CHAPTER VI

SUMMARY AND CONCLUSIONS

Kerala State lies in the south-west corner of the Indian peninsula between 8^{O} 18' and 12^{O} 48' north latitudes and 74^{O} 52' and 77^{O} 22' east longitudes, as a long narrow strip of land, 32 to 133 km. wide between the Western Ghats in the east and the Arabian Sea in the west with a 580 km long coastal line. The most conspicuous feature of the State is the rich diversity in the various physico-climatic features which significantly influence the climate, vegetation and the land use of the region. Even though, the State is blessed with abundant water resources, short-term variabilities in the rainfall and other weather parameters result in variations in the availability of these resources.

Furthermore, such variabilities influence the yields of many crops in the State. Under these circumstances, a detailed analysis of the variability of climatic parameters and the impacts of such variabilities is essential for agricultural planning. Therefore, these aspects have been focused upon and analyzed in the present study The thesis consist of six Chapters with a general introduction as the first one. The first two Sections of the second Chapter reviews the literature available on the various aspects covered in the present investigation. The third Section presents the methodology followed in studying droughts, climatic shifts and crop-weather relationships.

The third Chapter consists of a discussion of the important physico-climatic features and the agricultural status of the State. The location, extent, physiography, soil types, vegetation and drainage pattern over the State are discussed in the first Section, while details about the different climatological parameters are discussed in the second. The agricultural status of the State is presented in detail in the third Section. Some of the important features discussed in the Chapter are presented now.

The undulating topography of the State falls generally into three well defined natural divisions- lowlands, midlands and highlands. The high lands stretched along the east, are intersected by numerous streams and rivers - the State has a well - distributed drainage network consisting of 44 rivers.

Kerala has a unique cropping pattern. Owing to historical and climatic reasons, the State has developed commercial agriculture more than food crops. Now-a-days rubber is the most flourishing crop of the State. Though rice is the staple food of the people of the State, the high cost of the cultivation and comparatively low return on rice now-a-days has forced the State to depend upon the Central Government and neighboring States for their food needs. For a State such as Kerala, whose welfare depends very much on agriculture, a qualitative knowledge of the productivity and area under each crop is essential to pursue agroclimatic studies of the State. Physico-climatic features and agricultural status of the State is discussed in the third Chapter of the thesis.

Taking into consideration the physiography, climate, soil characteristics, sea water intrusion, irrigation facilities, land use pattern and the recommendation of the committee on Agro Climatic Regions and Cropping Patterns constituted by the Government of Kerala in 1974, the State was divided into five Agroclimatic regions such as Northern, Central, Southern, High Ranges and Problem areas. The special zone of "Problem Areas" comprises of 5 areas viz. Onattukara, Kuttanad, Pokkali, Kole and sugar cane lands spread over the six districts of Kerala viz. Alleppey, Quilon, Kottayam, Ernakulam, Trichur and Malappuram. The first four areas, in the past, witnessed luxurious paddy cultivation and coconut plantation, now is in the verge of devastation due to salt water intrusion and root wilt disease.

Copious rainfall during monsoon, a well-spread drainage pattern and temperature ranging between 22^{o}C and 30^{o}C, has elevated the State to a land of luxurious vegetation. The suitability of land and climate for a number of crops tempted the farmers to cultivate a host of crops in the State, and resulted in an intensive cultivation of dry land in the State. The overall intensity of cropping in Kerala is fairly high. 57.89% of land in the State is contributed for agriculture purpose, followed by forest (27.83%) Only 7 79% of the land falls under non-agricultural category.

Paddy, coconut, arecanut, tapioca, pepper and rubber are the most important crops of the State. Unfortunately, the State is short of food grains, especially rice which is the staple food of the people. In this context, distribution and productivity of cereals and millets, pulses, sugar crops, spices and condiments, fruits and vegetables are grouped under food crops and oil seeds, drugs and narcotics, plantation crops, fodder grass etc. are grouped under non-food crops. 46.09% of the total cropped area of the State is under food crops and 51.75% under non-food crops. The districts Alleppey, Trichur, Palghat Cannanore and Kasargode contribute more than 50% of their total cropped area for food crops, while Kottayam, Pathanamthitta and Calicut contributed more than 60% of their cropped area for non-food crops.

Even though a wide variety of crops are cultivated in the State, rice, tapioca, coconut, pepper and rubber are considered as the principal crops. About 5.37 lakh ha. of the State is under paddy cultivation with a productivity of 2.02 kg/ha. While Palghat ranks first, considering the area under under the crop, productivity-wise Pathanamthitta is the first with 2.62 kg/ha. Coming to the area and productivity of tapioca in the State, 1.35 lakh ha. land is under tapioca cultivation with productivity 19.5 kg/ha. Eventhough, Trivandrum ranks first, considering the area under the crop, Kottayam, Idukki and Wynad contribute the most in the case of productivity (more than 25 kg/ha.)

India with 1.1 million hectares of land under coconut plantation accounts nearly for 1/8th of area under coconut in the world. 8.77 lakh ha. of land in the State is under coconut cultivation with a productivity of 5843 nuts/ha. The three districts Calicut,Trichur and Ernakulam having a long coast line rank high in the case of coconut productivity. About 1.8 lakh ha. of the State is under pepper cultivation. Looking into productivity of the crop, the districts Idukki,Quilon and Pathanamthitta contribute the most. Rubber is the one crop which has registered an increase in area of about 50.7%. More than 50% of the land in the districts Kottayam, Ernakulam and Pathanamthitta is under rubber plantation. About 25% of the State area is in Kottayam district itself.

Every year the fate of agriculture in the State oscillates with the vagaries of south west monsoon, pre-monsoon and post-monsoon rainfall. As drought is a consequence of aberration in the distribution of rainfall, a detailed knowledge of the distribution of rainfall and nature of variability is a pre-requisite for drought studies of a region. The next Chapter focuses on the variability of rainfall over the region and the consequent climatic shifts. It also projects the drought climatology of the State employing the water balance procedures outlined by Thorntwaite and Mather(1955) and the drought criteria enunciated by Ram Mohan (1984)

Results of previous studies pertaining to spatial and temporal distribution of annual as well as seasonal rainfall over the State is presented in the first Section of Chapter Four. The second Section deals with appraisal of agroclimatic droughts over the State. Analysis of occurrence of different categories of droughts at selected stations over the State during the study period reveals that, the number of drought years of various categories vary widely from station to station. Alleppey experienced the least number of droughts and Kasargode the most. Vythiri was free from disastrous droughts during the entire study period. Konni experienced the largest number of moderate droughts (13), followed by Sherthala and Cranganore (12) Kasargode experienced the most number of large droughts (12)

Trivandrum, Cochin and Trichur experienced 10 large droughts each. Alathur and Calicut experienced 10 severe droughts during the study period. The stations which experienced largest number of disastrous drought years (3) are Thiruvalla, Sherthala, Marayur, Cranganore, Kuttiyadi and Irikkur. From the study it is evident that the frequency of occurrence of severe and disastrous droughts is more in the sixth and seventh decade and in the first half of the eight decade. In the years 1982 and 1983, most of the stations studied, experienced either a severe or disastrous drought stations especially in south Kerala experienced disastrous droughts. Significantly, the year 1984 was in strong contrast to the previous year, with most of the stations being drought free.

Since drought is a large scale rather than a local phenomenon, there is a distinct possibility of its simultaneous incidence over neighbouring and adjoining areas. When probabilities of spatial coherence of moderate droughts were looked into, it was found that when Kasargode, Karikode and Thiruvalla experienced moderate drought, the probabilities of drought occurrence in the other areas of the State are comparatively high. When Kasargode is the key station, thirteen other stations show moderate coherence. In the case of Karikode, ten other stations and in the case of Alleppey twelve stations show moderate coherence. When Manantoddy, Calicut, Mannarghat, Kottayam, Konni and Quilon experience moderate droughts, the probabilities of drought occurrence in the other areas of the State are generally low. Out of the nineteen stations only four stations show high coherence in the occurrence of moderate drought, simultaneous with other stations.

Coming to spatial coherence of large droughts when Mannarghat, Trichur and Kayamkulam are considered as the key station, moderate coherence is observed at 14,12 and 12 stations respectively, while in the case of Kottayam, only Cranganore and Cochin show moderate coherence. Seven stations in the State show high coherence with Quilon. No station showed high coherence with occurrence of large droughts in Cochin, Karikode, Kayamkulam or Trivandrum.

When the probabilities of spatial coherence of severe droughts were considered, the following results were obtained. Trichur exhibited moderate spatial coherence with 14 stations, the highest for any key station. Kasargode and Cochin had moderate coherence with 12 other stations. Trivandrum and Sherthala experienced high spatial coherence with 10 other stations. In general, the spatial coherence of severe droughts is higher than the coherence of large and moderate droughts.

Disastrous droughts, though the least frequent, exhibit the highest spatial coherence among all the categories of droughts. From the study it is seen that when Kayamkulam was the key station 12 stations showed 100% spatial coherence of disastrous droughts. When Sherthala was the key station 18 auxiliary stations exhibited spatial coherence of disastrous drought.

Comparing the spatial coherence of all categories of droughts, it is seen that moderate droughts have the least coherence, though they are the most frequent.

In order to study climatic shifts, the inter-annual variations of moisture index (I_m) were plotted. Kasargode had a total number of 21 shifts into the other climatic types. Humid stations Kottayam, Calicut, Cochin and Alleppey had 47,43 and 41 shifts respectively. Trivandrum, the only moist subhumid station studied, had a total of 42 shifts.

In order to analyse the impacts of these climatic shifts on the moisture regimes of different stations in the State a critical examination of the elements of water balance in such years was carried out. As is to be expected during dry years at most locations, water deficits increased and water surpluses fell below normal, while in the case of wet years surpluses increased and deficits fell below normal. However, such simple relationships are not always true. In some years water surpluses increased along with increased water deficits. Such a behaviour of the moisture regime is because water surpluses and water deficits are determined by the temporal distribution of rainfall and not by its magnitude.

The fifth Chapter deals with the impact of climatic variability on agricultural yields. Since correlation studies between yields of all the crops in the State and the derived parameter of Index of Moisture Adequacy have been inconclusive, case studies were taken up for coconut and rice crops. Data from experiments conducted at Regional Agricultural Research Station (RARS), Pilicode, was used for studying the crop-weather relationships of coconut, while data from RARS, Pattambi was used for studying the rice crop. After establishing correlations of different parameters with the observed yields, Principal Component Analysis (PCA) was carried out to eliminate inter-correlation amongst them. Meteorological parameters were thus selected after PCA to form a multiple regression statistical model in the case of coconut. In the case of rice, a physico-statistical model was developed using similar methodology. The salient features of the study and the models are presented.

For the study of crop-weather relationships of coconut, the time interval for nut development from primordium of the inflorescence to harvest was divided into four different periods.

The results of correlations worked out between each month's coconut production and the weather parameters influencing the yield 44 months prior to the harvest is as follows. During the first stage, only rainfall, minimum temperature and relative humidity were significantly correlated- the first two negatively and the latter one positively. During the second stage, the weather parameters positively correlated were moisture deficit, maximum temperature and soil temperature while actual evaporation, Index of moisture adequacy and morning relative humidity were negatively correlated. In the third stage, the parameters positively correlated were actual evapotranspiration, Index of moisture adequacy and minimum temperature, while moisture deficit was negatively correlated.

The method of Principal Component Regression (PCR) was employed for the development of the crop-weather model to predict monthly coconut production using the weather parameters of each stage. Only the significantly correlated weather parameters were considered for this.

Application of Principal Component Analysis reduced the number of variables from three to one in the case of Stage I, ten to four in the case of Stage II and fourteen to six in the case of Stage III prediction. Model equations were developed to predict yields at the end of each stage.

The regression model to predict the monthly coconut production at the end of last stage, 11 months prior to harvest (PROD 3) is

$$PROD\ 3 = 13921 + (4608.6 * PC1) + (-5996.8 * PC3) + (-2347.1 * PC3) + (-6776.0 * PC4) + (14244 * PC5) + (-5930.8 * PC6)$$

The R squared obtained was 0.6314 with a standard deviation of 3792 nuts.

The observed and estimated monthly nut production was in good agreement in a majority of the cases. 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.

For the study of Crop-weather relationship of rice, the crop growth period from seedling stage to harvest was divided into 6 stages. The average of the weather parameters constitute the independent variables that are to be related with the dependent variable, yield.

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. In the case of the Viruppu crop, 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.

Employing the method of Principal Component Regression, the PC scores were computed for each stage. These PC scores form the independent variables in the multiple regression model. The crop yield was predicted at the end of each stage. Further, the crop yield of each stage was included as one of the independent variables for the computation of yield of the following stage. The physico-statistical approach to crop-weather modelling is similar to the model developed by Robertson (1974)

The multiple regression model for the prediction of Viruppu crop yield 6 weeks before harvest (YIELD 6) is

$$YIELD6 = 43.784 + (-7.6113) * PC1 + (30.779) * PC2 + (38.163) PC3 + (-17.519) * PC4 + (0.9854) * YIELD5$$

where PC1,PC2,PC3,PC4 are the PC scores of the fifth stage and YIELD5 is the yield predicted after Stage IV.

The R square value obtained was 0.3255 It was seen that with each advancing stage the predicted yield was improving. Out of 30 years of yield prediction, the percentage deviation in the yield was above 15% in 12 years. However, the deviation of yield was within permissible limits of one standard deviation in most of the cases.

According to correlation studies of Mundakan crop yield and weather parmameters during each stage, both air temperature and soil temperature are important. 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, solar radiation hours and soil temperature was negatively correlated with yield. Significant correlation between rainfall and yield is seen only in the panicle initiation and flowering stages. Multiple regression models were developed to predict yields at the end of each stage.

The model developed to predict Mundakan crop yield at the end of the last stage, 7 weeks before harvest (YIELD 5) is

$$YIELD5 = 419.2 + (-4.8463) * PC1 + (8.3669) * PC2 + (17.529) * PC3 + (0.8862) * YIELD4.$$

where PC1, PC2 and PC3 are the PC scores of the fourth stage.

The R square obtained was 0.438, ie. 43.8% of variance of Mundakan crop yield is explained by IVth stage weather parameters and yield predicted (YIELD4) at the end of Stage III.

With each advancing stage, the R square value improved. The observed and predicted yield were in good agreement in a majority 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.

The results of the study revealed that Kerala State is well endowed with more than sufficient natural resources-physiography, vegetation, soil types, and river systems. The State also experiences heavy rainfall and large water surpluses during the southwest monsoon months every year. The annual average rainfall is about three times the national average. However, water deficits also do occur in many locations in the drier months of the year. The average annual water surplus is about 6 times the deficit. However 80% of the water surplus occur in the monsoon months and during December to February there is hardly any surplus anywhere in the State. The coexistence of water surplus and water deficit at different times of the year in the same region is a significant aspect of the agroclimatology of the State. During many years when the southwest monsoon rainfall is above normal, there is a sharp increase in water surpluses.

By a judicious conservation and management of the surplus water, the effects of water deficit can be mitigated. The large quantities of surplus water that now freely flow into the Arabian sea can be harnessed to a large extent by the construction of dams and reservoirs at proper locations. Since construction of large projects entail heavy capital outlay and large gestation periods and can cause environmental degradation, it is advisable to plan mini hydel projects at suitable locations.

By proper management and optimum utilization of the available water resources-both surface and subsurface- it should be possible to convert large areas of cultivable waste land into productive agricultural land, as also lands presently under non-agricultural use into agricultural use. By this process, agricultural development can be accelerated by increasing the area of cropping and the intensity of cropping and therefore the net sown area These steps would also mitigate the hazardous impact of water deficit and drought by making available water for supplemental irrigation in the required quantities at required locations.

As has been well documented, climatic variability is an integral part of the climate of any area. The short term variabilities are generally larger than the long term changes. It is these fluctuations that cause droughts in some years and floods in others. Temporary climatic shifts are also a result of such inter-annual and inter-seasonal variations in weather parameters, particularly rainfall.

Inter-annual climatic variability has distinct effects on agricultural productivity and yields mainly due to variations in rainfall and hence available soil moisture. In the present study, the influence of various weather parameters over two important crops over the State has been studied through the development of appropriate models.

If such models have to be used on a real time basis for forecasting yields of any crop a proper data base of meteorological and agricultural parameters has to be established. A better network of agrometeorological observatories has to be designed so as to make such exercises possible in more areas. One of the draw backs of such models is that they are generally location specific, crop specific and some times even species specific. Yet another general problem encountered in such studies is that meteorological data are from specific sites where as agricultural data are from large areas.

In conclusion, it may be said that the development of the State is linked to the harnessing of the large water surpluses that occur during the southwest monsoon season. Optimum utilization of the available resources throughout the year for agricultural purposes would have to be planned for improving the agricultural productivity of the various food and non-food crops. Only then can the agricultural development of Kerala be ensured paving the way for the overall development of the State into "God's own Country"