pod production of the rainfed crop from 1988 to 1992 is shown in Fig. 9.

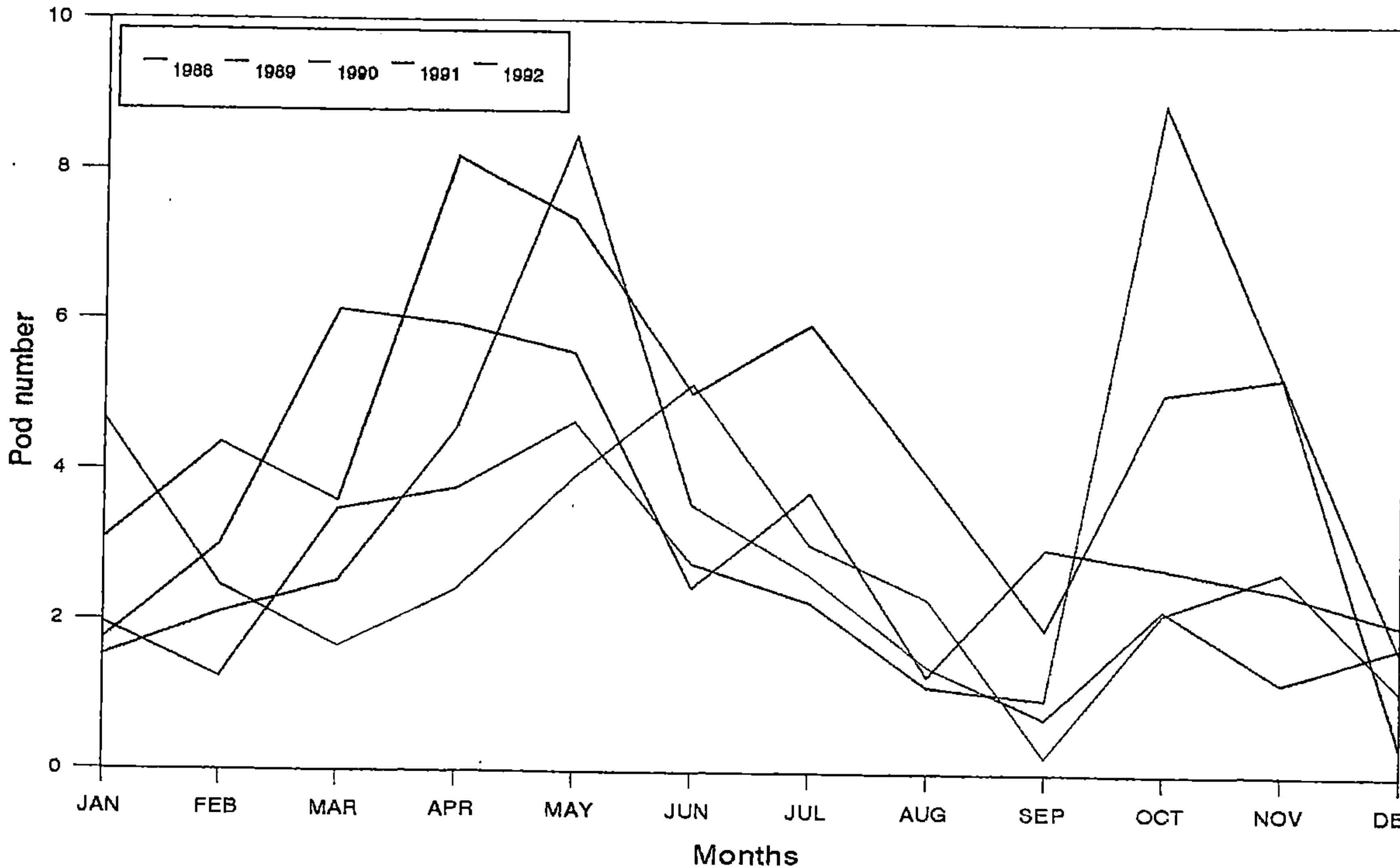


Fig. 9 Monthly mean pod production of 374 rainfed cocoa plants (1988-1992)

Fig. 10 gives the mean pod production over five years. The figures show a bimodal pattern for the cocoa crop corresponding to the two peak periods of flowering nearly five months apart. The percentage monthly pod yield is presented in Fig. 11.

From Table 11, it is clear that pod production is correlated to temperature, sunshine hours and relative humidity two to three months before harvest. Though the values were significant, it is difficult to explain their occurrence and they are to be taken as coincidence. Two months before the two peaks, temperature was comparatively higher, sky was clear and bright, relative humidity was low and rainfall was scanty. But for these values, the coefficients obtained were non-significant.

Correlation analysis between pod production and total rainfall gave significant negative correlation during second, third and fifth months (Table 11). The rainfall data were split up as monsoon rainfall and non-monsoon rainfall and analysed separately to get a clearer picture of the effect of this variable.

The results given in Table 12 show that heavy rainfall was detrimental, especially during the

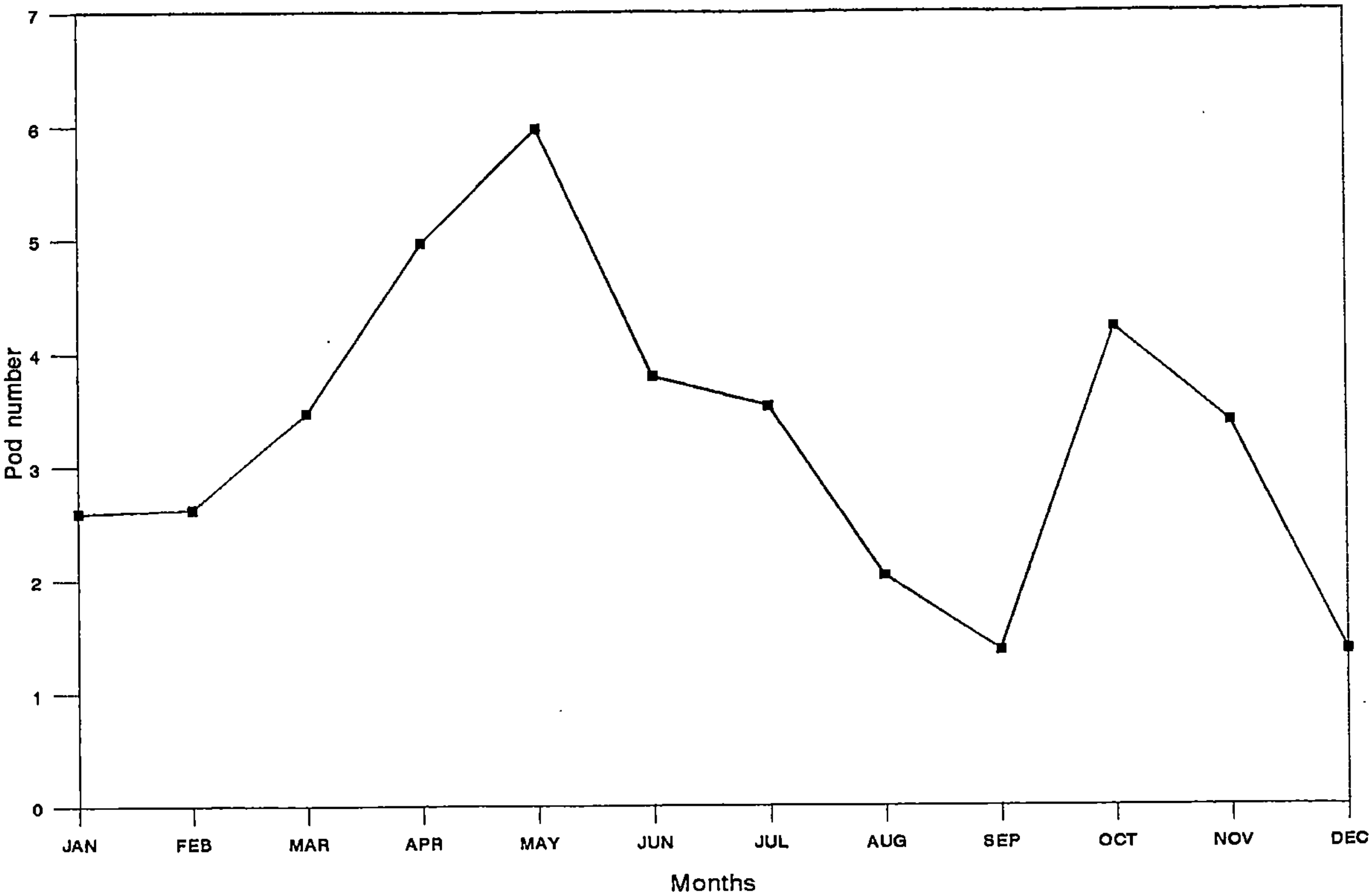
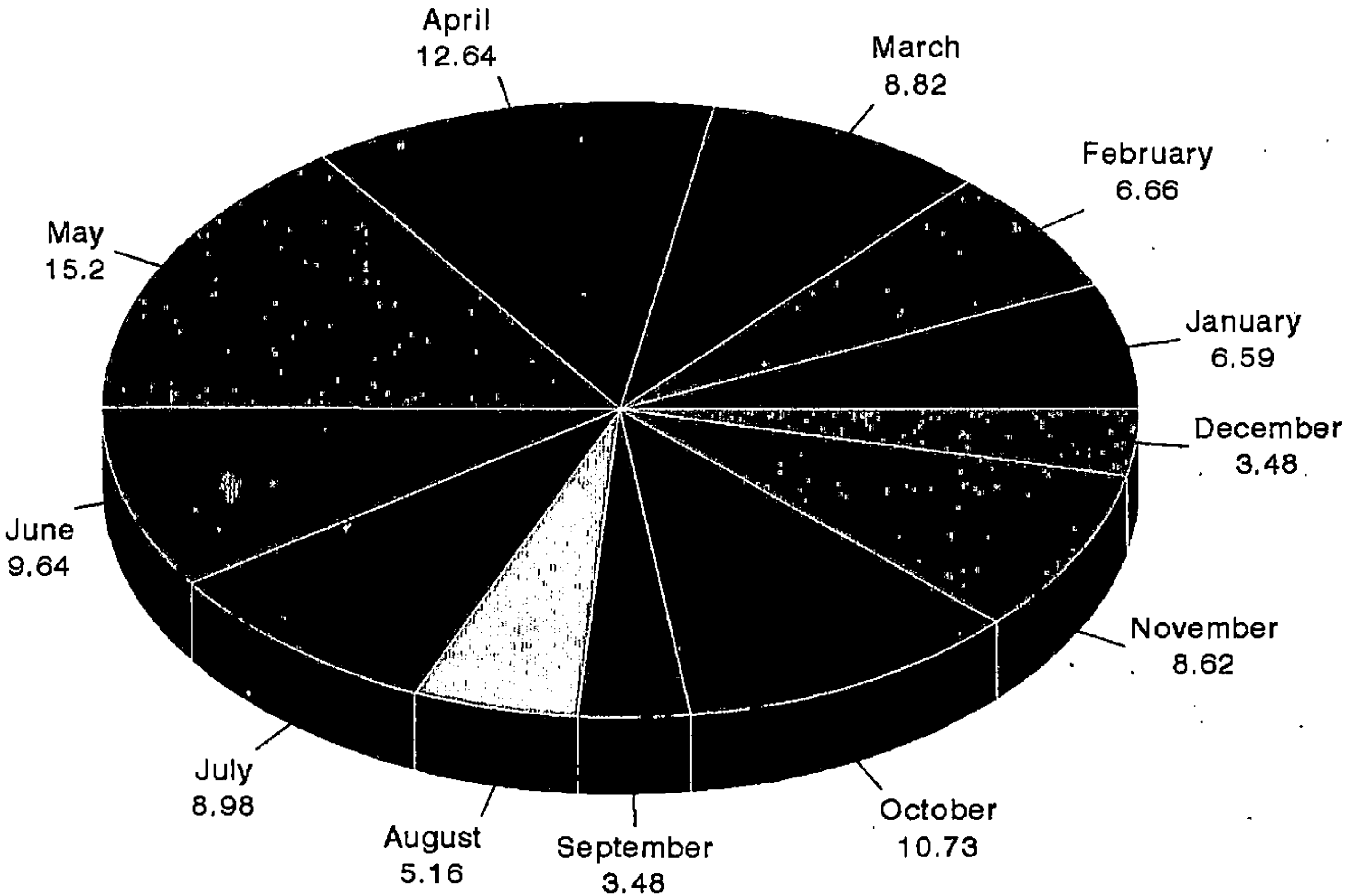


Fig.10 Monthly pod production of 374 rainfed cocoa plants (mean of 5 years)


April
12.64
March
8.82
February
6.66
January
6.59
December
3.48
November
8.62
October
10.73
September
3.48
August
5.16
July
8.98
June
9.64
May
15.2

period of flower initiation and development. This was in accordance with the observation of Alvim (1968). Non-monsoon rains six months before were however, beneficial. This is attributable to the fact that the first peak is apparently benefitted by the rains of early non-monsoon period during November and December.

Heavy rains can affect pod production in many ways. Studies on flower production have shown that flowering is severely affected by heavy rains. Rains may also interfere with pollination by affecting the population of pollinating midges and also by washing away of pollen. Even the set fruits are not fully free from the effect of heavy rains. There are chances for development of fungal diseases, especially black pod.

The results of correlation analysis between water deficit and pod production given in Table 13 indicate that water deficit was significantly correlated with pod production after two to three months. Unlike rainfed crop, irrigated crop showed positive correlation with water deficit of all seven months. Water surplus had negative relationship with pod production throughout the period.

The results of correlation analysis with pod load of previous one to seven months show that the load six months before harvest adversely affected the pod yield. In other words, the pod load of flower initiation period appeared to be more important.

The monthly distribution of pod production of the irrigated crop during 1988 to 1992 is shown in Fig. 12 and the mean of five years in Fig. 13. Under irrigated conditions the yield was more distributed even though the two peaks of April-May and October-November continued to be prominent. The percentage mean monthly pod production is presented in Fig. 14.

Table 15 gives the correlation coefficients for pod yield and weather variables. Maximum temperature, minimum temperature, sunshine hours, rainfall, number of rainy days and relative humidity recorded significant correlation at certain months. Values of fifth month were the highest for maximum temperature, sunshine hours, rainfall and number of rainy days, while that of fourth month correlated more with other variables.

Pod load showed significant, positive relationship with pod production after a lag of two to three months. The inverse relationship manifested during fifth to seventh months were not significant. This may be due to dominant influence of climate which

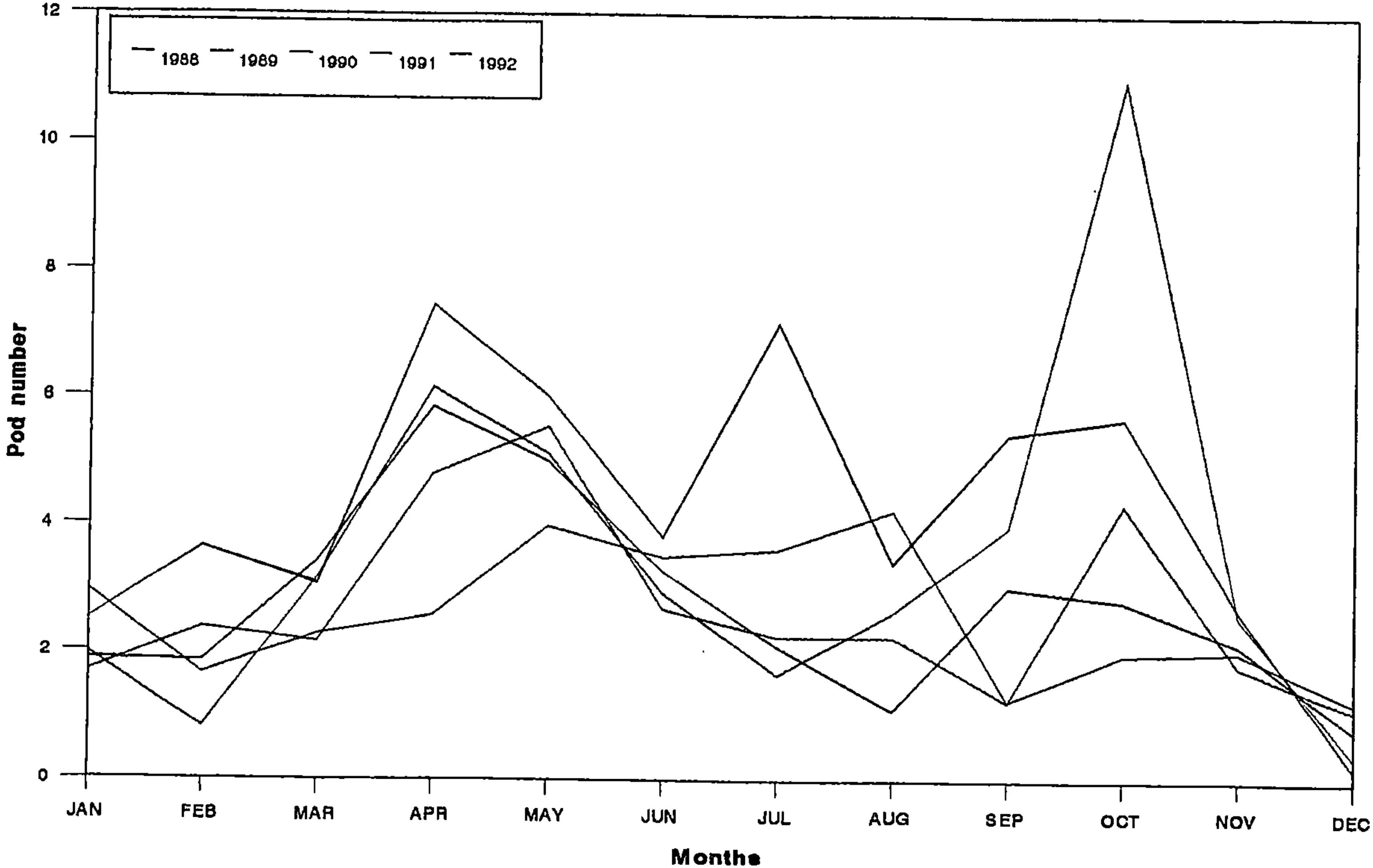


Fig. 12 Monthly mean pod production of 272 irrigated cocoa plants (1988-92)

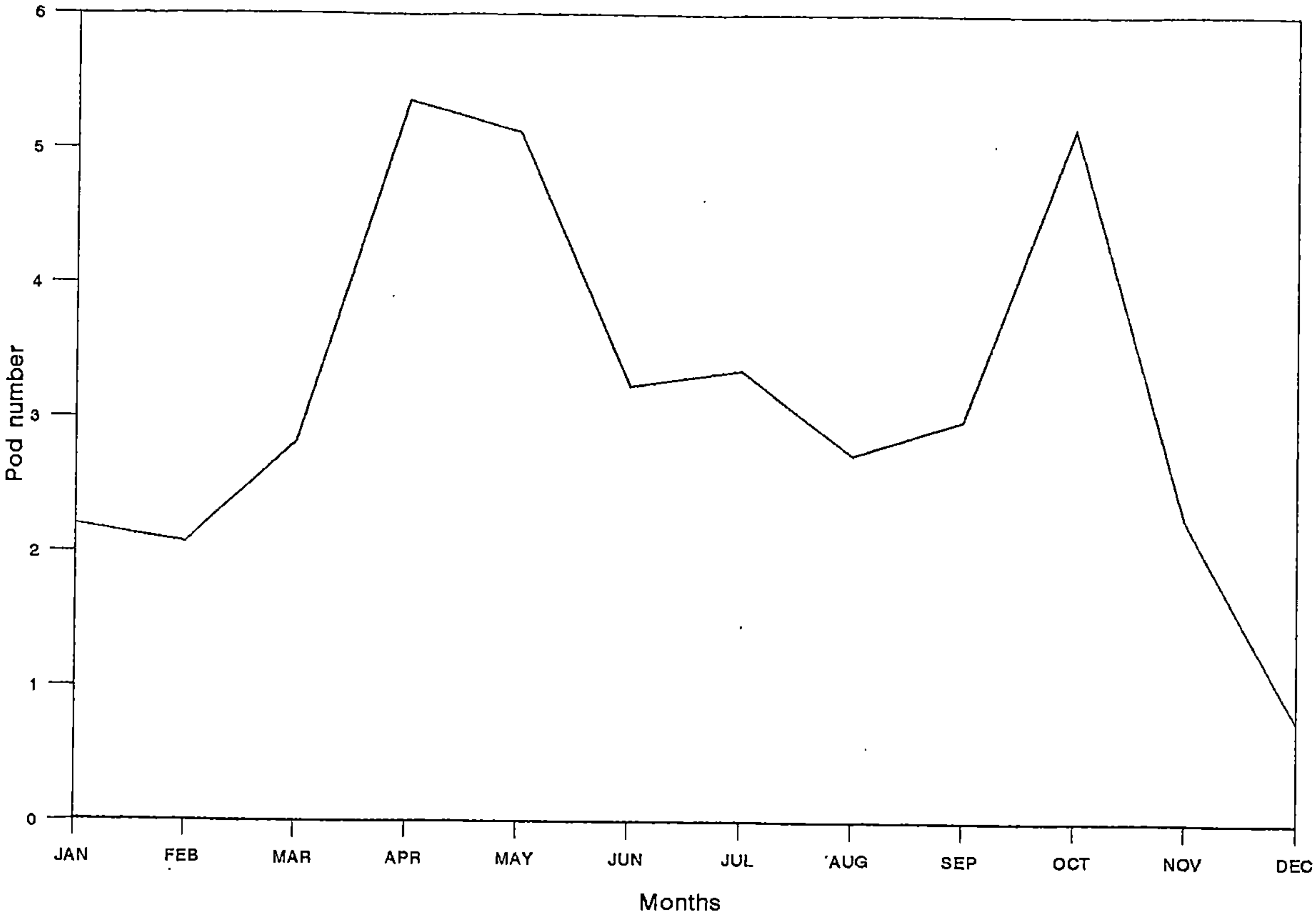


Fig. 13 Monthly pod production of 272 irrigated cocoa plants (mean of 5 years)

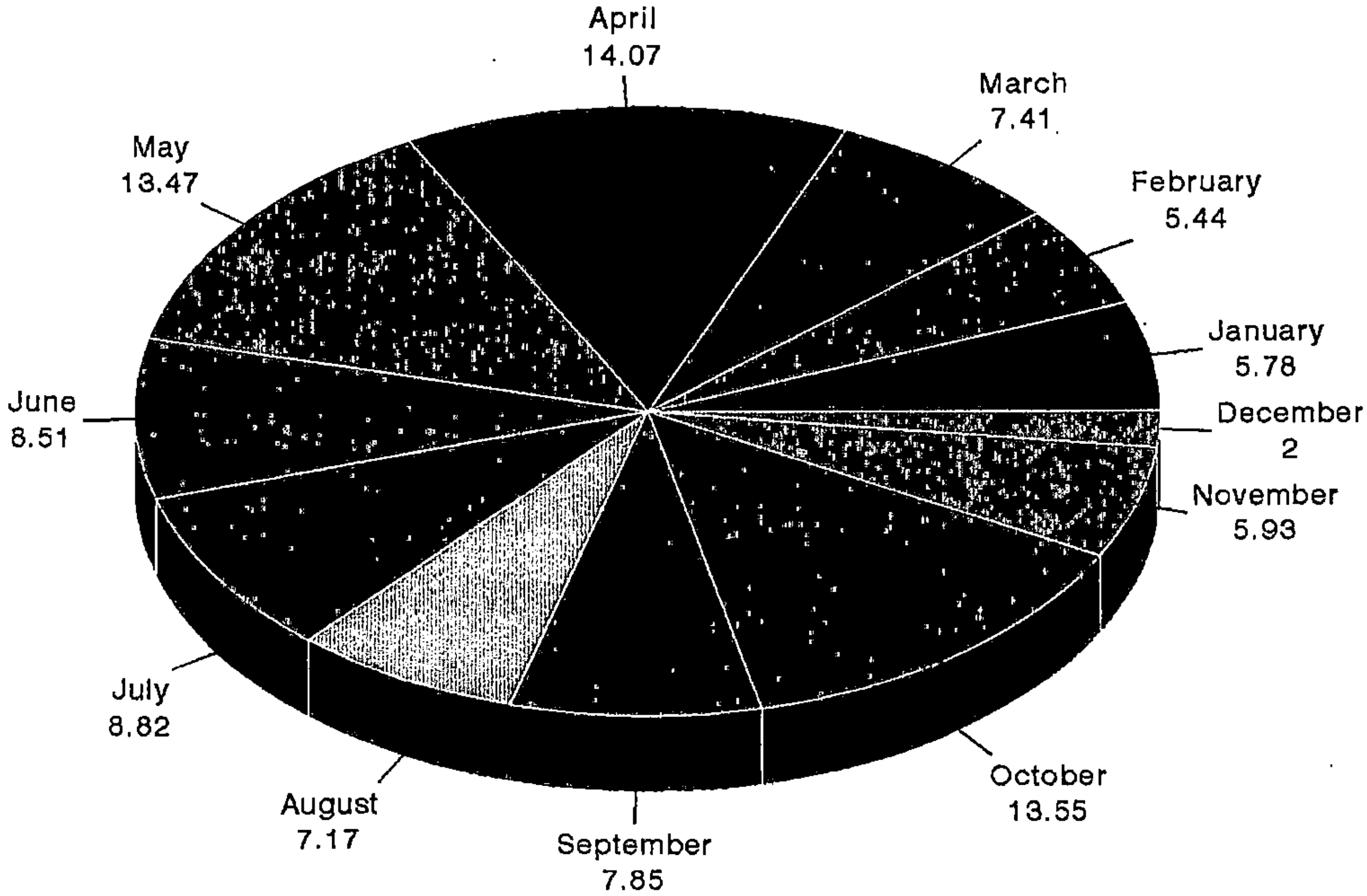


Fig. 14 Percentage monthly pod yield of irrigated cocoa (1988-92)

masked the expression of this factor. The monthly variation of pod production with weather parameters is presented in Fig.14 to 18.

Yield prediction

Step down regression analysis was carried out using SPAR1 package to develop a yield prediction model for cocoa. Weather variables showing significant correlation with pod yield were used. The factors chosen were maximum temperature, total rainfall, pod load and bright sunshine hours. The highest R^2 value (0.36) with minimum number of weather variables was obtained with maximum temperature, rainfall and pod load. The prediction equation was

$$y = 13.1 - 0.006\ x_1 - 0.002\ x_2 - 0.535\ x_3 + 0.307\ x_5 - 0.015\ x_6$$

Where y is the mean monthly pod number, x_1 and x_2 are the rainfall five and six months before, X_3 and X_5 are maximum temperature five and seven months before and X_6 is the pod load six months before.

It is to be noted that rainfall in rainy season does generally have a negative effect on crop performance, as there is more than adequate rainfall during the period whereas rainfall in non-monsoon

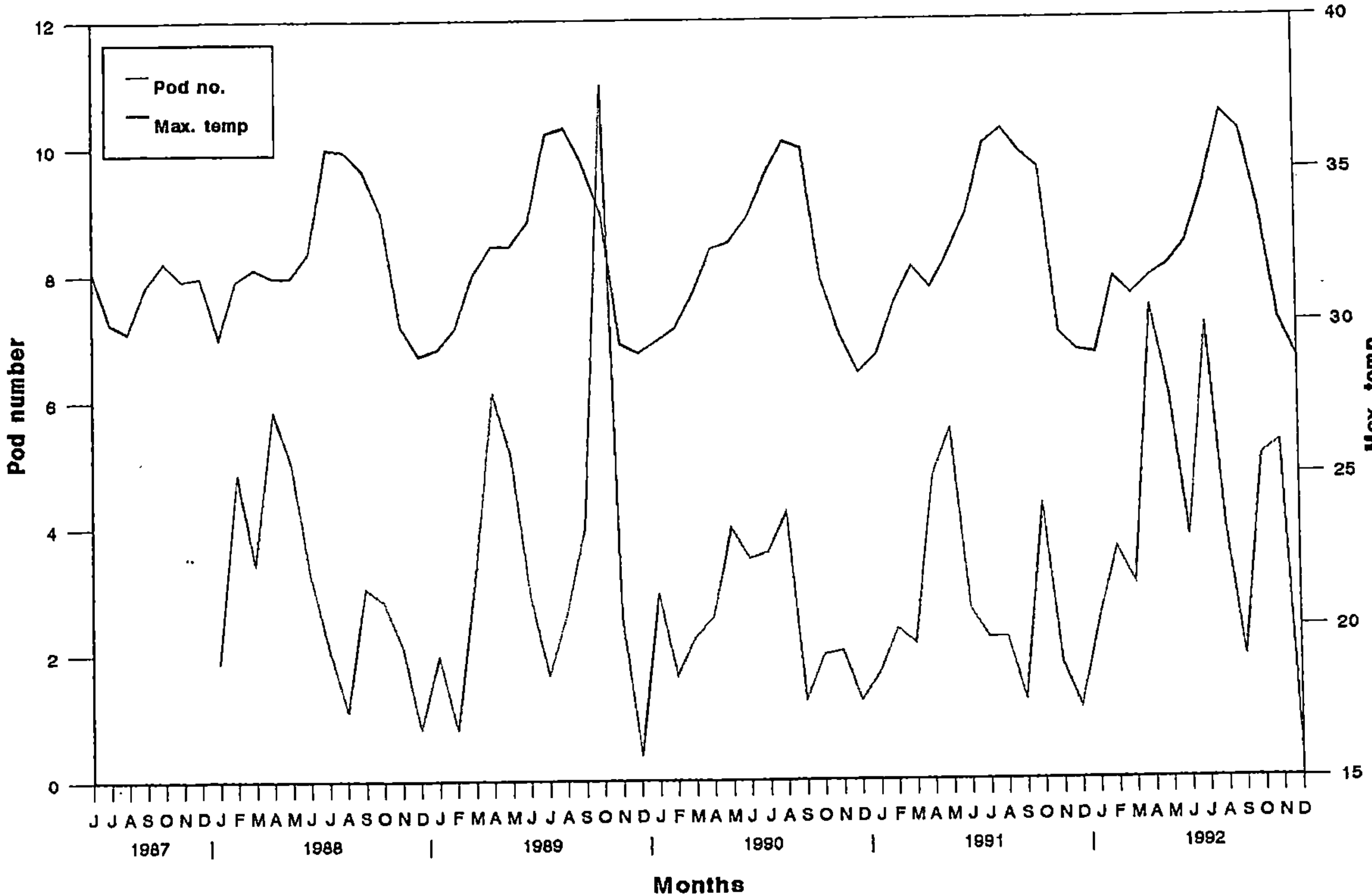


Fig. 15 Monthly variation of pod production and maximum temperature (1988-1992)

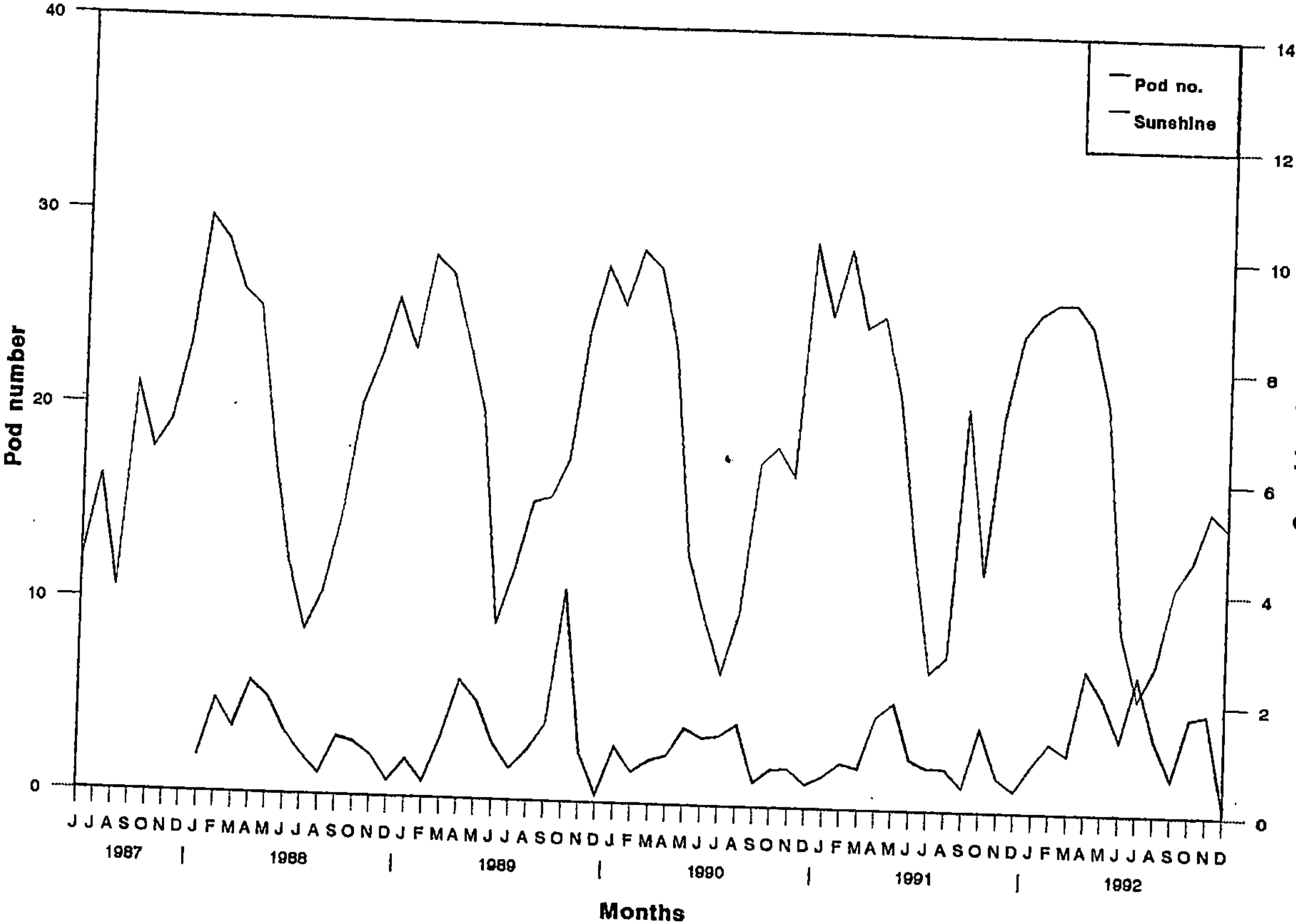


Fig. 16 Monthly variation of pod production and bright sunshine hours (1988-92)

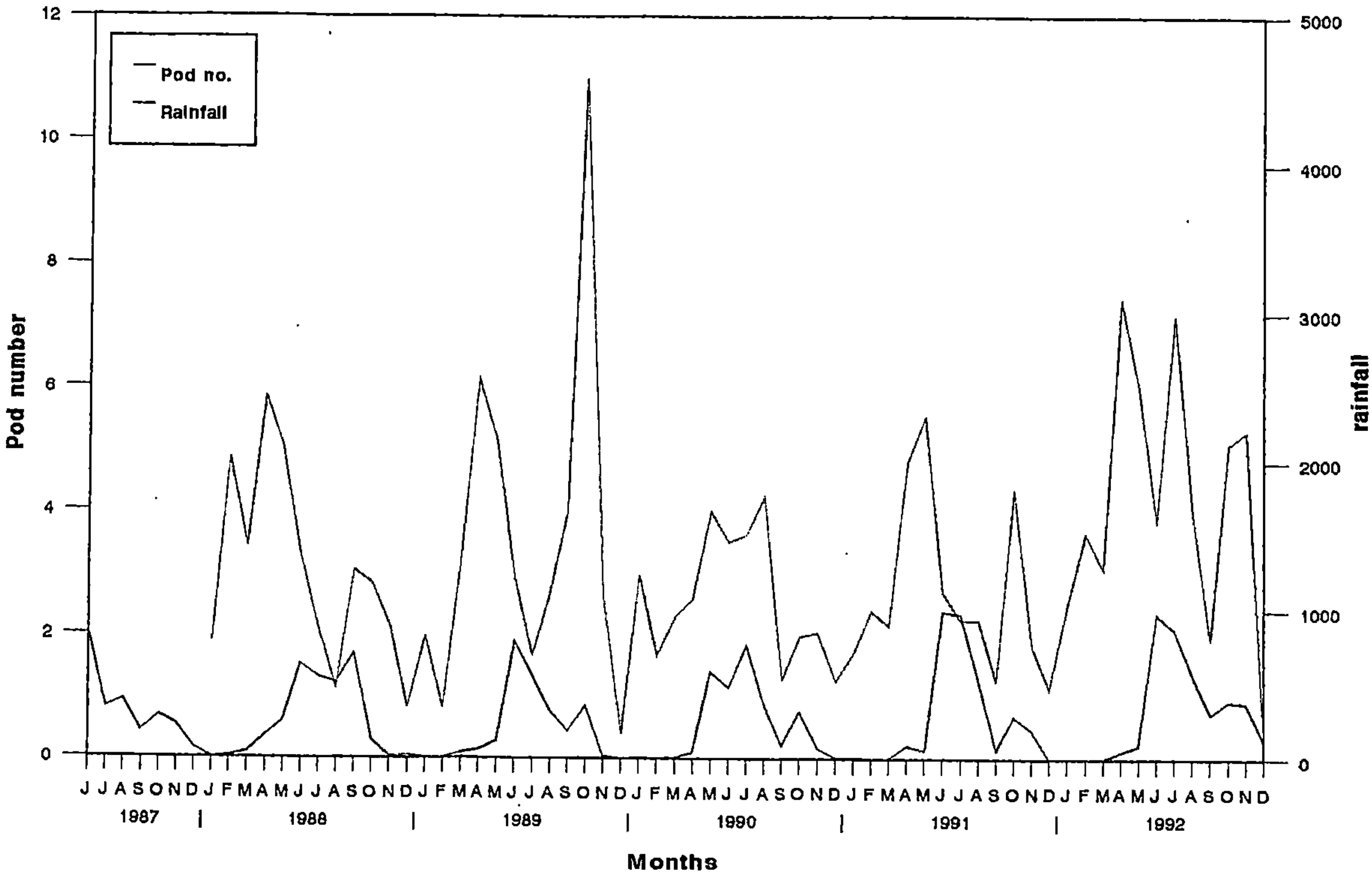


Fig. 17 Monthly variation of pod production and rainfall (1988-1992)

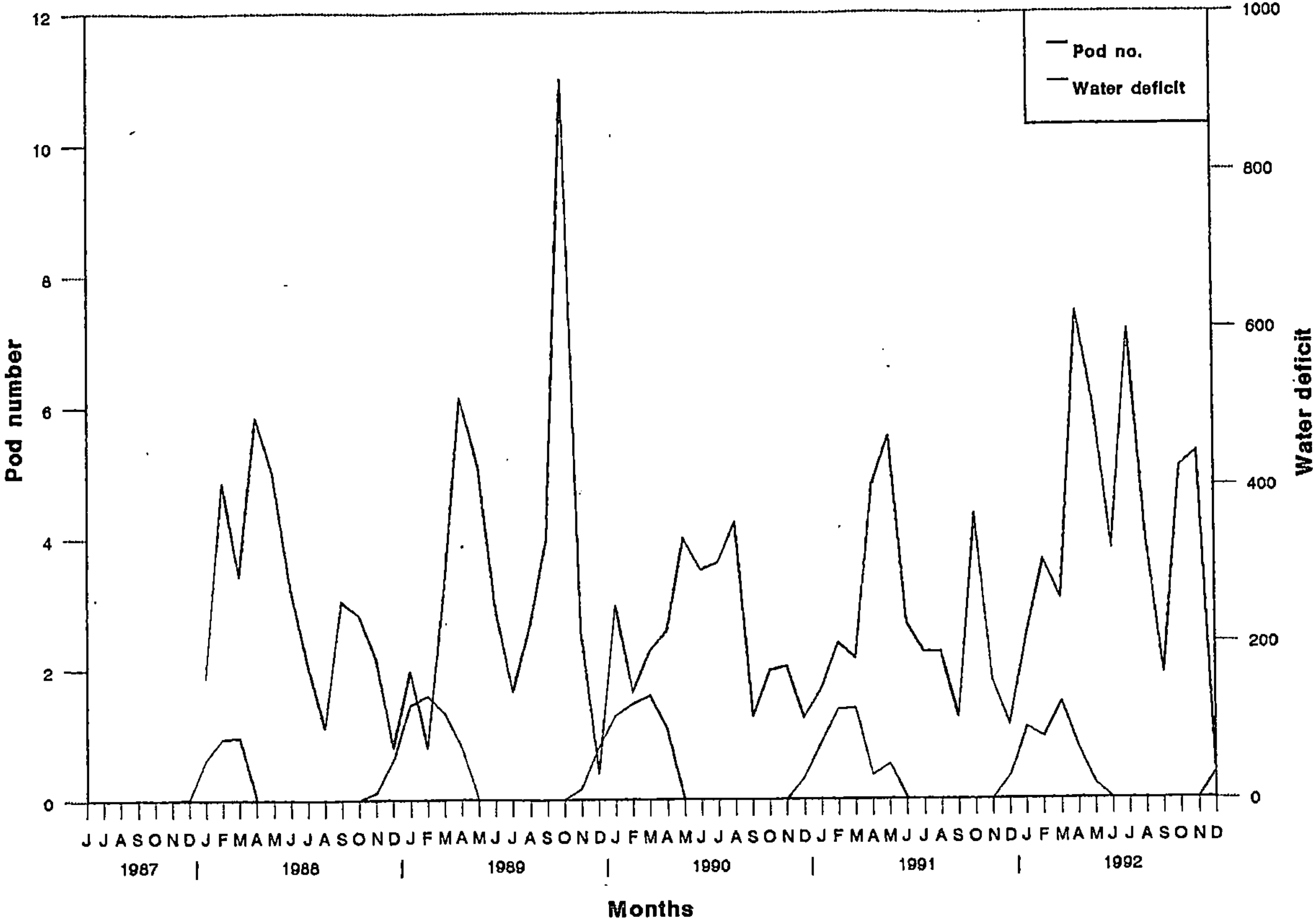


Fig.18 Monthly variation of pod production and water deficit (1988-92)

period is likely to favour crop performance. Entirely reverse relationship is observed because the intensity of rainfall is very high during monsoon in the area from where observations were recorded. A similar relationship is observed for other weather characters as well. Therefore the whole year was divided into monsoon and non-monsoon periods and separate prediction models were estimated. A single prediction model naturally fails as the effect of the same level of rainfall in summer and monsoon seasons will have entirely opposite effects on the crop performance and hence will have a very low coefficient of determination. For monsoon period R^2 value of 0.71 was obtained for weather factors of rainfall, maximum temperature, sunshine hours and pod load. The prediction equation was worked out to be

$$y = - 66.68 - 0.002\, x_1 + 0.371\, x_3 + 2.216\, x_4 - 0.112\, x_5 - 1.078\, x_8 + 0.012\, x_6$$

where X_4 is the maximum temperature six months before and X_8 is the bright sunshine hours six months before.

For non-monsoon period, the predictability was comparatively low, the R^2 value being 0.44. The prediction equation was

$$y = 28.32 - 0.015\, x_1 - 0.012\, x_2 - 0.463\, x_3 + 0.294\, x_5 - 0.926\, x_7 - 1.046\, x_8$$

where x_7 is the bright sunshine hours five months before harvest.

Analysis of the data on pod production and important weather variables for five years showed that there was some relationship between these variables and pod production. But it was not consistent and the values of correlation coefficient were not very high. The yield functions obtained by step-wise regression analysis had low predictability. However, an assessment of the raw data showed some relationship of climatic parameters and pod load with the seasonal fluctuations in yield. Apparently these could not be adequately related quantitatively through the statistical methods used. From the above and a study of the raw data, the following conclusions are drawn and explained.

1. Rainfall is the major factor deciding yield pattern.

2. Temperature, sunshine hours and pod load also contribute to the variation in yield. Other factors apparently have no direct effects.

3. Water stress as well as water surplus negatively influence yield.

4. The low yield of December-February period is because of heavy showers of the monsoon period. Pod load also has some influence.

5. April-May period has high yield because of profuse flowering in November-December and because of favourable conditions for fruit setting in the period that follows. This yield is also influenced by the total rainfall of November-December apparently as pod development is favoured by moisture availability during the dry period from December to April.

6. June to August yield is low because of moisture stress of the period of January to March that apparently was not favourable for fruit set. High pod load from developing pods also is partly responsible.

7. September yield is even lower than the preceding months probably as a result of very high temperature of April leading to poor fruit set in addition to the above factors.

8. The amount of monsoon rains and the number of rainy days of the monsoon period will adversely

affect the October-November yield. Good pre-monsoon rains will induce heavy flowering which should be followed by a moderate monsoon to get high October-November peak.

The above conclusions may be summed up as follows.

With receipt of pre-monsoon showers during May, there is profuse induction of flowering in about two weeks after receipt of significant rain. As climatic conditions are favourable and as pod load is low, most of these flowers are set. Continued growth and survival of these pods will, however, be dependent on the monsoon that follows. If the showers are heavy and incessant, many of the cherelles may fail to develop. Conditions will be favourable for the continued development of surviving pods during the months of August and September and the peak production of October - November results, the magnitude of which will depend primarily on the amount of pre-monsoon showers, its duration and the intensity of monsoon. The first two factors will favour high production in the October -November peak.

Conditions continue to be favourable during early June for flowering in cocoa. But most of these flowers either fail to set or the pods that are set fail to develop because of unfavourable climatic factors that follow. Heavy showers of late June to July inhibit flowering, leading to poor crop of December. Even though climatic conditions will be generally favourable for flower induction, setting and development during September and October, flower production and setting are comparatively low, primarily because of the negative influence of pod load.

Pod load as a factor will cease to be important by November following the second harvest peak of October-November. Accompanied by favourable conditions for flowering, setting and development, there will be profuse pod production during this period. Whether all these pods will ultimately develop to harvestable stage will depend on the moisture stress/ moisture availability during the rain-free period from December to April. For the climate of Thrissur, receipt of rains during November-December and the date upto which rains are received during December are the critical factors that will favour pod development for the first peak in April-May. Presumably for flowers that form during the months from January, the setting percentage will be low, apparently because of pod load from the crop that is set during November-December.

5.5 Crop orientation

Efforts made to orient the crop yield to the favourable season of October- November during 1995-'96 showed that the manipulation could be done without any reduction in yield. Actually there was an increase in yield in terms of both pod number and total wet bean weight. Bean size and dry bean weight also could be improved considerably through such a crop orientation. This means that providing a reproductive lag phase will help in the preservation of nutrients which will be manifested by higher pod yield. In other words, pod load and exhaustion of nutrients are the reasons for low monthly production of the crop.

However, the production pattern of 1993-94 period was not in conformity with this hypothesis. Here relief from pod load and preservation of nutrients could not produce the expected results. As understood from the studies on flowering and fruiting, it was the rainfall pattern which affected the pod distribution. Very heavy rains during south-west monsoon periods resulted in very low production during the oriented period of October to December.

In the light of the experience in 1993-'94, the practice of crop orientation to October-November cannot be considered to yield consistent results. If conditions are not favourable for pod set and development because of heavy and continuous rains during the period from June to September, the second peak of October-November may even fail. Fruit removal during other periods may mean near total crop loss under these conditions. Where the monsoon rains are moderate and do not normally induce crop loss, this practice may be workable as in most of the southern districts of Kerala.

The study on chemical defloration showed that ethephon is very much suited for defloration in cocoa. Whenever complete removal of flowers all on a sudden is needed, 150 ppm of this chemical can be used. Ethephon at 70-100 ppm will be sufficient for slow removal.

Summary

SUMMARY

An experiment was conducted in the department of Agronomy, College of Horticulture, Vellanikkara, during the period from March, 1993 to December, 1996 to investigate the probable reasons for seasonal variation in flower and fruit production of cocoa. Efforts were also made to orient the crop to favourable season of October-November, so as to overcome the difficulties of poor quality of beans during the peak season of April-May. Flower and fruit production were correlated with weather elements, namely, maximum and minimum temperature, bright sunshine hours, total rainfall, number of rainy days and morning and evening relative humidity. Weekly mean flower production was correlated with weather elements of previous one to twelve weeks and monthly mean pod number with the variables of one to seven months before. Soil water deficit, surplus and pod load of the corresponding periods were also correlated. The results are summarised below.

1) Flower production was positively correlated with maximum temperature and bright sunshine hours, while relative humidity, total rainfall and number

of rainy days recorded a negative relationship. Minimum temperature showed both positive and negative relationships.

2) Maximum influence of weather variables on flowering was five to seven weeks before flower opening.

3) Summer rainfall 10 to 21 days prior to flowering was highly correlated with flower production.

4) Pod load and soil water surplus influenced flowering negatively while deficit recorded a positive relationship during most of the period.

5) Equations were developed to predict flower production based on weather variables.

6) Correlation analysis between pod production and weather variables showed that the influence of weather elements varied with season. During monsoon season, high temperature, low rainfall and low relative humidity induced higher pod production five to six months later, while during non-monsoon period, a reverse condition was preferred.

7) Water surplus and pod load five to seven months earlier were negatively correlated with pod production. Water deficit had significant

positive influence during two to three months before.

8) Yield functions were developed to predict the yield using weather variables and pod load.

9) Though highly significant correlation existed between pod yield and different weather variables, it was the rainfall factor which actually determined yield. Fruit induction and development required rainfall whereas heavy, continuous rainfall caused crop failure.

10) The practice of crop orientation to October-November cannot be considered to yield consistent results. Under favourable conditions, the crop could be oriented without any reduction in total yield. If conditions are not favourable for pod set and development, the second peak of October-November may even fail.

11) Where the monsoon rains are moderate and do not normally induce crop loss, this practice may be workable as in most of the southern districts of Kerala.

12) Ethephon at 70-100 ppm induced slow defloration and at 150 ppm caused quick defloration.

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Appendix 1. Monthly weather data of Vellanikkara area 1988-1992)

Month and year	Max. temp. (°C)	Min. temp. (°C)	Bright sunshine hours	Total rainfall (mm)	No. of rainy days	Morning relative humidity	Evening relative humidity
Jan. 1988	32.4	22.0	10.4	0	0	70	42
Feb. 1988	35.8	23.1	10.0	7.8	1	77	36
Mar. 1988	35.7	24.4	9.1	37.9	2	86	48
Apr. 1988	35.1	24.3	8.8	145.4	9	85	55
May. 1988	33.7	25.4	6.2	242.6	6	89	63
Jun. 1988	30.0	23.7	4.2	632.1	25	93	80
Jul. 1988	29.0	23.2	3.0	545.0	26	94	82
Aug. 1988	29.2	24.3	3.7	507.8	25	94	77
Sep. 1988	29.9	23.2	5.1	700	24	93	77
Oct. 1988	31.7	23.3	7.1	116.6	9	91	67
Nov. 1988	32.6	22.9	7.9	11.0	1	80	55
Dec.1988	32.6	22.3	9.0	14.9	2	73	42
Jan. 1989	33.4	22.2	8.1	0	0	69	39
Feb. 1989	36.3	21.2	9.8	0	0	68	21
Mar. 1989	36.5	23.3	9.5	31.3	2	79	37
Apr. 1989	35.3	25.1	8.3	52.6	4	86	52
May. 1989	33.7	24.5	7.0	115.8	7	87	62
Jun. 1989	29.4	22.7	3.2	784.6	27	94	79
Jul. 1989	29.1	23.3	4.2	562.0	17	94	77
Aug. 1989	29.5	23.1	5.4	319.9	19	94	73
Sep. 1989	29.9	23.1	5.5	180.1	15	92	72
Oct. 1989	31.0	23.0	6.2	351.3	16	91	70
Nov. 1989	32.5	22.7	8.5	8.1	2	74	74
Dec.1989	32.7	23.2	9.7	0	0	72	47
Jan. 1990	33.5	20.8	9.0	3.5	0	65	34
Feb.. 1990	34.9	21.9	10.0	0	0	80	36
Mar. 1990	36.0	23.8	9.7	4.4	1	81	46
Apr. 1990	35.8	25.4	8.3	38.8	2	83	53
May. 1990	31.5	24.1	4.5	583.9	18	92	72

Continued.

Month and year	Max. temp. (°C)	Min. temp. (°C)	Bright sunshine hours	Total rainfall (mm)	No. of rainy days	Morning relative humidity	Evening relative humidity
Jun. 1990	29.7	23.3	3.4	467.3	25	93	76
Jul. 1990	28.4	22.5	2.4	759.3	28	94	82
Aug. 1990	29.0	23.0	3.5	356.4	22	94	75
Sep. 1990	30.7	23.4	6.2	87.5	8	91	67
Oct. 1990	31.9	23.2	6.5	313.3	12	92	69
Nov. 1990	31.2	22.6	6.0	69.8	3	87	62
Dec.1990	32.3	23.1	10.2	1.8	0	72	45
Jan. 1991	33.6	22.2	8.9	3.9	1	74	41
Feb. 1991	35.9	21.7	10.1	0	0	74	28
Mar. 1991	36.4	24.9	8.7	1.8	0	84	47
Apr. 1991	35.6	24.5	8.9	83.8	4	83	53
May. 1991	35.1	25.5	7.5	56.1	5	84	55
Jun. 1991	29.7	23.8	4.8	993.1	28	94	82
Jul. 1991	29.1	22.8	2.5	975.6	27	94	79
Aug. 1991	29.0	22.7	2.8	533.3	24	95	78
Sep. 1991	31.5	23.6	7.3	6135.0	7	91	64
Oct. 1991	30.9	23.2	4.3	281.7	14	90	74
Nov. 1991	31.5	23.0	7.1	191.3	9	87	63
Dec.1991	31.9	21.7	8.6	0.2	0	78	49
Jan. 1992	32.6	20.9	9.0	0	0	69	36
Feb. 1992	34.5	21.8	9.2	0	0	87	42
Mar. 1992	36.9	22.8	9.2	0	0	84	38
Apr. 1992	36.3	24.4	8.8	48.6	3	82	48
May. 1992	33.8	24.8	7.4	90.6	6	85	61
Jun. 1992	30.1	23.7	3.3	979.8	22	92	77
Jul. 1992	28.8	22.7	2.1	874.5	26	95	80
Aug. 1992	28.9	23.3	2.7	562.9	25	94	81
Sep. 1992	30.1	23.1	4.1	302.9	17	91	73
Oct. 1992	30.7	22.9	4.6	386.7	14	92	72
Nov. 1992	31.0	23.1	5.5	376.7	12	86	68
Dec.1992	31.1	22.3	8.9	2.0	0	75	47

Appendix 2 Weekly total flower production and weather variables of the corresponding period

Standard week no.	Weekly flower no. of plants without pod load	Weekly flower no. of plants with pod load	Maximum temperature (°C)	Minimum temperature (°C)	Bright sunshine hours	Total rainfall (mm)	No. of rainy days	Morning relative humidity	Evening relative humidity
12/ 93	46.2	63.7	35.3	24.3	8.70	0	0	84	50
13/ 93	7.7	12.8	35.4	24.1	8.60	0	0	83	52
14/ 93	4.0	6.0	36.3	23.9	10.00	2.2	1	80	54
15/ 93	3.7	6.1	34.5	24.4	9.20	25.3	0	84	56
16/ 93	3.3	4.3	35.5	25.7	9.30	0	1	83	54
17/ 93	58.5	27.6	36.6	26.0	8.60	4.6	1	84	55
18/ 93	107.5	63.6	35.3	25.7	7.90	3.0	0	84	55
19/ 93	10.8	4.6	35.4	25.9	8.60	1.4	2	82	56
20/ 93	16.9	6.3	34.1	23.8	6.00	31.9	1	86	65
21/ 93	76.6	13.6	34.5	25.7	6.60	6.0	3	88	62
22/ 93	37.0	3.4	32.8	24.0	4.30	103.8	6	90	69
23/ 93	55.9	25.1	29.6	23.3	1.80	236.6	7	95	80
24/ 93	24.7	10.7	29.2	23.8	1.90	237.9	4	95	81
25/ 93	15.3	8.1	30.4	24.5	4.40	85.5	5	94	73
26/ 93	6.7	1.5	29.2	23.6	2.90	186.4	6	94	82
27/ 93	2.3	0.1	28.6	22.7	2.00	188.9	7	95	78
28/ 93	0.5	0	28.7	22.6	1.80	167.8	6	92	83
29/ 93	0.9	0	28.9	22.9	2.80	128.1	6	94	76
30/ 93	2.0	0	28.0	23.1	2.90	101.0	6	94	80
31/ 93	0.9	0	29.1	23.7	3.60	96.4	5	95	76

Continued....

32/93	0.9	0	29.9	23.5	4.60	54.9	5	95	75
33/ 93	1.4	0	29.2	23.1	3.30	66.3	6	93	78
34/ 93	2.0	0.3	29.8	23.2	5.60	61.9	4	96	74
35/ 93	7.1	1.4	29.8	23.5	6.50	33.6	2	95	73
36/ 93	10.5	1.9	29.4	23.5	3.90	23.7	2	93	75
37/ 93	8.9	1.6	30.7	23.1	7.50	11.5	2	93	69
38/ 93	16.2	3.9	31.7	23.4	8.30	23.2	2	94	63
39/ 93	16.5	4.5	31.0	23.2	6.70	14.9	3	91	65
40/ 93	18.9	3.9	29.8	23.4	3.80	149.8	1	93	82
41/ 93	17.6	6.3	29.3	23.2	2.10	181.5	6	95	78
42/ 93	25.2	10.9	31.2	23.2	4.90	102.7	5	90	74
43/ 93	26.7	10.6	31.9	23.5	6.30	83.4	4	92	72
44/ 93	28.2	12.9	32.5	24.2	7.10	3.2	2	80	63
45/ 93	27.3	9.9	30.4	23.9	4.00	58.3	0	84	70
46/ 93	19.8	7.5	31.8	23.0	5.60	12.7	3	91	66
47/ 93	24.8	7.0	31.8	23.1	7.60	1.2	2	72	54
48/ 93	31.6	12.5	31.4	24.3	5.80	0.8	0	77	60
49/ 93	46.7	17.5	31.2	22.7	3.40	17.0	0	84	62
50/ 93	23.5	13.7	32.5	21.9	5.10	0	2	75	47
51/ 93	24.5	10.7	31.0	23.8	5.50	1.0	0	75	59
52/ 93	29.1	10.3	31.6	23.5	6.10	0	0	72	47
1/ 94	23.5	9.5	32.6	23.6	10.00	0	0	69	44
2/ 94	21.1	5.1	32.2	22.7	9.00	0	0	73	43
3/ 94	27.9	6.5	33.6	23.7	7.70	19.4	1	83	49

Continued...

4/ 94	27.1	5.5	32.8	22.0	9.20	0	0	65	32
5/ 94	27.7	6.0	33.9	21.0	9.80	0	0	81	37
6/ 94	141.9	32.1	34.6	23.8	7.80	0	0	77	43
7/ 94	75.9	14.9	34.4	23.1	8.20	1.7	0	86	45
8/ 94	64.5	16.9	35.7	23.0	7.80	0	0	83	36
9/ 94	26.9	4.7	35.8	22.5	10.20	0	0	56	20
10/ 94	44.5	11.7	37.2	21.8	10.10	0	0	71	20
11/ 94	27.3	5.6	37.4	23.7	9.80	0	0	83	36
12/ 94	57.3	17.8	35.2	25.4	8.80	1.2	0	90	56
13/ 94	35.6	9.9	35.4	25.4	8.30	19.8	1	86	57
14/ 94	15.6	3.9	35.8	23.5	8.30	37.1	3	85	54
15/ 94	12.2	2.3	34.8	23.7	6.10	79.8	4	90	58
16/ 94	421.5	45.8	34.3	24.5	8.50	27.6	2	89	61
17/ 94	524.0	119.7	34.6	25.3	7.00	20.7	1	86	63
18/ 94	168.3	60.1	34.3	25.0	10.20	0	0	85	58
19/ 94	34.8	19.1	34.1	25.2	9.00	11.6	1	84	58
20/ 94	4.3	2.1	34.0	24.6	7.50	82.2	2	92	62
21/ 94	63.1	8.8	33.9	25.3	7.60	3.5	1	89	62
22/ 94	106.2	20.1	30.2	22.8	2.80	171.8	7	95	80
23/ 94	77.8	12.9	26.6	22.9	0.08	280.0	7	96	92

Appendix 3 Weekly water deficit, water surplus and increase in pod load (12/93 to 24/94)

Week no.	Water deficit	Water surplus	Increase in pod load
12/ 93	30	0	0.5
13/ 93	30	0	0.7
14/ 93	27	0	0.9
15/ 93	3	0	1.0
16/ 93	27	0	3.9
17/ 93	22	0	4.6
18/ 93	24	0	10.5
19/ 93	26	0	20.0
20/ 93	0	0	27.9
21/ 93	16	0	39.1
22/ 93	0	0	58.8
23/ 93	0	75	72.9
24/ 93	0	223	80.9
25/ 93	0	67	105.8
26/ 93	0	170	117.0
27/ 93	0	177	112.4
28/ 93	0	152	115.5
29/ 93	0	114	114.4
30/ 93	0	86	129.9
31/ 93	0	78	138.4
32/ 93	0	36	147.1
33/ 93	0	48	151.2
34/ 93	0	42	161.1
35/ 93	0	17	149.0
36/ 93	0	9	134.4
37/ 93	0	0	103.3
38/ 93	0	0	81.1
39/ 93	0	0	60.1
40/93	0	130	53.6
41/93	0	169	42.6
42/ 93	0	89	31.8
43/ 93	0	70	24.5

Continued..

Week no.	Water deficit	Water surplus	Increase in pod load
44/ 93	0	0	19.7
45/ 93	0	25	23.3
46/ 93	0	0	26.2
47/ 93	1	0	28.5
48/ 93	3	0	30.5
49/ 93	0	0	33.5
50/ 93	6	0	41.5
51/ 93	8	0	48.4
52/ 93	12	0	56.5
1/ 94	17	0	67.3
2/ 94	19	0	75.4
3/94	3	0	79.3
4/94	29	0	87.2
5/ 94	20	0	89.5
6/ 94	21	0	88.1
7/ 94	16	0	88.1
8/ 94	22	0	90.5
9/ 94	35	0	73.7
10/ 94	29	0	67.0
11/ 94	28	0	65.6
12/ 94	24	0	66.9
13/ 94	8	0	63.8
14/ 94	0	0	72.4
15/ 94	0	0	66.8
16/ 94	0	0	81.7
17/ 94	1	0	103.4
18/ 94	15	0	109.7
19/ 94	6	0	101.7
20/ 94	0	0	125.6
21/ 94	7	0	137.4
22/ 94	0	47	108.1
23/ 94	0	271	101.4

Appendix 4 Monthly soil water deficit, water surplus and increase in pod load (1988-92)

Month and year	Water deficit	Water surplus	Increase in pod load of rainfed crop	Increase in pod load of irrigated crop
Jan. 1988	53	0	141.1	84.8
Feb. 1988	79	0	130.5	91.4
Mar. 1988	80	0	102.7	71.7
Apr. 1988	0	0	65.6	46.4
May. 1988	0	0	67.1	31.4
Jun. 1988	0	533	46.2	32.1
Jul. 1988	0	490	67.4	49.4
Aug. 1988	0	439	60.9	41.8
Sep. 1988	0	639	53.1	28.8
Oct. 1988	0	37	45.6	20.6
Nov. 1988	9	0	43.1	28.7
Dec.1988	52	0	51.2	34.1
Jan. 1989	121	0	85.7	73.6
Feb. 1989	133	0	93.2	94.8
Mar. 1989	111	0	89.9	70.4
Apr. 1989	68	0	58.1	42.4
May. 1989	0	0	43.2	37.4
Jun. 1989	0	498	39.1	62.8
Jul. 1989	0	493	92.4	105.7
Aug. 1989	0	243	168.2	126.2
Sep. 1989	0	112	94.2	32.2
Oct. 1989	0	273	63.6	23.0
Nov. 1989	14	0	86.9	42.2
Dec.1989	67	0	51.4	33.1
Jan. 1990	107	0	48.7	42.7
Feb. 1990	123	0	73.0	53.3
Mar. 1990	133	0	100.0	64.8

Continued...

Month and year	Water deficit	Water surplus	Increase in pod load of rainfed crop	Increase in pod load of irrigated crop
Apr. 1990	89	0	99.3	61.2
May. 1990	0	268	60.9	62.2
Jun. 1990	0	418	37.9	52.4
Jul. 1990	0	704	24.6	26.7
Aug. 1990	0	293	52.9	33.2
Sep. 1990	0	17	49.1	29.9
Oct. 1990	0	236	31.4	25.2
Nov. 1990	0	0	41.9	33.4
Dec.1990	27	0	57.0	42.6
Jan. 1991	72	0	84.9	56.0
Feb. 1991	115	0	135.3	83.4
Mar. 1991	116	0	149.4	74.0
Apr. 1991	31	0	72.4	42.7
May. 1991	45	0	49.2	37.3
Jun. 1991	0	715	29.5	35.2
Jul. 1991	0	923	29.7	39.6
Aug. 1991	0	479	43.3	55.7
Sep. 1991	0	0	36.0	28.1
Oct. 1991	0	210	55.4	30.4
Nov. 1991	0	107	83.3	50.2
Dec.1991	29	0	102.8	63.6
Jan. 1992	91	0	126.5	80.8
Feb. 1992	79	0	179.7	114.3
Mar. 1992	123	0	151.7	91.3
Apr. 1992	66	0	123.2	83.8
May,1992	19	0	117.4	98.6

EFFECT OF WEATHER ON COCOA AND IMPROVEMENT OF BEAN SIZE THROUGH SEASONAL CROP ORIENTATION

By

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ABSTRACT OF A THESIS

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ABSTRACT

With an objective of understanding the probable reasons for seasonal fluctuations in flowering and fruiting and also to orient the cocoa crop to a season favourable for bean size, a four year investigation was carried out at the College of Horticulture, Vellanikkara during 1993-96. The influence of weather variables on flowering was studied by correlating weekly flower production with weather parameters of previous one to twelve weeks. This was done using plants with and without fruit load. Flower production was also correlated with increase in fruit load of previous one to twelve weeks. The possible effects of soil moisture deficit and surplus on flowering was also studied.

The influence of weather on fruiting was studied by correlating monthly pod yield with weather variables of previous one to seven months. The influence of fruit load on fruiting was also studied by correlating monthly pod yield with increase in fruit load of previous one to seven months.

For crop orientation study two sets of plants were used, one as control and the other as treatment. The plants used as control were retained as such

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without disturbing pods. In the other set, defloration was done excepting during the period from April to July.

The results revealed that maximum temperature and bright sunshine hours were positively correlated with flower production while rainfall, relative humidity and number of rainy days were negatively correlated. However, summer rains had positive effect. Fruit load had negative influence on flowering.

For pod production the seasonal difference was much pronounced. During monsoon season a comparatively dry condition with high temperature and low relative humidity caused high pod production after five to six months, while in a non-monsoon period production was favoured by high humidity and high rainfall. Pod load affected flower and fruit production adversely. Models were developed to predict flower and fruit production from weather variables and pod load.

The crop orientation study showed that the crop could be oriented to the favourable season of October-November without affecting the total annual yield. However, during years of heavy incessant rains the practice may fail.