CHAPTER EIGHT

RAINFALL AND RAINFED AGRICULTURE

8.1 INTRODUCTION

The importance of farming, rice farming in particular, to the economy of Sierra Leone was discussed in chapter one (sections 1.4 and 1.5). Also, in the previous five chapters a series of analyses were carried out to determine spatial and seasonal variations in a number of rainfall and soil moisture parameters, as well as variability in these parameters from year to year. The main objective of this chapter is to demonstrate the usefulness of the above analyses, especially its practical relevance to rainfed agriculture. To meet this objective, a key crop (upland rice) was chosen as a case study, and the analysis is limited to two agricultural research stations. Reasons for selecting this crop and stations are given below

Throughout the analyses and discussions in this chapter, emphasis is placed on the constraints imposed by the character of rainfall and soil moisture on various aspects and operations during the upland rice farming year. The rationale for selecting this crop were discussed in section 1.5 of chapter one. Two additional reasons for selecting this crop, apart from its economic importance are: (i) its exclusive reliance on rainfall for its moisture requirements for growth and development, which makes it extremely susceptible to the fluctuations in rainfall incidence and distribution during the growing season, and (ii) the high degree of sensitivity of most of the operations involved in its cultivation to rainfall.

Most of the analysis in this chapter is based on data at Rokupr (Northwest), the national, and regional (West African) Rice Research Station. The reasons for selecting this station for the case study include the availability of several years of agronomic and phenological data on rice, including planting and harvest dates, and over fifty years (1935-1987) of continuous daily rainfall records. This makes it possible to compare the results of the analysis to actual observations. Where appropriate, data from Njala (C. South), which is another long-established agricultural and climatological research station were also analysed to complement the results from Rokupr. Based on the results obtained at these two stations, the analysis in previous chapters which dealt with the whole country could then be applied.

The life cycle of the rice crop is usually divided into a number of sequential phenelogical stages including; the establishment or germination stage which occurs within the first ten days after sowing; the vegetative period which lasts for about sixty days for a 120-day variety; the reproductive stage which can be subdivided into (i) pre-heading period during which booting and flowering occur, processes that determine the potential size of the crop yield, and (ii) the post-heading or ripening period during which the ultimate yield based on the amount of starch that fills spiklettes is determined (Yoshida 1981).

The rice crop is highly sensitive to moisture deficiency. The degree of sensitivity, however, varies according to the stage of growth of the crop. In a study of water requirements by two upland rice varieties using drainage lysimeters in the humid to sub-humid zones of West Africa, Lawson and Alluri (1980) observed a maximum rate of water use of 5.11-6.14 mm/day between the 15th-16th weeks after planting. The period from about twenty days before heading to ten days after heading has been suggested as the most critical period for moisture stress in rice (De Datta, 1975). The main impact of water deficits at this stage is a high percentage of sterile or unfilled grains, which can result to a significant reduction in yields. However, in Brazil, Jones (1981) noted that in upland rice, moisture stress causing stomatal closure for periods of up to eight days at this stage has little effect on percentage of filled grains, although longer periods do affect yields.

Bearing in mind the various developmental stages of rice and their varying sensitivities to rainfall and soil moisture, and also the different operational stages involved in its production, an analysis has been carried out for four critical phases of the upland rice farming calendar as follows.

(i) The pre-season or land preparation phase.

(ii) The early season or sowing and germination period.

(iii) The mid-season or growth (vegetative) period.

(iv) The late season which includes the reproductive and ripening stages.

8.2 RAINFALL AND PRE-SEASON OPERATIONS

Based on a generalised farming calendar published by the Ministry of Agriculture (PEMSU 1983), and the various agro-hydrologic periods that were identified in chapter seven, figure 8.1 was constructed to demonstrate the relationship between seasonal regimes and the farming calendar at Rokpur. There is clearly an overlap between certain operational phases and the seasons, which helps to illustrate the potential risks and uncertainties involved in the timely accomplishment of some farm operations.

One aspect of upland rice cultivation that is closely related to the local rainfall regime is the traditional "slash-and-burn" method of preparing the land for cultivation which was mentioned in chapter one. The agroclimatological relationships of this system of farming are little known and written about, apart from the occasional references to the problem in anthropological studies (Schieffelin 1975), or in farming system research (Gourou 1966, Richards 1986). But as the following analysis and discussion also show, "slashing" or brushing (cutting down) the vegetation is a relatively less rain-sensitive operation than burning.

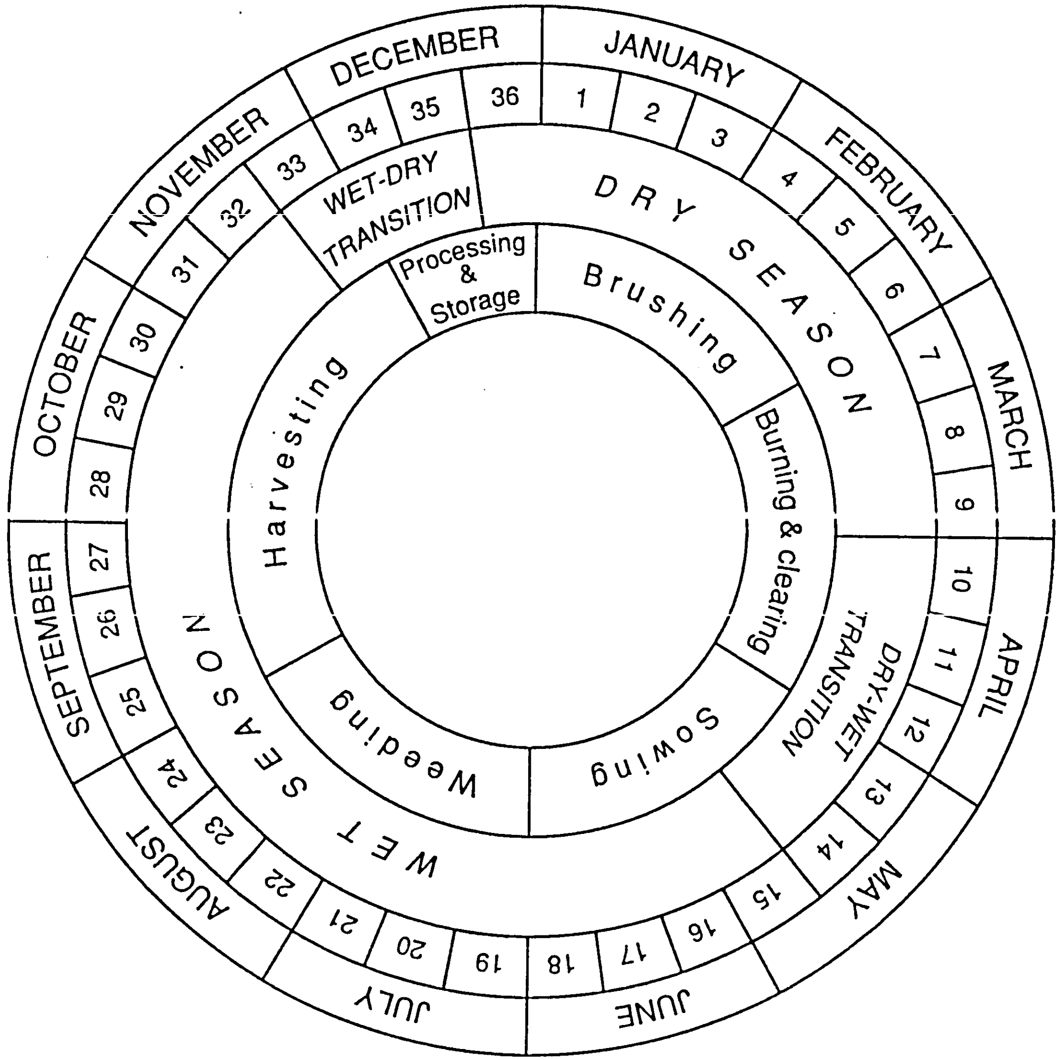

Figure 8.1 Seasonal regimes and the farming callender at Rokupr.

8.2.1 Rainfall and farm brushing operations

By the end of one farming year in November-December, the farmer would have had an idea of which plot of land to cultivate next season, a decision that is normally finalised in early January the following year. The choice of a suitable farm site is governed by several factors, including the availability and access to farmland, the age of the bush in terms of number of years since last farmed, soil type, dominant plant species, nearness to an old farm, and availability of labour (Richards 1986).

In many areas, brushing of farm sites commences between late January and early February. The process involves cutting down the vegetation at the chosen plot by matchet and axe, and leaving it to dry out before it is burnt several weeks later. Often however, it is customary for the farmer to wait until after the first heavy rainstorm in late January or early February before commencing brushing operations. This rain is aptly referred to as "bush-washing rain", because it washes down from the vegetation many flowers, ripe seeds, and other plant matter that irritate the skin during brushing (Gwynne-Jones et al 1978).

To determine the likelihood of getting this type of rainfall at Rokupr and Njala, a probability analysis was carried out on the daily rainfall records using subroutine "DRPROB" of Program "RAIN CRACKER". The method is based on the relative frequency of occurrence of rainfall. The number of times a given rainfall amount occurred for a particular day of the year was divided by the total number of days on record for that day.

An indication of the probability of getting various amounts of "bush-washing' rain at Rokupr and Njala during the months of January and February is given in figure 8.2 and 8.3. Generally, there is a less than 10% chance of getting any amount of such rain at Rokpur in any year. At Njala the probability is also less than 10% for January, but increases steadily towards the end of February.

Such a low probability of getting "bush-washing" rain has serious implications for the entire success of upland rice cultivation. Ideally, the earlier the brushing is completed, the better the chance that the felled vegetation will dry out properly to guarantee a good burn. Waiting for the first "bush-washing" rain that may not eventuate is a risky gamble, with some farmers often leaving the operation too late, and then being caught out by the return of the rains. The agronomic, and labour requirement implications of a bad "burn" due to insufficient drying of the vegetation are discussed in the next section.

There are several other, non-climatic factors that can delay farm brushing. These include poor health, shortage of labour, financial constraints, and other commitments by the farmer. Further discussion of the causes and effects of these factors is beyond the scope of this study.

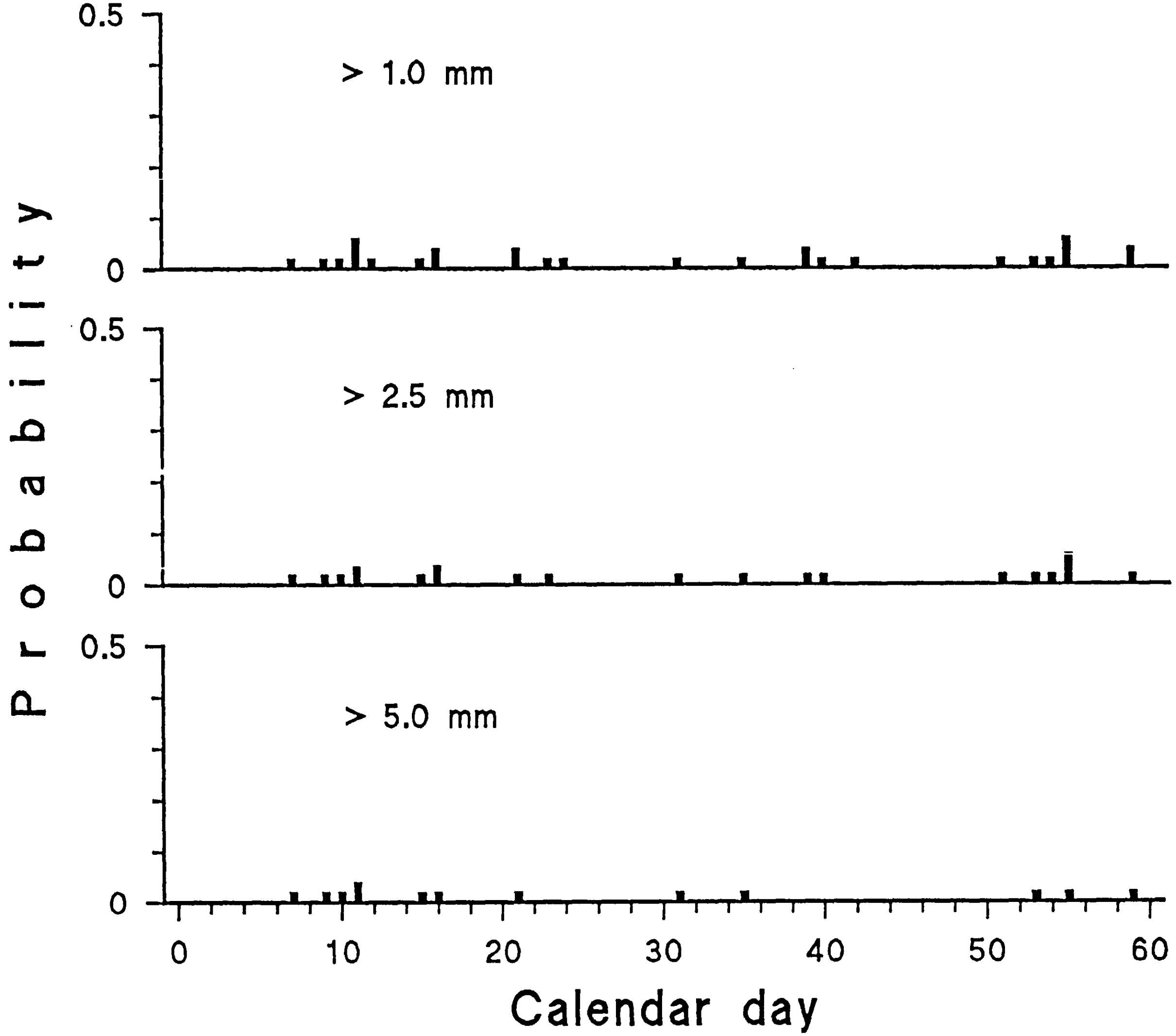

Figure 8.2 Probability of various amounts of "bush-washing" rain between January-February at Rokpur (1935-1987)

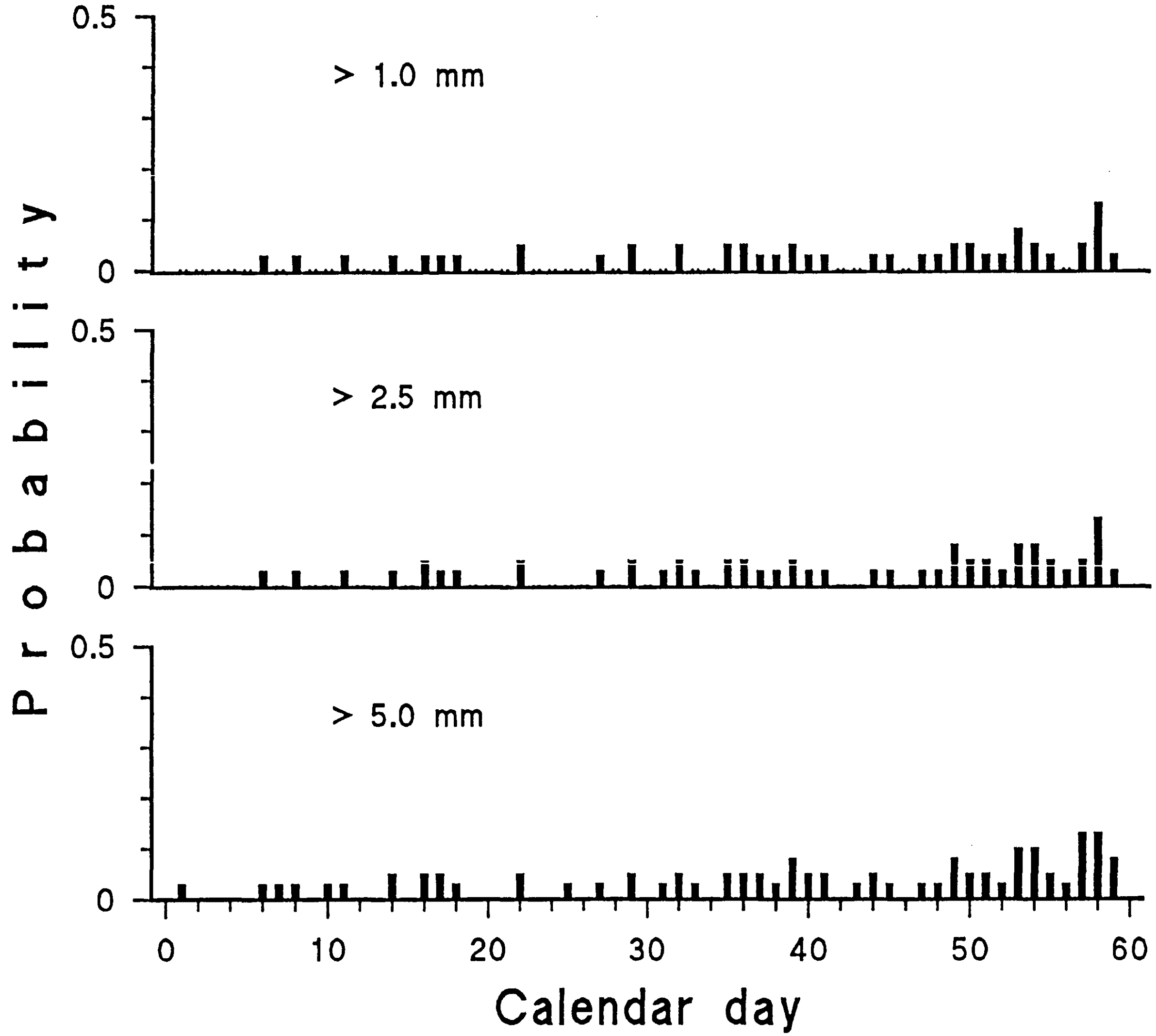

Figure 8.3 Probability of various amounts of "bush-washing" rain between January-February at Njala (1947-1989)

8.2.2 Rainfall and the burn

Burning of the farm plot takes place after the vegetation has sufficiently dried out, normally some 4-6 weeks after the last brushing operation. There are several advantages credited to burning. Apart from being the quickest and easiest way of clearing the land for cultivation with small hand implements, it is also a means of adding fertility to the soil in the form of ashes rich in potash and phosphates (Gourou 1966). Other benefits of the burn include the killing of weed seeds and harmful pests and bacteria by the heat generated by the fire.

On the other hand, burning also has some disadvantages, which include the destruction of useful bacteria in the soil, and exposure of the soil to wind and water erosion in the absence of protective cover.

Despite its disadvantages, burning is an integral, and indeed a critical part of upland rice farming in Sierra Leone. A bad burn creates many problems for the farmer. In the first place, this means the farmer and his/her family have to clear the unburnt vegetation using hand implements, and piling it up into burn fires. This is a slow and highly labour-demanding process that often leads to considerable delays in the accomplishment of subsequent operations, or even abandonment of part or all of the unburnt farm plot. A poorly burnt farm is also likely to suffer from greater weed infestation, and hence more competition and reduced fertility for the crop (Richards 1986).

Two groups of factors determine the success or failure of the burn, biotic factors such as the nature and species composition of the vegetation, and climatic factors such as the strength and direction of the prevailing wind, rainfall and moisture levels in the soil. The most important climatic problem is unseasonally early, heavy rainfall. According to Richards (1985, 1986), two or three heavy rainstorms in late February and early March can seriously affect the burn, especially if they occur at 10-14 days intervals. The main effect of rain is to dampen the felled vegetation, especially the combustible material at or near the ground (the "fuel" - Luke and McArthur 1978), thus preventing it from drying out properly. Rain also encourages the early germination of weed seeds within the unburnt farm, adding to the problem.

The impact of unseasonally early rainfall on upland rice farming in Sierra Leone is well documented in the Colonial Reports (1900-1960), and the Annual Reports of the Department of Agriculture. According to estimates by Scotland (1919), quoted by Richards (1985), this factor alone can reduce yields in upland rice farms by up to 20-30 percent in some years

Since the beginning of this century, there have been a number of years when early rainfall seriously disrupted farm burning, and hence rainfed cultivation, especially that of upland rice. Unfavourable conditions were reported throughout the country in 1936, 1955, and 1978. The year 1936 was reported as a particularly bad year, and described in the colonial records as one of the worst in living memory, when "bad burns due to early rains limited the area under cultivation, and the upland crop was short in many places". In 1955 "adverse climatic conditions for upland rice caused lower yields" (Sierra Leone Colonial Reports 1937, 1956).

In the central parts of the country, early rain in February and March disrupted bush burning in at least six years between 1912-1957. Agricultural records at Njala (C. South) show that the rice crop in the area was badly affected due to poor burns in 1918, 1923, 1932, 1936, 1939, and 1951. Richards (1986) suggests that similar disruptions occurred in 1959, 1963, and 1981.

In more recent times, poor burns due to unseasonally early rainfall in 1978 triggered a major food (rice) crisis in the second half of 1979. This food crisis prompted the institution by Government and the Ministry of Agriculture of a "Crash Rice Programme" whose goal was to "formulate a viable grassroots rice production programme that will render quick solutions to the current crisis" (Ministry of Agric. and Forestry 1979).

In chapter seven a Dry Season Intensity Index (DSI-Index) based on the total number of drydays per decade with "deficit" soil moisture and their respective maximum spells was used to determine the start and finish of the Dry Season at the eight representative stations. It was suggested that, once the index fell below a value of fifty, the Dry Season could be considered to have become too "humid", thus indicating the end of the season. Since a bad burn is partly attributed to both rainfall and soil moisture levels, this composite dryness index is seen as a potentially useful climatic parameter for determining the suitability of a given period for farm burning. The use of a composite dryness index which is based on both rainfall and soil moisture, and its various advantages were discussed in earlier chapters.

To demonstrate the use of the DSI-Index, two years with contrasting rainfall and soil moisture conditions during the peak period of farm burning were compared with each other, and also with the long-term average at both Rokupr and Njala. For Rokupr 1955, which was reported by the Department of Agriculture as a "bad" year for farm burning, was compared with 1957, a good year, and also with the average for 1935-88. Figure 8.4 shows Dry Season values of the DSI-Index at Rokupr for the three periods.

In 1955 the index showed a sharp decrease to values a little above fifty during the eight and ninth decades, and to ten during the tenth decade (early April), which is usually the peak period of farm burning. On the other occasions, the index remained well above fifty up to the twelfth decade (late April) for the average, and the fifteenth decade for 1957.

At Njala conditions in 1963, which was a "bad" year for farm burning, were compared to 1964, a "good" year, and the 1947-66 average. Again the DSI-Index was well below fifty during the peak period for farm burning (figure 8.5).

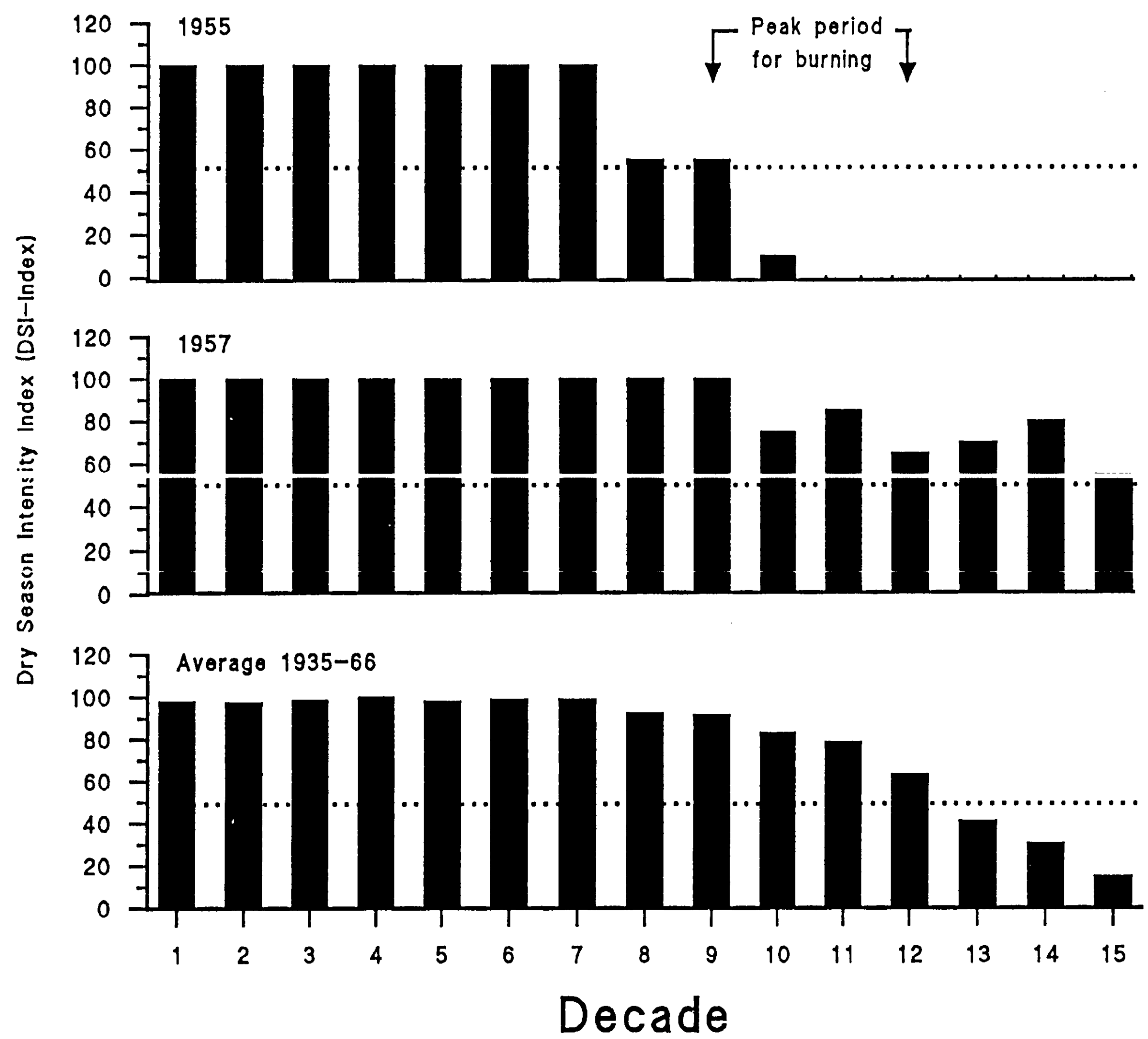

Figure 8.4 Dry Season Intensity Index for 1st–15th decades for 1955, 1957, and 1935–1988 average at Rokupr (Northwest)

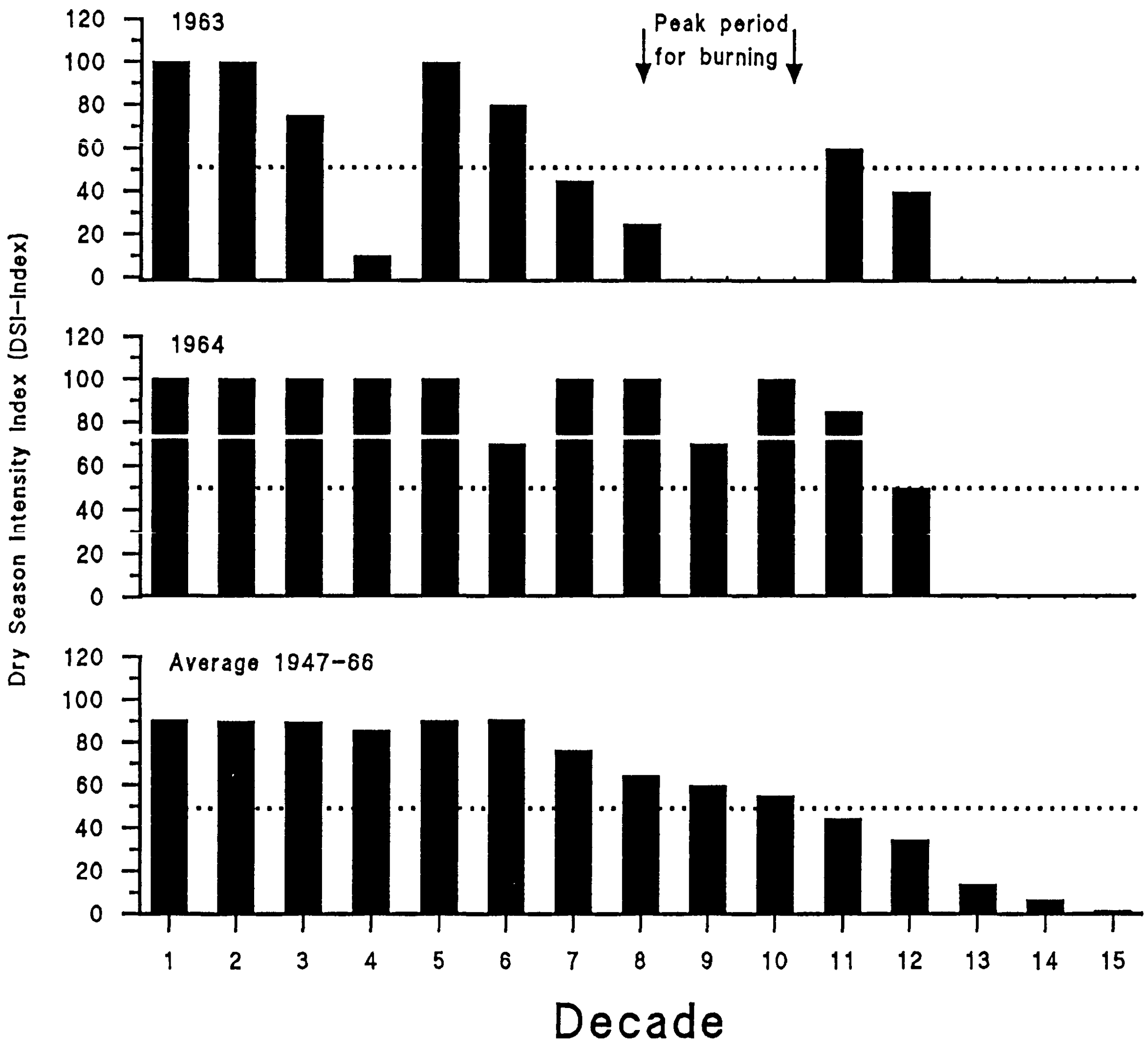

Figure 8.5 Dry Season Intensity Index for 1st-15th decades for 1963, 1964, and 1947-66 average at Njala (C. South)

Further indication of the relationship between the magnitude of the DSI-Index and the quality of the burn is presented in figure 8.6 using a 54-year data set at Rokupr. Only those years that were described in the Colonial Reports, and the Annual Reports of the Department of Agriculture as "good" or "bad" years for burning were indicated in the diagram. There is a general agreement between the reported "good" and "bad" years, and the magnitude of the DSI-Index during the peak period of farm burning. However, is was only during the 10th and 11th decades that the index was consistently below fifty during the "bad" years. This tends to suggest that the critical period for determining the quality of the burn at the station starts from the 10th decade (early April).

It is also worth noting that, given the localised nature of Dry Season rainfall, conditions are bound to vary considerably from one locality to another within relatively short distances. This means that a "bad" year in one area may well be a "good" one in another, and vice versa. This perhaps explains why some years, when the rainfall effects might have been localised, were not included in the national reports of bad years.

For planning purposes, it is often the likelihood of certain events occurring or not occurring that is of interest. Figure 8.7 illustrates inter-annual variability in the DSI-Index at Rokupr between the 1st-15th decades (January-May). The median value of the index exceeds sixty between the 9th-12th decades which is the peak

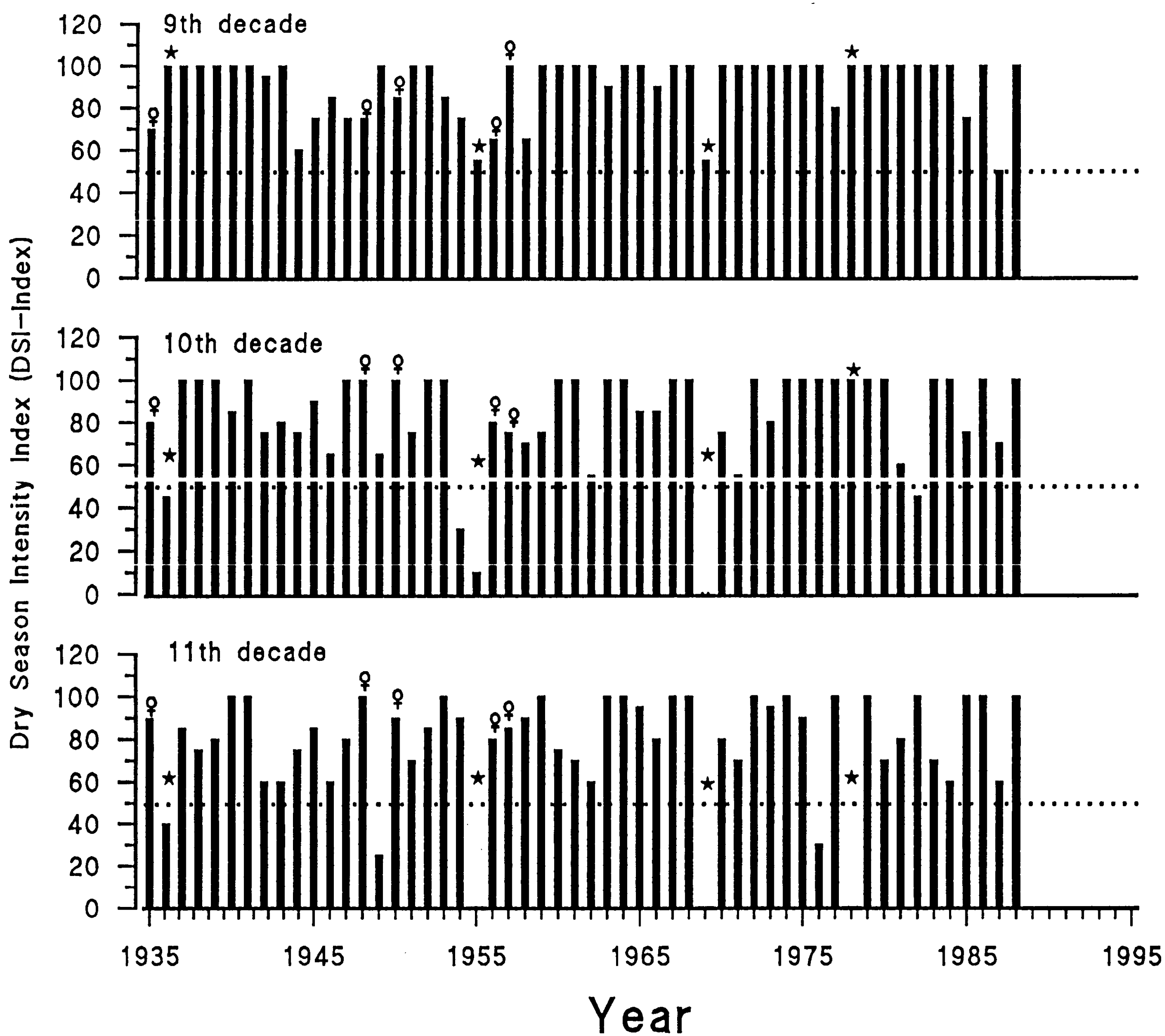

Figure 8.6 Annual variations in DSI-Index for three decades - Rokupr 1935-88
[★ = reported "bad", and ♀ = "good" years for farm burning]

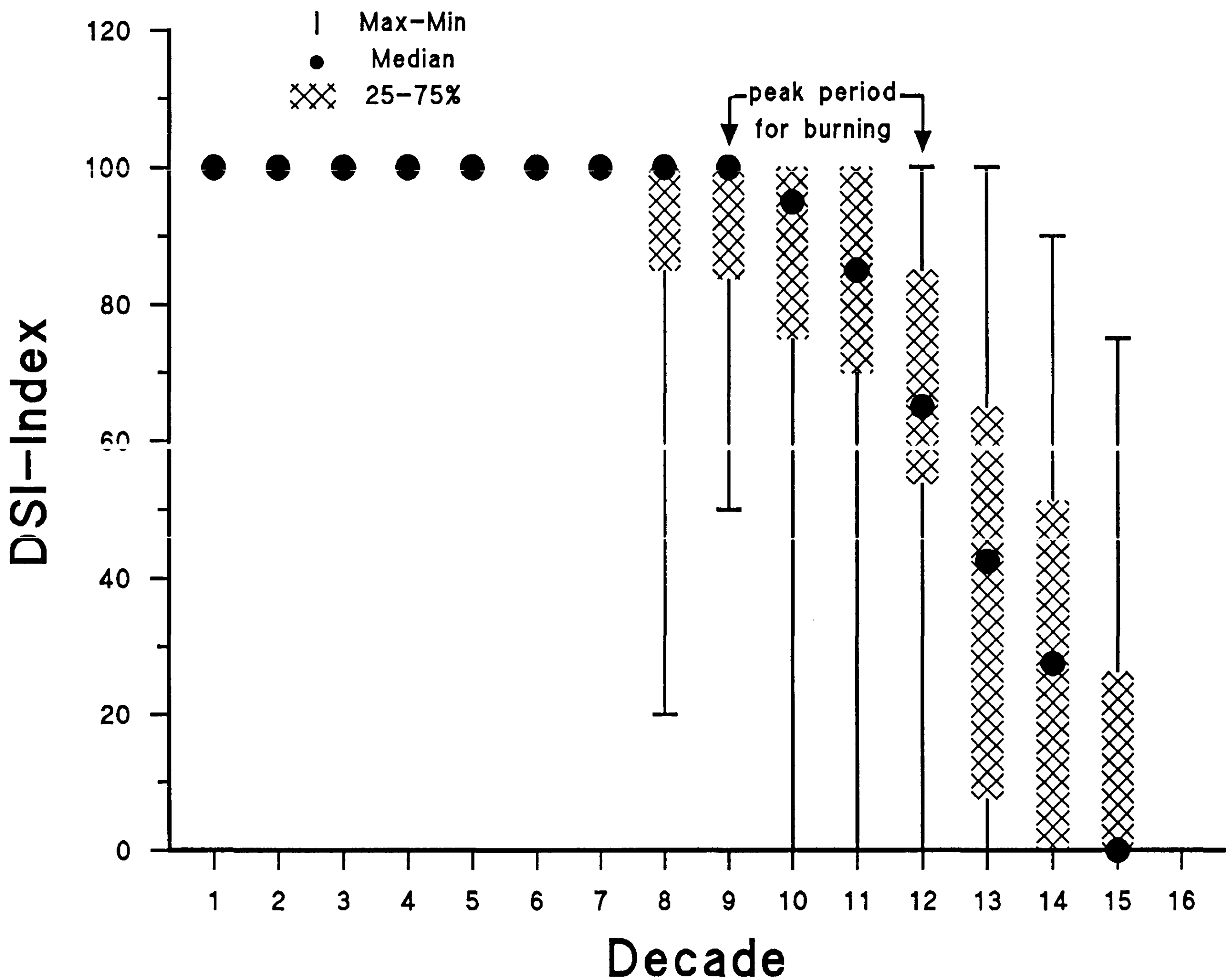

Figure 8.7 Variability of DSI-Index 1st-15th decades - Rokupr (1935-88)

period of farm burning. The chance of getting a DSI-Index of fifty or less from the 10th-12th decades is 9%, 11%, and 24%.

To avert the risk of a poor burn the farmer is sometimes tempted to effect the burn too early, often at the sign of the first distant flash of lightning in the evening. If this happens to be an isolated storm, with the bulk of the rains yet to come, there will be ample time for tree stumps to regenerate and blossom, and for weed seeds to germinate in the burnt farm plot, thereby creating more labour problems for the farmer during planting.

8.3 THE EARLY SEASON OPERATIONAL PHASE.

The planting period for upland rice in Sierra Leone starts from the end of the Dry/wet Transition (late May) and continues well into the middle of the Wet Season in July or August, depending on the variety and the type of soil. Early sowing is recommended practice because of its associated advantages, some of which were discussed in section 1.4 of chapter one.

Proper timing and scheduling of planting operations has many other advantages. Jackson (1989) presents a general review and discussion of the merits and problems of early planting for several crops other than rice. Early planting will allow the crop to complete its growth cycle within the season, and so avoid moisture stress at the critical stage of flowering and yield formation. Additionally, early planting will minimise competition for the limited supply of nutrients from weeds at the early growth stages of the crop. According to Igeleke (1988), within twenty days of the first rains, "explosive" biological activity is usually triggered in the soil profile, resulting in a sharp increase in soil nitrate content. This creates a biologically favourable environment for plant growth. Delayed planting after the biological activity is weakened can lead to poor crop establishment, and subsequently reduced yields.

The main requirement for successful sowing of upland rice is the ready availability of soil moisture for the germinating seed, provided this is not followed by a long dry spell. However, determining the start of such a period is not easy. Past experience gives guidance about probabilities of the full establishment of the Wet Season, but high rainfall variability increases the degree of uncertainty. This explains why traditional farmers often wait, sometimes past the optimum period, before sowing their crops.

Because of the advantages of early planting outlined above, and the need to avoid the risk of crop failure due to the variability in rainfall and soil moisture at the start of the season, a methodology for determining the earliest safe planting date and the end of the rainfed cropping period has been developed in this study. This procedure follows from the previous chapter where two indices, a Dry Season Intensity Index (DSI-Index), and a Wet Season Intensity Index (WSI-Index) were derived from a number of parameters that characterise the Dry and Wet

Season, respectively. It was also suggested that conditions which the DSI-Index represent are not suitable for rainfed cultivation, unlike the WSI-Index which represents favourable conditions.

In this analysis the two indices were used simultaneously to determine the start and end of the rainfed cropping period, defined as a continuous period during the year when the WSI-Index is equal to or greater than the DSI-Index.

Figure 8.8 shows the average start and finish dates of the rainfed cropping period at Rokupr for the period 1935-1988, based on the above method and definition. On average, the planting period starts on the 14th decade (late May), and ends on the 33rd (late November), with no mid-season breaks. The onset of the planting period occurs during the Dry-Wet Transition period, a decade before the mean start of the Wet Season, as defined in chapter seven.

When applied to individual yearly data, the definition produced "false" starts, and "premature" terminations to the cropping period in some years. To take into account these "false" starts, and "premature" terminations an extra constraint was introduced into the definition, as was done for the Dry and Wet Season definitions in chapter seven. The earliest safe planting date was defined as: beginning from decade number one (January), the first occasion when the WSI-Index equals or exceeds the DSI-Index, provided that two consecutive decades with a WSI-index less than the DSI-Index do not occur within the next three decades. Alternatively, the end of the rainfed cropping period was defined as the first occasion after the planting period has begun when the WSI-Index equals or falls below the DSI-Index, provided that two consecutive decades with a WSI-Index greater than the DSI-Index do not occur within the next three decades. However, this method is essentially a means of "detecting" the start of the planting period, and requires knowledge of rainfall conditions thirty days in advance. This tends to limit the usefulness of the technique to "predict" earlier planting dates and hence take advantage of a longer growing season.

Figure 8.9 shows annual variations in the start of the rainfed cropping period (earliest safe planting date) at Rokupr. The annual time series were "smoothed" by the same procedure used in previous chapters. The earliest start to the cropping period occurred on the 10th decade (early April) in 1955, and the latest on the 17th (mid-June) which occurred five times between 1935-1988 - i.e. in 1941, 1944, 1947, 1957, and 1985. Most of the years between the late 1930's and the early 1950's had a start date beyond the 15th decade (late May). Following a period of several years with an early start (before the 14th decade) in the 1950's, there was a trend towards a late start that continued to 1988.

The graph (figure 8.9) also gives an indication of the frequency with which a given start date can be expected at the station. The median start date of the planting period is mid-May (14th decade), with a 25%

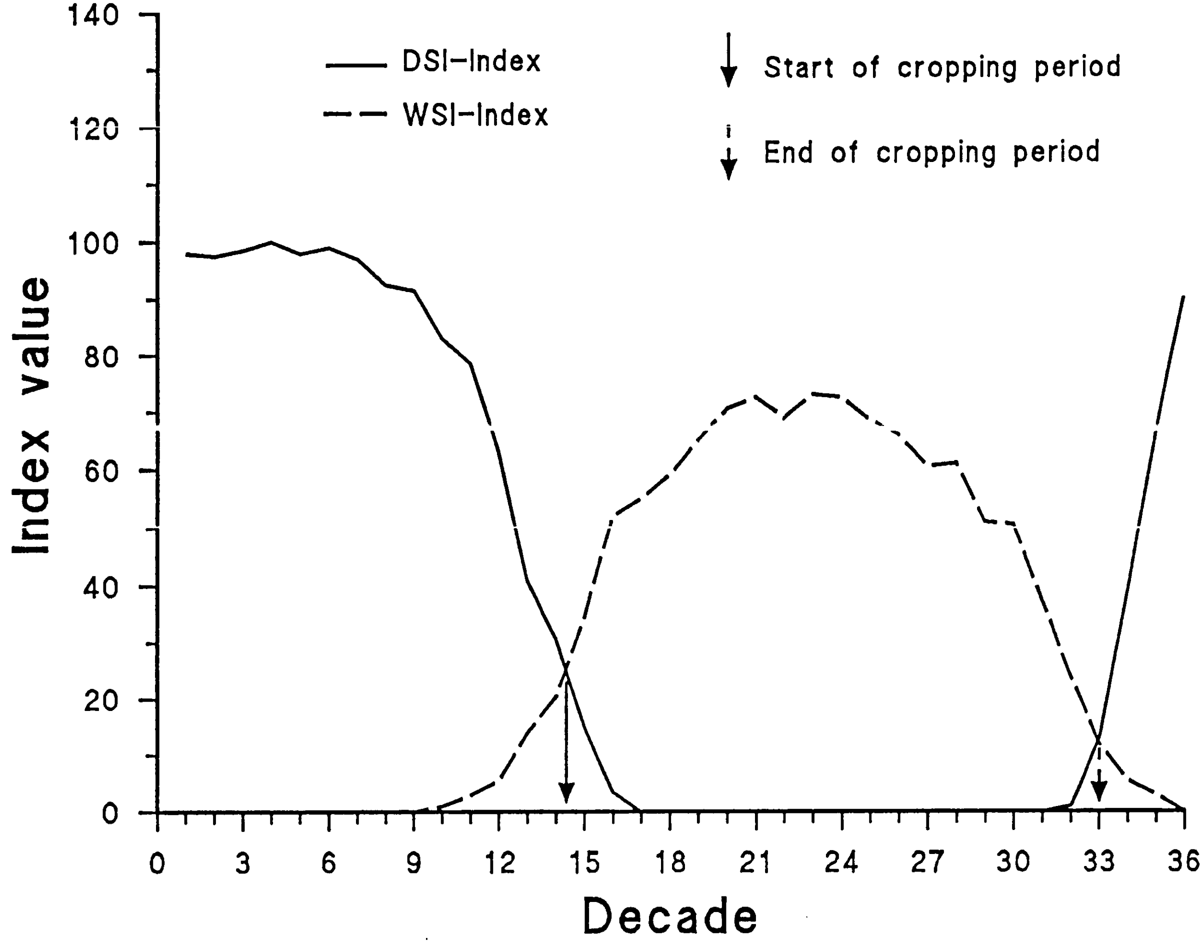

Figure 8.8 Identification of start and end of rainfed cropping period based on two moisture indices – Rokupr (1935–88)

chance that it will occur a decade before or after that date.

To assess the usefulness of this approach, planting dates derived from the analysis were compared to actual planting dates for ROK3, a medium-duration (130-150 days) upland rice variety that is widely cultivated in Sierra Leone (figure 8.10). Between 1973 and 1988, only on one occasion (1985) did planting occur two decades earlier than the derived start date. This was a rather curious observation for two reasons. It was the earliest planting date during the sixteen year period (1973-1988). Also, the WSI-Index (all zero values) was consistently less than the DSI-Index during the preceding three decades, meaning that there was no evidence of a "false" start to the planting period that could have prompted the move to plant early.

In three years (18% of the cases) the actual planting dates coincided with the derived dates, while in five years (30%) planting occurred a decade after the derived date. However, since decades are ten days long such disagreement can be expected. In 1978, which incidentally was also the earliest derived start date, planting occurred four decades after the derived date. That year the dry season ended abruptly after the 10th decade.

8.4 MID-SEASON CONDITIONS

The impact of both soil moisture deficit and surplus on crops was discussed in chapters one (section 1.6), and

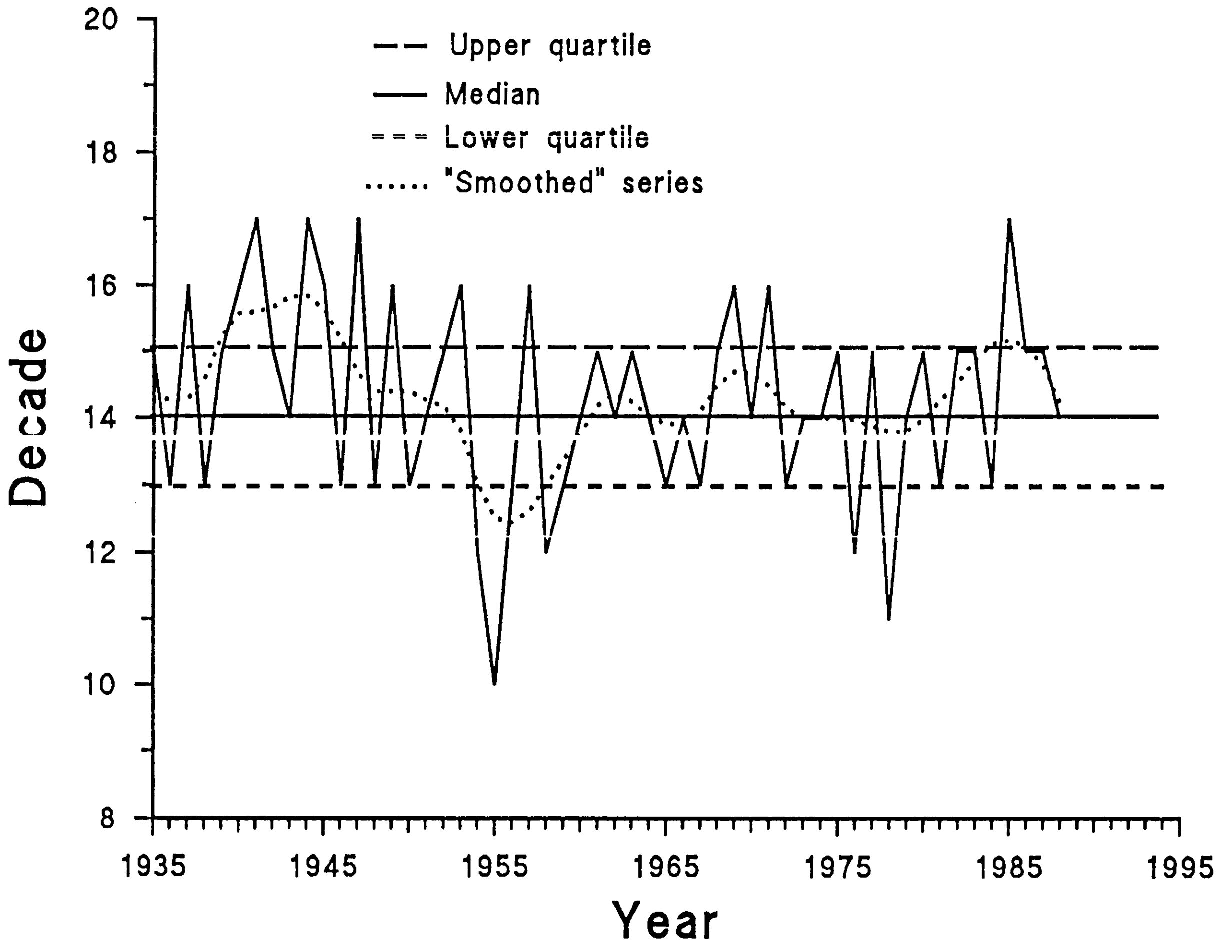

Figure 8.9 Annual variations in start of rainfed cropping period at Rokupr 1935–88

six (section 6.1). From the discussion in chapter six of the decadal distribution of drydays and raindays and their inter-annual variability, it is apparent that moisture deficit due to lack of rainfall during the middle of the Wet Season is not a serious agroclimatic constraint in Sierra Leone. Rather it is the frequent occurrence of rainfall, and excess moisture that poses problems for a large part of the season (LRSP 1980).

Frequent heavy rainfall during the growing period affects certain farm operations like weeding and fertilizer application. Based on the seasonal distribution of the various raindays discussed in section 7.4 of chapter seven, and sections 6.3.4 - 6.3.8 of chapter six, the risks of rain hampering these, and other rain-sensitive operations is considerable in all regions.

Excess water during the growing period causes three major problems. As surface runoff, it can cause severe soil erosion, especially on steep slopes and unprotected soils, as well as causing physical damage to plants. However, other factors such as soil type and moisture content, cropping system, and methods of soil and water control are also important in determining the magnitude of the problem. If excess water drains into the soil profile, it can leach away many vital plant nutrients. In low-resource, subsistence agriculture where there is very little, or no use of artificial fertilizers, loss of natural nutrients due to excess water in the soil can have a major impact on yields. Additionally, in poorly drained soils, especially those in low-lying areas,

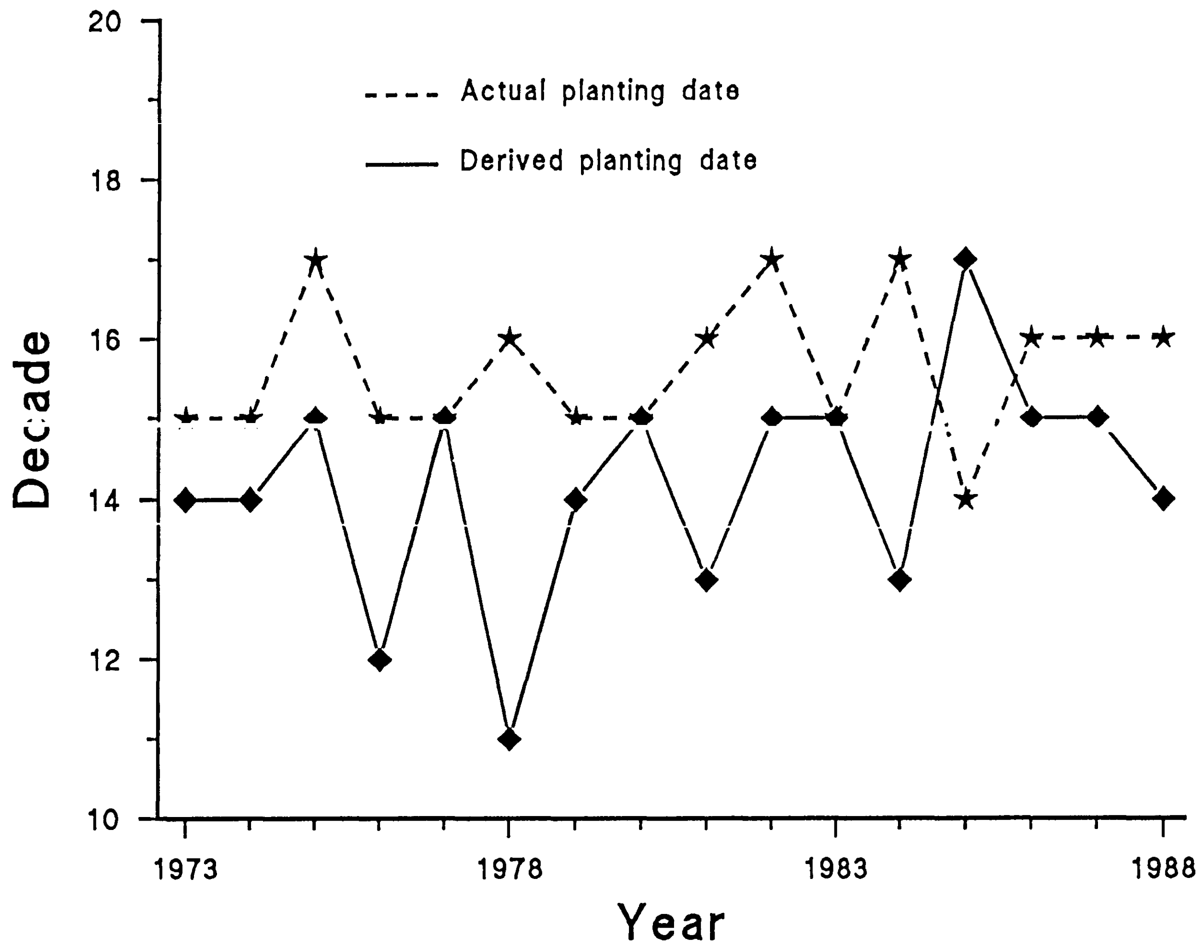

Figure 8.10 Comparison of actual and derived planting dates for rainfed rice (ROK3) at Rokupr Rice Research Station (1973–88)

rainwater can stagnate, leading to waterlogged conditions that inhibit plant growth due to poor aeration (Nieuwolt 1982).

By the definition of raindays in chapter four, Type IV Raindays (RD4) are those that describe conditions of excess soil moisture. The total numbers of these days and their maximum spells per decade were discussed in section 6.3.7 of chapter six. It was suggested in that discussion that most areas can expect to receive at least five days per decade with excess moisture between the 15th-30th decades (June and October) every year. At Rokupr, six out of every ten days between the 19th-24th decades (July and August) have excess moisture.

As a further indication of the risk of excess moisture at the station, the total number of RD4 days per growing period, and their maximum spell lengths were computed and the results were presented in figures 8.12-8.13. Figure 8.12 shows a median of ninety days (45% of the total days) with "surplus" moisture during the growing period. There is a 25% chance of getting more than ninety-seven days, or less than eighty-three. The 1960's had a relatively high frequency of occurrence of RD4 days, as was the period between the late 1970's and early 1980's. The least number of these days occurred during the late 1940's and early 1970's.

Raindays with "surplus" soil moisture at Rokupr tend to occur in spells lasting from six days to twenty-three days (figure 8.13), with a median number of eleven days. The trend line shows distinctive peaks in the late 1940's and the early 1960's, and troughs between the late 1930's and early 1940's, the 1950's, late 1960's, and mid-1980's.

8.5 LATE SEASON CONDITIONS

The general impact of water deficits at different stages of growth of rice were discussed in section 8.1. It was suggested that the reproductive stage was the most sensitive to water deficit, having the greatest impact on yields, especially for upland rice (Jones 1981, and Lawson 1980). Often the moisture deficit is caused by an early termination of the growing period, before the rice crop reaches maturity. The net effects of drought stress at this stage is a high percentage of sterile and unfilled grains (Yoshida 1981).

To assess the risk of early termination, decades when the growing period ended at Rokupr, based on the definition suggested in section 8.4, were determined for each year between 1935-88. As figure 8.11 shows, the earliest termination date was the 32nd decade (late November), which occurred in five years, while the latest was the 36th (late December) which occurred in five years. The median termination date is the 34th decade (early December). Early termination, relative to the median date, occurred most frequently between the late 1940's and early 1950's, the early 1960's and mid-1970's. Late termination to the season, on the other hand, occurred most frequently in the late 1950's, and between the late 1960's and early 1970's.

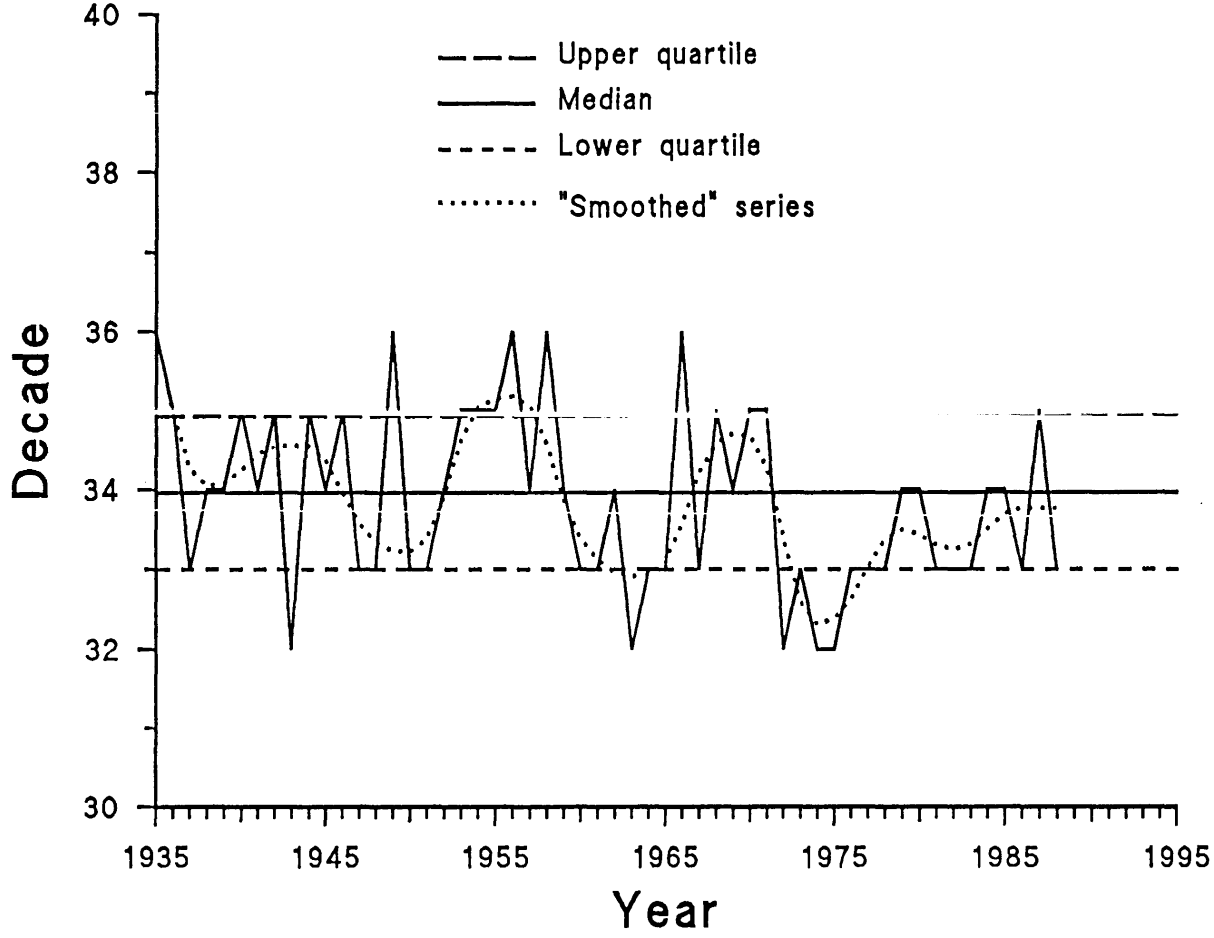

Figure 8.11 Annual variations in end of rainfed cropping period at Rokupr 1935–88

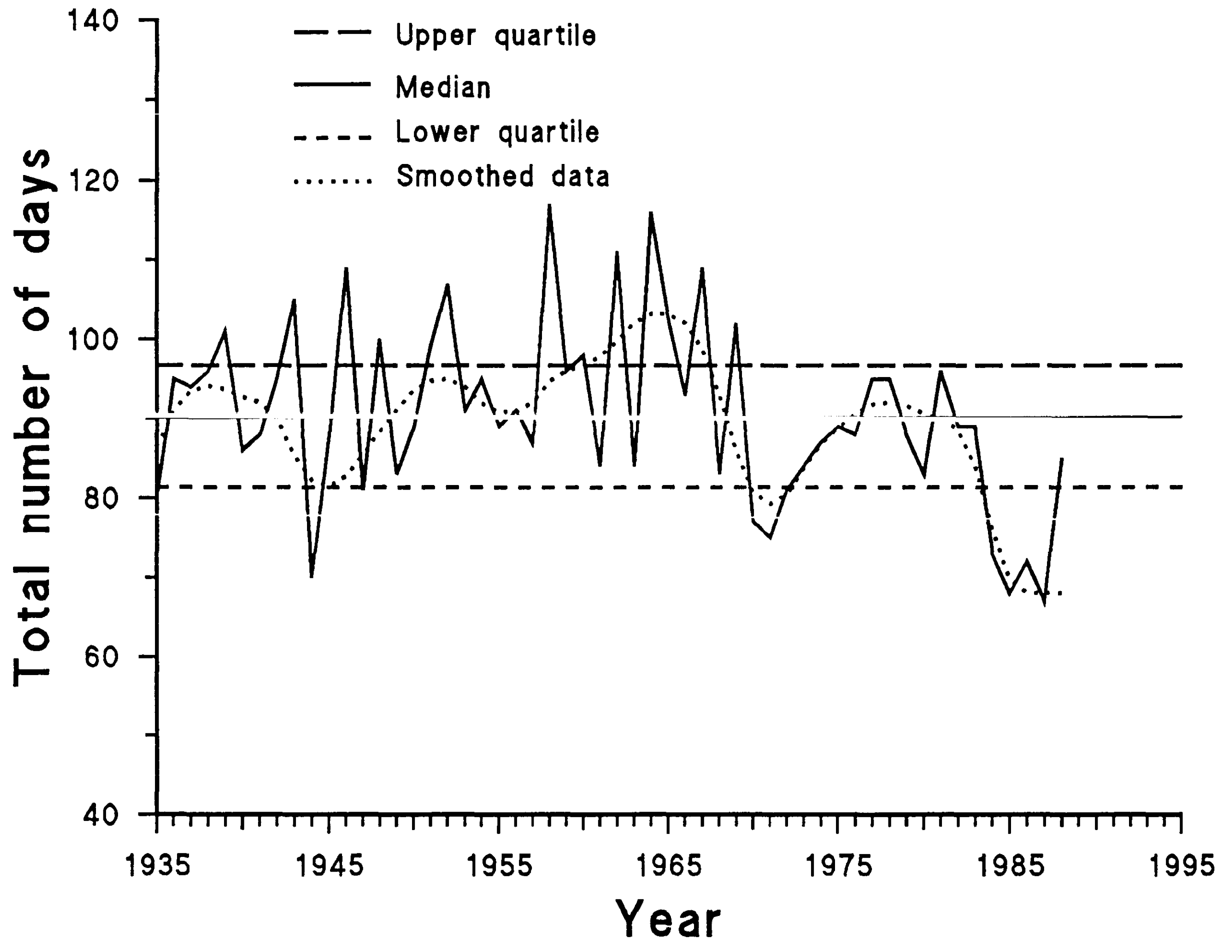

Figure 8.12 Annual variations in raindays with "surplus" moisture (RD4) at Rokupr (1935–88).

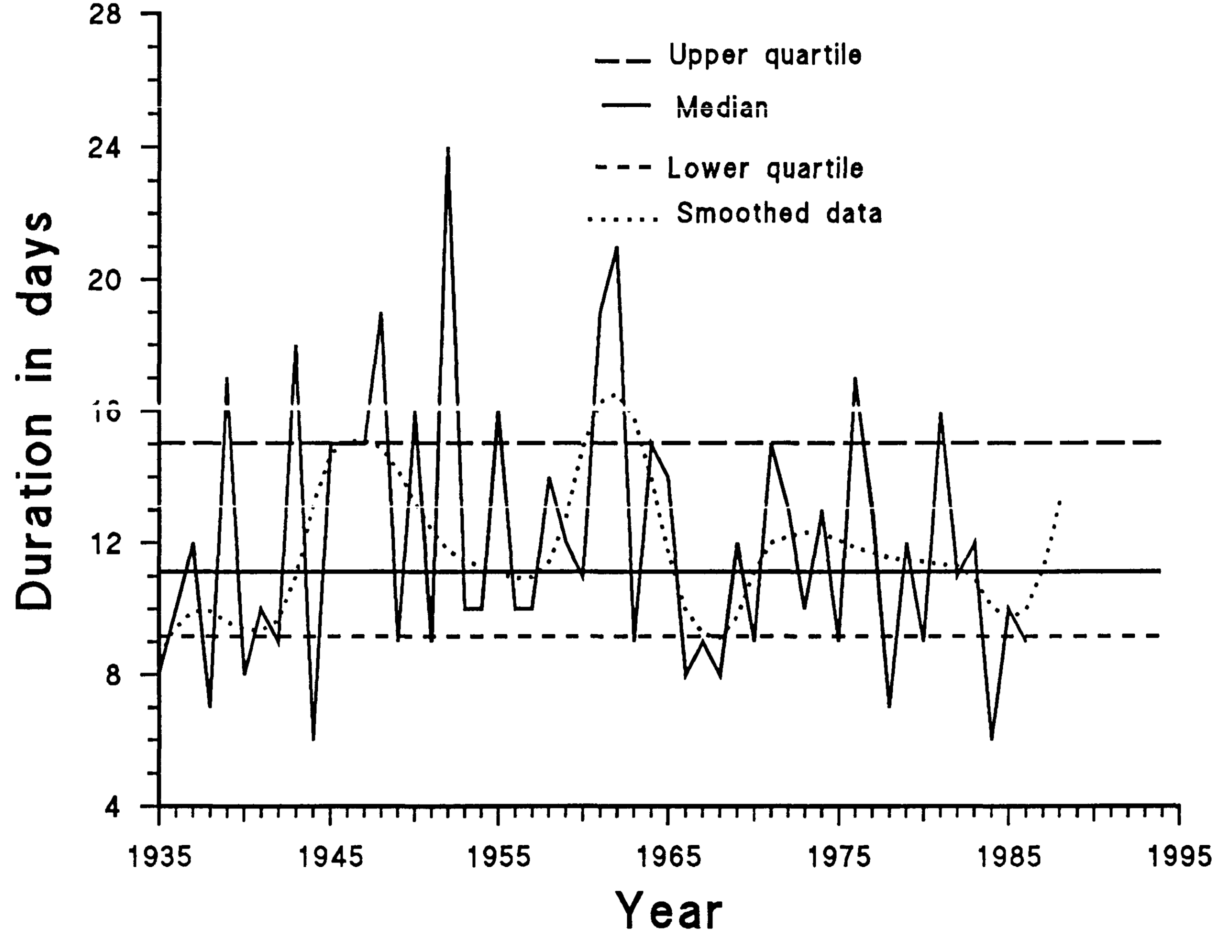

Figure 8.13 Annual variations in maximum spells of raindays with "surplus" moisture (RS4) at Rokupr 1935–1988

The duration of the rainfed cropping period was derived by subtracting the start date from the termination date for each year on record Duration of the cropping period ranges from 170 days in 1947 to 260 days in 1955 (figure 8.14). The median duration is about 200 days, which is enough to support long duration varieties, or even a second short duration crop, if the former crop is sown at the earliest planting date. On the other hand, there is a 25% chance of the growing period lasting longer than 220 days, or less than 190 days in any one year. The 1950's had exceptionally long (more than 200 days) rainfed cropping periods. Relatively shorter cropping periods (mostly less than 200 days) occurred in the early parts of the 1940's, 1960's, 1970's and 1980s. These results show that it is rare for the length of the season to create problems for upland rice cultivation at Rokupr.

8.7 SUMMARY

The different types of drydays and raindays discussed in the previous chapters have been used to characterise the major phases of the rainfed cropping period, using upland rice as a sample crop, and data from two agricultural research stations. The results of this analysis show that (a) "bush-washing" rain cannot be relied on by the farmer as a guide to start land clearing operations, because of the variability in its occurrence from year to year; (b) the risk posed by unseasonally early rainfall to farm burning is considerable, given the frequency with which it has occurred in the past. This

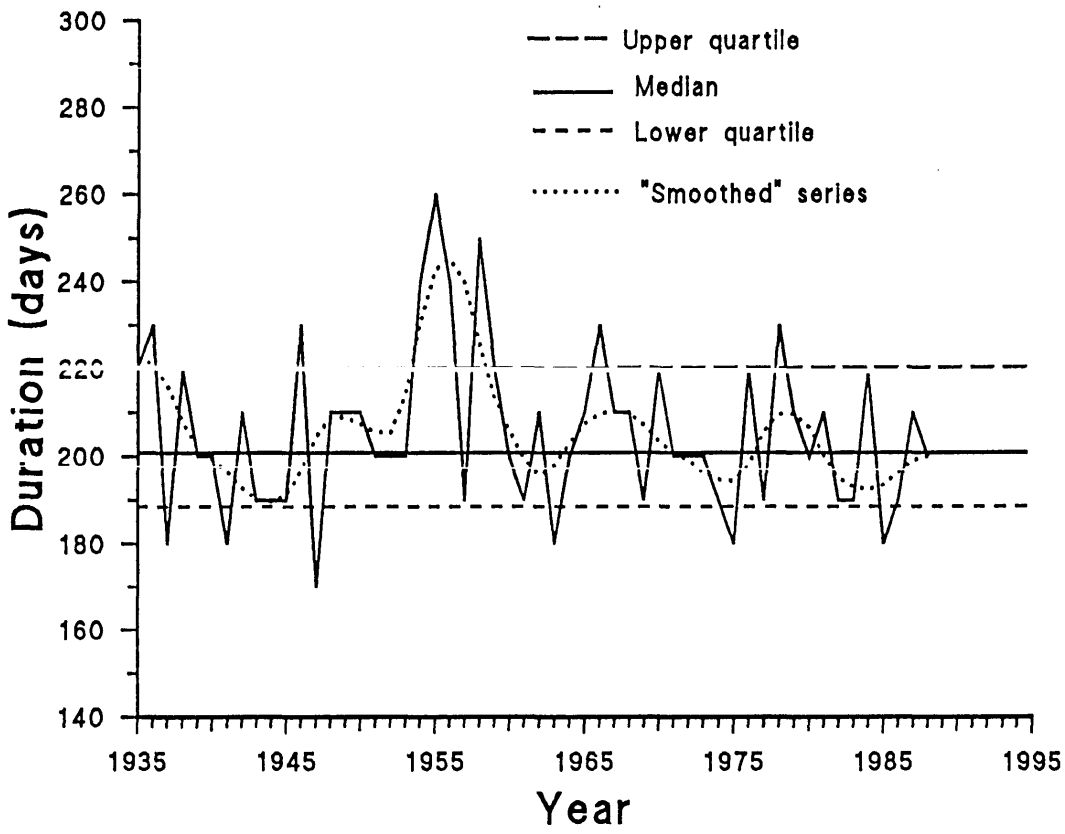

Figure 8.14 Annual variations in duration of the rainfed cropping period at Rokupr 1935–88

risk is adequately indicated by a simple Dry Season Intensity Index (DSI-Index); (c) The start of the planting period varies from year to year at any given location. Actual planting dates for upland rice compared favourably with estimated dates base on the time when the Wet Season Intensity Index (WSI-Index) is equal to or greater than the DSI-Index. (d) the rainfed cropping period in Sierra Leone is long enough to support long-duration varieties of upland rice, if sown at the earliest planting date.

CHAPTER NINE

DISCUSSION AND CONCLUSION

9.1 INTRODUCTION

The main focus of this study, as outlined in chapter one, is on daily variability in rainfall and its implications for the development of rainfed agriculture in Sierra Leone, West Africa. To underscore the importance of the study the general impact of rainfall on the agricultural system was outlined, focussing on the tropical situation. Following a review of various approaches to the acquisition, processing, analysis, and application of rainfall information to agriculture, an appropriate methodological approach to the study was developed, which then formed the basis for all subsequent analyses. The primary objectives of this concluding chapter, therefore, are:

(a) to summarise and discuss the major findings of the study as they relate to the aims and objectives outlined in chapter one;

(b) to highlight limitations, and suggest aspects of the study needing further research.

9.2 THE RAIN-GAUGE NETWORK AND RAINFALL DATA

The past and present rain-gauge network was examined to determine its adequacy in providing a realistic estimate of the spatial and temporal characteristics of rainfall over the country. A number of issues emerged from that analysis, the most important being:

(i) about 35% of the total land area of the country is not sampled by the rain-gauge network, based on standards recommended by the World Meteorological Organisation (WMO). The interior plateau in the north and east is the least represented, with about 82% of its total area not sampled by the network. Given the limited spatial extent of tropical rainstorms, coupled with the effects of permanent features such as relief, local variations in rainfall, especially over short-time periods, are bound to be considerable. The low rain-gauge coverage, especially over the interior plateau, can therefore be considered as a major limitation to understanding these spatial variations in rainfall. For applied purposes, this calls for great caution in attempting to extrapolate data from a single station to ungauged areas, especially for use in planning rain-sensitive agricultural operations.

(ii) there is a close link between the history of instrumental rainfall observation and the recent political and economic history of the country. The first rain-gauge was installed in the Freetown Peninsula by British settlers in 1874, and about forty years later in the interior following the proclamation of the hinterland as a Protectorate in 1396. In many cases, gauges were installed at locations that were relatively accessible, often at administrative centres along major lines of communication. A significant relationship was also established between district population densities, and rain-gauge network densities. Based on these facts, it is apparent that several of the gauges were located on the basis of availability and convenience of an observer(s), rather than on the basis of climatological need and suitability of the site, which helps to explain why there is a relative concentration of rain-gauges in densely populated areas. This also highlights the need for a better network, with a greater spatial coverage and more evenly distributed gauges, to provide relevant information on the local rainfall regime that can be used in agricultural planning.

(iii) over 80% of the rainfall data has come from stations not operated by the Meteorological Department, which indicates a heavy reliance on non-professional, mainly volunteer observers, most of whom are expatriates. Nevertheless, the quality of the rainfall data was found to be generally high, thanks to the vigilance of the Meteorological Department which, through regular inspections of stations and careful scrutiny of monthly reports, ensures that high standards of observation are maintained.

Many stations have relatively short rainfall records which makes assessment of temporal variability in some parts of the country difficult. In the tropics where rainfall conditions vary considerably from year to year, an understanding of the magnitude and direction (s) of temporal variability is important in agricultural planning at the individual farmer, sectoral, or national levels. However, several other stations have reasonably long records which have been used to indicate variations in rainfall since the 1930's. On the other hand, even the relatively shorter records provide useful background information about the local rainfall regime which may be useful for assessing the type(s) of agricultural systems that can be supported by the rainfall regime.

9.3 RAINDAY AND DRYDAY CONCEPTS.

A large part of the study was concerned with daily variability in rainfall and soil moisture conditions, and their implications for rainfed agriculture in different parts of the country. Although raindays and drydays are commonly used to describe and quantify variability in these conditions, these concepts mean different things to different researchers. The fundamental cause of these differences in definitions is often the purpose for which the definition is made. After reviewing a wide range of existing definitions, two broad categories were identified, "meteorological" and "agricultural". The merits and limitations of each approach, vis-a-vis the objectives of this study, were discussed. What clearly emerged from that review was a need for an approach to rainday/dryday definition that;

(i) minimised the confusion in the climatic literature which is engendered by the different definitions.

(ii) can be applied to many disciplines such as meteorology/climatology, hydrology, agriculture, and other environmental sciences.

To meet this need, a new approach to rainday/dryday definition that takes into account both the occurrence/non-occurrence of rainfall, and the amount of soil moisture on a particular day was proposed. Soil moisture levels were determined by a simple daily water balance model based on a number of assumptions and simplifications, including a 100% infiltration rate, and all rainwater that enters the soil profile being equally available for transpiration. The various combinations of rainfall and soil moisture states produced three types of drydays, and four types of raindays, each day denoting a certain "type" of moisture condition.

An analysis of the spatial patterns of raindays and drydays so defined indicated that:

(i) the north and northwest experience many more days with "deficit" and fewer days with "adequate" soil moisture, compared to the east and the south. In terms of rainfed cultivation, long duration crops seem better adapted to conditions in the east and south, while short duration crops are more appropriate for the north and northwest.

(ii) on the other hand, the spatial patterns of raindays with "surplus" soil moisture indicate potentially higher erosion risks in the south and west than the north, northwest and the east.

(iii) the central parts of the country experience moderate conditions with fewer and shorter maximum spells of days with "deficit" soil moisture than the north and northwest, but also fewer and shorter maximum spells of days with "surplus" than the west and south.

The value of this approach, especially for characterising water-related aspects of the agricultural environment was illustrated by an example using upland rice, whose culture is exclusively rainfed. Results obtained from that analysis are discussed later in this chapter.

9.4 CHARACTERISTICS OF RAINFALL REGIONS

Due to the uneven distribution of rainfall stations and the unequal lengths of records, it was decided to identify, using objective criteria, stations which are representative of different rainfall regimes. This involved the use of a combination of Principal Component Analysis and Cluster Analysis techniques to divide the country into regional units with fairly similar rainfall and soil moisture regimes. Eight regions were ultimately identified as representing the different rainfall climates of the country. For each region the station with the longest, and/or the most complete daily rainfall records was then chosen for subsequent analysis. The limitations of using data from one station to represent rainfall and soil moisture conditions over a whole region are discussed in section 9.8 of this chapter.

The most important differences in regional characteristics as far as rainfed agricultre is concerned are:

(i) the Northern Plateau region is, in relative terms, the driest of the eight regions, closely followed by the Northwest and the West Coast regions. These regions have the largest number, and longest maximum sequence of drydays with "deficit" soil moisture, and the least number of raindays with an "adequate" supply of soil moisture per year.

(ii) the Eastern Plateau, the South, and Central South experience more humid conditions, having relatively fewer drydays and more raindays with "adequate" soil moisture for plant growth.

(iii) days with "surplus" soil moisture occur most frequently on the Freetown Peninsula Mountains, and also in the South. Problems of excess water and soil erosion are therefore likely to be more prominent in these, than other areas.

9.5 SEASONAL DISTRIBUTION OF RAINDAYS AND DRYDAYS

The analysis of the frequency of occurrence of raindays and drydays revealed that:

(i) on an annual basis, drydays with soil moisture "deficits" (DD1) are the most frequently occurring days anywhere in Sierra Leone, accounting for between 28-40% of the total number of days per year. The second most frequently occurring days are raindays with "surplus" soil moisture (RD4) which account for between 18-31% of all days. This high frequency of occurrence of DD1 and RD4 days denotes extreme conditions of dryness and wetness in the climatic regime. For nearly 60% of the days in an average year conditions are either extremely wet or extremely dry.

These extremities in moisture conditions have serious implications for the development of rainfed agriculture in the country. The large number of DD1 days means that for about one-third of the year no dryland cultivation is possible, except under supplemental irrigation. But the financial and environment costs of irrigation agriculture, especially for the small-scale farmer, can be enormous (Barrow 1987).

Excess water is as great a problem in agriculture as water shortage. The large number of RD4 days creates problems of soil erosion, flooding, leaching of mineral nutrients, and physical damage to crops during the growing season.

(ii) about 30% of all days in an average year, which include those with or without rainfall (DD3 and RD3), have an "adequate" supply of soil moisture for plant growth. This is enough to support many short duration crops, although it is the distribution of these days during the year that determines the suitability for rainfed cultivation. These aspects are discussed in a later section.

(iii) Compared to other day types, the total number of raindays with "deficit" and "limiting" soil moisture

(RD1 and RD2) are few everywhere, most of them occurring at the start of the rains when light showers from small masses of cumulus clouds (cumulus fractus) are common. High ambient temperatures at this time of the year cause much evaporation of precipitation before it reaches the ground (sometimes producing the optical meteorological phenomenon called 'virga'), and also on the ground.

A detailed analysis of seasonal regimes was undertaken by focusing on the distribution of raindays and drydays in each ten-day period. The following facts emerged from that analysis.

(i) each type of rainday and dryday has a preferred time of occurrence, with none being experienced throughout the year. However, it is common for two or more types of days to occur within a given ten-day period.

(ii) between the 34th-9th decades (December-March) the predominant day types are generally drydays with "deficit" soil moisture (DD1), most of which occur in spells of 7-10 days. However, there are regional differences in total numbers of these days and the lengths of their spells. As discussed earlier, areas where DD1 days are most common, and their maximum spells are longest, include the north, west, and northwest. Eastern and southern districts have relatively fewer and shorter maximum spells of DD1 days.

(iii) an important outcome of this study is the identification of a period of mixed and variable conditions between the 10th-17th decade, when all the seven types of days may be experienced within a ten day period. These variable conditions are a major source of risk and uncertainty for rainfed cultivation, especially for sowing/planting which normally occurs at this time of the year in most areas. A "good" day for a certain agricultural operation may soon be followed by one or more "bad" days that may hamper the operation.

(iv) between the 18th-30th decades it is common for most areas to experience only three types of days within a decade i.e. raindays with "adequate" and "surplus" soil moisture (RD3 and RD4), and drydays with "adequate" soil moisture (DD3). The advantages or disadvantages of such conditions will depend on specific agricultural water requirements and susceptibility to rainfall.

(v) Another period of mixed and variable conditions returns between the 31-33th decade, again with a possibility of all seven day types being experienced within a decade.

9.6 AGRICULTURAL SEASONS

Two major seasons (one Dry and one Wet), and two transitional periods (a Dry-Wet and Wet-Dry) have been identified in Sierra Leone. What differentiates the seasons from the transitional periods is the relative dominance of 1-3 types of days during the seasons, compared to the transitional periods when all the seven day types may occur within a decade.

The Dry Season was identified using an intensity index (DSI-Index) that is based on the total number of drydays with "deficit" soil moisture and their maximum spell lengths that occur within a decade. The main features of the Season can be summarised as follows:

(i) the season begins earliest and ends latest in the north, west, and northwest. Long Dry Seasons in these areas (120-140 days) limit rainfed cultivation to short-medium duration annual crops. Such conditions are also more favourable for animal husbandry than the more humid conditions of the east and south which promote animal diseases like the dreaded trypanosomiasis transmitted by the tsetse fly.

(ii) low levels of soil moisture precludes any upland cultivation during the Dry Season, except under irrigation. However, high evapotranspiration rates due to a combination of high temperatures and low humidities, and socio-economic factors greatly limit the prospects for small scale irrigation agriculture in Sierra Leone.

(iii) another disadvantage of the long Dry Season is that it leaves the soil bare of vegetation and unprotected from the high intensity rainstorms at the start of the rains. Apart from the agronomic implications discussed below, rapid soil erosion also results to siltation of streams and rivers, causing frequent flooding of rich agricultural lands along the lower reaches of the major rivers.

(iv) the main advantage of the Dry Season is the opportunity it presents for preparing the land before cultivation through the annual traditional "slash-and-burn" system of farming. This method of land clearing requires long dry spells to enable the felled vegetation to dry out properly before it is burnt down. Heavy rainstorms at this time of the year affect the burn, as discussed in section 9.7 of this chapter.

The Wet Season was identified using an intensity index (WSI-Index) based on the total number of days with both rainfall and abundant soil moisture, together with the maximum spells of those days. The season was found to be characterised by the following:

(v) lasting for 110-160 days, it is long enough to support major annual food crops like rice and millet. The season starts earliest and ends latest in the east and the south. Because of the long Wet Seasons, many medium and long duration food crops, as well as plantation cash crops are widely grown in these areas.

(vi) excess soil moisture during the Wet Season is a major agronomic problem everywhere, although it is relatively greater in the south and the west where raindays with "surplus" soil moisture (RD4) occur most frequently. Excess soil moisture causes accelerated soil erosion, leaching of mineral nutrients from soils, and frequent inundation of low-lying areas. The erosion problem is, however, minimised by the traditional farming systems whereby tree stumps and some unburnt sticks are left in the field plot during cultivation. These help to check erosion processes induced by rainwater.

(vii) another important feature of the Wet Season in Sierra Leone that was identified in this study is the complete absence of soil moisture deficits during the middle of the season which might occur as a result of long dry spells. Unlike many other parts of the tropics, yield reductions or crop loses due to mid-season water deficits are not a major threat to rainfed agriculture. Rather, it is the problem of excess water and frequent rainfall that must be of concern to the farmer. Long rain spells can affect the harvesting and processing of quick maturing crop varieties which have been introduced in the last few decades to supplement the traditional, long maturing varieties.

(viii) the Dry and Wet Seasons are separated by Transitional periods (DWT/WDT) whose main features are many different types of drydays and raindays, none of which occur in spells of ten days or longer. Such mixed and variable conditions increase the high level of risk and uncertainty that characterise rainfed agriculture in the tropics.

9.7 IMPLICATIONS FOR RAINFED AGRICULTURE

The usefulness of the previous analyses was tested by applying some of the results to different stages of upland rice cultivation, the most important farming system in Sierra Leone. Results of that analysis show that:

(i) there is no evidence to support the traditional practice of delaying the cutting down of the vegetation in order to create new farmlands until after the first "bush-washing" rain between late January and early

February. Such rain has a less than 10% chance of occurring every year. The main argument in support of the practice is reduced skin irritation during the brushing of the vegetation, which advantage is out-weighed by the merits of early brushing that lead to a well-burnt farm.

(ii) the threat of unseasonally early rainfall to farm burning is a serious agroclimatic constraint in Sierra Leone. A low Dry Season Intensity Index (DSI-Index), indicating rainfall occurrence and high soil moisture levels, prior to and during the peak burning period is often linked to bad burns. Historical records show that this problem occurs fairly often in many parts of the country, with adverse effects on agriculture and food supply. Since the beginning of this century there have been more than ten reported cases when bad burns due to early rainfall disrupted farm burning, with serious consequences for upland rice farming.

Although a number of factors, including rainfall, were mentioned as important in determining the quality of the burn, it is also worth noting that a poor burn can be induced by the farmer for economic reasons. Along or near major roads, firewood sales are a major income supplement for the subsistence farmer. Due to increasing demands in urban areas firewood prices have sky-rocketed in recent years. To take advantage of this increase in prices, many farmers now effect the burn early, before the vegetation dries out properly, to ensure a good supply of firewood from the unburnt vegetation (Richards 1986). The consequences of this practice are as grave as those of unseasonally early rainfall, except for the additional cash income which the farmer derives in this case. Poor burns due to early rainfall and deliberate burning are a contributing factor to the low rice yields from upland farms reported in many ares.

(iii) the usefulness of the results of this study were clearly borne out by the comparison of "derived" and "actual" planting dates at the Rokupr Rice Research Station. In nearly 40% of the years (1973-88) the derived date was within one decade of the actual planting dates for one variety of upland rice (ROK3). However, based on this approach, planting could have occurred earlier than it did in about six (37%) years.

(iv) due to the long wet season and the lack of mid-season breaks, it seems that early planting of upland rice is not very critical in some parts of Sierra Leone, at least with regard to water availability throughout the crop's growth cycle. This explains why the planting period sometimes extends well into the middle of the Wet Season. Another implication of a long Wet Season is the possibility it presents for double cropping short duration varieties of the same or different crops within one season.

(v) despite the numerous advantages of early planting discussed in chapter eight, farmers still plant late for reasons other than a reliably long Wet Season. Variability of rainfall at the start of the Wet Season creates considerable uncertainties so that the farmers often wait until the level of risk of crop failure is sufficiently low. One of the merits of the suggested approach to the definition of Wet Season onset is its ability to eliminate risks of "false" starts.

Since most farmers use small implements like the hand hoe, it is necessary to delay planting (sometimes past the optimum planting time) until the soil is sufficiently humid and workable. Also, the use of small implements, coupled with the reliance on household labour, means that only a small portion of the farm can be worked on within a given time. Farmers often get round this problem by hiring labour, or forming reciprocal labour groups in order to complete planting early (Richards 1986).

(vi) Although lack of data precluded a detailed consideration of the harvest, the distribution of raindays suggest that there is a high risk of frequent rain hampering the harvesting and processing of rice (especially for early maturing varieties) at the later part of the Wet Season.

9.8 LIMITATIONS OF THE STUDY

Although the results obtained in this study have practical relevance to the development of rainfed agriculture in Sierra Leone, there are a number of limitations that must be acknowledged.

(i) as discussed in chapter three, and also in section 9.2 of this chapter, the rain-gauge network does not adequately sample some parts of the country, especially the Eastern Highlands, the Northern Plateau, and the northern parts of the Northwest Region. Given the marked spatial variability (especially during short-term periods) as demonstrated in this study, knowledge of the spatial patterns and temporal distribution of rainfall and soil moisture over these areas must be seen as inadequate.

For better tactical and operational planning of agricultural activities at all levels (national, regional and farmer), a much denser, and more evenly distributed rain-gauge network is required than exists at the present. However, due to technical, financial, and manpower problems, as well as a narrow perspective of the role of meteorology in economic development by successive Governments and bureaucrats, prospects for maintaining, let alone expanding the network are remote. This is evidenced by the closure of several long-standing rainfall stations in the past 10-15 years.

(ii) the majority of rainfall stations have short records (< 30 years), some of them fragmentary. Such records have limitations in assessing the reliability with which certain events can occur. Additionally, the records are of non-uniform lengths which makes it difficult to select a common period for a detailed analysis of spatial patterns.

(iii) another limitation of this study worth mentioning concerns the assumptions underlying the model used to compute the water balance and soil moisture parameters. Lack of daily measurements of radiation, sunshine, temperature, and wind speed precluded the direct estimation of some water balance parameters using actual measurements. This necessitated the use of the only available potential evapotranspiration (PE) data. However, the use of these data is unlikely to create many problems since its computation was based on known physical principles and established methods that are widely used by the FAO in agroclimatological surveys.

(iv) Although conditions are relatively homogeneous within a given region, compared to areas outside the region, spatial variability still occurs. Because of the problem of spatial variability within each region the use of data from one station to represent conditions within a whole region must be seen as a limitation.

(v) the discussion of seasonal characteristics in chapter eight was limited to those aspects (i.e. types of days and spells) that were considered in previous chapters. This was done in line with the main objectives of the study outlined in chapter one. However, there are other important features that characterise an agricultural season which have not been considered. These include such aspects as the frequency of dry and wet spells of various categories (2-9 days long) within a given season; and the total amount of rainfall per season, and also per spell within seasons.

9.9 ASPECTS FOR FURTHER STUDY

This study aimed to describe and quantify water-related aspects of the agricultural environment by integrating both the atmospheric (rainfall) and the soil components of water into a single parameter. The methodology and some of the results presented also have direct agricultural applications, especially in such critical areas as determining safe planting dates, and assessing the risks of water deficits and excess during the growing season.

However, further research needs to be undertaken in a number of areas to test and validate the accuracy, and hence improve the potential usefulness of the methodology and approaches proposed in this study. These areas include:

(i) the basic assumptions underlying the water balance model need to be tested and verified for specific locations. Also, the model needs to be refined to take into account (a) specific crop-water requirements of major crop types and varieties other than rainfed rice that are actually grown or potentially adoptable, and (b) water holding capacities and infiltration capacities of the major soil groups in Sierra Leone.

(ii) long-term evaporation and evapotranspiration data are required to test and refine the water balance model over a number of seasons. Despite the associated problems, in future it may be possible to estimate these parameters using sample data from selected synoptic, climatological, or agricultural stations.

(iii) more information is required about the frequency with which rainfall has disrupted early season operations such as farm burning in the past, to provide a suitable framework for testing the validity of the "derived" results. Such information might be obtained from a variety of sources, including agricultural reports, newspaper reports, or from surveys involving the farmers themselves.

(vi) although the focus of this study is on rainfed agriculture, there is a potential for application of the proposed approach to water-related problems in other systems of agriculture. With appropriate refinement and integration, this approach can also be applied to research problems in such diverse areas as soil erosion, drought, floods, and other related studies in meteorology /climatology, engineering hydrology and water resources.

9.10 GENERAL CONCLUSION

Despite the limitations imposed by the data and methods of analysis, this study provides a better understanding of the short-period characteristics of rainfall in Sierra Leone than previous studies based on monthly and annual totals. By intergrating rainfall and soil moisture into a single parameter, the nature and magnitude of the water constraint in rainfed agriculture is adequately illustrated. A wise application of the information in decision-making will therefore minimise the risks and uncertainties in agricultural production associated with the short-term variability in rainfall.