CHAPTER V

CROP - WEATHER RELATIONSHIPS - CASE STUDIES OF COCONUT AND RICE

5.1 Introduction

Every crop variety has its own optimum requirements of weather, climatic and other factors of the environment to which it selectively responds. These requirements and responses which effectively control the growth and development of any given crop in a given environment vary not only between crops or families but also from species in the same family and even from variety to variety in the same species. At times, in the same variety the responses may vary from one growth stage to another. Again, optimal requirements for total dry matter production may be quite different from that required for the maximal yield of the economically important parts of the crop. For example, in the case of grain crops, good vegetative development is generally conducive for good yield. However, this relationship is not valid above a limit and the yields are more influenced by the ear-head capacity and the ambient weather conditions. The influence of weather phenomena on crop growth and yield depends on the crop growth stage. For example, a moderate wind or a light rain, when the crop is near harvest, may do more damage than even heavy rains and high winds in the vegetative phase. Further, the weather requirements for maximum yield per plant are not the same as for maximum yield per unit area. Thus, the plants contributing to bumper crop yields, function, more often than not, much below their individual potentiality.

In the light of the above, the types of weather responses a crop ecologist can expect to encounter are really innumerable.

However, as pointed out by Went (1957), the problem of weather relations of crops is not so intractable as may seem at first.

Firstly, the crops are often influenced significantly by one or two factors that are more crucial for their growth and development. For example, during kharif, when the temperatures are equable, it is the distribution of the rainfall quantum that assumes paramount importance. Similarly, in the case of irrigated rabi crops,the temperature regime in the reproductive phase becomes crucial.

Secondly, crops belonging to the same family or related families may show a typical response towards a particular climatic element.

Thirdly, while differences in climatic responses between the species may be quite different and sometimes spectacular, the range of various climatic parameters to which a species shows a significant response is quite often not very wide. The intra-varietal weather responses in a species are much more limited.

Fourthly, as pointed out by Went(1957), the greater latitudinal coverage of plant species compared to their altitudinal distribution show that natural selection, while having a profound influence on the photoperiodic reponse, has very little influence on the temperature response of plants.

The above considerations should enable an investigator to arrive at the approximate climatic requirements of any crop species under examination. The technique to be explored for arriving at the climatic requirements of crop plants has been indicated by Went (1957) and De Villiers (1966) and has been referred to by Venkataraman (1968) and Venkataraman and Krishnan (1992)

As is well known, both thermal and hygric factors are equally important for the growth and development of any crop. The derived parameters of actual evapotranspiration (A.E.) from the water budget procedure used in the present study integrates these two factors through a comparison of water supply (precipitation) and water need (Potential Evapotranspiration (P.E.), computed using temperature and duration of sunlight) Correlation studies were carried out using annual values of the ratio A.E/P.E (I_{ma} used in drought studies earlier) and the yields of various crops at different districts of the State. In many cases, correlations were found to be positive and significant, that is adequate moisture for the growth and development of plants resulted in higher yields. On the other hand, there were also a large number of cases where the positive correlations were not significant and even cases where there were negative correlations. No definite conclusions could be drawm from these studies and hence are not being presented. Perhaps, the relationship between these parameters controls only a small fraction of the crops yields. It was felt that to gain a deeper insight into the relationship between yield and specific weather parameters, case studies of some crops should be undertaken. Therefore, in the present study two case studies - one each for coconut and paddy have been attempted and crop-weather models developed to forecast crop yields at different stages of crop-growth. The choice of coconut and paddy was made because these two are the most important of perennial and annual crops in the State respectively Moreover, availability of experimental data for coconut from Pilicode and for paddy from Pattambi also influenced the final choice.

5.2 Case study - Coconut:

5.2.1 Introduction

The coconut palm is one of the most useful plants in the world. Grown in more than 80 countries of the tropics, it is the most important of all cultivated palms.

The coconut palm has been known to exist in most regions of the tropics from pre-historic times. Although the original home of the coconut palm is not clearly known,it has been possible to trace the history of coconut culture in most of the countries. The major coconut growing countries of the world are found in Asia, Oceania, West Indies, Central and South America, East and West Africa.

Although India is the third largest coconut producing country in the world, the per capita availability of coconut is as low as 10 nuts per year, whereas it is as high as 282 nuts in Philippines, 53 nuts in Indonesia and 156 nuts in Sri Lanka. An important reason for this situation is that coconut is not grown in all the states of the country but is confined to the coastal states which ultimately have to meet the entire domestic demand. As much as 65 percent of the total coconut area is concentrated in Kerala, a small state accounting only for 1.18 percent of the total land area of the country

Coconut is the first ranking crop in the State. The area under the crop, the production and productivity of the crop in the State from (1975-1976) to (1991-1992) is given below (Status report)

	1975-'76	1980-'81	1985-'86	1992-'93
Area (ha.)	693	651	687	877
Production (million nuts)	3439	3296	3453	5124
Productivity (nuts/ha.)	4963	4617	5023	5843

The production in 1975-76 was 3,439 million nuts while in 1992-'93 it was 5,124 million nuts. Coconut is mostly grown in home steads and small farms in Kerala. There are about 25 million holdings, with an estimated total of 170million coconut palms, the palm density being 299/ha. Calicut is the leading district having about 56% of its total area under coconut crop, followed by Trivandrum (40%) and Alleppey (36%) The area under coconut is the lowest in Wynad (2.91%) The yield rate is maximum in the districts of Trichur (6264 nuts/ha), and minimum (1338 nuts/ha) in Wynad.

5.2.2 Characteristics of the coconut palm

The coconut palm is tall and stately in appearance and attains a height of about 15 to 30m when fully mature. It has a tall, stout somewhat flexible trunk, rising from a swollen base surrounded by a mass of roots. Its characteristics phenological phases and climatic requirements have been described in detail by Thampan (1981)

The genus 'Cocos' formerly included about 30 species, almost all American. These species have been subsequently assigned to several new genera and the genus Cocos is now considered as monotypic containing only one species, C.Nucifera L.

The adult palm usually carries 30 to 40 paripinnate leaves in its crown. The leaf consists of a central stalk, p to 6m long, with a row of over 200 narrow and tapering leaflets 1 to 1.5m in length. The life span of a leaf, from its emergence to shedding, is about 2.5 to 3 years and a new leaf appears in the crown every three or four weeks in a healthy palm.

In the adult palm, though the leaves are produced in succession, the interval between the opening of two successive leaves is influenced by the genetic make-up of the palm, soil fertility and seasonal conditions.

In a growing seedling, the trunk begins to form after the emergence of 12 to 18 leaves. In the first few years, it rapidly increases in thickness and thereafter, the girth is maintained at a steady level. The uniformity in the thickness of the trunk is very often influenced by the environmental factors, especially the availability of nutrients and moisture. Under normal situations the diameter of the stem is often 30 to 40cm, some times reaching 1m at the base.

The coconut palm has no tap root, but has a thick growth of a string- like root system emanating from the blunt bottom of the stem. The number of roots produced by a fully grown tree ranges from 1500 to 8000 depending on the soil conditions. The direction of the main roots is more or less horizontal. The normal length of the roots of a mature tree is about 5m in firm soil and 7m in sand.

In a coconut palm which has reached the normal bearing stage, every leaf axil produces a spadix or inflorescence. The annual production of spadices, therefore coincides with the number of leaves produced by the palm which under normal conditions ranges from 12 to 15. Under unfavourable circumstances, especially when the initial formation of the spadix coincides with the dry weather period, a few of the spadices fail to develop.

The inflorescence develops within a strong, tough, pointed double sheath called spathe. When the spathe is fully grown, it splits along its underside from top to bottom and releases the inflorescence. This usually occurs from 75 to 90 days after the first appearance of its top in the leaf axil. The primordium of the inflorescence begins to form in the leaf axil about 32m before the opening of the spathe and the formation of a leaf starts about 36 months before the appearance of spadix in its axil. The coconut palm is monoecious, producing both male and female flowers on the same inflorescence. The number of female flowers produced by an inflorescence is a highly variable factor and is influenced by the season, soil-conditions, the variety and the inherent yield potential of the palm. In India, the female flower production rate is generally high during the period March to May the highest being in May and the lowest from September to January In general, the number of female flowers per inflorescence varies within a wide range of 10 to 50, though figures outside the range are also not very uncommon.

In the coconut palm, especially in the tall variety, there is a gap between the male and female phases. The opening of the spathe coincides with the effective emission of pollen by the male flowers. The male flowers after opening shed pollen for about 24 hours and then drop off. Pollen discharge or anthesis will continue for about 18 to 20 days (male phase) because of the fact that maturation of inflorescence is a progressive process. The pollen remains viable for two to nine days after it is discharged.

Normally, the female flowers commence to open by the twenty-first day, but during the summer months the flowers may open even from the 18th day onwards. The female phase, ie., the period from the opening of the first female flower to the opening of the last female flower is from four to seven days. The period during which the female flower remains receptive varies in different places with a normal range of one to three days.

Overlapping of phases of two successive inflorescences is a characteristic conditioned by the interaction between genotype and environment. There is so far no consensus on the major agency responsible for pollination. Both wind and insects are considered to have equally important roles as carriers in the pollination.

After pollination, the unfertilized flowers turn brown and fall from the inflorescence. A number of fertilized flowers also fail to develop properly and they too are shed. Generally, not more than 25 to 40 percent of the female flowers reach maturity.

After fertilization it takes about 11 to 12 months for the flower to develop to maturity as large ovoid fruit which is popularly known as 'nut' The fleshy perianth leaves of the flower adhere at the base of the nut throughout this period.

It is possible to estimate the yield of a palm by counting the developing nuts in the crown. Leaving the buttons uncounted, all the nuts present should be available for harvest during the following 11 to 12 months. Very often immature nuts, three or four months old, drop off the bunches due to various reasons. Immature nut fall is heavy during prolonged spells of dry weather and also immediately after the first rain preceded by a dry period.

(a)Climatic requirements

The coconut palm is a tropical crop and grows best when favoured with a hot moist climate. Though not very fastidious or exacting in its climatic requirements, the palm does exhibit growth preferences.

The palm prefers an equable climate and does not tolerate extremes of temperature. Between the tropics of Cancer and Capricorn, the only places where the palm is not found are those which are either too cold or too dry. For vigorous growth and good yield, a mean annual temperature of $27^{O}C$ is stated to be the best. The palm fails to flourish in areas where the mean temperature falls below $21^{O}C$ and also where the temperature fluctuations are considerable. Occasional short spells of low temperatures and slightly higher temperature than the optimum is likely to be tolerated by the palm, if it is not associated with very low humidity, hot dry winds and inadequate soil moisture supply.

Heavy and well spread rainfall ranging from 100 to 300Cm is required by the palm. The distribution of rainfall, drainage status and moisture-holding capacity of the soil are more important than the quantum of total rainfall. In a study at the Central Plantation Crops Research Institute, Kasargode, India it was observed that the yield of coconuts in any year is profoundly influenced by the seasonal rains from January to April received two years prior to the harvest. In the coconut palm, the primordium of the spikelets of the inflorescence is formed about 15months before the opening of the spathe, and of the female flowers before 12 months. Even after the spathe is opened, the female flowers require about 11 to 12 months to reach full maturity. Therefore, severe drought during the early formative period of the inflorescence may kill the growing points due to desiccation resulting in the abortion of spadix. Rainfall has been found to influence not only the number of nuts produced by the palm but also the size and quality of nuts.

In an experiment in Trinidad (Smith,1966), it was found that the yield in a particular year was correlated with the integrated soil water deficit over the 29 months preceding the beginning of the season. It was found that for most coconut growing areas, coconut crops do not respond to any rain over 35.56cm in a month. Rainfall in excess of this limit does not become available to the palms because the surplus moisture is lost either by surface run-off or seepage. A study on the influence of rainfall on coconut crop revealed that during the period September- December any rain in excess of 35.56cm in a month was significantly harmful to the crop During this period of the year, the temperature is low and humidity is high and these climatic factors interfere with the normal transpiration process of the leaves, resulting in the accumulation of excessive moisture in the soil and a reduction in the effective period of sunshine. But excessive rainfall during the period January- April was not found harmful, probably due to the accelerated transpiration facilitated by high temperature and low humidity (Abeywardena, 1968) The experience in India is that there is a certain maximum rainfall beyond which any further precipitation will be of no practical use. But the critical range of rainfall or the effective rainfall is subject to variation from region to region and is mainly controlled by the soil types and microclimate.

Although a hot humid climate is good for the growth of the palm, very high humidity throughout the year interferes with the moisture and nutrient uptake of the palm and also encourages incidence of various pests and diseases. A dry and windy atmosphere is always beneficial provided the soil moisture availability is adequate. Under unfavourable soil moisture stress, only a light wind is desirable.

The coconut is more or less a coastal crop. The palms on the sea coast benefit from a humid climate which is less subject to wide fluctuations of temperature. They are also benefited by better supplies of sub-soil moisture due to the continuous seepage of fresh water to the sea from higher inland areas. Further, the constant movement of the sub-soil moisture near the coasts caused by the ebb and flow of the tide is also beneficial to the palms.

In the principal coconut growing countries, plantations are found established on a wide variety of soils ranging from littoral sands to the heaviest clays. In India, coconuts are found grown on almost all soil types. In general, the major soil types used for coconut in India are laterite, alluvial, red sandy loams, coastal sandy and reclaimed soils with a pH ranging from 5.2 to 8.0. Though coconut is grown on a wide range of soil types, water supply is the single important factor that determines the suitability of a particular soil type. In areas of heavy rainfall, well-drained soil types are the most ideal. On the other hand, in areas of poor rainfall or where long spells of dry periods are likely, it is always desirable to have deep and fine soil types possessing good water- holding capacity

(b) Varieties of Coconut

There are only two distinct varieties of coconut, the tall and dwarf. Owing to cross pollination, especially in the talls, a wide range of variations occur within the same variety.

The tall variety is extensively cultivated in all the coconut tracts of the world. This variety is characteristically tall, growing to a height of about 15 to 18m. The crown has 25-40 fronds and the length of a fully opened frond is about 6m. It is a comparatively hardy type, late bearing, and lives upto a ripe age of 80 to 90 years. West coast tall, Lakshadweep Ordinary, Andaman Ordinary, Kappadam, Laguna San Ramon, Macapuno, Spicata are the types which come under tall variety.

Dwarf coconuts are known to occur in most of the coconut growing countries. This variety is characterised by its short stature and earliness in bearing. Under normal conditions, the palm starts flowering in about three to four years when the tree is just above the ground, and a fully grown tree rarely exceeds 5m in height. Some of the important dwarf types grown in India and elsewhere are Chowghat 'Dwarf Green' Chowghat 'Dwarf Orange', Malayan Dwarf, Gangabondam, Coconino, Mangipod etc.

The manifestation of heterosis or hybrid vigor in a perennial crop like the coconut palm was first reported from India in 1932. The inter- varietal hybrids produced in these countries for commercial plantings are the Tall x Dwarf, Dwarf x Tall and Tall x Tall.

(c) Pests and Diseases

The coconut palm is susceptible to the attack of a large number of pests of major and minor importance. All these are capable of causing considerable damage to the palm resulting in reduced yields.

The Rhinoceros beetle is the most serious pest of the coconut palm and is found in all the coconut growing countries. The cock chaffer popularly known as 'white grub' which cause damage to the coconut palms by feeding on the root system, live inside the soil and usually occur in the sandy or sandy loam soil tracts of Kerala state in India. The grubs are active with the onset of monsoon, especially in the months of May and September Other pests which cause damage to the coconut palm are the red palm weevil, asiatic palm weevil, slug caterpillar, the flying fox, the robber crab etc.

Among the many diseases of the coconut palm, only those caused by fungi and hematodes have been fully understood. Some of the pathogenic diseases are Bud rot, Grey leaf spot or blight, the leaf rot, red ring disease etc. Stem bleeding, root wilt, tatipaka, Cadang-Cadang, Lethal yellowing etc. are some of the diseases of uncertain etiology.

5.2.3 Crop-weather relationships

The climatic requirements of coconut have been discussed by Copeland (1931), Menon and Pandalai (1958), Ochse et al. (1961), Papadakis (1970) and Domros (1974) Weather influence on the development and yield of coconut has been discussed by Krishnamarar and Pandalai (1957), Menon and Pandalai (1958)

It is seen from these that the coconut palm is more tropical than the other crops. Outside 20^{o} latitude on either side of the equator, fruit bearing is unsatisfactory (Menon and Pandalai, 1958) The main centres of coconut production are confined to the coastal area, in the latitudinal belts 15^{o}S to 15^{o}N (Ochse et al., 1961) Coconut requires a mean annual temperature of 27^{o}C, in which the coldest month has a mean temperature of 20^{o}C, hottest months has a mean temperature less than 35^{o}C, the lowest mean minimum temperature is greater than 10^{o}C and the diurnal variation is less than 6^{o} to 7^{o}C (Menon and Pandalai, 1958; Domros,1974) However, a very low maximum temperature brought about by cloudy conditions restricts production and may call for the use of growth regulators (Papadakis,1970) Coconut is grown at altitudes of less than 750m except near the equator where it is grown up to about 1,350m (Menon and Pandalai, 1958)

Earlier studies indicated that only rainfall influences coconut yields significantly Gadd (1922), reported that shedding of buttons-a phenomenon related to yield was high in the rainy season. Gadd (1923) gives explanation for the physiological droughts encountered by the crop during rainy season. Patel (1938) pointed out that coconut yield in any particular year is influenced by the January to April rains for two years prior to harvest, together with the rains received in January to April of the year of harvest. On the west coast of India, a well distributed annual rainfall of 2,500 mm is considered optimum (Radha et al., 1962) According to Wickramasuriya (1968) rainfall has no effect on the number of spadix. Abeywardena (1968) revealed that during the period September-December, any rain in excess of 35.56cm in a month was significantly harmful to the crop. When mean annual precipitaion is less than 1,000 mm or when monthly rainfall is less than 50 mm at a stretch, the crop would require to be irrigated. Coconut is light loving. A minimum of 4 hours of bright sunshine per day and an average of at least 6 hours per day for the year as a whole is required. Arelative humidity regime of 80 to 90% is preferred by the crop. The relative humidity can go down to 60% but for brief periods only (Domros, 1974) Coconut crop can also stand stiff breezes and is felled only by cyclonic storms. Air containing salt spray is considered to be beneficial.

Since coastal areas have high humidity, equable warm temperatures and good subsurface feed of water on account of high water-table, they are the preferred habitat for the plants However, coconut can also be successfully raised in inland areas with irrigation and in non-coastal areas whwre water-table fluctuationms provide the crop with requisite amounts of aeration and soil moisture.

Though Kerala is known as the land of the coconut, the per palm production is much less (33 nuts/palm) when compared to that of the other coconut growing States. Within the State, the per palm production is much less in the northern districts. Higher nut yields are recorded in the southern districts despite the prevalence of root wilt disease.

The weather influences on the growth and yield of coconut at the Central Coconut Research Station, Kasargode, on the West Coast of India, have, been studied by a number of workers. The works of Sayeed and Narayana (1953), Gangooly and Nambiar (1953) and Sayeed (1955) have been summarised by Krishnamarar and Pandalai (1957) The works of Patel and Anandan (1936), Pillai and Satyabalan (1960), Lakshmanachar (1962) and Vijaylakshmi et al. (1962) can be summarised as follows. The main features emerging are as follows: (a) Leaves are produced most rapidly in September October while the rate of leaf production is low in summer, (b) leaf shedding is the least in the rainy season; (c) production of infloresences is highest in summer and the least in winter; (d) abortion of infloresences is rare in summer and more prevalent in rainy season; (e) in summer the male phase is of the shortest duration and more percentage of female flowers are produced; (f) shedding is high in the monsoon period and low in winter; (g) yield of good nuts is high in summer; (h) barren nuts are more in the hot weather and rainy season; (i) summer crop is of superior quality

Patel and Anandan (1936) found that the yield of coconut in any particular year was influenced by the rain fron January to April of the preceding two years as well as that of the year of harvest. Vijayalakshmi et al. (1962) found that in general the weight and volume of nuts were higher in those bunches that reaches the stage of stigmatic receptivity during summer Lakshmanachar (1962) found that rainfall received from the third to seventh month after inflorescence had the greatest impact on production.

The coconut gardens in the northern region of Kerala which grow under the rainfed and good management conditions do suffer due to lack of soil moisture in summer. If the pre-monsoon showers fail, the effect of prolonged dry spell or drought on coconut production is much more severe. Prasada Rao (1982) enunciated in Kerala that a the continuous dry spell for six months with high moisture deficit and high water surplus during July decreased the coconut yields in the subsequent year considerably. The effect of drought incident, intensity, and duration on coconut palm was studied by Prasada Rao (1985), based on the visual symptoms like drooping of leaves, immature nut fall, and button shedding etc., under the drought condition in 1983. Investigation of the impact of drought on nut yield (Prasada Rao,1986) led to the conclusion that, decline in annual nut yield was seen only in the subsequent year, while decline in monthly nut yield commenced in the eight month after the drought was over, and continued for twelve months with the maximum effect at the thirteenth month. The association of increasing trend in intensity and frequency of agricultural drought in the recent years with the decreasing trend in nut yield in coconut in the district of Kasargode was studied by Prasada Rao (1990) Thirty to fifty percent yield decline in coconut was seen in the subsequent year due to severe soil moisture stress that occurred during summer 1983,1985 and 1989 (Prasada Rao et al., 1993) Park (1934) found that the severe drought experienced in Puttalam (Ceylon) in 1931 affected the yield of nuts for a period of about two years with the maximum effect at about thirteen months after the conclusion of drought.

Being a perennial crop with long phenophases of 44 months, advance information on behaviour of coconut yields is of great importance to Government agencies as well as planners and related agencies. Several workers (Balasubrahmanian,1956; George,1988; Jacob Mathew et al, 1986; Jacob Mathew et al., 1988; Nayar and Unnithan,1988; Vijaya Kumar et al., 1988 a & b; Saraswathi and Mathew, 1988; Pillai et al, 1988; and Abraham Varughese and Mohamed Kunju,1988) have attempted crop weather relationships of coconut for forecasting nut yield. In an outstanding paper Abeyawardena (1983) developed a forecasting model for forecasting nut yield a year ahead based on the drought index (R^2 = 0.98) for the entire Sri Lanka. Attempts were made by Prasada Rao (1990) in developing a model to assess the yield a year ahead employing yield moisture index and index of moisture adequacy during the summer. A multiple regression equation was developed by Prasada Rao (1996) using the index of moisture adequacy from December to May during the same year of harvest, one year prior to harvest, and two years prior to harvest to estimate the annual nut yield.

5.2.4 Crop-weather model

(a) Experimental data used for study

Details of crop and weather data collected from the Regional Agricultural Research Station, Pilicode, (12^{o} 12'N 75^{o} 10'E) is given below.

Parameter	Years of data
Crop	
Coconut monthly production	September 1986-December 1990.
Meteorological (monthly data)	
Maximum temperature (TMAX)	January 1983-December 1990.
Minimum temperature (TMIN)	-do-
Soil temperature (5cm depth) (STI)	-do-
Soil temperature (70cm depth) (STII)	-do-
Morning relative humidity (RHI)	-do-
Evening relative humidity (RHII)	-do-
Evaporation (EVP)	-do-
Rainfall (RF)	-do-
Rainy days (RD)	-do-
Solar radiation hours (SRH)	-do-

The soil type at the research station is laterite. The monthly nut yields have been collected from all the species of the coconut palm available at the station. The meteorological data has been measured at the station observatory as part of the ongoing research programs. All the data for this study has been obtained from the records maintained at the station.

The monthly data of rainfall and temperature were used to compute the monthly water balance using Thornthwaite and Mather (1948,1955) procedure. Potential evapotranspiration was computed using the formula given by Thornthwaite (1948) While Actual Evapotranspiration (A.E.) and Moisture Deficit (MDEF) values were derived from the water budget procedure. As explained earlier (Section Three of Chapter Two) the Index of Moisture Adequacy (I_{ma}) was computed as A.E/P.E * 100.

(b)Methodology employed

The methods of correlation and regression analysis are most widely used for studying crop-weather relationships and weather based yield prediction. PCA is usually employed to nullify the inter-correlation between the variables. Before applying these techniques ,it is necessary to process the available agro-climatic data to a suitable form.

The yields of agricultural field crops are the result of growth and development processes extending over a long period of time. Within the growing season, the type of weather required may be subjected to considerable changes. The whole of the growing season must, therefore, be divided into smaller periods which are closely linked to the yield development processes.

In the present study, the time interval for nut development from primordium of the inflorescence to harvest was divided into four different periods such as primordium of the inflorescence to initiation of spikes (44 to 28 months before harvest), initiation of spikes to female flowers initiation (27 to 24 months before harvest), female flower initiation to opening of spathe (23 to 12 months before harvest) and the opening of the spathe to harvest. Correlations were worked out between each month's coconut production and the weather parameters influencing the yield 44 months prior to the harvest. Variables which showed a significance of 99% and above were selected to form the independent variables for the multiple regression equation. These variables were subjected to PCA and the PC scores were calculated. The PC scores of the selected PC's were the independent variables in the multiple regression models, explained in Section 2 of Chapter 2 developed to predict the monthly coconut production.

(c) Results

(i) Results of correlation analysis

When the weather parameters of the first 3 periods (44 to 28 months before harvest, 27 to24 months before harvest, 23 to 12 months before harvest) were correlated with the corresponding monthly nut yield, the following results were obtained

During the first stage, only three weather parameters significantly influence the development, and in turn affect the final nut yield. These are total amount of rainfall, morning relative humidity and minimum temperature (Table 5.1) Rainfall and minimum temperature are negatively correlated and morning relative humidity, positively correlated with production. During the second stage the weather parameters positively correlated are moisture deficit, maximum temperature and soil temperature while actual evapotranspiration (AE) ratio of actual

Variables	Stage I Coefficients	Stage II Coefficients	Stage III Coefficents	Stage IV Coefficents
AE	-0.0690	-0.4187 *	0.3922 *	-0.2088
AE/PE	-0.0288	-0.4086 *	0.4095 *	-0.2361
MDEF	0.0146	0.4193 *	-0.3653 *	0.1613
RF	-0.4120 *	-0.0240	0.1015	-0.3826 *
RHI	0.3885 *	-0.4206 *	-0.0728	0.0899
RHI	-0.0554	-0.2177	-0.3417	-0.1127
TMAX	-0.2240	0.4069	0.3218	-0.2111
TMIN	-0.4492	0.0829	0.4334	-0.4115
STI	-0.2040	0.3837	-0.2724	0.0720
STII	-0.2040	0.4114	-0.0949	0.0679
SRH	0.1041	0.2166	0.0917	0.2425
RD	-0.2627	0.1216	0.0755	-0.3130
EVP	-0.1142	0.3560	0.730	-0.0221

* - Significant at 95% level

Table 5.1 Results of correlation analysis - Coconut

(Contd.)

Cochin

Category of year	Water need(cm)	Rainfall (cm)	Water deficit(cm)	Water surplus(cm)	Moisture index	Climatic type
Normal year	171.1	311.3	31.00	167.0	92.5	B_4
Wettest year (1937)	168.3	314.2	34.00	178.1	85.6	B_4
Driest year (1976)	174.3	217.0	48.80	91.4	24.45	B_1
Disastrous drought years i (1935)	169.27	211.56	57.23	976.9	23.9	B_1
ii (1983)	182.50	254.30	61.44	125.84	35.3	B_1

Kottayam

Category of year	Water need(cm)	Rainfall (cm)	Water deficit(cm)	Water surplus(cm)	Moisture index	Climatic type
Normal year						
Wettest year (1933)	166.96	457.71	27.43	319.17	174.7	A
Driest year (1965)	175.41	201.6	37.99	56.98	10.8	C_2
Disastrous drought years i (1979)	179.24	255.37	51.71	126.44	41.7	B_2
ii (1983)	181.73	233.20	56.79	101.45	24.6	B_1

(Contd.)

Alleppey

Category of year	Water need(cm)	Rainfall (cm)	Water deficit(cm)	Water surplus(cm)	Moisture index	Climatic type
Normal year	171.8	310.0	21.70	160.0	85.0	B_4
Wettest year (1977)	177.6	364.7	21.50	208.9	105.5	A
Driest year (1973)	173.3	289.2	30.10	152.6	70.7	B_3
Disastrous drought years i (1982)	180.07	205.74	58.69	88.44	16.5	C_2
ii (1983)	182.64	249761	65.67	126.23	33.2	B_1

Trivandrum

Category of year	Water need(cm)	Rainfall (cm)	Water deficit(cm)	Water surplus(cm)	Moisture index	Climatic type
Normal year	171.9	183.9	29.9	51.9		
Wettest year	164.4	303.6	29.7	171.9	86.5	B_4
Driest year	172.3	112.7	55.6	00.0	-32.25	B_1
Disastrous drought years i (1976)	172.26	112.73	55.55	00.0	-32.2	C_1
ii (1983)	180.99	135.61	53.63	00.0	-29.6	C_1

evapotranspiration to potential evaporation (AE/PE) and morning relative humidity are negatively correlated. In the third stage, the parameters positively correlated are AE, AE/PE and minimum temperature, while moisture deficit is negatively correlated. The correlations of other parameters are not significant.

From the entire data period, the month which gave the highest production was April, 1987 and the lowest production was in December,1987 In both the cases correlation analysis points to a negative correlation between rainfall during the first stage and production.

Coming to the second stage, which is only four months out of the entire development stage of the nut, in the case of highest production month, this period falls from January to April 1985, with rainfall only in the month of April, while for the lowest production month it was from September to December 1985, having rainfall during all the months. A negative correlation with AE and AE/PE and a positive correlation with moisture deficit, soil temperature and maximum temperature are observed

From the third stage correlation results, we can come to a conclusion that more rainfall is favoured during this stage. In both the cases (highest and lowest production), a good rainfall period is encountered by the nuts. But, in the highest production case, rainfall is received during the former phase and in the lowest production, during the latter phase of the stage.

Coming to the fourth stage, according to correlation results high rainfall amount and rainy days do not favour a good production. From the figures it is evident that, in the case of highest production, the nuts come across heavy rainfall (south west monsoon) during the early stages, while for the lowest production case heavy rainfall is in the latter phase of the stage The developing nuts might have come across drought conditions during its opening of spathe which resulted in button shedding.

(ii) Development of a crop-weather model Coconut

Only the parameters which are significantly correlated at each stage of the development of the coconut are considered for Principal Component Regression (PCR) The variables considered for Principal Component Regression (PCR) after Ist stage are rainfall (RF1), morning relative humidity (RHI1) and minimum temperature (TMIN1) Application of PCA reduced the number of variables from three to one (Table 5.2) since only those components which have eigen values of 1.000 or greater were selected for further computations. In this case, the first principal component which had an eigen value of more than one was selected to calculate the PC scores (PC1) employing the eigen vectors, following the procedure explained in Section Three of Chapter Two.

The linear multiple regression equation developed to predict the monthly coconut production after the Ist stage (PROD1) is

PROD1 = 13920 + (-2417.8) * PC1

where PC1 is the independent variable

It is clear from Table 5 5 that, 17% (R^2 = 0 1699) of the variance of monthly coconut production is explained by first

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	1.058E+06	100.0	100.0
2	8.063E-01	0.0	100.0
3	6.904E-02	0.0	100.0

FACTOR	VECTORS
RFI	1.0000
RHII	-0.0001
TMINI	0.0002

Table 5.2 Eigen values and eigen vectors of Stage I weather parameters - Coconut

stage variables. 83% of the variance is due to other factors such as cultural practices, pests and diseases etc. The standard deviation was 5398.

For the development of prediction model after the IInd stage the variables considered are the three significant variables, RF1, RHI1, TMIN1 of the first stage and the seven significant variables of the second stage - actual evapotranspiration (AE2), ratio of actual evapotranspiration to potential evapotranspiration (AE/PE2), moisture deficit (MDEF2), morning relative humidity (RHI2), soil temperature at 70 cms. (STII2) and maximum temperature (TMAX2) Application of PCA reduced the number of variables from ten to four (Table 5.3), following the same conditions as stated above.

The linear multiple regression equation developed to predict the monthly coconut production after the IInd stage (PROD2) following similar procedure is

$$PROD2 = 13920 + (3083.2 * PC1) + (3228.6 * PC2) + (4209.1 * PC3) + (-2181.7 * PC4)$$

When the first and second stage variables are considered for the development of the model the R squared obtained is 0.3595 (Table 5.5) That is 36% of the variance of coconut production can be explained by the selected weather variables. The standard deviation in this case is 3792, lower than that obtained after first stage.

Finally, all the three stages ie. from primordium of the inflorescence to opening of spathe are considered to develop a linear model. The variables included for the Principal Component

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	1.058E+06	96.5	96.5
2	3.846E+04	3.5	100.0
3	127.4	0.0	100.0
4	1.410	0.0	100.0
5	6.603E-01	0.0	100.0
6	2.359E-02	0.0	100.0
7	8.197E-02	0.0	100.0
8	4.825E-02	0.0	100.0
9	1.042E-05	0.0	100.0
10	4.374E-055	0.0	100.0

Vectors

Factor	1	2	3	4
RF1	1.0000	0.0023	0.0019	0.0010
RHI1	-0.0001	0.0035	-0.0161	-0.0566
TMIN1	0.0002	-0.0010	-0.0044	-0.0920
AE2	0.0002	-0.6635	0.7440	-0.0707
AE/PE2	-0.0000	-0.0013	-0.0003	0.0016
MDEF2	-0.0029	0.7479	0.6568	-0.0856
RHI2	0.0012	-0.0132	-0.0865	-0.9340
STI2	-0.0001	0.0126	0.0643	0.1958
STII2	-0.0004	0.0083	0.0486	0.2335
TMAx2	0.0000	0.0052	0.0273	0.1037

Table 5.3 Eigen values and eigen vectors of Stage II weather parameters - Coconut

Regression model for the prediction of monthly coconut production 11 months before harvest are RF1, RHI1, TMIN1, of the Ist stage, AE2, AE/PE2, MDEF2, RHI2, STI2, STII2, TMAX2 of the IInd stage and the four significant variables of stage III-Actual evapotranspiration (AE3), ratio of actual evapotranspiration to potential evapotranspiration (AE/PE3), moisture deficit (MDEF3) and minimum temperature (TMIN3) of third stage. Application of Principal Component Analysis reduced the number of variables to be included in the model from fourteen to six (Table 5.4)

The regression model to predict the monthly coconut production 11 months prior to harvest (PROD3) is

$$PROD3 = 13921 + (4608.6 * PC1) + (-5996.8 * PC3) + (-2347.1 * PC3) + (-6776.0 * PC4) + (14244 * PC5) + (-5930.8 * PC6)$$

The R squared obtained is 0.6314 (Table 5.5) with a standard deviation of 3792 nuts. That is 63.14% of the variance of monthly coconut production can be explained by the weather changes which take place during 44 to 11 months prior to harvest. It is evident from the three experiments that the impact of weather parameters on the monthly production is increasing after each stage, and therefore the estimated yield after the third stage (PROD3) is closest to the observed yield.

The observed and estimated monthly nut production was in good agreement in a majority of the cases (Table 5.6) Out of 52 sets of monthly production values only 6 cases showed more than 50% deviation. However, the percentage deviation in nut production was within permissible limits as the deviation stayed within one standard deviation in most of the cases Hence, the

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	1.059E+06	95.0	95.0
2	3.884E+04	3.5	98.5
3	1.671E+04	1.5	100.0
4	171.0	0.0	100.0
5	81.78	0.0	100.0
6	1.261	0.0	100.0
7	5.597E-01	0.0	100.0
8	2.187E-01	0.0	100.0
9	8.042E-02	0.0	100.0
10	3.315E-03	0.0	100.0
11	7.308E-03	0.0	100.0
12	1.929E-03	0.0	100.0
13	2.914E-05	0.0	100.0
14	1.491E-05	0.0	100.0

Vectors

Factor	1	2	3	4	5	6
RF1	-0.9995	0.0020	0.0316	-0.0001	0.0030	0.0010
RHI1	0.0001	-0.0034	0.0022	0.0154	0.0023	-0.0158
TMIN1	-0.0002	0.0010	0.0003	0.0011	-0.0056	-0.0813
AE2	-0.0001	0.6572	-0.0960	-0.5188	0.5320	-0.0763
AE/PE2	0.0000	0.0013	-0.0002	0.0003	-0.0003	0.0010
MDEF2	0.0028	-0.7418	0.0905	-0.4578	0.4711	-0.0919
RHI2	-0.0011	0.0133	0.0022	0.0474	-0.0782	-0.8955
STI2	0.0001	-0.0125	0.0017	-0.0408	0.0571	0.2613
STII2	0.0004	-0.0083	0.0012	-0.0348	0.0354	0.3101
TMAx2	-0.0000	-0.0052	-0.0000	-0.0168	0.0230	0.1094
AE3	-0.0232	-0.1011	-0.7688	0.4594	0.4321	-0.0154
AE/PE3	-0.0000	-0.0001	-0.0004	0.0001	0.0000	-0.0016
MDEF3	0.0215	0.0839	0.6249	0.5518	0.5450	-0.0155
TMIN3	-0.0000	-0.0001	-0.0016	0.0079	0.0085	0.0046

Table 5.4 Eigen values and eigen vectors of Stage III

Weather parameters - Coconut.

Stage	Predictor Variables	Coefficients	R Square	Standard deviation
I	Constant	13920.0	0.1699	5398
	PC1	- 2417.8		
II	Constant	13920.0	0.3595	4891
	PC1	- 3083.2		
	PC2	3228.6		
	PC3	4209.1		
	PC4	- 2181.7		
III	Constant	13921.0	0.6314	3792
	PC1	4608.6		
	PC2	- 5996.8		
	PC3	- 2347.1		
	PC4	- 6776.0		
	PC5	14244.0		
	PC6	- 5930.8		

Table 5.5 - Coefficients of Coconut production prediction model - Coconut

σ = 3792

Months	observed	estimated	deviation	percentage deviation
1	8947.00	11212.64	.25	25.3
2	7413.00	12354.26	.67	66.7
3	6325.00	11958.50	.89	89.1
4	7496.00	11513.52	.54	53.6
5	9895.00	13102.32	.32	32.4
6	17596.00	14291.01	-.19	-18.8
7	23366.00	18706.95	-.20	-19.9
8	27457.00	23913.20	-.13	-12.9
9	24251.00	19385.24	-.20	-20.1
10	16274.00	19388.57	.19	19.1
11	20426.00	17788.01	-.13	-12.9
12	22504.00	16596.15	-.26	-26.3
13	20394.00	19307.21	-.05	-5.3
14	16009.00	15636.73	-.02	-2.3
15	12206.00	11561.71	-.05	-5.3
16	9598.00	10817.95	.13	12.7
17	8638.00	12127.05	.40	40.4
18	12633.00	12759.81	.01	1.0
19	12523.00	16429.86	.31	31.2
20	13573.00	17536.46	.29	29.2
21	11565.00	18756.15	.62	62.2
22	9355.00	16459.45	.76	75.9
23	15282.00	15853.19	.04	3.7
24	12489.00	13891.70	.11	11.2
25	14555.00	15255.69	.05	4.8
26	9699.00	11875.95	.22	22.4
27	10615.00	9794.12	-.08	-7.7
28	7826.00	9695.19	.24	23.9
29	9498.00	9421.02	-.01	-.8
30	16344.00	12009.08	-.27	-26.5
31	25841.00	16907.49	-.35	-34.6
32	23857.00	22789.19	-.04	-4.5
33	18913.00	21698.57	.15	14.7
34	21861.00	19252.33	-.12	-11.9
35	17683.00	19242.65	.09	8.8
36	24163.00	17572.75	-.27	-27.3
37	16637.00	20883.27	.26	25.5
38	17498.00	17664.84	.01	1.0
39	15239.00	13434.89	-.12	-11.8
40	8716.00	9129.08	.05	4.7
41	11699.00	8026.64	-.31	-31.4
42	11999.00	7499.79	-.37	-37.5
43	15768.00	13974.31	-.11	-11.4
44	11660.00	13461.41	.15	15.4
45	14321.00	10622.73	-.26	-25.8
46	6172.00	8687.40	.41	40.8
47	8792.00	7731.52	-.12	-12.1
48	11386.00	8378.71	-.26	-26.4
49	6249.00	10591.64	.69	69.5
50	10675.00	8047.90	-.25	-24.6
51	5575.00	4794.79	-.14	-14.0
52	4369.00	4025.50	-.08	-7.9

Table 5.6 Comparison between actual and estimated - monthly coconut production

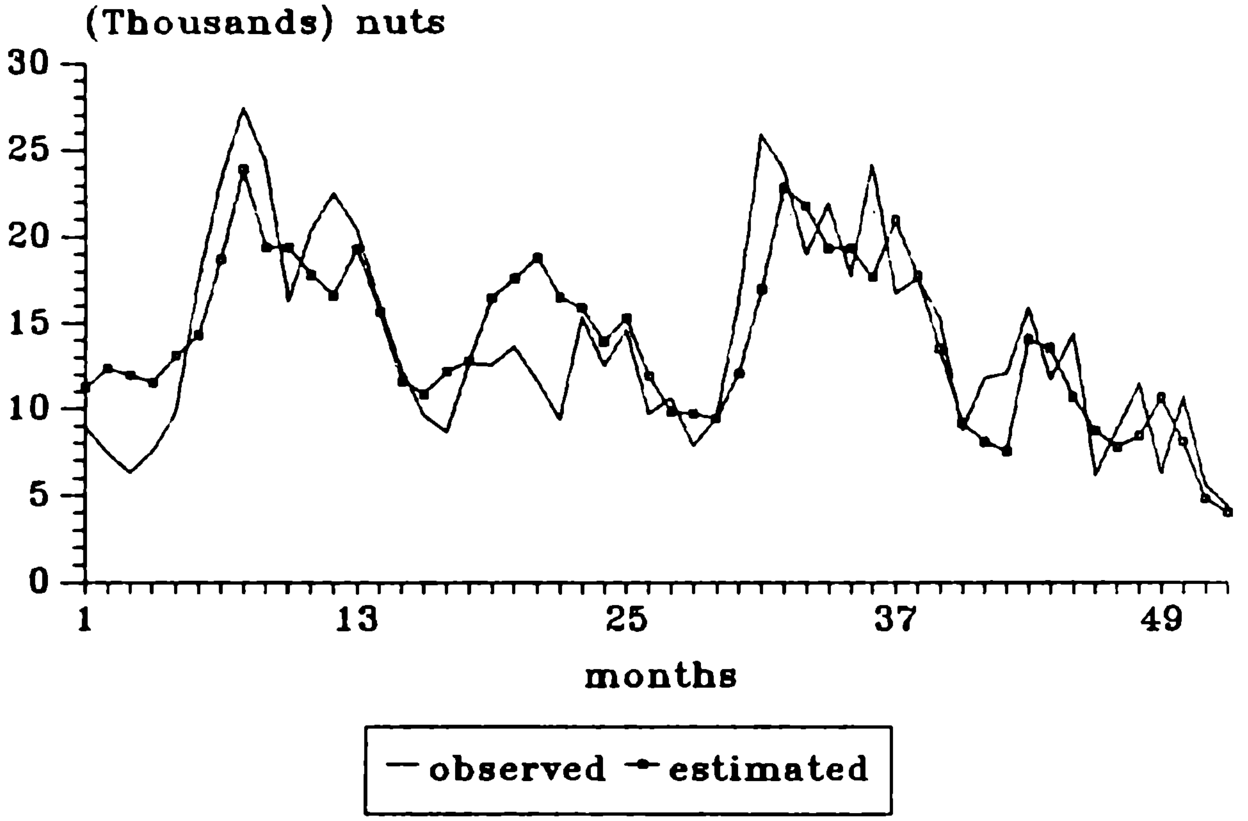

Fig 5.1 Observed and predicted monthly coconut production

equation is a good fit for estimating coconut production eleven months ahead. Fig 5.1 gives the fit between observed and estimated values.

5.3 Case study - Rice:

5.3.1 Introduction

The cultivation of rice certainly fate to the earliest age of man, and long before the era of which we have historical evidence rice was probably the staple food and the first cultivated crop in Asia. Hogan(1970) reported that,, according to the Archaeological Survey of India, four terraces for rice cultivation on the banks of the Ravi River in South -west Kashmir date to the Pleistocene or Ice Age.If this be so, it would appear that rice is an older cereal grain than is generally recorded by historians.

Carbonized paddy grains and husks, estimated to date 1000 to 800 BC, have been found in Lothal in Gujarat, which is considered to be the southward extension of the Harappa and Mohenjadaro culture of the Indus Valley civilization assigned to 2300 BC(CSIR 1966) Excavations at Mohenjadaro brought to light rice grains on earthen vessels, thus providing evidence that this cereal was an important food in this region some 2500 years BC (Andrirs and Mohammed,1958)

The ancient Indian name for rice, 'dhanya' meaning 'sustainer of the human race', indicates its age-old importance. Some of the very ancient Tamil puranas contain descriptions of particular varieties of rice which are used in certain religious offerings, showing that even in ancient times, varieties with definite grain characteristics were recognized, and Susrutha (1000 BC) in his Ayurvedic Matera Medica recognized the differences among rices that existed in India, separating them into groups based on their growth periods, water requirements and nutritional values (Ramiah and Rao,1953)

The varieties of cultivated rice are legion and the variation of characters exhibited by them enables the crop to be grown with success over a wide range of climatic and cultural conditions; from dry land in more or less arid conditions with irrigation, to deep undrained swamps, and varying depths of water. In 1982 the IRRI collection of rice species includes 67000 Asian cultivars, 2000 African rices, 1100 wild rices and 690 genetic testers.

Oryza sativa L. is divided into four subspecies as follows Vasconcellos (1953) (1) Indica (2)Japonica (3)Brevindica and (4) Brevis Gustchin. The last two are not generally recognized. The Japonica forms are typical of the more northerly (and southerly)areas of paddy cultivation and flourish under very long photo periods. Seedlings of cold water-tolerant japonica varieties may grow and develop faster than seedlings of indica varieties when the temperature of soil or water is low (Adair et al. 1966) The grain of japonicas is commonly shorter and broader than is usual for indicas; japonicas usually have broad leaves rather hairy glumes and translucent endosperm.

The types of rice favoured in a country depend on climatic and cultural conditions, and whether the rice is destined for export or local consumption. Of the total production in India and

Pakistan, about 13 percent is long grain, 32 percent medium-grain and 55 percent short- grain rice.

No expert can, by visiting and area, or by examining climatic conditions and the chemical nature of the soil, prescribe with any certainty the variety of paddy to which the situation is suited. The many factors influencing the growth of paddy are so complex and so much is incompletely understood, that the vagaries of the crop can only be countered by the process of trial and error.

5.3.2 Characteristics of the plant

Rice is a grass (Gramineae) belonging to the genus Oryza Linn. of which two species are cultivated, O. sativa Linn. and O. glaberrima Steud.

Oryza sativa is widely grown in tropical and subtropical regions, either as a dry land (upland) crop but more usually in water. The ripe seed is the staple food in many Eastern countries. It is not, however, and aquatic plant, for the roots of aquatics produce but few branches and no root hairs, whereas the roots of paddy- whether grown as a dry land crop or in water- are much branched and possess a profusion of root hairs.

Under normal conditions the root system of the plant is fairly compact, tending to develop horizontally rather than vertically, the plant therefore draws its nutrients from near the surface of the soil (Sasaki,1932) showed that under standard conditions after transplanting the roots develop at first near the soil surface, then gradually penetrate deeper in the soil.

The extreme depth reached by mature root system was 90 cm. Root development is influenced by soil texture, cultivation, water and air in the soil, the amount of available food supply and the system of transplanting.

Sato (1938) observed that the number of roots increases gradually from the early period of growth towards tillering, and the shooting period reaches the maximum at heading time, gradually deceasing until harvest time.

The main stem or culm is differentiated from the growing point of the embryo, enclosed at first by the coleoptile. The ultimate height of the stem depends on the number of internodes and their length and may be much affected by environment but under comparable growth conditions is characteristic of varieties.

The leaves are alternate and borne in two ranks along the stem. The leaf consists of two parts, a sheath enveloping the stem and a blade or lamina. The number of leaves borne on an axis is equal to the number of nodes. Leaf structure, a varietal character, allows increased light absorption and utilization of light energy by the plant, resulting in increased yield potential (Purseglove,1968)

The blade is long and narrow, usually pubescent or hispid, or (less usually) glabrous. Japanese scientists, and especially Matsushima (1969 b) have shown that high yield of grain is positively correlated with the uppermost two or three leaf blades being short and erect to increase the photosynthetic efficiency of the plant.

The angle of the flat leaf is important, since it affects shading of lower leaves. Radiation capture and hence carbon assimilation is hindered by mutual shaking by the plants leaves. A high final angle of the flag leaf, from which much of the carbohydrate in the grain is derived, is an important yield component. Singh(1981) showed that the flag leaf plays an important role in assimilation of plant nutrients and thus influences grain yield.

Varieties in various regions are designated as kharif, winter, spring and summer crops and each class is sub-divided into early and late types purely on the basis of the local normal time of harvest.

5.3.3 Rice in Kerala

Over a very large part of the rice growing areas in India and other countries, single crop of rice alone is raised from June-July to November-December. Two and sometimes three crops are raised in Kerala on the same land, the cultivating seasons corresponding to the rainy periods of the tract. The three main seasons for rice are fairly well defined, the virippu or the autumn crop is raised from April- May to September - October followed by the Mundakkan crop (winter crop) from September October to December- January while the typical Punja (Summer crop) is raised from December-January to March-April (Sahadevan, 1966)

Any account of the rice seasons will not be complete without a mention of the age-old astronomical basis on which agricultural seasons and calendar of operations are prescribed for raising rice and various other crops in Kerala. The year is divided into 12 months, the names of the month corresponding to the 12 signs of the Zodiac (Rasis) The Agricultural year commencing on 1st of Medam (Aries) is again divided into 27 parts (on an average 13.5 days each) and each part known as nattuvela meaning period of the sun is given the name of each of 27 nakshatras or lunar mansions through the moon passes in her monthly journey through the stars.

The period prescribed for the sowing of autumn rice is Bharani and Karthika nattuvelas, (about April 27 to May 23), the period of sowing sprouted seeds in puddle is the Makayiram nattuvela corresponding to June 8 to June 20 and the best period for transplanting is the Thiruvathira nattuvela (June 22nd to July 4) similarly the nursery for winter crop is to be raised in Ayilyam and Makam nattuvela (August 3 to August 29) and transplanting completed before October 10. The summer crop has to be planted before the end of February at the latest.

It is now well established that within any season long days and humid conditions with adequate rains or water supply help towards satisfactory vegetative growth of the rice plant while bright weather and short days with a diminishing supply of water favour the flowering phase. These requirements are very nearly met during the periods specified in terms of natuvelas as given above.

The success of the autumn crop depends on the timely and adequate premonsoon showers received from April to June before the south-west monsoon breaks out in June. The winter crop usually is affected by drought in the post-flowering period in November-December, if north-east monsoon rains are either in adequate in quantity or ill-distributed. The largest area under summer crop is grown by dewatering flooded areas. Very often breaching of bunds and intrusion of salinity affect the crop adversely

The varieties could be broadly grouped into upland and low land varieties. The upland varieties would thrive under low land conditions but the converse is not true. Among the low land varieties, salt tolerant types and deep water types (floating rices) come under district categories. These and the upland varieties are grown in the autumn season (viruppu) in Kerala like the typical autumn varieties. The winter varieties (mundakkan) come under a different group. Varieties grown during summer season (Punja) can also be raised in both autumn and winter seasons.

Photo-sensitivity brings about still another distinction among the varieties particularly in regard to those having long (about 150 days) and medium (130 days) duration. Being photo-sensitive, these varieties flower only at a particular time of the year irrespective of the time of sowing. They should therefore be grown only in the season for which they are recommended. Short-term varieties (about 100 days) are generally photo-insensitive and can be grown in all the three seasons, whatever the season, these come to maturity within the same period, the duration remaining more or less unchanged except in high altitude areas. For upland and summer varieties the duration does not go above 115 days while the medium and long term rices are exclusively grown in wet lands during autumn and winter season.

5.3.4 Crop weather relationships

The weather conditions during the crop growth period of paddy greatly decide the crop's response to added inputs (Tanaka et al.,1964; Mahapatra and Badekar, 1969) Among the various weather factors that affect the growth and yield of rice, air temperature plays an important part. Each development stage and growth process response differently to the same temperature conditions (Izhizuka et al., 1973) Low temperature slows down the rate of germination and root development. High temperature during the vegetative stage increase the tiller number and retards the rate of development For rice, unlike the other crops, both water temperature and air temperature are important. At germinating seedlings stages, water temperature is more influencial than air temperature. And at later stages, both the day time and night time temperatures are important. For upland rice, the optimum temperature for germination is 30^{o}C (Hall, 1966) while the lower limit is 20^{o}C (Downey and Wells, 1974) Dedatta (1970) attributed low average yield in the tropic's warm climate during early growth periods. Sreedharan (1975) reported that a minimum air temperature of 25^{o}C to 26^{o}C is ideal for shoot and root growth. The optimum temperatures for elongation and leaf emergence are 25^{o}C and 30^{o}C respectively (Robertson, 1975) Kang and Heu (1976) also observed that lower temperature during nursery period of rice resulted in higher plant height.

Yield reduction in rice due to low temperature was recorded in North India due to cold injury Due to cold weather, significant yield reduction (20 40%) was noticed on account of high spikelets sterility during the rabi season. The most comprehensive work on the effect of cold injury to rice crop has been done in Japan where low temperature is the main limiting factor in rice production. Nishiyama et al., (1969) showed that the critical low temperature for inducing sterility is 15^{o}C - 17^{o}C in highly cold tolerant varieties at meiotic stage of crop growth. Their studies suggested that the critical temperature for sterility is about 15^{o}C 20^{o}C. A significant negative correlation between yield and the minimum temperature 30 days after transplanting and significant correlation between yield and maximum temperature over the 45 days before maturity are reported by Datta and Zrate (1970)

During reproductive stage, within a temperature range of 22 to 31^{o}C, spikelets number per plant increases as the temperature crops (Yoshida,1973) He also suggested that the optimum temperature for rice shifts from high to low as the growth advances from vegetative to reproductive stages. The rice plant is very sensitive to low temperature about 9 days before flowering (Satake, 1976) and high temperature at flowering (Satake and Yoshida, 1978)

Variability of rainfall affects the rice crop generally at the reproductive stage. If the variability is associated with an untimely cessation at the reproductive or ripening stage, yield reduction is severe. Rainfall variability is more critical for upland rice than for low land rice. Venkateswarlu et al., (1976) reported high pannicle number in rabi (500) compared to kharif

(400) season, thus being responsible for high yields in the former.

Solar energy is the major governing factor for photosynthesis and hence dry matter production and yields are dependent on solar radiation to a considerable extent. The low light intensity upto flowering in kharif, imposes a ceiling on tillering and reduces dry matter production as compared to rabi season (Venkateswarlu,1977; Venkateswarlu et al., 1977)

Several workers pointed out the positive influence of solar radiation received during different critical growth stages on grain yield. Stansel (1966), and Murata and Togari (1973) reported it to be the three weeks before and after flowering. Ghildyal and Jan (1967), and De Datta and Zarate, (1970) reported it to be the one week before harvest and according to Matsushima (1970) it is fifteen days before and twenty five days after flowering. Evans (1972) reported that grain filling was very poor in the absence of light. Low light intensity during the reproductive phase has a pronounced effect on spikelet number and, hence, on yield.

Rice is generally a short day plant and sensitive to photo period. The observations of Venkataraman and Narasimhamurthy (1973) showed that the variation of only 30minutes in photo period can significantly affect crop development. The photo periods insensitive rice varieties enable the farmers in the tropics and subtropics to plant rice at any time of the year without great changes in duration.

Flowering of rice does not occur below 40% Relative humidity and is best at 70 to 80 % Relative humidity High humidity during post flowering stage appeared to have a detrimental effect on yield.

Estimation of rice yield before harvest is of immense help for planning purposes. On the basis of rainfall, IMD divided the country into 33 meteorological subdivisions and developed equations to forecast wheat and rice yields on a subdivisional basis. Regression models were developed by Das (1970) for the Bihar plains and by Das and Mehra (1971) for Kerala. Rao and Das (1971) made a comprehensive survey of weather and rice crop yield. Srinivasan and Banerjee (1973) applied Fisher's technique to find out effect of rainfall on rice crop at Karjat (Maharashtra) Adopting this technique at Adhutarai and Coimbatore (Tamil Nadu), Srinivasan and Banerjee (1978) found that additional rainfall above the normal, exerts negative influence during sowing, tillering and flowering stages of rice.

Appa Rao et al (1977) modified the equations developed for the Bihar Plains and Kerala. They found that pre-planting rainfall increase the yield but minimum temperature during flowering leads to yield reduction. Effects of weather variables on rice yield and its forecast at Raipur district, Madhya Pradesh was done by Jain et al (1980) and Agarwal et al(1983) Crop-weather relationships of rice at Ankapalle, Andhra Pradesh was investigated by Rupa Kumar et al (1984) Studies on water balance and rice production in Cannanore District of North Kerala was done by Prasada Rao and Nair (1984) The study showed that water surplus during the crop growth period results in heavy flooding and this leads to low crop productivity

High humidity and high temperature during the rainy season often favour pests and diseases outbreak, IRRI (1986) in three trials conducted at Pattambi reported that low yields are the results of heavy infestation of pest and disease which occur more dominantly in later part of the wet season. Joseph(1991) observed that weight of 100 grain was significantly higher for planting done on 20 July at Pattambi. Chowdhury and Gore (1991) applied Curvilinear technique to rice crop in Bhandara district (Maharashtra) and observed that combination of seasonal mean maximum temperature of 30.5° C, 81% relative humidity and rainfall of 1000mm during physiological growth phases, ie., between elongation and grain formation gives optimum rice yield. Effect of temperature on the duration of vegetative phase of rice varieties in low lands of Kasargode district, Kerala was investigated by Prasada Rao (1994) Studies on effect of weather on paddy yield by Curvilinear technique at Pattambi, Kerala were carried out by Samui and Chowdhury (1994) The study brought out clearly that maximum and minimum temperatures play an important role towards rice production at Pattambi.

5.3.5 Crop-weather model

(a) Experimental data used for study

Details of crop and weather data collected from the Regional Agricultural Research station Pattambi ($10^{o}48$'N, 76^{o} 12'E) of Kerala Agricultural University located 25m amsl is given below.

Parameters	Years of data
Crop	
Crop yield of Tall Indica	1961 - 1990
(Viruppu and Mundakkan)	
Meteorological (Weekly)	
Rainfall (RF)	1961 - 1990
Maximum temperature (TMAX)	-do-
Minimum temperature (TMIN)	-do-
Soil temperature 5cm. depth (STI)	-do-
Soil temperature 15cm. depth (STII)	-do-
Morning relative humidity (RHI)	-do-
Evening relative humidity (RHII)	-do-
Solar radiation hours (SRH)	-do-

The crop yield data of Tall Indica has been obtained from permanent manurial experiment (Cattle manure - 4485 kg/ha + Ammonium sulphate - 22.4 kg/ha. + P_2O_5 and K_2O each 22.4 kg/ha.) conducted in the lowland laterite soils of the research station.

(b) Methodology employed

The crop growth period from seedling stage to harvest is considered to be 22 weeks and 20 weeks in the case of Viruppu and Mundakkan crop respectively The entire growth period was divided into 6 stages (Table 5 7) which appear to be the most appropriate growth stage divisions for the paddy crop in Kerala.

Viruppu Crop	
crop stage	weeks
nursery	(20th-23rd week) (4 weeks)
tiller initiation	(24th -25th week) (2 weeks)
active tillering	(26th - 29th week) (4 weeks)
panicle initiation	(30th -32nd week) (3 weeks)
flowering stage	(33rd 35th week) (3 weeks)
flowering to harvest	(36th -41st week) (6 weeks)

Table 5.7 Growth stages in rice crop- Viruppu.

As in the case of the coconut crop in the case of the rice crop too, the methods of correlation and regression analysis are widely used to study crop weather relationships. Firstly the rainfall amount from 17th to 19 th week is correlated with the final crop yield and a regression model is developed to predict the final yield using the sowing rains. The average of the weather parameters and total rainfall in the six stages is computed. These parameters constitute the independent variables that are to be related with the dependent variable, yield. But as a matter of fact, all the weather parameters are inter-correlated. Principal Component Analysis (PCA) is usually employed to nullify the inter-correlation between the variables. In the first instance correlations were worked out between the rice yield and the eight meteorological parameters pertaining to each stage of the crop growth. All the variables were subjected to PCA. Only those components which have eigen values of 1.000

or greater were selected for further computation. The PC scores were computed for each stage. Based on the scores some components were selected as the independent variables in the multiple regression model. The crop yield is predicted at the end of each stage. Further the crop yield of each stage is included as one of the independent variable for the computation of yield of the following stage. Thus, the model for Stage II will include the yield value estimated at the end of Stage I. While that of Stage V will include estimated yield at the end of Stage IV. This physico-statistical approach to crop-weather modelling is similar to the model developed by Robertson (1974) This approach enables a better insight into the influence of the weather during the growing season on the production of rice and to develop a numerical model for assessing the influence of advancing weather conditions on the final yield. The aim of this model is to make it applicable for ultimate use in crop yield forecasting from meteorological parameters.

In the case of the Mundakkan crop,its period is taken to be the 39th week to the 6th week of the following year.The sowing rains considered to be from the 36th to the 38th week. The division of crop stages in the present study given in Table 5.8.

Mundakkan Crop crop stage	weeks	
nursery	(39th-42nd week)	(4 weeks)
tiller initiation	(43rd -44th week)	(2 weeks)
active tillering	(45th 48th week)	(4 weeks)
panicle initiation	(49th -51st week)	(3 weeks)
flowering to harvest	(52nd - 6th week)	(7 weeks)

Table 5.8 Growth stages in rice crop- Mundakan.

The methodology followed by Viruppu crop is repeated in the case of Mundakkan too.

5.3.6 Results

(a) Viruppu crop

(i) Results of correlation studies

The results of correlation analysis between viruppu crop yield and weather parameters in the different stages of crop development is given in Table 5.9 From the table, it is observed that in all the stages excepting the last (ripening phase), soil temperature shows significant negative correlation with the yield. During the nursery period of the crop, higher relative humidity favours a better yield. Even though, several workers pointed out the positive influence of solar radiation received during different growth stages on grain yield, in the present study, a negative correlation is exhibited during active tillering stage. In none of the stages rainfall exhibits any significant correlation with yield. This can be attributed to the fact that deficiency in moisture is rarely encountered by the crop, during viruppu season.

(ii) Development of crop-weather model - Viruppu

The rainfall amount during the two weeks preceding sowing is employed to predict the yield (YIELD 1) The linear regression equation developed to predict the yield for sowing rains is

YIELD1 = 2909.7 + (-0.48716 * SRF)

where SRF is the sowing rains

From Table 5.15 it is clear that only 0.2% of the variance of Viruppu crop yield can be attributed to sowing rains.

Coefficients

Variables	Stage I	Stage II	Stage III	Stage IV	Stage V
Rainfall (RF)	0.1078	0.0534	0.0832	-0.1838	-0.0586
Morning Relative Humidity(RHI)	0.3165*	0.2367	0.0748	0.1196	-0.0086
Evening Relative Humidity (RHII)	0.3244*	0.2399	-0.0001	-0.1642	-0.0537
Solar radiation hour (SRH)	-0.3138*	-0.2490	-0.3015*	0.0413	-0.0072
Soil temperature at 5cm (ST I)	-0.3914*	-0.3352*	-0.5606*	-0.3326*	-0.3153*
Soil temperature at 15cm (ST II)	-0.2867	-0.2709	-0.4530*	-0.2442	-0.1508
Maximum temp-erature(TMAX)	0.0074	0.1268	-0.2366	0.0932	-0.0580
Minimum temp-erature (TMIN)	-0.2482	-0.1278	0.0577	0.0889	0.1433

* Significant at 95% level

Table 5.9 Results of Correlation analysis between weather Parameters and yield - Viruppu Crop

Prediction after Ist stage

All the eight varables, rainfall (RF) maximum temperature (TMAX), minimum temperature (TMIN), soil temperature at 5cm (ST I) soil temperature at 15cm (ST II), morning relative humidity (RHI) evening relative humidity (RHII) and solar radiation hours (SRH) of the Ist stage are subjected to Principal Component Analysis and components exhibiting eigen values more than 1.00 are selected. Application of PCA reduces the number of variables from eight to five (Table 5.10) Employing the eigen vectors in table the five PC scores are calculated. The PC scores thus obtained and the predicted yield from the previous stage (YIELD I) form the input variables in the linear multiple regression equation.

The linear multiple regression model developed to predict the paddy yield of Viruppu season, 18 weeks before harvest (YIELD 2) is

$$\text{YIELD 2} = -3439.0 + (-118.04) * PC1 + (83.808)*PC2 + (-108.86) * PC3 + (-72.97) * PC4 + (-223.38) * PC5 + (2.1966) * \text{YIELD 1}$$

It is clear from Table 5.15, which presents the results, that 18% of the variance of Viruppu yield is explained by first stage weather parameters and YIELD 1.

Prediction after IInd stage

When all the eight variables of IInd stage are subjected to PCA, and components exhibiting eigen value more than 1.00 are selected, the number of variables is reduced to five (Table 5.11) Employing the eigen vectors in table the PC scores thus obtained and the predicted yield of previous stage (YIELD 2) form

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	3.383E+04	99.2	99.2
2	271.1	0.8	100.0
3	5.638	0.0	100.0
4	1.432	0.0	100.0
5	1.087	0.0	100.0
6	6.340E-01	0.0	100.0
7	3.466E-01	0.0	100.0
8	1.126E-01	0.0	100.0

VECTORS

FACTOR	1	2	3	4	5
TMAX	-0.0031	0.0672	0.3208	-0.3863	0.5017
TMIN	-0.0027	-0.1022	-0.0283	-0.3174	-0.0505
STI	-0.0056	-0.0762	0.1408	-0.3337	0.5981
STII	-0.0142	-0.5873	-0.6666	-0.1442	0.1033
RHI	0.0117	0.3877	-0.1396	-0.7205	-0.4725
RHII	0.0371	0.6402	-0.6192	0.1343	0.3925
SRH	-0.0088	-0.2694	-0.1704	-0.2843	0.0033
RF	0.9991	-0.0396	0.0153	-0.0050	-0.0028

Table 5.10 Eigen values and eigen vectors of Stage I weather parameters - Viruppu Crop.

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	2.558E+04	98.1	98.1
2	467.0	1.8	99.9
3	13.58	0.1	100.0
4	2.508	0.0	100.0
5	1.387	0.0	100.0
6	6.454E-01	0.0	100.0
7	2.554E-01	0.0	100.0
8	6.024E-02	0.0	100.0

VECTORS

FACTOR	1	2	3	4	5
TMAX	-0.0023	0.0543	0.1282	0.2798	0.1651
TMIN	-0.0034	-0.0512	-0.0338	0.3047	0.5542
STI	-0.0067	-0.0296	0.0518	0.4394	0.3543
STII	-0.0318	-0.4616	-0.2072	0.2644	0.2871
RHI	0.0111	0.1151	0.1357	-0.6961	0.6682
RHII	0.0619	0.5351	-0.8312	0.0405	0.0924
SRH	-0.0457	-0.6888	-0.4764	-0.2822	-0.0521
RF	0.9964	-0.0811	0.0222	0.0054	-0.0018

Table 5.11 Eigen values and eigen vectors of Stage II weather parameters - Viruppu Crop

the input variables for the multiple regression model at this stage.

The linear multiple regression model developed to predict the Viruppu yield 16weeks before harvest is

$$YIELD\ 3 = -617.21 + (-53.493) * PC1 + (58.223) * PC2 + (-387.1) * PC3 + (64.274) * PC4 + (6.1998) * PC5 + (1.2147) * YIELD\ 2$$

The R square value is 0.2163 ie. 21% of the variance of Viruppu crop yield (Table 5.15) can be explained by the eight weather parameters of IInd stage selected for analysis and the yield predicted after the previous stage.

Prediction after IIIrd stage

As a result of further application of PCA to all the eight weather parameters of the IIIrd stage, and selection of components which exhibit eigen value more than 1.00, the number of variables reduces to three in this case (Table 5.12) Employing the eigen vectors given in table the three PC scores and the yield obtained from the previous stage model (YIELD 3), form the independent variables in the linear regression model to predict the Viruppu crop yield 12 weeks before harvest (YIELD 4)

The regression model developed to predict YIELD 4 is

$$YIELD4 = -568.05 + (154.61) * PC1 + (133.58) * PC2 + (66.34) * PC3 + (1.1977) * YIELD\ 3$$

The R squared value obtained is now 0.2691, which shows that 26.9% of the variance of Viruppu crop yield 12 weeks before harvest can be explained by the eight weather parameters of IIIrd stage and the yield predicted after previous stage.

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	5.473E+04	100.0	100.0
2	5.431	0.0	100.0
3	1.406	0.0	100.0
4	8.981E-01	0.0	100.0
5	6.816E-01	0.0	100.0
6	3.030E-01	0.0	100.0
7	5.428E-02	0.0	100.0
8	3.520E-02	0.0	100.0

VECTORS

FACTOR	1	2	3
TMAX	-0.0019	0.1521	-0.1101
TMIN	-0.0002	0.1317	-0.3741
STI	-0.0011	0.1482	-0.2876
STII	-0.0025	0.1389	-0.4234
RHI	0.0013	-0.1288	-0.7145
RHII	0.0110	-0.9252	-0.1365
SRH	-0.0026	0.2136	-0.2384
RF	0.9999	0.0118	0.0002

Table 5.12 Eigen values and eigen vectors of Stage III weather parameters - Viruppu Crop

Prediction after IVth stage

Application of PCA once again to all the eight weather parameters of stage IV, reduces the number of variables to three (Table 5.13) Employing the eigen vectors given in the table the three PC scores are calculated. The three PC scores and the yield obtained from the previous stage model (YIELD 4), form the independant variables in the linear regression model to predict the Viruppu crop yield 9 weeks before harvest (YIELD 5)

The regression model which can predict YIELD 5 is

YIELD 5 = 170.72 + (-86.127) * PC1 + (41.279) * PC2 + (112.50) * PC3 + (0.9406) * YIELD 4

It is clear from Table 5.15 that, 32% of variance of Viruppu crop yield is explained by IVth stage weather parameters and predicted yield (YIELD 4) of previous stage

Prediction after Vth stage

Finally, the eight weather parameters of Stage V, selected for analysis are subjected to PCA, and .employing the criteria of eigen value greater than one, only four components are selected for further analysis. The eigen vectors shown in Table 5.14 are used to compute the four PC scores. The four PC scores thus obtained and the yield predicted after the previous stage (YIELD 5) form the independent variables of the prediction model of Viruppu crop yield 6 weeks before harvest (YIELD 6) The prediction model to predict YIELD 6 is

YIELD 6 = 43.784 + (-7.6113) * PC1 + (30.779) * PC2 + (38.163) * PC3 + (-17.519) * PC4 + (0.9854) * YIELD5

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	2.668E+04	99.9	99.9
2	13.24	0.0	100.0
3	1.154	0.0	100.0
4	9.257E-01	0.0	100.0
5	4.383E-01	0.0	100.0
6	3.601E-01	0.0	100.0
7	1.257E-01	0.0	100.0
8	5.974E-02	0.0	100.0

VECTORS

FACTOR	1	2	3
TMAX	-0.0030	0.0372	-0.0988
TMIN	-0.0021	0.0202	0.3376
STI	-0.0028	0.0441	-0.2095
STII	-0.0035	0.0662	-0.3470
RHI	0.0031	-0.1034	-0.3387
RHII	0.0164	-0.9798	-0.1069
SRH	-0.0062	0.1446	-0.7654
RF	0.9998	0.0178	-0.0033

Table 5.13 Eigen values and eigen vectors of Stage IV weather parameters - Viruppu Crop

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	1.048E+04	99.9	99.9
2	9.243	0.1	100.0
3	1.870	0.0	100.0
4	1.092	0.0	100.0
5	5.826E-01	0.0	100.0
6	5.246E-01	0.0	100.0
7	1.233E-01	0.0	100.0
8	8.859E-02	0.0	100.0

VECTORS

FACTOR	1	2	3	4
TMAX	-0.0034	0.1020	-0.0139	0.1443
TMIN	0.0004	0.0124	-0.1148	0.3024
STI	-0.0032	0.0462	-0.0948	0.6196
STII	-0.0057	0.1333	0.1279	0.6741
RHI	0.0086	-0.1199	0.9452	0.0664
RHII	0.0297	-0.9592	-0.1492	0.1611
SRH	-0.0095	0.1845	-0.2137	0.1381
RF	0.9994	0.0325	-0.0053	0.0022

Table 5.14 Eigen values and eigen vectors of Stage V weather parameters - Viruppu Crop

STAGE	PREDICTOR VARIABLES	COEFFICIENTS	R SQUARE	STANDARD DEVIATION
Sowing rains	Constant	2909.7	0.0020	528.7
	SRF	- 0.48716		
Stage I	Constant	-3439.0	0.1808	528.5
	PC1	- 118.04		
	PC2	83.808		
	PC3	- 108.86		
	PC4	- 72.97		
	PC5	- 223.38		
	Yield 1	2.1966		
Stage II	Constant	- 617.21	0.2163	516.9
	PC1	- 53.493		
	PC2	58.223		
	PC3	- 387.1		
	PC4	64.274		
	PC5	6.1998		
	Yield 2	1.2147		
Stage III	Constant	- 568.05	0.2691	478.8
	PC1	- 154.61		
	PC2	133.58		
	PC3	66.34		
	Yield 3	1.1977		
Stage IV	Constant	170.72	0.3199	461.9
	PC1	- 86.127		
	PC2	41.279		
	PC3	112.50		
	Yield 4	0.9406		
Stage V	Constant	43.784	0.3255	469.5
	PC1	- 7.6113		
	PC2	30.779		
	PC3	38.163		
	PC4	- 17.519		
	Yield 5	0.9854		

Table 5.15 Coefficients of Crop yield prediction model

(Viruppu crop)

$\sigma = 469.5$

Years	Observed	Estsimated	Deviation	Percentage deviation over actual
1961	3505.00	2741.77	- .22	-21.8
1962	3568.00	2805.09	- .21	-21.4
1963	3153.00	2849.18	- .10	- 9.6
1964	3477.00	2891.64	- .17	-16.8
1965	3950.00	2994.28	- .24	-24.2
1966	3314.00	2929.03	- .12	-11.6
1967	2543.00	2771.22	.09	9.0
1968	3193.00	2903.62	- .09	- 9.1
1969	3166.00	2903.62	- .08	- 8.3
1970	2611.00	2808.50	.08	7.6
1971	2848.00	2842.66	.00	- 0.2
1972	2814.00	3045.29	.08	8.2
1973	2868.00	3070.75	.07	7.1
1974	2814.00	2576.38	- .08	- 8.4
1975	3186.00	2676.61	- .16	-16.0
1976	2692.00	2863.56	.06	6.4
1977	3017.00	2961.37	- .02	- 1.8
1978	2854.00	2933.52	.03	2.8
1979	2083.00	2802.21	.35	34.5
1980	2097.00	2947.03	.41	40.5
1981	2461.00	2701.30	.10	9.8
1982	3220.00	2860.33	- .11	-11.2
1983	2173.00	2754.45	.27	26.8
1984	2802.00	3011.19	.07	7.5
1985	3134.00	3031.95	- .03	- 3.3
1986	3382.00	2901.49	- .14	-14.2
1987	2923.00	3040.68	.04	4.0
1988	1799.00	2695.02	.50	49.8
1989	1810.00	2844.39	.57	57.1
1990	2765.00	3064.01	.11	10.8

Table 5.16 Comparison between actual and estimated

Viruppu crop yield

The R square value obtained is 0.3255 ie. 32.55% of the variance of the Viruppu crop yield can be explained by the Vth stage weather parameters and predicted yield after the fifth stage (YIELD 5)

From Table 5.15 it is seen that with each advancing stage the predicted yield is improving: R^2 value is increasing and standard deviation reducing. However, observed and estimated viruppu crop yield were not in good agreement in a majority of the cases (Table 5.16) Out of 30 years of yield prediction, the percentage deviation in the yield was above 15% in 12 years. Moreover, the percentage deviation was found to be high in the later years of study period, which may be due to sensitivity of the crop to cultural practices, pests and diseases etc. However, the deviation of yield was within permissible limits of one standard deviation in most of the cases. Fig 5.2 gives the fit between the observed and estimated values of viruppu crop yield.

(b) Mundakkan crop

(i)Results of correlation studies

The results of correlation analysis between Mundakkan crop yield and weather parameters in the different stages of crop development is given in Table.5.17 From the table it is observed that both air temperature and soil temperature are important for rice. Soil temperature is influential during all the stages except panicle initiation, whereas air temperature (maximum and minimum temperature) is influential during active tillering phase of the crop period. During the nursery period of the crop, reduction in solar radiation hours and soil temperature favour a better yields. This may be attributed to the fact that lower

Coefficients

Variables	Stage I	Stage II	Stage III	Stage IV	Stage V
Rainfall (RF)	0.0471	0.0275	0.1062	-0.3353*	0.3817
Morning Relative Humidity(RHI)	0.0657	0.0669	0.1308	-0.1215	0.0055
Evening Relative Humidity (RHII)	0.3835*	0.2078	0.1804	-0.2893	0.0436
Solar radiation hour (SRH)	-0.3732*	0.0063	-0.1354	0.4866*	-0.0444
Soil temperature at 5cm(STI)	-0.4799*	-0.2976	-0.4785*	0.1944	-0.3817*
Soil temperature at 15cm (ST II)	-0.5345	-0.3449*	-0.5405*	0.0598	-0.3053
Maximum temperature (TMAX)	-0.2618	-0.0450	-0.3346	0.2046	-0.1826
Minimum temperature (TMIN)	-0.2206	-0.2322	0.4058*	-0.3085	-0.0742

* Significant at 95% level

Table 5.17 Results of Correlation analysis between weather parameters and yield - Mundakan Crop temperature during nursery period results in increased plant heights. The table ascertains the results of studies carried out on rainfall variability and yield. Significant correlation between rainfall and yield is seen only in the panicle initiation and flowering stages. When relation between solar radiation hours and crop yield were looked into it is seen that a high value of radiation hours during panicle initiation stage favours high yield.

(ii) Development of crop-weather model- Mundakan crop

Employing the rainfall amount during the two weeks preceding sowing the final yield (YIELD 1) is predicted. From

YIELD 1 = 3155.1 + 1.31 * SRF

From Table 5.22 it is clear that only 6.32% of the variance of Mundakan crop yield can be attributed to sowing rains.

Prediction after Ist stage

All the eight variables, rainfall (RF) maximum temperature (TMAX), minimum temperature (TMIN), soil temperature at 5cm (ST I) soil temperature at 15cm (ST II), morning relative humidity (RHI) evening relative humidity (RHII) and solar radiation hours (SRH) of the Ist stage are subjected to Principal Component Analysis and components exhibiting eigen value more than 1.00 are selected. Application of PCA reduces the number of variables from eight to two (Table 5.18) Employing the eigen vectors in table the two PC scores are calculated. The PC scores thus obtained and predicted yield of the previous stage YIELD 1, form the input

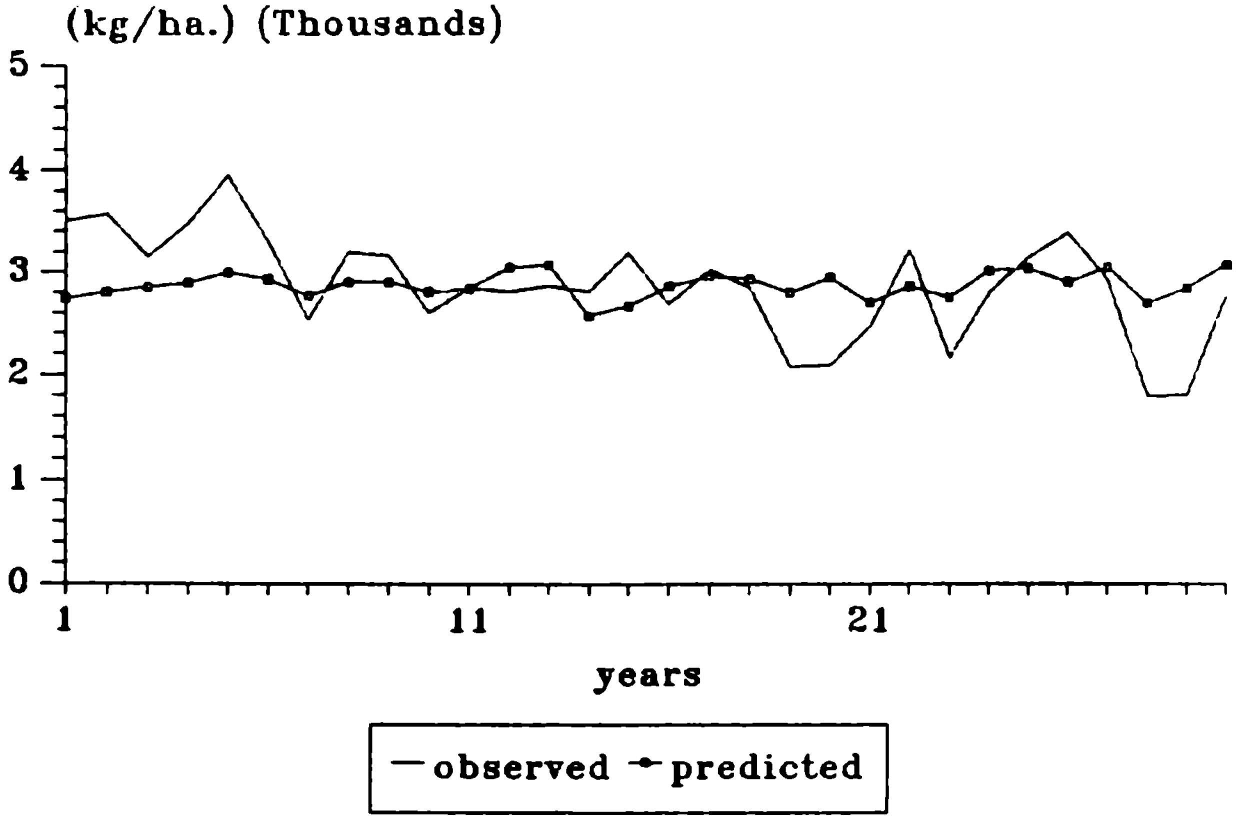

Fig 5.2 Observed and predicted Viruppu crop yield

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	3.931	49.1	49.1
2	1.538	19.2	68.4
3	0.955	11.9	80.3
4	6.162E-01	7.7	88.0
5	3.647E-01	4.6	92.6
6	3.364E-01	4.2	96.8
7	2.026E-01	2.5	99.3
8	5.610E-02	0.7	100.0

VECTORS

FACTOR	1	2
TMAX	-0.4293	0.2516
TMIN	-0.0204	0.6099
STI	-0.4493	0.0503
STII	-0.4551	0.0833
RHI	0.0437	-0.4492
RHII	0.4470	-0.1120
SRH	-0.3744	-0.3556
	0.2538	0.4631

Table 5.18 Eigen values and eigen vectors of Stage I weather parameters - Mundakan crop

variables in the linear multiple regression equation to predict yield of Mundakan crop 16 weeks before harvest.

The linear multiple regression model developed to predict the paddy yield of Mundakan season, 16 weeks before harvest (YIELD 2) is

$$\text{YIELD 2} = -2023.7 + (67.156)\text{PC1} + (-38.055)\ \text{PC2} + (0.2757)\ \text{YIELD 1}$$

It is clear from Table 5.22 which projects the results that, 23.1% of the variance of Mundakan yield is explained by first stage weather parameters and YIELD 1.

Prediction after IInd stage

When all the eight variables of IInd stage are subjected to PCA, and components exhibiting eigen value more than 1.00 are selected, the number of variables is reduced to five (Table 5.19) Employing the eigen vectors in table the PC scores thus obtained and the predicted yield of previous stage (YIELD 2) form the input variables for the multiple regression model at the IInd stage.

The linear multiple regression model developed to predict the Mundakan yield 14weeks before harvest is

$$\text{YIELD 3} = 864.48 + (28.445) * \text{PC1} + (45.597) * \text{PC2} + (0.89167)\ \text{YIELD2}$$

The R square value is 0.2597 ie. 25.97% of the variance of Mundakan crop yield can be explained by the eight weather parameters of IInd stage selected for analysis and the yield predicted at the end of Stage I

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	4.482	56.0	56.0
2	1.287	16.1	72.1
3	8.731E-01	10.9	83.0
4	5.124E-01	6.4	89.4
5	4.052E-01	5.1	94.5
6	2.610E-01	3.3	97.7
7	1.365E-01	1.7	99.5
8	4.360E-02	0.5	100.0

VECTORS

FACTOR	1	2
TMAX	-0.3898	-0.2167
TMIN	0.0440	-0.8249
STI	-0.3883	-0.2881
STII	-0.4200	0.0072
RHI	0.2402	0.2730
RHII	0.4471	-0.1674
SRH	-0.3742	0.1715
EVP	0.3483	-0.2398

Table 5.19 Eigen values and eigen vectors of Stage II weather parameters - Mundakan crop

Prediction after IIIrd stage

Once again ,the application of PCA to all the eight weather parameters of the IIIrd stage, and selection of components which exhibit eigen value more than 1.00 has been carried out. The number of variables reduces to two in this case (Table 5.20) Employing the eigen vectors given in the table, the two PC scores and the yield obtained from the previous stage model (YIELD 3), form the independent variables in the linear regression model to predict the Mundakan crop yield 10 weeks before harvest (YIELD 4)

The regression model developed to predict YIELD 4 is

YIELD 4 = -735.1 +(17.045) * PC1 +(17.653)*PC2 + (1.2487)*YIELD 3

The R squared value obtained in this case is 0.4114, which shows that 41.14% of the variance of Mundakan crop yield 10weeks before harvest can be explained by the eight weather parameters of IIIrd stage and the yield predicted at the end of IInd stage.

Prediction after IVth stage

Application of PCA once more to all the eight weather parameters of stage IV, reduces the number of variables to three (Table 5.21) Employing the eigen vectors given in the table the three PC scores are calculated. The three PC scores and the yield obtained from the previous stage model (YIELD 4), form the independant variables in the linear regression model to predict the Mundakan crop yield 7 weeks before harvest (YIELD 5)

The regression model to predict YIELD 5 is

YIELD 5 = 419.2 + (-4.8463) * PC1 + (8.3669) * PC2 + (17.529) * PC3 + (0.8862) * YIELD 4

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	4.423	55.3	55.3
2	1.308	16.4	71.6
3	0.989	12.4	84.0
4	4.977E-01	6.2	90.2
5	3.862E-01	4.8	95.0
6	2.091E-01	2.6	97.7
7	1.325E-01	1.7	99.3
8	5.484E-02	0.7	100.0

VECTORS

FACTOR	1	2
TMAX	-0.3965	-0.2594
TMIN	0.0004	-0.7629
STI	-0.3696	-0.2872
STII	-0.3749	-0.1301
RHI	0.3414	0.1169
RHII	0.4368	-0.1539
SRH	-0.3498	0.3800
RF	0.3687	-0.2636

Table 5.20 Eigen values and eigen vectors of Stage III weather parameters - Mundakan crop

	EIGENVALUES	PERCENT OF VARIANCE	CUMULATIVE PERCENT OF VARIANCE
1	3.980	49.8	49.8
2	1.655	20.7	70.4
3	1.013	12.7	83.1
4	4.408E-01	5.5	88.6
5	3.521E-01	4.4	93.0
6	3.293E-01	4.1	97.1
7	1.615E-01	2.0	99.2
8	6.767E-02	0.8	100.0

VECTORS

FACTOR	1	2	3
TMAX	-0.3062	-0.4680	0.1439
TMIN	0.1417	-0.4742	-0.6832
STI	-0.3966	-0.3873	-0.0597
STII	-0.4066	-0.2681	-0.0108
RHI	0.2841	-0.4002	0.5782
RHII	0.3863	-0.3978	0.2173
SRH	-0.3933	0.1010	0.3567
RF	0.4231	-0.0748	0.0116

Table 5.21 Eigen values and eigen vectors of Stage IV weather parameters - Mundakan crop

It is clear from the Table 5.22 that now 43.8% of variance of Mundakan crop yield is explained by IVth stage weather parameters and yield predicted (YIELD 4) at the end of Stage III.

From the Table 5.22 it is evident that with each advancing stage the R square value is improving. The observed and predicted yield was in good agreement in a majority of the cases (Table 5.23) unlike in the case of the viruppu crop. Out of 27 years of yield prediction, the percentage deviation in the yield was above 15% in only 8 of the cases. Moreover, the percentage deviation was found to be low in the later years of study period. The deviation of yield was within permissible limits as the deviations were always within one standard deviation in most of the cases.

The advantages of the physico- statistical model developed here over simple empirical statistical models is that the final crop yield can be predicted at any stage of the crop growth period employing the predicted yield at the end of the previous stage and the antecedent weather parameters. In the present model, the multi collinearity between the independent variables is eliminated and the dimensionality of the input variables is reduced. Fig. 5.3 gives the fit between the observed and estimated yields by the model.

These two case studies of the coconut and rice crops confirm that the crop yields are dependent to a large extent on weather parameters. The statistical model employed in the case of coconut and physico-statistical model employed in the case of rice can be applied for estimating yield with a fairly high

STAGE	PREDICTOR VARIABLES	COEFFICIENTS	R SQUARE	STANDARD DEVIATION
Sowing rains	Constant	3155.1	0.0632	568.1
	RF	1.31		
Stage I	Constant	2023.7	0.2310	536.6
	PC1	67.156		
	PC2	-38.055		
	Yield 1	0.2757		
Stage II	Constant	864.48	0.2597	526.5
	PC1	28.445		
	PC2	45.597		
	Yield 2	0.89167		
Stage III	Constant	- 735.10	0.4114	469.4
	PC1	17.045		
	PC2	17.653		
	Yield 3	1.2487		
Stage IV	Constant	419.22	0.4380	469.0
	PC1	- 4.8463		
	PC2	8.3669		
	PC3	17.529		
	Yield 4	0.88616		

Table 5.22 Coefficients of Crop yield prediction model

(Mundakan crop)

σ = 469

Years	Observed	Estsimated	Deviation	Percentage deviation over actual
1	2888.00	3067.86	.06	6.2
2	3790.00	3534.22	- .07	- 6.7
3	3066.00	3171.09	.03	3.4
4	5060.00	4511.87	- .11	-10.8
5	2232.00	2548.87	.14	14.2
6	3964.00	3651.91	- .08	- 7.9
7	3484.00	2687.17	- .23	-22.9
8	2624.00	3123.30	.19	19.0
9	2976.00	3082.07	.04	3.6
10	3044.00	3282.41	.08	7.8
11	2949.00	3583.18	.21	21.5
12	2706.00	2876.92	.06	6.3
13	3148.00	3164.23	.01	0.5
14	3030.00	3779.72	.25	24.7
15	3632.00	3946.57	.09	8.7
16	3869.00	3208.94	- .17	-17.1
17	3314.00	3133.65	- .05	- 5.4
18	3463.00	3612.51	.04	4.3
19	2530.00	3115.53	.23	23.1
20	3502.00	3027.01	- .14	-13.6
21	3206.00	3467.78	.08	8.2
22	3117.00	3292.71	.06	5.6
23	3981.00	3358.60	- .16	-15.6
24	3929.00	3651.97	- .07	- 7.1
25	3425.00	3578.05	.04	4.5
26	3804.00	3446.10	- .09	- 9.4
27	3295.00	3124.65	- .05	- 5.2

Table 5.23 Comparison between actual and estimated Mundakan crop yield - Mundakan crop yield

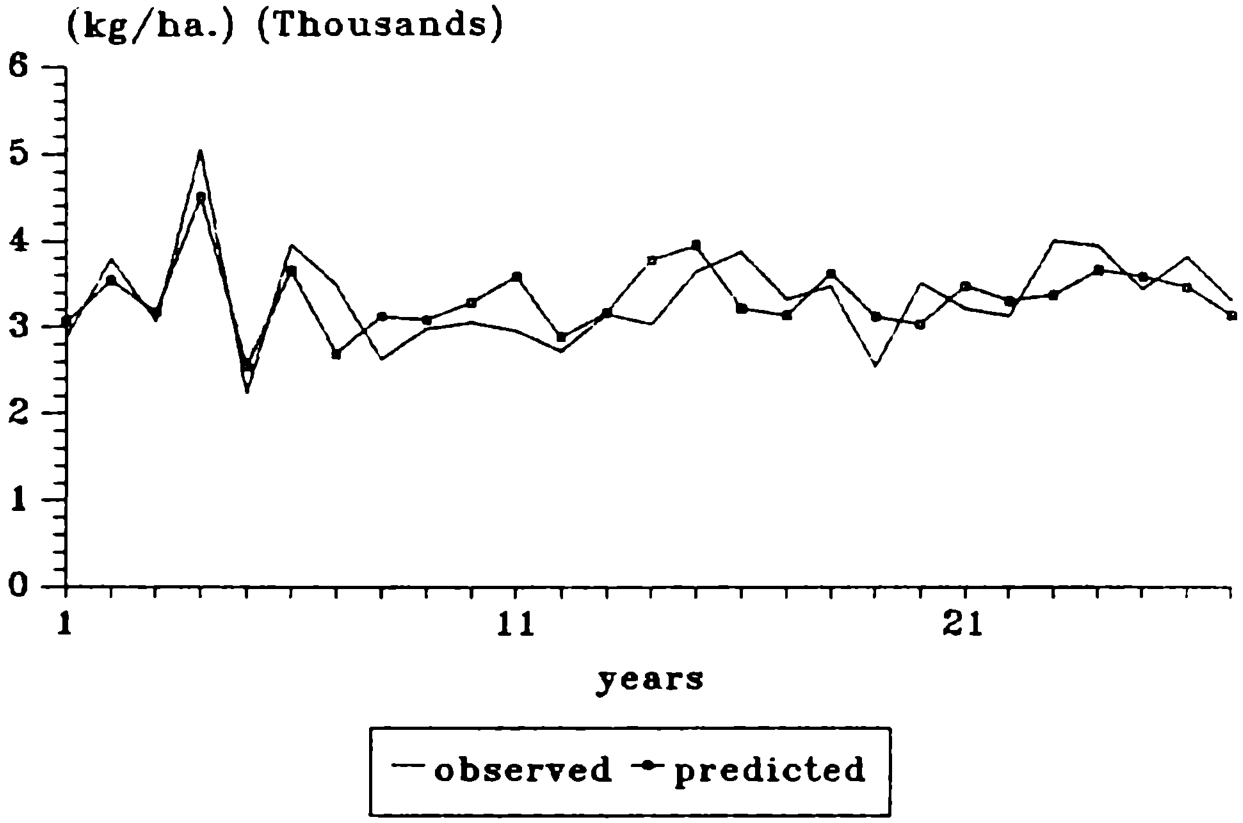

Fig 5.3 Observed and predicted Mundakan crop yield

degree of confidence. However, it should be noted that the equations developed are specific to the locations and to the concerned crops.These models can be applied at other sites and for other crops as well, if sufficiently long period data is available.