EFFECTIVE RAINFALL AND BEAN YIELD IN A TROPICAL SEMI-ARID ENVIRONMENT: A CASE STUDY OF SOUTH EASTERN MACHAKOS DISTRICT; KENYA

BY

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This Thesis is my original work and has not been presented for a Degree in any other University.

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This Thesis has been submitted for examination with our approval as University supervisors.

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For Jane and Mutinda for their inspiration
during the hard time I was doing my field work.

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ABSTRACT

The importance of understanding crop water requirements, effective rainfall and rainfall variability after onset date in the semi-arid areas of Kenya cannot be underestimated in planning and implementing policies geared to increasing food production. This is more so in the areas of South Eastern Machakos where rainfall hardly averages 800mm annually and with high variability from one season to the other, yet farmers have to grow food crops for their dietary and other special needs. The two bean varieties namely, Mwezi Moja and Bean I are becoming quite popular in South Eastern Machakos probably due to their being able to complete their life stages at a relatively shorter time than other varieties grown in the area.

One way of promoting high production of the two varieties of beans (Mwezi Moja and Bean 1) is certainly through understanding their water requirements, evaluating how much of the rainfall received in the study area is `effective´ for the two varieties and investigating whether rainfall variability can be predicted depending on the date of the onset. Due to this realization, the present study was set out to achieve the following basic goals:

a) To calculate the Crop Water Requirements of Common bean (*Phaseolus vulgaris*, Mwezi Moja and Bean I varieties) grown in a tropical, semi-arid environment, namely, South Eastern Machakos District of Kenya.

b) To examine the portion of total rainfall which is effective for the two varieties (in (a) above) to meet their water requirements, and,

c) To investigate if rainfall variations after the start of the rain can be predicted.

To estimate crop water requirements (ET(bean)), Pan Evaporation Formula was found suitable. This is because it was found to require less input of meteorological data, most of which can be estimated as compared to other formulae of estimating ET(bean). At the same time it gives reliable estimates of crop evapotranspiration. The crop water requirements for both bean varieties was found to be 281 mm over the entire bean season as worked out from the field experiments.

In computing effective rainfall, a water balance model was used. This model has been used in the past by other researchers for example Kashasha (1982), Stewart (1972) and Ndolo (1985). The "effective" rainfall during the time of the experimental trials at Katumani was found to be 198mm over the whole season for each of the two bean varieties which was also the figure for the whole area over the 26 year period used. The ET(bean) value had a standard deviation of 16.2mm. The ET(bean) deficit was consequently 30% of the seasonal effective rainfall (Pe). Thus 70% of ET(bean) was shown to have been met by rainfall received in the study area.

Rainfall variability after onset of the season was estimated using three different methods, namely the coefficient of variation, probability analysis, and simple linear regression analysis. Each method was applied to each of the three types of onset seasons ("early", "middle" and "late"), derived depending on the time the season commenced over the 26 year period used). The F-test was performed to investigate the presence or absence of significance between variations and the advance of days from each defined onset date. The result of this study indicate that the mid and late- onset seasons show lower variations in rainfall frequency after onset date, while the early onset season has high variations which could not be predicted using the methods of analyses adopted in this work. Appropriate recommendations to farmers for crop calendar design are made in addition to identifying new avenues for future research.

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THESIS ORGANIZATION

Chapter one of this Thesis introduces the study problem, namely bean production in marginal areas and outlines the need for attention towards marginal lands of Kenya for agricultural development. The complexities involved in embarking on cash crop production are described and articulated towards the attainment of self-sufficiency in food production. Further, the research problem is explained and linked to the research objectives and hypotheses pertinent to this investigation. The literature review is presented so as to highlight the previous investigations and identify gaps in knowledge, thus justifying the present one.

In Chapter two the background information on the study area, as well as the prevailing climatic conditions is presented. Chapter three discuss the statistical methods and other procedures used to collect and analyse research data. The fourth Chapter presents results derived by methodologies explained in Chapter three. A full discussion of these results is given.

Finally, chapter five summarizes the research findings, in addition to giving recommendations that are relevant to both bean farmers, future researchers and policy planners so as to achieve an increase in bean production whithin the study marginal areas.

CHAPTER: ONE

1.0 STATEMENT OF THE RESEARCH PROBLEM

The Republic of Kenya is known to have one of the highest population growth rates in the world. Due to this phenomenon arable land in higher rainfall areas (receiving high rainfall amount) has for some time now been overcrowded. The result has been a rapid expansion of smallholder farming into more marginal zones with annual rainfall below 1000 mm.

The new communities that emerge from overcrowded high potential areas who invaded (and still continue to invade) the drier areas lack background information in selecting the most appropriate crops and practices most suited to these new environments. They tend to import agronomic technologies and practices that are evidently more suitable for the wetter areas from which they have come to these new areas. This often leads to an eventual breakdown of the fragile ecosystems of the marginal lands (U.N: 1977,). Due to this realization, the 1984/89 Kenya development plan and the Food Policy (GOK, 1981) both call for research on economically and socially appropriate technological packages of farming recommendations for semi-arid lands together with improved delivery systems for implementing them.

Agricultural production within marginal lands is often limited by inadequate soil moisture. Given the vastness of Kenya's marginal lands(about 75% to 85%), it is conceivable that soil moisture inadequacy greatly hampers crop production (Mugah and Stewart, 1984). This situation calls for exhaustive investigation of those factors that govern crop water utilization under conditions of limited soil moisture.

Thus knowledge of water requirements of crops grown under semi-arid conditions is a key requirement for agricultural production in the area. Further, methods should be devised so as to predict crop performance in terms of yield. Certainly this need calls for an understanding of `effectiveness` of rainfall received in each season for each particular crop in marginal areas.

Most studies in East Africa have been concentrated on cereal crops particularly maize which are seen as the staple crops for most East African societies (Stewart and Mugah, 1979, Kashasha, 1982, Stewart and Faught, 1984). Other studies have tended to concentrate on cash crops such as coffee and tea which constitute the backbone of the economies of these countries (Laycock and Wood,1963; Laycok,1970; Pereira,1970; Mutiso, 1981 and Ndolo, 1985;). The over emphasis on cash crops at the expense of food crops can have bad effects in times of poor weather (Odingo, 1985). Also, other studies have shown that, not unexpectedly, the outcome of this process is a decrease in dietary standards, as noted by Benard (1969). This phenomenon is known to prevail elsewhere in the world where high value cash crops have been introduced. In Kenya it is dramatically illustrated by food shortages that are common. Indeed, the over-reliance on cash crops has in-built dangers as summarized by Jarret (1977,pp 113) as follows:

> **"Admittedly we have gone far from our starting point (in development), but this example (of food shortages) does sharply remind us that when producers venture into the hurly-burly of cash cropping and all that this entails, they may well find that they have left behind them any life of comparatively placid self-sufficiency, which they may previously have enjoyed. The path of economic development is tortuous and rocky, and no one who treads along it can tell whither it will lead".**

Thus as we commit more land to cash crop farming in a bid to earn the foreign currency, we should always also give priority to food crops. It is important to note that any food policy aimed at self-sufficiency in food production should be a balanced one, stressing on both carbohydrate giving and protein supplying crops (and others). This is where the latter crops need their fair share in research. Again it is true that most societies in Kenya (especially in the rural areas) heavily rely on beans for the supply of protein, highly needed in the body as the animal supply has become limited due to high consumer prices of meat.

The need to understand quantitative plant water relations and more so, being able to predict crop production depending on meteorological conditions becomes extremely important (Hanks and Hill; 1980) This is especially so in marginal lands where water is the most limiting factor in crop production. Unfortunately it is in these marginal lands where the future of this country rests (GOK, 1984)

This study attempts to investigate the crop-water requirements of two drought resistant bean varieties namely, **Mwezi Moja** and Bean I. It aims at testing how their production can be boosted bearing in mind that the study area (i.e South Eastern Machakos District) experiences variable rainfall both in amount and frequency. Thus, part of this investigation will be devoted to finding if rainfall spread (frequency) over the season can be predicted based on the date the season starts (i.e onset date). The research also investigates how much of the rainfall received in the study area is effective for bean production.

1.2 RESEARCH OBJECTIVES.

The objectives of this research are:-

1. To establish the crop water requirements of **Bean** I and **Mwezi Moja** varieties $ET_{(bean)}$ under dryland farming conditions in South Eastern Machakos District.

2. To establish the portion of total rainfall in any one year which is effective for the production of the said bean varieties to meet their water requirements.

3. To establish if rainfall variation after the start of the season can be predicted.

1.3 RESEARCH HYPOTHESES

A number of researchers stress the importance of formulating research hypotheses in scientific investigation (Draper and Smith 1981, Chartejee and Price 1977 and others). In this investigation working hypotheses were formulated and are as follows:-

1. **Ho:** The rainfall received in the study area does not significantly meet the crop water requirement of **Mwezi Moja** and **Bean I** varieties.

   H1: The Alternative.

2. **Ho:** The rainfall frequency (variations) after onset of the season cannot be predicted (in the study area).

   H1: The Alternative.

3. **Ho:** Temporal distribution (variations) of rainfall in the study area does not affect bean crop water requirements ($ET_{(bean)}$).

   H1: The alternative.

1.4 OPERATIONAL CONCEPTS

In this study, some operational concepts have been used. It is therefore necessary to define them so that the reader may have a clear understanding of the subject matter. The definitions given as below are maintained throughout this research. They are as follows:

(a) Effective rainfall/precipitation:

Many workers have defined effective rainfall in different ways as reported by Dastane (1974). They include Thornthwaite (1931), Hayes and Buell (1955), Harshfield (1964), U.S.A. Department of Agriculture (1967), Miller and Thompson (1970), and Ogrosky and Mockus (1974). Dastane (1974, pp 6) gives an illustration of the portions of hydrological cycle that should be seen as constituting the effective precipitation (or rainfall) depending on one's field of interest. He pinpoints the weaknesses of the definitions given by other workers and infers that the definition of effective precipitation should be dynamic.

This worker considers "effective" rainfall as defined by Doorenbos and Pruitt (1977) as, rainfall that will satisfy the crop water requirements. It excludes deep percolation, surface runoff and interception in **mm/period.**

(b) Crop coefficient (kc):

Crop coefficient (or "crop"factor) is a factor relating evaporation from the soil and transpiration from the plant, and is the ratio between maximum crop evapotranspiration (ET_{crop}) and reference crop evapotranspiration (ET_0) when a crop is grown in large fields under optimum growing conditions ($kc = ET_{crop}/ET_0$) (Doorenbos and Pruitt, 1977).

(c) crop water requirement ($ET_{(crop)}$):

$ET_{(crop)}$ is the depth of water needed to meet the water loss through evapotranspiration of a disease - free crop, growing in large fields under non-restricting soil conditions (including soil water and fertility) and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977).

(d) Evapotranspiration (ET_p):

Doorenbos and Kassam (1979) define evapotranspiration as the amount of water lost from the soil with a large area of continuous cover of green like plants with an optimum supply of moisture and ample plant nutrients. ET_p thus, is an estimate of the maximum rate of water loss from the soil and plant cover to the atmosphere that can take place under a given set of climatic conditions.

(e) Reference crop evapotranspiration (ET_0):

Defined as the rate of evapotranspiration from an extended surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, and not short of water, in mm/day (Doorenbos and Pruitt, 1977).

(f) Date of onset (or onset date):

Stewart and Kashasha (1984) term date of onset as the first amount of rainfall greater than or equal to 20 mm from the month of February during the long rains and October during the short rains in marginal lands of Eastern Kenya. While Dennett, Rogers and Stern (undated) define onset of the rains in Katumani and Kampi-ya-mawe, as when 10 mm of rain falls on day one, followed by three dry days and another 10 mm on day five. They however assert that, for the rain to be effective the 20 mm of rain should fall on say one or two consecutive days and that the five day period enters the definition because of convention. Stewart and Hash (1981), however took the onset date or rather "date of onset" as the first day of the period, the earliest being on 20th October and 10th February during the short and long rains, respectively, while the "onset" itself refers to the period after the date of onset. This work will adopt the definition as given by Stewart and Hash (1981), but will take the earliest date of onset as 20th February during the long rains and 20th October during the short rains.

Onset date before or on 20th October during the short rains or before or on 10th March during the long rains is termed in this work as the start of a season category referred to as "Early onset" season while onset after 20th October but before 10th November during short rains or after 10th March but before 1st April during the long rains is referred to as the start of a season category designated here as the "middle (or mid) onset" season. Finally a season whose onset date is after 10th November or after (or on) 1st April is here designated as the start of "late onset" season for long and short rain seasons respectively. In brief it follows that as for the long rains;rainfall records in the study region approximately indicate that:

(i) Onset of rainfall is expected after 20th February.
(ii) "Early onset" - onset before or about 10th March.
(iii) "Mid onset" - onset after 10th March but before 1st April.
(iv) "Late onset" - onset after 1st April or thereabout. And for the short rains:
(i) "Early onset" - onset before or about 20th October.
(ii) "Mid onset" - after 20th October but before 10th November.
(iii) "Late Onset" - onset after 10th November or thereabout.
(Note : onset during short rains is expected any time after the 1st week of October).

(g) Dry Spell.

A Dry spell of "n" days is defined as a sequence of" n" dry days preceded and followed by a wet day(s). The threshold amount of rainfall for a day to be adopted as dry or wet has differed in previous works. Mungai (1984) defines a wet day as one on which 1.0mm or more of rain fell. Thus a dry day was taken as a day when the daily rainfall was less than 1.0 mm . Dennett *et al*,(undated) in a report on rainfall at Kampi-ya-mawe and Katumani defines a dry day as the day when 0.05 mm or less was received . In this work, a dry day is taken as the one on which less than 1.0 mm of rain fell. This limit (of 1.0mm) is the official definition of a dry day in Kenya(Kenya Meteorological Department).

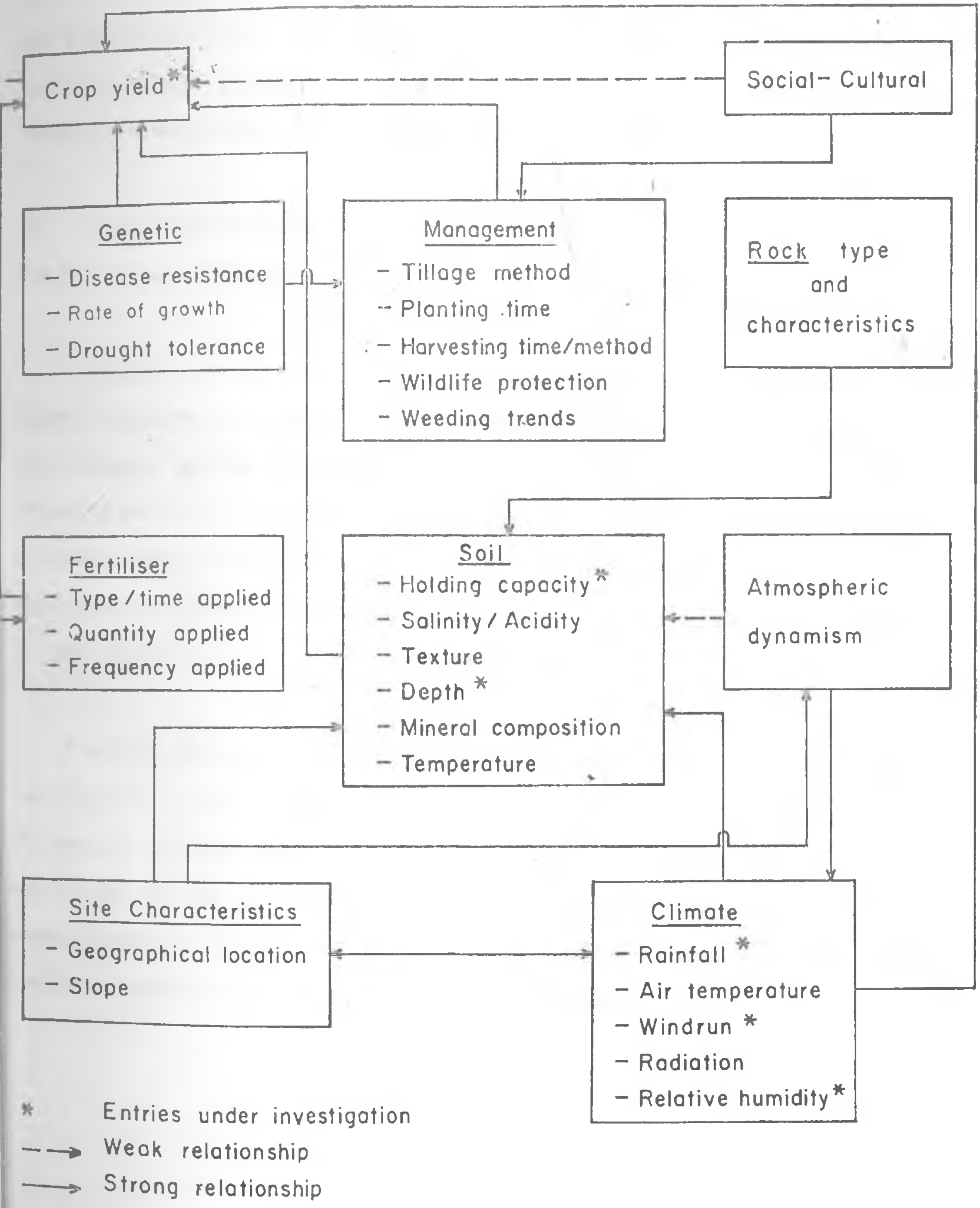
1.5 CONCEPTUAL MODEL.

Crop environment inter-relationships are complex since they incorporate both the biotic and the abiotic components which are by themselves inter-related (Ndolo, 1985).

The success of any crop in terms of production is determined by many factors within the crop environment. A shift in any of the environmental factors could mean failure in yield in spite of the others remaining favourable.

In the case of this study, some environmental factors were assumed to be favourable and constant (Fig. 1.0), so that the others could be investigated in relation to their effects on the bean crop yield. Naturally this may lead to certain limitations in my results, but it certainly is a better method for such agro-climatological studies.

Fig. 1.0 CONCEPTUAL CROP PRODUCTION MODEL.



To accomplish the goals of this study, a guiding plant-environment model was developed (**Fig. 1.0**). The model may not be fully exhaustive but it serves the purpose for which this study is designed. It should be regarded as a guideline to showing how intricate the crop-weather and soil relations can be. It also illuminates those factors or aspects of weather and soil used to assess crop water interactions in this work.

1.6 LITERATURE REVIEW.

1.6.1 General Literature

Literature on crop water relations is readily available as this has been a subject for several investigations in recent years. These studies, particularly gained impetus after Penman`s classical work (Penman, 1948) in which he showed that meteorological data can be used to calculate potential evapotranspiration rate, from a green crop with adequate water supply. In this study Penman states that to satisfy potential transpiration rate, it is not essential to keep the soil waterlogged.

Further, Hakias ***et. al.***, (1955) concludes that soil moisture becomes a limiting factor for transpiration and plant growth when it is reduced to the permanent wilting point. On the other hand, Fritschen and Shaw (1966) emphasize at the need for considering crop development when estimating evapotranspiration. This is because at different stages of plant growth, and development the rate is bound to be different.

Studies on evapotranspiration can lead to estimates of water needs of crops(Wood, 1963; Laycok, 1964 and Pereira, 1970) and due to their significance, research in this area has led to the publication of evaporation maps for East Africa (McCullogh, 1965; Dagg *et. al*, 1970). Additionally a number of studies have included direct measurements of evaporation using pans, many of which were installed in a network of agrometeorological stations more than two decades ago (McCullogh, 1965; Dagg, 1969; Wang`ati, 1972).

Braun (1977) combined rainfall and E_t estimated from the Penman E_o values (estimation of open water evaporation) to calculate probabilities that rainfall during the growing seasons will be less than the equivalent of 2/3 and 1/2 of Eo. Crop failure is assumed in the later case, while 2/3 is taken as approximation of the "ideal" water requirements of a typical crop (a disease free crop adequately supplied with soil nutrients).

Dagg (1965) recognizes that both crop water requirements and crop water ability to extract water from the soil changes with growth stages as the season advances, and the extractable soil water further depends on soil depth and holding capacity. Research on the design and installation of weighing lysimeters (Glover and Forsgate, 1964; Forsgate *et. al*, 1965) has resulted in determination of water requirements of sugarcane (Blackie, 1969), tea (Dagg, 1970), maize and beans (Wang`ati, 1972), rice (Ndolo, 1985), beans (Munga, Lenga and Stewart, 1984) and bananas (Nkedi-Kizza, 1973).

Stewart and Mugah (1979) relate weekly water requirements of Katumani Composite B maize to Class A pan evaporation rates,, forming crop coefficients for use in estimating water requirements elsewhere in the same environment.

Another approach was followed by those researchers who first derived soil moisture stress terms from climatic data and soil characteristics and then related these variables to grain yields. In these studies, it was found that the ratio of derived actual evapotranspiration at defined phenological periods to grain yields of wheat and sorghum varieties were more closely correlated with yields than a number of other indices used to characterize the crop water environment (Mack and Ferguson, 1968; Baier and Robertson, 1968; Fitzpatrick and Nix, 1969; and Nix and Fitzpatrick, 1969).

Not only the type of meteorological variables employed in yield estimation changed, but also the periods of time over which these variables were related to crop response became shorter. While earlier statistical studies were based on annual and monthly totals and means (Wood, 1963) daily if not hourly values had to be used in the biophysical crop weather models because the former estimates were less accurate and it was now possible to use better and more reliable methods made possible by the advancement in technology

The recent studies show that any crop weather analysis should be specific enough to consider only the crop life stages (Mugah ***et al.***, 1984; Stewart and Faught, 1984; Kashasha, 1982; and Stewart and Kashasha, 1984). Annual averages and means are of little importance in giving the desired crop weather interaction (da Mota, 1978).

In the tropics the most important crop-weather phenomenon is rainfall (Woodhead, 1970; Jackson, 1977). A successful season is more or less judged by the amount of rainfall received at that given season, this success will further depend on the rainfall characteristics over that season namely intensity, frequency and duration. Analysis of rainfall events over shorter duration using probability analyses has become common (Woodhead, 1982; Mungai, 1984), for it helps us to estimate the amount and spread of the rainfall in a given season. This subject will be pursued further in this investigation, for there is still deficiency in research in this field.

Although total amount of rainfall has been used to estimate crop production and in zonation of high and low agricultural potential areas in Kenya, it should be noted that not all the rainfall received in a given place is available for the crop. It is only a particular proportion (fraction) that is effective for the crop (Dastane, 1974; and Doorenbos and Pruitt, 1977). Research on effective rainfall and crop production has been done in the recent past, and its importance has been recognized in crop production planning (Stewart and Faught, 1984; Stewart and Hash, 1981; Stewart and Kashasha, 1984; and Ndolo, 1985).

Kashasha (1982) extends the analysis on effective rainfall for maize production to nine localities encompassing an area of 13,000sq km in Machakos and Kitui districts. Important findings were that, the essential correlations found at Katumani Dry land Research Station exist in all nine localities considered in his investigation. He identifies regions where there may be a period "too late" for planting maize. Periods are also determined for each locality during which risks for maize production are relatively low.

Stewart and Kashasha (1984), apply the term "onset windows" to the early onset periods when planting of maize is advised, and define the acceptable dates in each locality for each of the two seasons. Pertinent examples of general crop-versus environmental relationship may be seen in Stewart and Hagan (1969) for alfafa, Stewart *et al.*, (1976) for grain sorghum and beans, Stewart and Hash (1981), and Kashasha (1982) for maize, and Ndolo (1985) for rice. Methods developed are utilized by Doorenbos and Kassam (1979) to estimate water production functions of crops.

Frere and Popov (1979) describe the methods of calculating crop yield using climatic parameters and have used them to analyse rainfall records in Tanzania and other countries for the purpose of establishing drought warning criteria.

Stewart and Hash (1981) conclude that, the analysis of effective rainfall in dry land farming can be used to evaluate the suitability of a crop for a given site before planting because **(a)** It defines the earliest and the latest acceptable dates of onset of rains for growing a given crop and **(b)** Quantifies the initial rainfall which should be accepted by the farmer as the signal to plant his crop and reveals that, date of onset of the rains can be correlated with total seasonal rainfall expectations. Hence, it pinpoints ranges of dates properly termed **`early´**, **`late´** and **`too late´** as regards planting. This in turn can be used to group yields as either good, fair or poor.

From the above review, it is evident that the desirable dates of planting in Kenya`s semi-arid lands depends on the seasonal expectations of rainfall. It is also important to note that the frequency by which further rainfall will occur after date of onset is paramount because it will enormously affect the yield. This becomes especially vital for a crop that completes its life stages in a short span of time, and in areas where rainfall is known to be variable (Braun,1977) as is the case in the study area namely South Eastern Machakos District. This indeed is investigated in the present research.

1.6.2 Crop Related Literature Review.

Investigation on bean crop water relations has been done mostly in temperate environment and mostly with the crop under irrigation. Therefore little has been done as proposed herein.

Doyle (1979) working in California found that soil moisture was the primary factor affecting pod set of Lima bean, however, the capacity pod set did not assure high yield if competition among developing pods for essential metabolites resulted in blossom and pod obcission. The investigation showed that maintaining the soil moisture above 75% of field capacity increased Lima bean yield when a hot dry period of moderate severity occurred during the pod setting.

Mack and Varseveld (1979) working with experimental plots on snap beans found that pods were increased by irrigation and plant density in four field experiments. Higher yields were obtained with the -0.6 **bar** soil potential regime which represented removal of 40 to 45% of the available soil water at the 30 **cm** depth. The yields were lowest with -2.5 **bars** soil water potential which represented 65 to 75% water removal.The conclusion by the two researchers is that, for snap beans, availability of extractable water in the soil is very essential and determines the expected yield.

Doorenbos and Kassam assert that, the common bean (***Phaseolus vulgaris***) does not have a specific soil requirement but friable, deep soils with pH of 5.5 to 6.0 are preferred. Fertilizer requirements for high production are 20 to 40 **kg/ha**. nitrogen, 40 to 60 **kg/ha**. phosphorous and 50 to 120 **kg/ha**. potassium. The capacity of the beans to fix nitrogen makes it less affected by nitrogen inadequacy in the soil, hence the crop can meet its requirements for high yield. However a starter dose of nitrogen is beneficial for good early growth (Stewart and Fought, 1984). The two workers put water requirements of bean for maximum production of 60 to 120 days crop as from 300 to 500 **mm** depending on climate. When grown for the fresh product, the total growing period of the crop is relatively short, and during the ripening period, which is given as 10 days long, the crop evapotranspiration is relatively small because of the drying of the leaves.

Cackett and Metelerkamp (1963) found that the water use pattern for variety Red Canadian wonder bean was similar to that of maize (***Zea mays***) but the pattern for bean had a wider flat peak covering the period from nine to twelve weeks after planting.

In East Africa research on bean water relations has lagged behind in spite of the obvious importance of the crop in the region. Using Lysimeter Wang'ati (1972) studied water use of beans and maize and concluded that, the bean crop (***Phaseolus vulgaris***) variety Canadian wonder and maize crop in warm tropical climate in East Africa is closely related to the leaf area index and hence ground cover. However, the frequency with which the canopy is wetted by rain has a strong effect on the internal resistance of the crop canopy on the ratio of potential evapotranspiration and open water evaporation (E_t/E_0) and hence on total water use during the season. He however cautions on transfer of E_t/E_0 values recorded in one area to other environments on the ground that they are likely to underestimate the given crop water requirements.

Mugah, Lenga and Stewart (1984) using lysimeter measurements of bean water requirements (**Mwezi Moja** variety) versus estimates based on climatic parameters at the Kenya Agricultural Research Institute (K.A.R.I), Muguga (a rather wet and cooler area near Nairobi-altitude 2095 metres and rainfall 954 mm. per annum) concluded that, the water requirements (ET_m) of **Mwezi Moja** bean averaged over a successive 10-day interval and taking 85 days to complete its life stages was 407, 379, and 358 mm using the three meteorological formulae, namely, the modified Penman formula, Radiation method and the Pan evaporation method respectively. The three methods well approximated the lysimeter measurements of 362 mm closely, with the pan evaporation method being the closest.

Stewart and Faught (1984) using meteorological data from Katumani and setting field experiments established linear relationships between crop yield and seasonal rainfall for both intercropped and monocropped maize and beans. They worked correlations on dates of onset related to seasonal rainfall rather than the actual evapotranspiration (ET_a) and maximum evapotranspiration (ET_m) ratio (ET_a/ET_m), and recommended that:

a) Onset criteria and planting dates of beans are same as for maize

b) The seeding rate for both medium and high level management is 12,0000 seed/ha. to result in 100,000 plants/ha.

c) Nitrogen fertilizer is only applied in high level management, always at the planting time.

In spite of the various investigations done on beans, much more is needed. This is in particular on investigations which could serve as guideline in bean production in Kenya's dry lands. Crop water requirements calculated in cooler and wetter areas can not be used as a baseline for planning crop production in semi-arid lands (Wang'ati, 1972) for it is bound to flactuate with the changing environment.

Correlating seasonal total rainfall with onset dates as suggested by Stewart and Faught (1984) or by Kashasha (1982) may not be very useful in areas where the rainfall is known to be highly variable and unreliable most of the time. In my view it is more useful to the farmer to know or to be able to estimate the frequency of rainfall after onset date than knowing total rainfall at the end of the season. This is the Thesis of the current research, a pioneering approach.

1.7 JUSTIFICATION OF THE STUDY.

Studies on effective rainfall and crop production are important in the planning agricultural expansion as they give an insight into how a particular crop is likely to perform in a given area (Stewart and Faught,1984; Stewart and Hash, 1981; Kashasha, 1982; Stewart and Kashasha, 1984, and Ndolo,1985). This realization and the emphasis on expanding food production in semi-arid lands of Kenya crowns the subject of this research with the obvious importance (GOK, 1981).

The selection of the two varieties of bean under investigation was partly because of their known tolerance to inadequacy of soil moisture (Stewart, and Faught, 1984) and partly because the bean crop is second to maize in importance in Machakos District (MDC,1970, pp 14) and in the medium potential areas of Kenya as a whole (Keya *et. al.*, 1979; Chui,1988). Secondly, due to competition from maize, its yields have been reported to be as low as 32% of the sole crop bean (Chui and Nadar, 1984).

The hectarage under beans in the study area is high, though fluctuates from year to year according to the scanty data available (**Table 1.0**). The production and the income farmers get from bean is also high.

Although many varieties of beans are planted in the study area for instance, Mexican 142, French bean and Canadian Wonder, it is only Rose Coco and Mwezi Moja which are more popular (Eijnatten et. al., 1975). Bean 1 variety, an improved variety from Katumani National Dry land Farming Station, has shown that it matures earlier and is tolerant to pest attack, and it takes shorter time to cook than other locally grown varieties (MDC, 1985). It was therefore thought necessary to undertake research on water requirements of the two varieties (Bean 1 and Mwezi Moja). The insight into this should give a wider choice to the farmer on the suitability of each variety in the study area and elsewhere in similar environments.

Table 1.0: Bean production and the monetary value received in Machakos District.

Year	Area (ha.)	Production (tons)	Value (K£)
1970	46,957.75	–	80,644
1983	77,606	69,846	17,461,525
1984	43,500	5,872	228,370
1985	77,000	35,000	17,000,000

Source: Annual Report Machakos District (1985): Ministry of Agriculture.

CHAPTER: TWO

2.0 THE STUDY AREA.

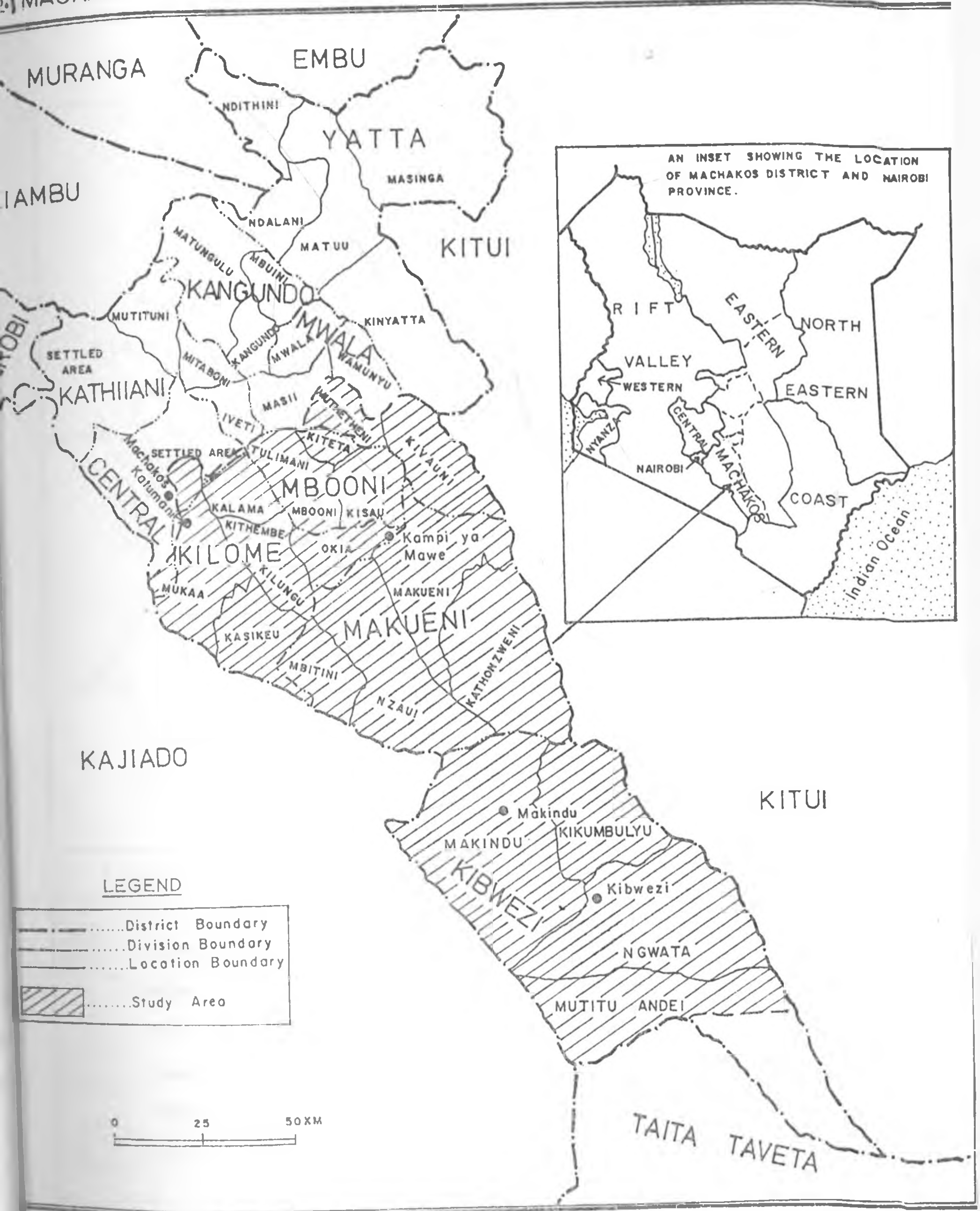
2.1 INTRODUCTION:

The study area is South Eastern Machakos in Machakos District, Eastern Province of Kenya. The District extends some 275 km from north-west to south-east. To the west is the Kajiado District, Taita-Taveta to the south east, Kitui to the east, Embu to the north east, and Kiambu District and Nairobi Province to the north-west (**Fig.2.1**). In total Machakos District has an area of approximately 14,250 sq km.

However, the actual study area includes that part of the District (Machakos) south east of Machakos town (1 **deg.**30`S, 37 **deg.**20`**E**) a town about 75km south east of Nairobi (as marked in **Fig.2.1**) and extends south-eastwards to border Kitui and Taita-Taveta District. The study area occupies about 65% of the district and includes Kilome, Makueni, Kibwezi and Mbooni divisions.

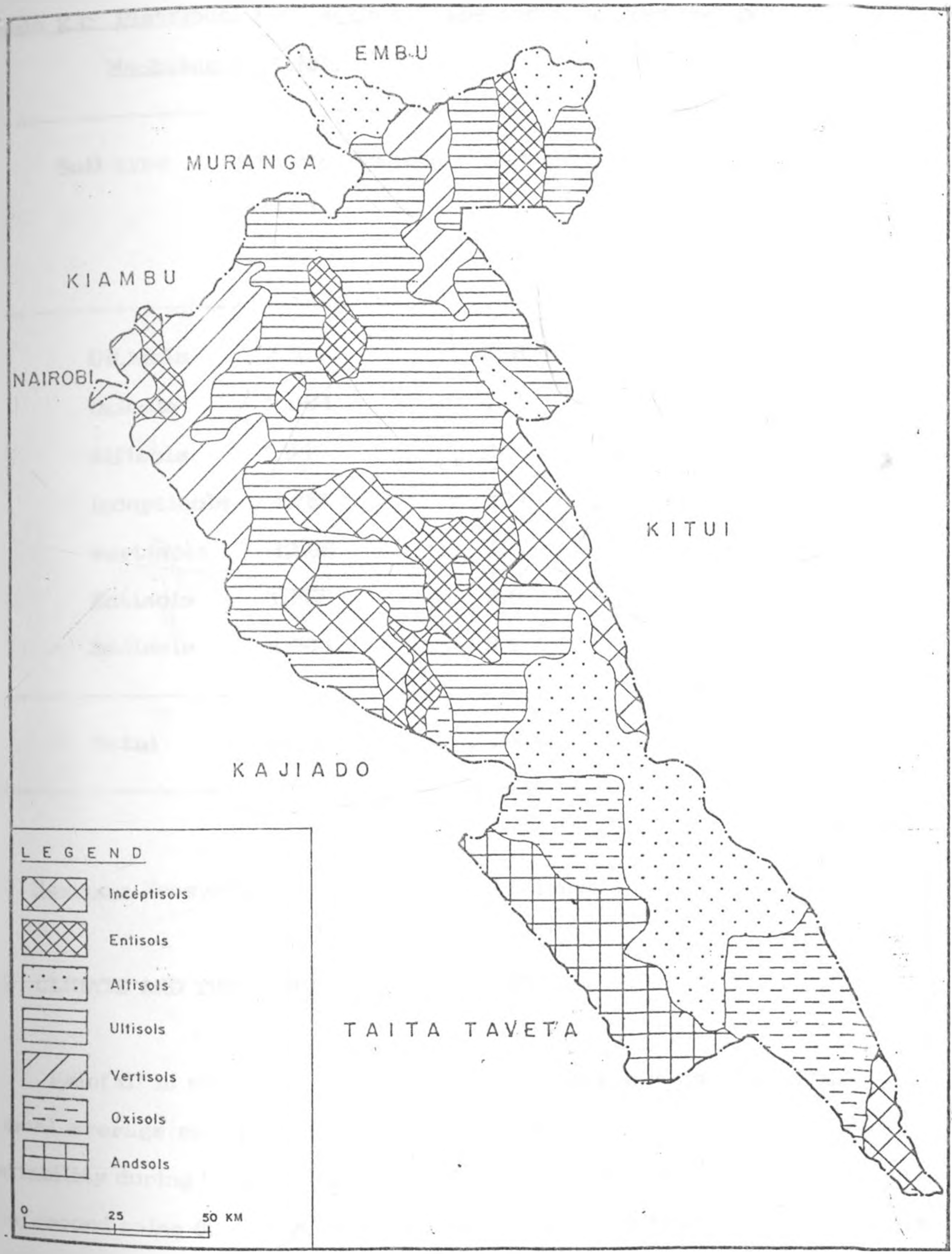
The area has seven basic soil types namely; entisols, inceptisols, alfisols, ultisols, oxisols, vertisols and andosols. However, the most common ones are ultisols, oxisols, inceptisols and alfisols (not necessarily in that order) (**Table 2.1** and **Fig. 2.2**)

2·1 MACHAKOS DISTRICT: LOCATION OF THE STUDY AREA.



By Isaac O. Ayuyo

FIG. 2.2 : MACHAKOS DISTRICT : MAJOR SOILS



Source : *Ecosystems LTD Nairobi, Kenya* (1985)

Table 2.1: Distribution of soils by type and area covered in Machakos District.

Soil type	Approximate area covered. (sq. km)	Percentage of total District area(%)
Ultisols	4,521	31.8
Oxisols	2,004	14.1
Alfisols	1,935	13.6
Inceptisols	1,785	12.6
vertisols	1,598	11.2
Entisols	1,366	9.6
Andisols	1,004	7.1
Total	14,213	100%

Source : Ecosystems Ltd. 1985; Nairobi-Kenya

2.2 CLIMATE AND THE MICRO-CLIMATE CONDITIONS

Rainfall in the study area varies temporally and spatially. The total annual average ranges from 500mm and 1300mm with the total 60% rainfall reliability during the growing period of the first rains being 50-450mm, and the second rains 60-530mm (Jaetzold and Schmidt, 1983 pp 49). The rains are normally concentrated into two short seasons, that is, end of March-May and end of October-December.

The movement of the **ITCZ** (inter-tropical convergence zone) over the area disrupts monsoon wind flow and provides the basis for increased rainfall activity. This results in March-April and October-November being the wettest periods. In the October-December rainy season the **ITCZ** is located south of the equator and is a zone of the low pressure and convergence (Dennett ***et al**,.* (undated)). Precipitation occurs where conditions are favourable (Musembi, 1984). In April, the low pressure develops along the Equator associated with passage of the overhead sun, causing wide spread convection of wind and hence precipitation over large parts of the study area. From March to May the position of the sun shifts northwards, followed by a lag of 4-5 weeks by the position of the **ITCZ**.

The rains in the more northerly areas have been known to begin later in the March-May season and less earlier for the October-December season (Akonga *et. al.*, 1987). This is attributed to the progress of the ITCZ, although the actual time of the onset of rains is quite variable, even in stations within relatively close proximity (in the order of 25 km.) (Stewart, 1983). Since plants are vulnerable to moisture deficits in the first few weeks after germination, the timing of the "onset of rains" is crucial in agricultural planning. In the study area the termination of the March-May rains appear to be fairly regular, allowing predictions of seasonal rainfall based on the date of onset of the rains and the rainfall amounts during the first few weeks (Stewart and Faught, 1984, Kashasha, 1982, Dennett ***et. al.**,* (undated)).

Thus the March-May season is generally called the "long rains" and the October-December season the "short rains", although seasonal length and reliability vary across the study area. The length of the October-December rain season becomes longer as one moves towards the southern parts of Kenya (Akonga *et. al.*, 1987, pp 24). This season is sometimes referred to as the long rains in the lower parts of the study area (Southern Machakos District) where they are more reliable i.e last longer with higher totals compared to the actual "long rains" in the March-May season (Downing, Mungai and Muturi,1987, pp 24).

Indeed the study area in general experiences high variability of rainfall with highest amounts received in the months of November (**Table 2.2, 2.3, 2.4,** and **2.5**). The average annual rainfall ranges from 591 in Makindu, 658 in Kampi-ya-mawe, 661 in Katumani to 704 mm in Kibwezi (**Tables i-iv,** in **Appendix I**). In general, the study area is demarcated (in terms of rainfall) by isohyet 500 and 800 mm (**Fig.2.3**)

2.3 AGRICULTURAL POTENTIAL OF THE STUDY AREA:

Machakos District is one of the largest (in Kenya) in terms of total land area as well as being one of the poorest in agricultural potential. Commercial agriculture is practiced in areas with limited coverage due to poor soil and unsuitable climate. Hence, smallholder rainfed agriculture has become difficult in more than 80% of the District area. Despite the

Table 2.2: Mean and extreme rainfall records (in mm) at Katumani (1962 - 1987).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MEAN	47	38	77	148	62	11	5	4	7	37	148	82
LOWEST	0	0	0	20	0.6	0	0	0	0	0	34	12
H/ST	190	120	216	315	151	62	38	20	43	154	462	262

Note:H/ST is Highest

Source: Field Data.

Table 2.3: Mean and extreme rainfall records (in mm) at Kampi-ya-mawe. (1962-1987).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MEAN	41	29	86	147	44	11	2	6	6	40	178	97
LOWEST	0	0	3	1	5	0	0	0	0	0	64	0
H/ST	136	78	296	298	132	118	9	22	32	212	341	228

Source: Field Data.

Table 2.4: Mean and extreme rainfall records (in mm) at Makindu (1962-1987).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MEAN	36	30	59	121	26	4	1	2	3	31	183	101
LOWEST	0	0	0	9	0	0	0	0	0	0	16	3
H/ST	234	135	205	292	98	32	5	26	32	175	467	318

Source: Field Data.

Table 2.5: Mean and extreme rainfall records at Kibwezi D.W.A Plantation (1962-1987).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
MEAN	36	33	81	118	34	3	6	2	6	34	220	133
LOWEST	0	0	6	7	0	0	0	0	0	0	25	15
H/ST	372	183	205	304	186	21	149	20	45	135	583	289

Source: Field Data.

environmental hardships, during the seasons of reliable rainfall, the farming community produces appreciable quantities of food crops which meet domestic food reqirements (GOK, 1989). Thus the agricultural sector in Machakos District has, and should continue to be the main source of income in the district. The present emphasis is on provision of food security for rapidly growing population and at the same time generate household incomes.

To achieve the aims noted above, methods of farming practiced should ensure that the fragile semi-arid ecosystem on which the farmers depend does not breakdown. Successful farming should henceforth depend on the types of crops grown and environmental perception. Any scientific contribution towards achieving this end should be a welcome gesture in the study area.

CHAPTER: THREE.

3.0. RESEARCH METHODOLOGY.

3.1 INTRODUCTION:

The research methods and models used in the data analyses are given in this Chapter. Each model or method adopted was found suitable within the perspectives of the research objectives as revisted below:

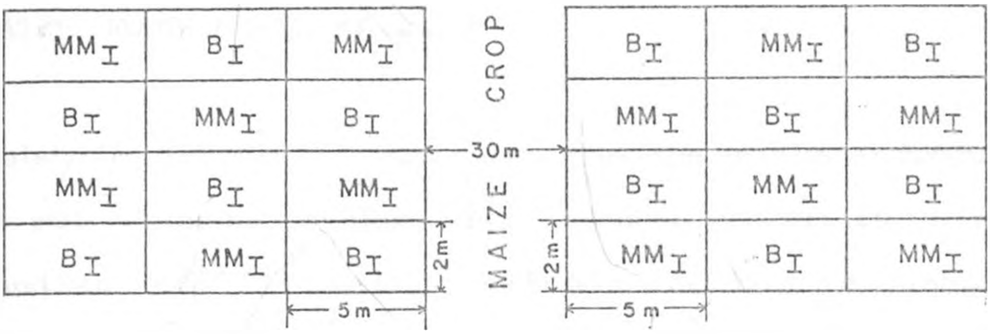
(1) To calculate crop water requirements of **Mwezi Moja** and **Bean 1** varieties under dry land farming conditions that prevail in South Eastern Machakos District of Kenya.

(2) To examine the portion of total rainfall which can be taken as effective for the said varieties (in (1) above) so that they can meet their crop water requirements and,

(3) To determine if rainfall variations after the start of the season can be predicted.

To achieve (1) above, an experiment was conducted from 8th November, 1988 to January 26, 1989 at the Katumani National Dry Land Research Station. **Mwezi Moja** and **Bean 1** varieties were planted (mono-cropped) in two blocks. The blocks were subdivided into 6 plots (**treatments**) each of size 5 by 2 metres. Randomization of the varieties was done and the final feature is shown in **Figure 3.1**. Spacing was done 50 by 30 cm between and within rows, respectively.

Fig. 3.1. : PLOT LAYOUT – PLANTED ON 8TH NOV. 1988 AT KATUMAI NATIONAL DRYLAND FARMING STATION



MM_I	B_I	MM_I
B_I	MM_I	B_I
MM_I	B_I	MM_I
B_I	MM_I	B_I

B_I	MM_I	B_I
MM_I	B_I	MM_I
B_I	MM_I	B_I
MM_I	B_I	MM_I

B_I . . . . Bean I variety
MM_I . . . . Mwezi Moja variety
Design . . . . . . Randomized complete block (RCB)
Spacing. . . . . . 50 x 30 cm between and within rows respectively
Size . . . . 2 x 5 metres per treatment
Harvest. . . . . . 0.871 and 0.874 for MM_I and B_I, respectively

Sampling : To select the subplot for taking soil measurements in each decade (10 – days), random numbers assigned to each were the guiding factor. This gave each subplot an equal chance of being sampled

Two seeds were placed in each hole. After two weeks one plant was uprooted so that only one seedling remained to grow. Other parameters are considered in the subsequent sections.

3.2 CROP WATER REQUIREMENTS ($ET_{(bean)}$).

To calculate bean crop water requirements and the crop water production models. The methodologies developed by Doorenbos and Pruitt (1977) and Doorenbos and Kassam (1979), and adopted by Food and Agriculture Organization (F.A.O) were found most suitable. The specific models are summarised as follows:

$$ET_{(crop)} = ET_o.K_c \text{ ------------------------------ } (3.1)$$

and

$$ET_o = K_p.E_{pan} \text{ ------------------------------ } (3.2)$$

where :

$ET_{(crop)}$ = crop water requirements or crop evapotranspiration.

ET_o = reference crop evapotranspiration.

E_{pan} = pan evaporation in mm/day or period and represents the mean daily value of the period considered.

K_{pan} = pan coefficient.

K_c = crop coefficient.

To calculate bean crop water requirements, Equation 3.1 and 3.2 above can be written as:

$$ET_{(bean)} = ET_o.K_c \text{ ------------------------------ } (3.3)$$

and

$$ETo = K_{p(Katumani)} * E_{pan(Katumani)} \text{----------} (3.4)$$

The above equations were used in calculations of estimates for crop water requirement $ET_{(bean)}$ using the meteorological data gathered in the study area and the field estimates.

3.3 REFERENCE CROP EVAPOTRANSPIRATION. (ET_o).

To calculate reference crop evapotranspiration (ET_o), pan coefficients were extracted using the method given by Doorenbos and Pruitt 1977 pp 34 and are given in **Table 3.1**. These coefficients depends on the wind run and relative humidity. Ground cover situation also affect pan coefficients (K_p)(Kaila, 1983). Since bean crop is a short crop, it was assumed there was no need to adjust the K_p values due to ground cover. During the time when the experimental trials were conducted (8th November, 1988 to January, 26th 1989) the surrounding environment was green.

Daily pan evaporation was taken for each day and averaged to represent the 10-day interval for the whole of the bean season. To standardize the pan readings, a factor of 1.05 was used (Kaila, 1983) so that the readings are harmonized with the U.S.A class A pan evaporation (see the third entry in **Table 4.1**).

Table 3.1 Pan coefficients (Kp) for Katumani Class A pan estimates depending on windrun (km/day or m/sec) and relative humidity (%).

Decade (10-day period)	1	2	3	4	5	6	7	8	1-8
Windrun km/day	104	122	126	118	116	98	89	82	107
Windrun m/sec	1.2	1.45	1.46	1.36	1.34	1.14	1.03	0.9	1.24
Relative humidity (%)	69	74	66	73	83	69	66	68	71
Pan coeff.(Kp)	0.8	0.85	0.8	0.85	0.85	0.8	0.8	0.8	0.8

Source : Field estimates:

Method of extraction adopted from Doorenbos and Pruitt (1977 pp 34)

3.4 CROP COEFFICIENT (K_c).

From equation 3.1 and 3.3 section 3.2, $ET_{(bean)}$ cannot be computed unless the crop coefficients (K_c) is known. This is essential since $ET_{(crop)}$ (crop water requirement) is the sum of transpiration by the crop and evaporation from the soil (E_{soil}) (Doorenbos and Pruitt, 1977 pp 37). It is important to note that the value of crop coefficients largely depends on the reference crop evapotranspiration (ET_o) and the frequency with which the soil is wetted by rain and/or irrigation (**Fig.4.1**). The results of this analysis for Katumani are given in **Table 4.1, Chapter Four.**

Crop water requirements for both bean varieties was calculated. Since the two varieties took the same period to complete their growth stages and had same $ET_{(bean)}$, one table was used to represent results of both varieties (**Table** 4.2). and discussed row by row in **Chapter Four.**

3.5 EFFECTIVE RAINFALL (P_e)

A simplified water balance model used to estimate effective rainfall or actual evapotranspiration (ET_a) by the crop has also been applied by Stewart and Hash, (1981); Kashasha, (1982) and Ndolo, (1985).

The equation used to compute P_e is given by:

$$P_e = R + IRR - R_o - {}_dL \text{ ------------------(3.5)}$$

where:

Pe = effective precipitation

R = rainfall (or precipitation)

IRR = Irrigation or any other source of water apart from rain.

R_o = runoff.

${}_dL$ = drainage loss (beyond the rooting depth)

IRR in this study was zero since the source of water was only the rain.

With regard to the calculation of effective rainfall, Stewart and Hash (1981) suggest that one only requires the following:

- **(i)** the daily rainfall record,
- **(ii)** the daily class **"A"** pan evaporation record or equivalent,
- **(iii)** a one-time measurement of soil depth and field capacity, and,
- **(iv)** a reasonable basis for assuming runoff is prevented, weeds controlled and the seeding rate sufficient to produce a stand which can fully utilise the rainfall.

Daily rainfall records were available at the Katumani Agro-Meteorology office from the date of planting to the end of the bean crop season. The records were analysed on the basis of a decade (10 days period).

Measurements of soil field capacity and depth were taken for each 10 day period (except when the day of taking the measurements was rainy, and in which case the following day was considered). The soil data used in this study is presented in **Table 3.2.**

Table 3.2: Soil Moisture Characteristics as measured at Katumani Dry land Research Station.

Depth(cm)		Wilting point (lower limit) cm_3/cm^2	Field capacity(FC) (drained upper limit) cm^3/cm^2	Saturated cm^3/cm^2	Estimated Bulk Density g^2/cm^3
Abs.	int.				
10	10	0.140	0.250	0.300	1.35
20	10	0.140	0.250	0.300	1.35
30	10	0.140	0.290	0.320	1.35
50	20	0.150	0.300	0.330	1.40
70	20	0.170	0.300	0.340	1.40
80	20	0.170	0.300	0.350	1.40
110	20	0.180	0.310	0.360	1.40
130	20	0.180	0.320	0.370	1.40

Note : Abs.= Absolute int. = interval

Source: Field Data recorded at Katumani Dryland Research Station, (1988).

3.6 RAINFALL VARIABILITY:

Rainfall in the study area varies in amount from season to season and year to year (**Table 2.2–2.5**). The variability is more pronounced within seasons than from year to year (**Appendix I Tables I–IV**), an observation noted by

Stewart and Hash (1981) and Akonga, *et. al.*, (1987). To asses the suitability of beans in the study area, it was found necessary to investigate how rainfall varies after date of onset. In the present case variability was considered for three types of onset (early, middle, and late), for both short and the long rains. To assess variability after onset date, the coefficient of variation was found suitable.

3.6.1 Coefficient of Variation (C.V):

The coefficient of variation is used to show dispersion between groups especially where their means are different. It becomes misleading to compare the absolute magnitudes of the standard deviations of given groups under investigation (Blalock, 1981). The solution is to find the size of the standard deviation relative to that of the mean (**Appendix II, Artical** a)

In this work, to calculate the coefficient of variation the following steps were undertaken :

- **(a)** Probabilities of dry spell 15 days long computed after the onset date.
- **(b)** Mean probabilities computed for each 15 days interval from the date of onset up to the end of the season.
- **(c)** Standard deviations computed from **(a)** above, and
- **(d)** The coefficient of variation computed as the ratio between standard deviation and the mean. This was done for each season category, grouped depending on the date of onset and extracted from 26 years period (1962-1987).

(e) Plots of coefficient of variation versus time (in days) after onset date were made (**Fig. 4.2–4.9,**), which represents the variation (or rainfall frequency after onset date).

3.6.2 Probability Analyses:

From section **3.6.1 (a)** and **(b)** plots for the probability of a dry spell 15 days long after the onset date versus time (in days) were made to generate time series curves (**Figures.4.10–17 Chapter Four**) and the method used in computing the probabilities is explained in **Appendix IIb.**

3.6.3 Evaluation of Rainfall Variability using Simple Linear Regression Analysis:

Besides using the coefficient of variation to assess variability of rainfall after the onset date, simple linear regression model was used to assess the degree of association between consecutive 15 days (i.e 15-days interval) from the date of onset and the probability of dry spell of same days. The rationale was to establish predictability of rainfall variability based on the date of onset. This result would guide farmers on what to expect in terms of variability depending on the onset date. The farmers would inturn adjust their timing schedule (seasonal calendar) accordingly to maximize the opportunities offered by the season and thus increase bean production.

The Simple Linear Regression Model used to assess the variability of rainfall is presented as follows, (Gomez and Gomez, 1976; Draper and Smith , 1981; Chartterjee and Price, 1977):

$$Y_i = \beta_o + \beta_1 X_i + U_i, \quad i = 1, 2, 3, \ldots\ldots n; \ldots\ldots(3.6)$$

Where:

Y_i = the ith observation of the dependent variable

β_o and β_1 = Intercept and slope terms for the regression equation, respectively

X_i = the ith observation of the independent variable

μ_i = a random disturbance, associated with the ith observation.

The assumptions made by this model and other properties are outlined in the quoted references.

To test linearity of the obtained regression equations, the analysis of variance **ANOVA** test was used (**Table 3.3**).

The computed value was compared to the critical **F**- value from the **F**-distribution tables with **n-1** and **n-2** degrees of freedom at **p=0.05** level of significance, to determine if the mean square explained by the linear regression is indeed significant. This prompts an explanation on whether the regression is due to a "real" effect rather than to random sampling.

Thus if the computed **F**-value is greater than the critical **F**-value from the **F**-distribution tables, then there is a significant linear relationship between **X** and **Y**. Hence, the developed equation (**equation 4.4-4.9)** based on

Table 3.3: Analysis of Variance (ANOVA) Table.

Source of variation	Degrees of Freedom (D.F)	Sum of Squares(SS)	Mean Squares (M.S)
Accounted for by regression	1	$\sum_{i=1}^{n}(\hat{Y} - \bar{Y})^2$	$\dfrac{\sum_{i=1}^{n} (\hat{Y} - \bar{Y})}{1}$
Unaccounted by regression	n - 2	$\sum_{i=1}^{n} (Y_i - Y_i)^2$	$\sum_{i=1}^{n}(Y_i - \hat{Y})/n-2$
Accounted for by mean totals	n - 1	$\sum_{i=1}^{n} (Y_i - \bar{Y})^2$	

Source: Draper and Smith (1981).

The F-statistics for Table 3.3 was based on the formula:

$$F = \frac{\text{Mean Squares by Regression}}{\text{Mean Square due to Residuals}} = \text{MSRegr./MSRes.}$$

Thus,

$$F = \frac{\sum_{i=1}^{n} (\hat{Y}_i - \bar{Y})/1}{\sum_{i=1}^{n} (Y_i - \hat{Y})/n-2} \qquad (3.7)$$

where: Y_i = as explained in Eqn. 3.6

Y = the mean of the dependent variables

n = number of the observations

model 3.6, may be used for prediction purposes, as reported in **Chapter Four.**

3.7 RESEARCH LIMITATIONS:

The time and finances which were allocated to this research did not allow for crop water requirements to be calculated over a long time period as would have been desirable, since this could have entailed setting up experiments at all the stations (Makindu, Kibwezi, Kampi-ya-mawe and Katumani). Further, such experimental set up would have to cover several years. Moreover, stations such as Kibwezi and Kampi-ya-mawe do not have records of all the meteorological data necessary for this type of work (for example Kampi-ya-mawe and Kibwezi do not take evaporation measurements). Due to these constraints, it was assumed that the results derived in Katumani on crop water requirements were representative for the whole study area. Effective rainfall was likewise computed for Katumani and this was also considered to approximate conditions in the other stations. Stewart and Kashasha (1984) argue that, the results of effective rainfall got in one station can effectively represent a large area within the same environment. Thus, it was assumed that Katumani, where $ET_{(bean)}$ and effective rainfall were computed represents the whole of the semi-arid zones in the study area. It was on this basis that the rainfall in the other stations was used to get an interpolation of the effective rainfall for the stations which do not record evaporation data.

Only one method (formula) of estimating crop water requirements for beans (**Pan evaporation formula**) was used. Thus it was assumed that the method estimates crop water requirements accurately. This assumption is supported by Mugah *et. al.,* (1984) and Jackson (1977).

However, may be another method could have given more accurate results especially the lysimeter and nuclear resonance methods (which is more laborious and expensive to install) of estimating crop water use. However, these other approaches were not considered due to financial constraints.

The meteorological data taken from the Kenya Meteorological Department and the Katumani Agro-Meteorological office were assumed to be accurate. At present, there is no reason to doubt their accuracy. However, as observed by Sarraf (1971), sometimes meteorological data have error margins of the order of 20%. For the purpose of this study this aspect was not considered.

Soil measurements have at times been a problem to researchers since soil type, texture, depth and colour vary from even shorter distances apart, and this naturally affects the crop stand and performance (Doorenbos and Pruitt, 1977). Again, volumetric measurements have to be harmonized with gravitational ones at times when the equipment constraints allow one type of measurements to be done. This tends to delay any obvious comparison.

CHAPTER: FOUR.

4.0 RESULTS AND DISCUSSION.

4.1 INTRODUCTION

In this **Chapter**, the results of the research are presented under the subtopics of crop water requirements, effective rainfall (Pe), and rainfall variability. Tables are used to summarize the findings whenever found more appropriate, and a short discussion of the results follows.

4.2. RESULTS OF THE EVALUATION OF THE CROP WATER REQUIREMENTS OF BEAN 1 AND MWEZI MOJA VARIETIES.

A sample calculation of the $ET_{(bean)}$ is shown in **Table 4.1** which is explained by row, below:

Row 1: contain the entries of ten day groups from the date of planting to the end of the bean season, which was found to be 80 days for both varieties. This is the duration noted by Nadar and Chui (1984) at Katumani for Mwezi Moja bean variety.

Row 2: represents the entries of pan evaporation data collected daily and averaged over ten days. At the end of the entry is the average pan evaporation for the whole crop season at Katumani.

Table: 4.1 A Sample Calculation of $ET_{(bean)}$ in ten day period by Pan Evaporation Method at Katumani (1988-Short rain season):

1. Decade (10-day group)	1	2	3	4	5	6	7	8	1-8
2. Epan(Katumani Class A pan evap.)mm/day	4.33	3.78	4.58	4.29	3.37	4.9	4.83	4.06	4.27
3. 1.05*Epan(U.S.A Class A pan evap.) mm/day	4.55	3.97	4.81	4.5	3.54	5.15	5.07	4.26	4.48
4. Pan Coefficient (Kp)	0.8	0.85	0.8	0.85	0.85	0.8	0.8	0.8	0.8
5. Reference crop evapo-transp.(ETo)mm/day	3.64	3.37	3.85	3.83	3.01	4.12	4.06	3.41	3.6
6. Crop coefficient (Kc)	0.75	0.75	1.03	1.05	1.05	1.04	1.02	0.9	0.95
7. Crop water requirement(ET(bean) mm/period)	2.73	2.67	4.0	4.02	3.2	4.3	4.14	3.07	3.42
8. Cumulative $ET_{(bean)}$ mm/period	27.3	54	94	134.2	166.2	209.2	250.6	281.3	281.3

Source: Field Data.

Row 3: represents the Katumani pan evaporation data standardized to U.S.A class **A** pan evaporation readings. This was done by multiplying the Katumani pan evaporation (E_{pan}) by a factor of **1.05** (Kaila, 1983).

Row 4: shows the entries of pan coefficients for Katumani site, extracted using the method advanced by Doorenbos and Pruitt (1977) and adopted by Food and Agriculture Organization (F.A.O). The values depend on wind run and relative humidity during the time of interest (**Fig.3.1**).

Row 5: contains a register of the reference crop evapotranspiration (ET_o). It is generated by multiplying **row 3** and **4**, and represents the rate of evapotranspiration from an extended surface with 8 to 15 cm tall, green crop cover of uniform height, actively growing, completely shading the ground and not short of water (in mm/day).

Row 6: are the entries of crop coefficients for both bean varieties extracted using the method recommended by Doorenbos and Pruitt (1977 **pp** 38). The local data needed in extracting the crop coefficients is the rate of crop development and recurrence of significant rainfall or and irrigation. The present study has calculated the recurrence of significant rainfall for 26 years in the study area to be 4 days (**Fig 4.1**).

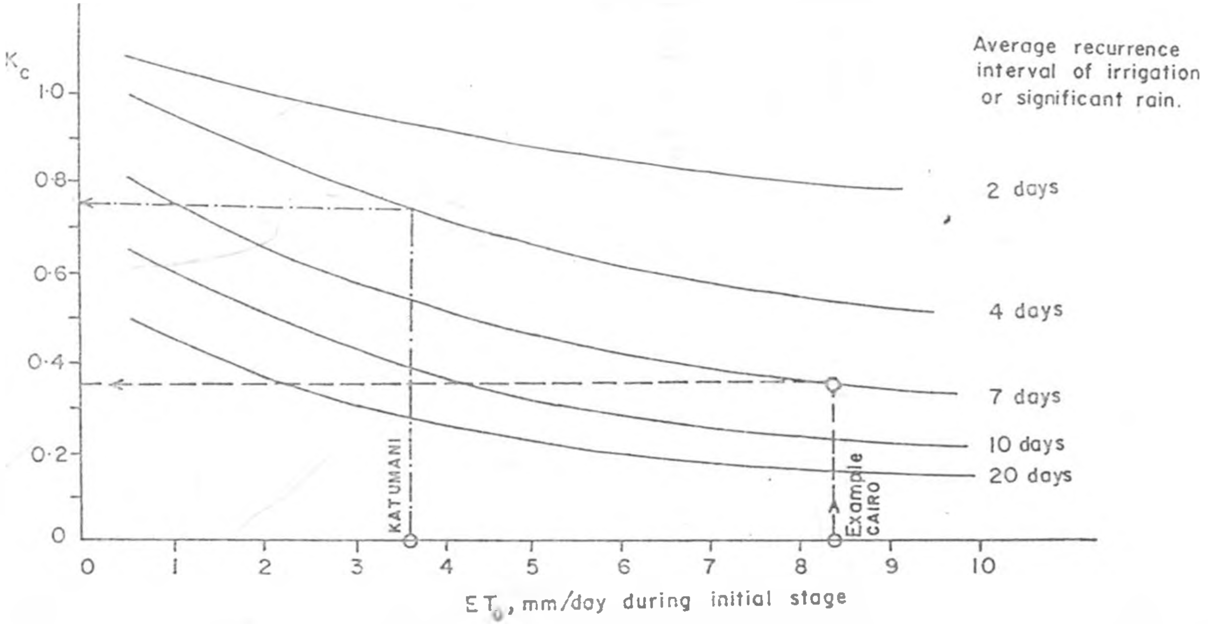


FIGURE 4·1: AVERAGE K_c VALUES FOR INITIAL CROP DEVELOPMENT STAGE AS RELATED TO ET_0 AND FREQUENCY OF IRRIGATION AND/OR SIGNIFICANT RAIN.

Source: Modified from Doorenbos and Pruitt (1977).

Table: 4.2: A Sample Calculations for effective rainfall at Katumani (short rains 1988):

1. 10 day groups	1	2	3	4	5	6	7	8	1-8
2. E_{pan} (Katumani class A evap.) mm/period	4.33	3.78	4.58	4.29	3.37	4.9	4.83	4.06	4.27
3. K_p(U.S.A class A pan Evap.	4.55	3.97	4.81	4.5	3.54	5.15	5.07	4.26	4.48
4. $ET_{(bean)}$(crop water requirement,mm/period)	27.3	26.7	40.0	40.2	32.0	43.0	41.4	30.7	281.3
5. Surplus/Deficit water requirement(mm/period).	1.5	35.6	-37.7	3.7	76.7	-16	41.9	4.5	110.2
6. Pe (Effective rainfall)mm/period	27.3	26.7	0.0	40.2	32	0.0	41.4	30.7	198.3
7. dL(Drainage loss)mm/period	0.0	21.6	0.0	0.0	62.7	0.0	27.9	0.0	96.2
8. ETo(reference crop evapotranspiration (mm/period)	36.4	33.7	38.5	38.3	30.1	41.2	40.6	34.1	36.0
9. 10-day rainfall mm/period	28.8	62.3	2.3	43.9	108.7	27	83.3	35.2	391.5

$$\text{Seasonal Effective rainfall} = \frac{198.3}{391.5} * 100 = 50.6\%$$

Source: Field Data.

Row 7: is the entry of crop water requirements $ET_{(bean)}$ in mm/day.

Finally, in **row 8** the entries of the cumulative $ET_{(bean)}$ from the initial stage to the end of the crop's season are given. At the end of each row is the average value for each entry over the entire bean season.

4.3. EVALUATION OF EFFECTIVE RAINFALL (Pe).

The water balance model in **equation 3.5** was used to compute effective rainfall, following the approach developed by Stewart (1972), Kashasha (1982) and Ndolo (1985), and as discussed in Chapter Three. The results which are summarized in **Table 4.2** are explained below.

Row 1, 2, 3, 4 and 8 are as explained above (**section 4.2**). The remaining entries, namely **rows 5, 6 and 7**, are subsequently explained.

Row 5: represents the surplus or deficit crop water requirements. If the rainfall received within that decade (10- days) is more than $ET_{(bean)}$, then a surplus is entered and a deficit if $ET_{(bean)}$ is more than the 10-day rainfall as entered in the last entry (**Table 4.2**).

Row 6: are the entries of effective rainfall for each ten day group. Rainfall is taken as effective if it satisfies the crop water requirements $ET_{(bean)}$. However the two are not synonymous because not all the moisture is available for the crop. At Wilting Point though there is some moisture remaining in the soil, the crop cannot utilize it and hence transpiration tends towards zero. Rainfall has to bring soil moisture to its Field Capacity from the wilting point before it is considered to be effective.

Finally, to estimate drainage loss ($_dL$), it is assumed that any rainfall that falls will satisfy the $ET_{(bean)}$, before it goes into the soil to bring the soil profile to Field Capacity (**Fc**). After the field capacity is reached, any other soil water in excess is lost through deep percolation (drainage loss). This is shown in **row 7** in **Table 4.2**. This study assumed that runoff is negligible. The site selection was made on the basis of minimizing runoff as well as achieving adequate drainage.

FIGURE 4·2: PROBABILITY TIME SERIES GRAPH.

Kampi ya Mawe: Long rains.

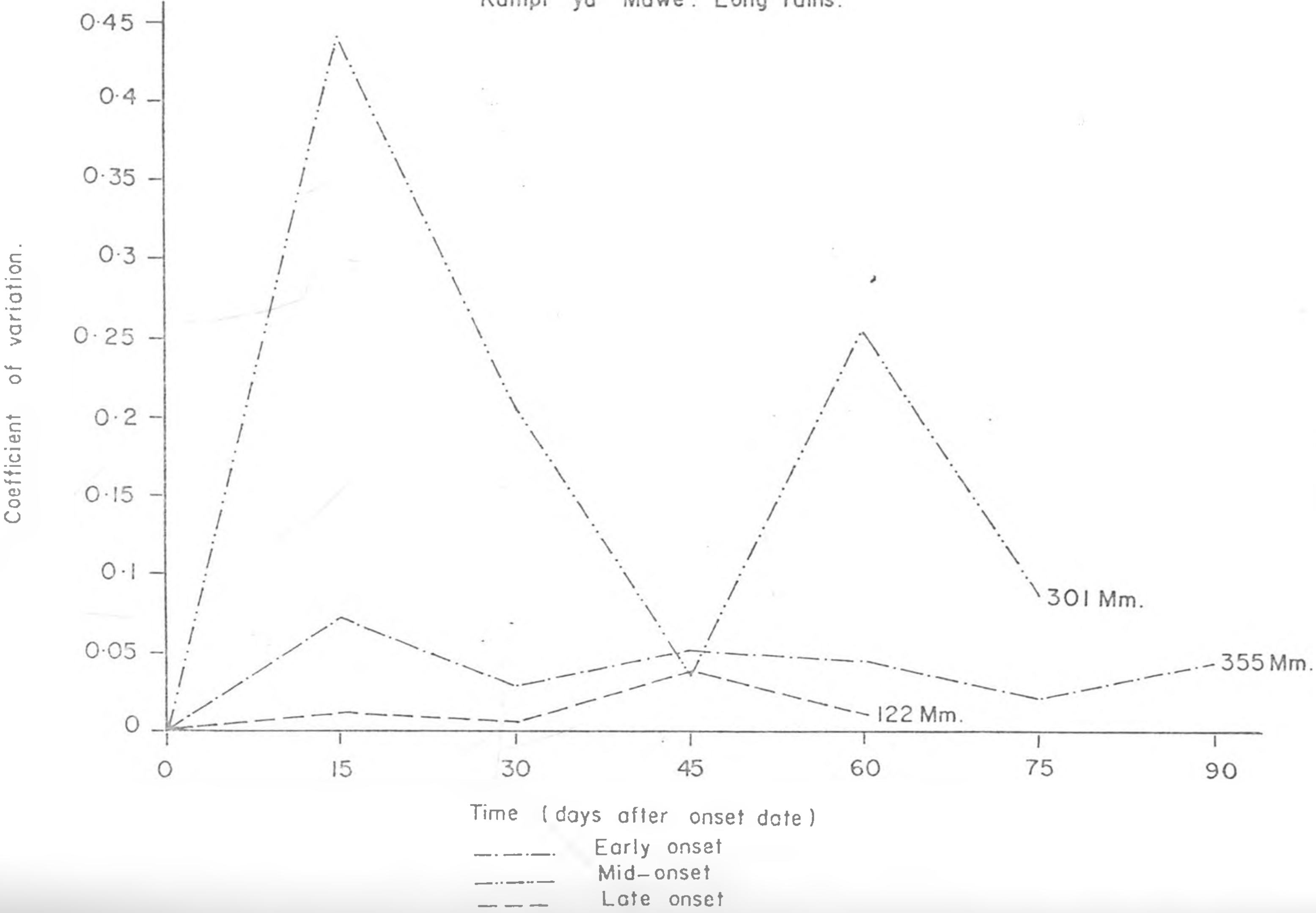


FIGURE 4·3: PROBABILITY TIME SERIES GRAPH.

Kampi–ya–Mawe: short rains.

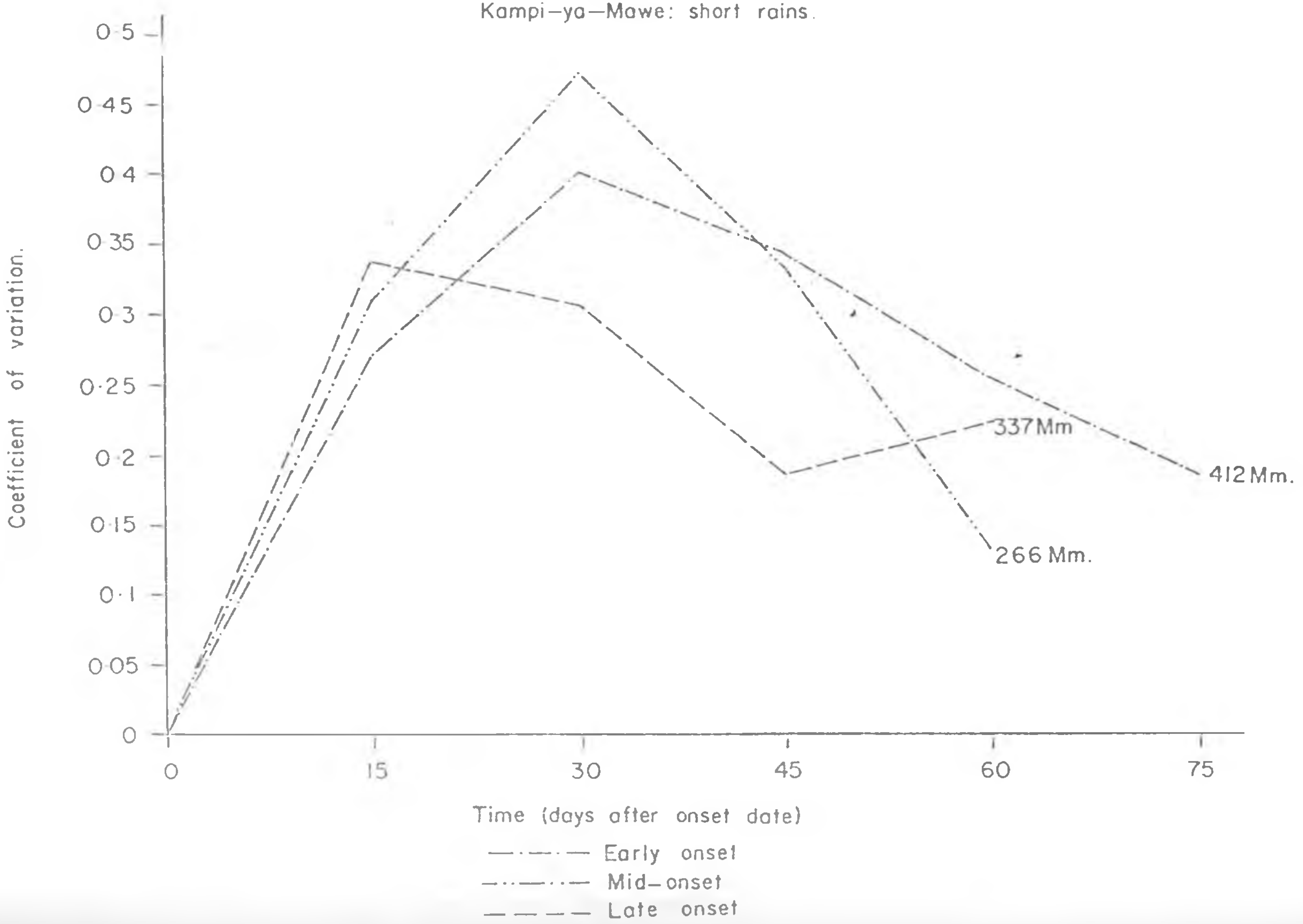


FIGURE 4·4: PROBABILITY TIME SERIES GRAPH.

Katumani : long rains.

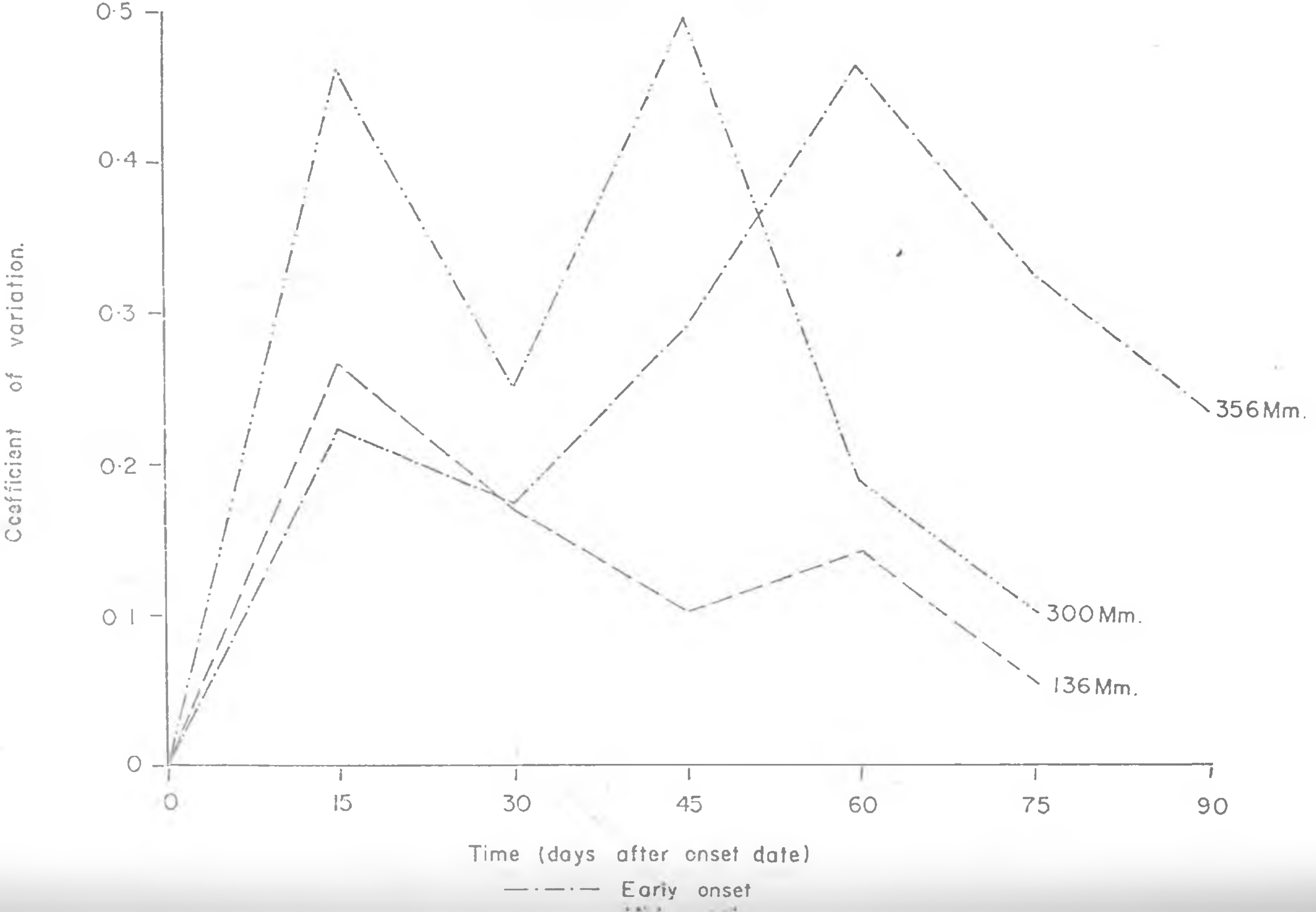


FIGURE 4·5: PROBABILITY TIME SERIES GRAPH.

Katumani: short rains

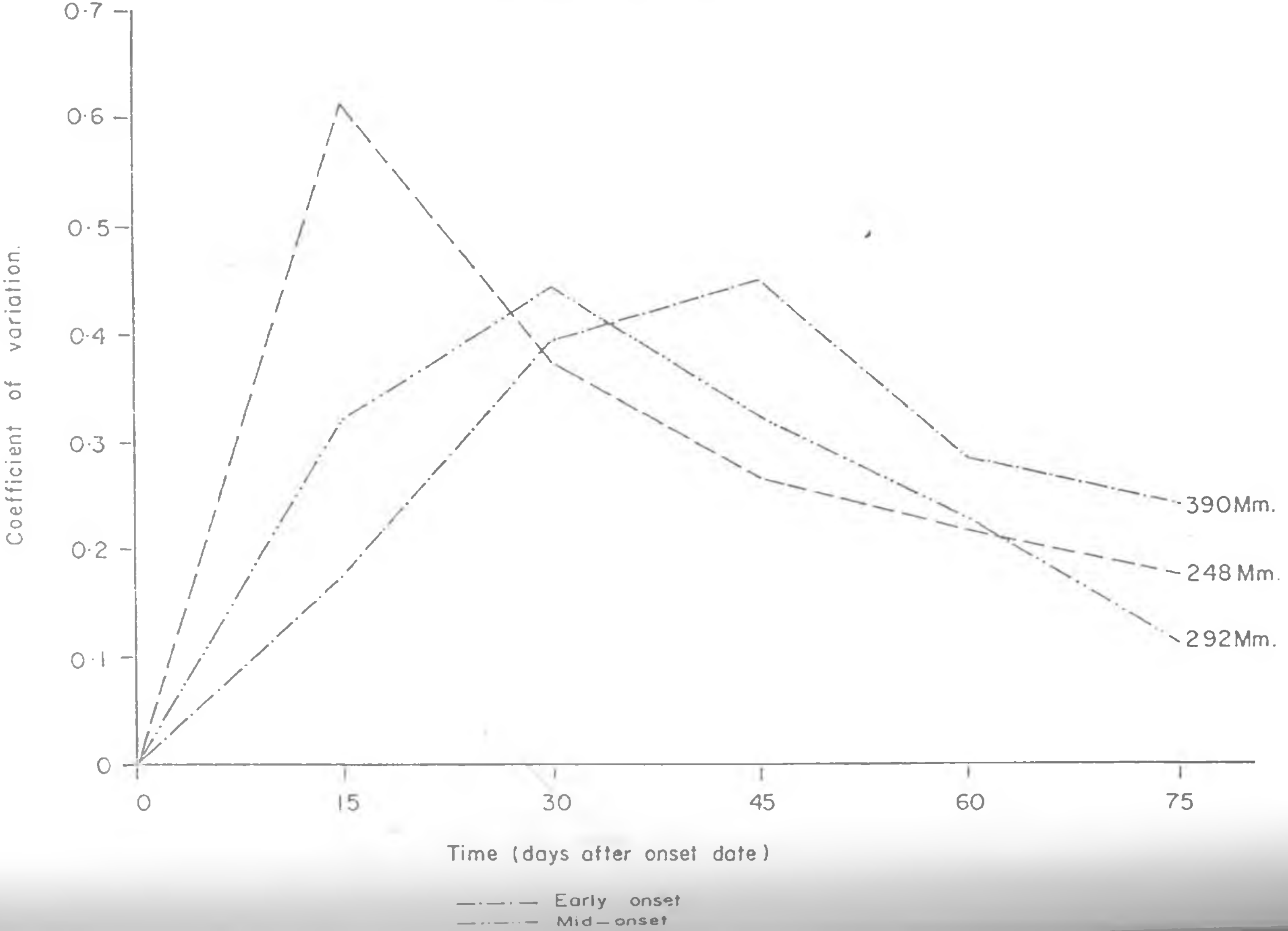


FIG. 4·6: PROBABILITY TIME SERIES GRAPH.

Makindu Long rains

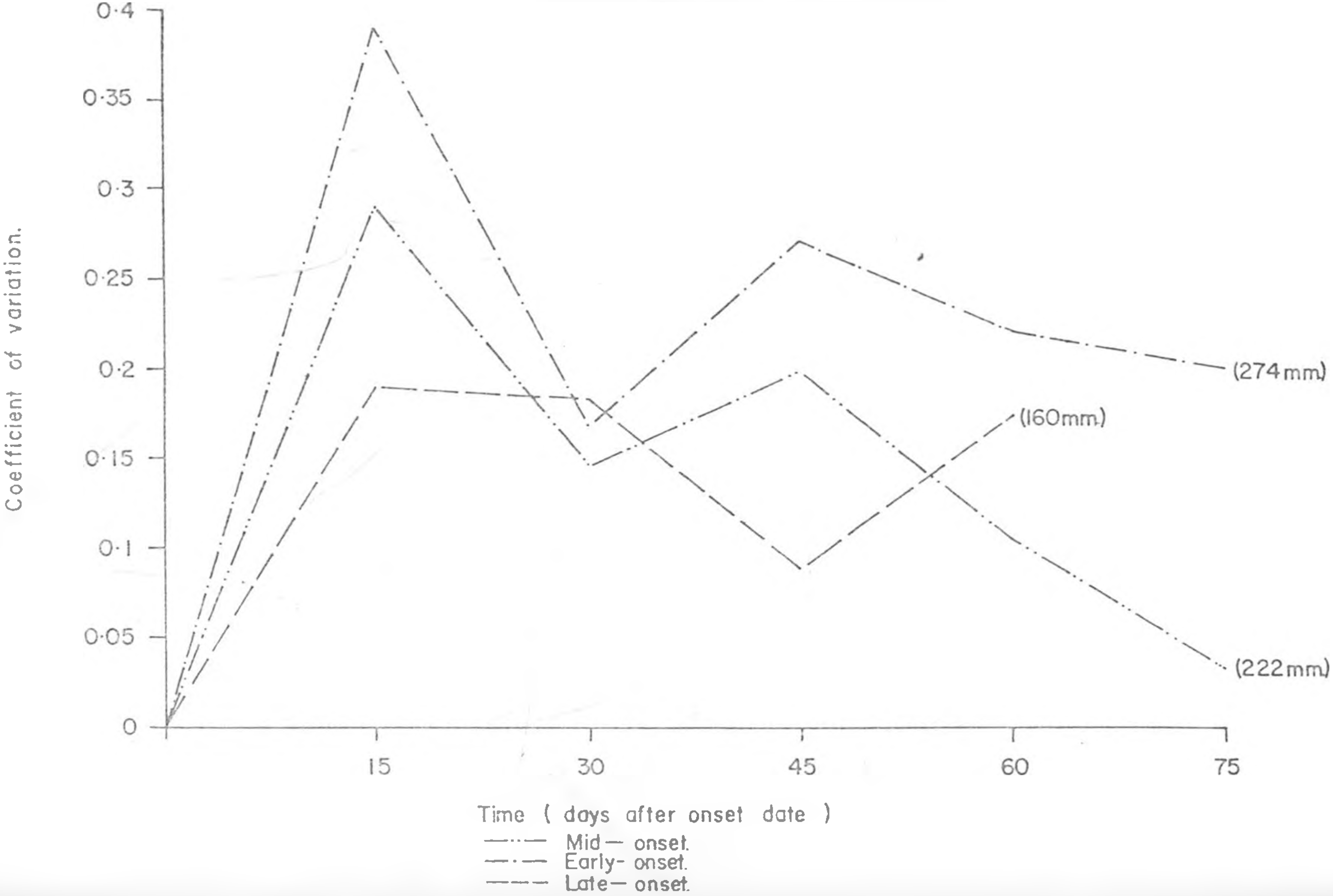


FIG. 47: PROBABILITY TIME SERIES GRAPH.

Makindu : Short rains.

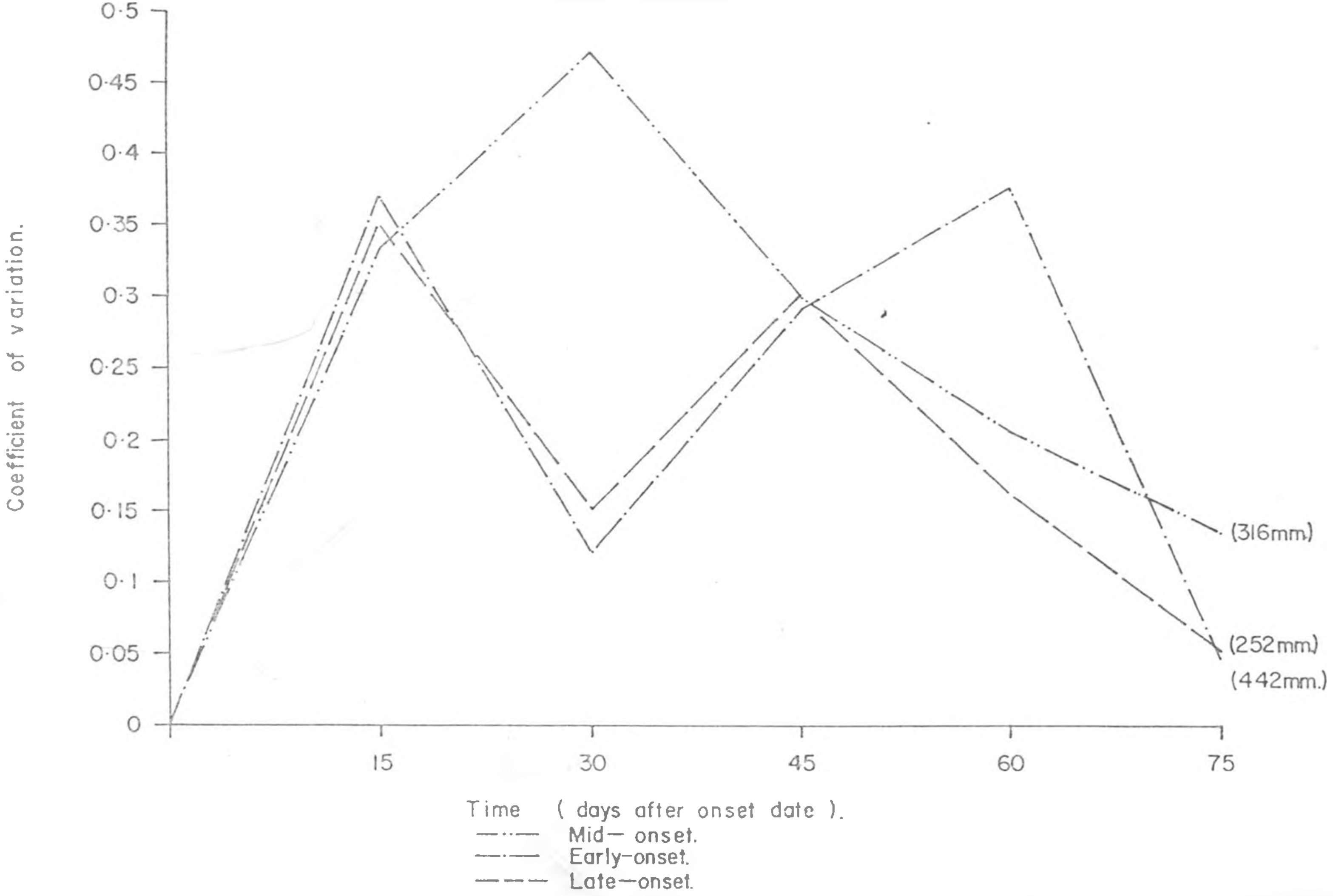


FIG. 4·8: PROBABILITY TIME SERIES GRAPH.

Kibwezi : Long rains.

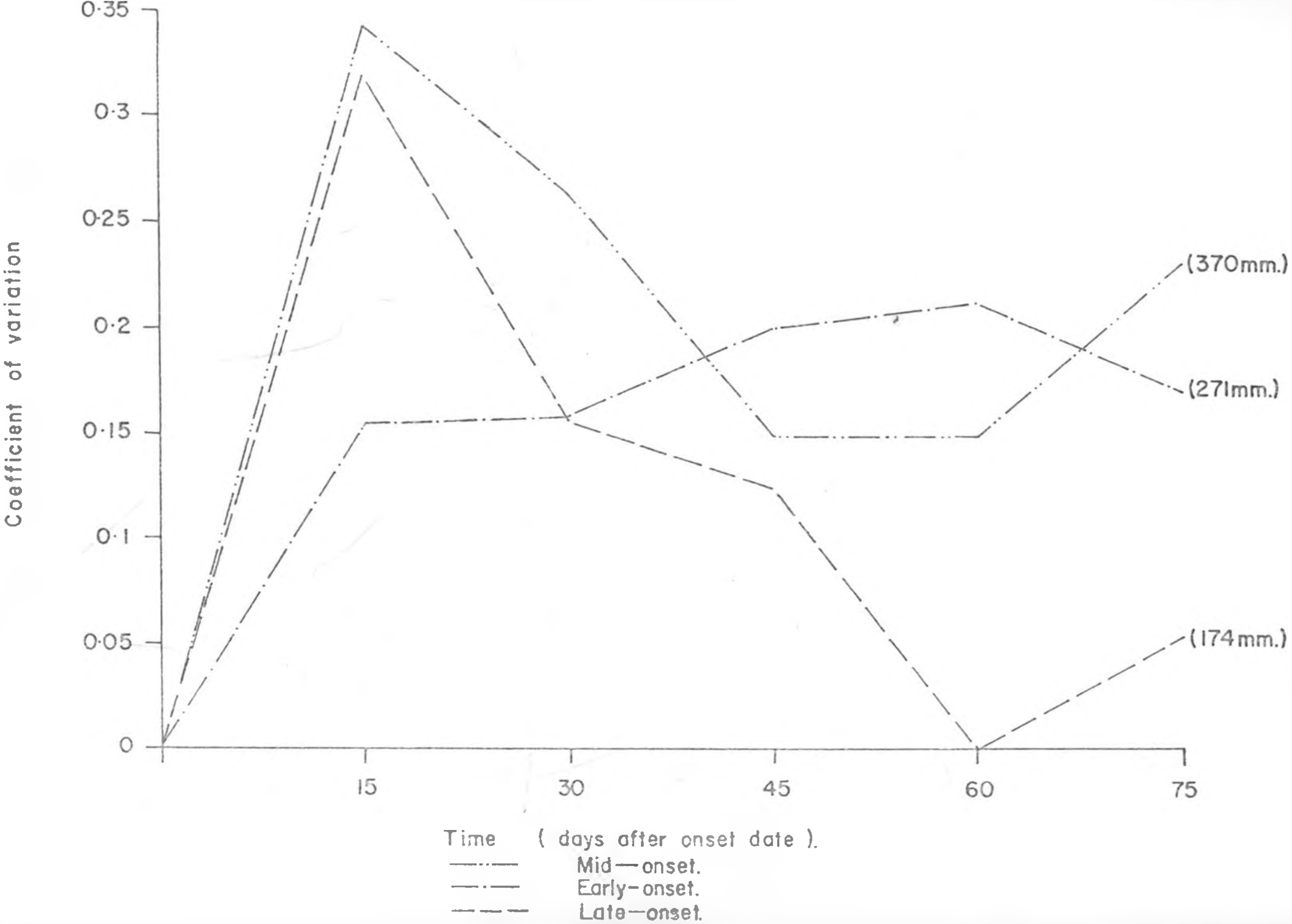
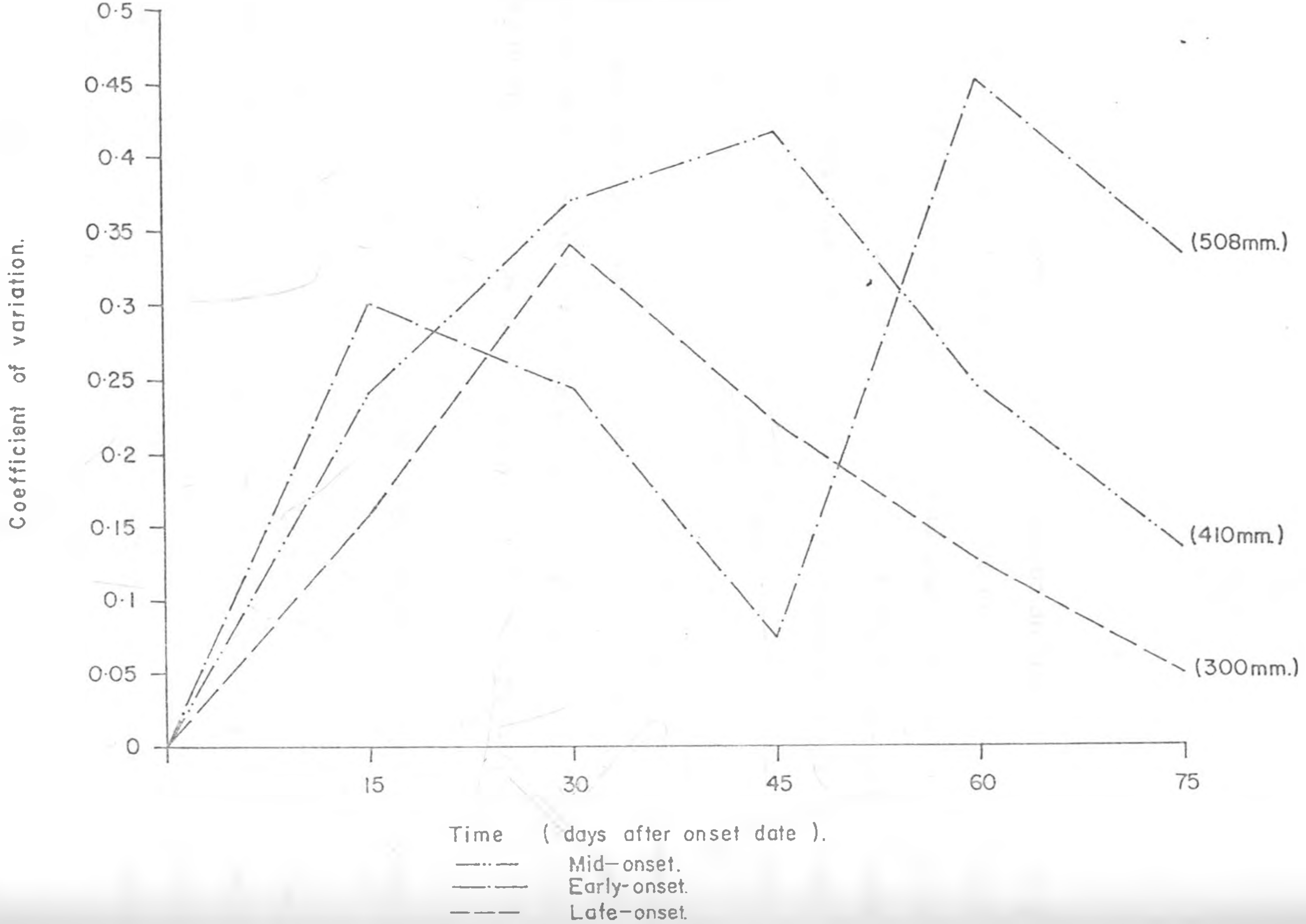


FIG. 4·9: PROBABILITY TIME SERIES GRAPH.



Kibwezi : Short rains.

4.4 EVALUATION OF RAINFALL VALIABILITY.

4.4.1 Coefficient of Variation:

The scenario of rainfall variability after date of onset is shown by time series plots (**Figures 4.2–4.9**). Notice that all the plots start at zero. This is because the first day (onset date) is wet. Again it is important to note that, the plots do not necessarily explain the rainfall variation between day 1 and 14. However the subsequent dry spell events are well explained from day 15.

4.4.2 Probability of 15 Days Dry Spell.

Probability of rainfall events have been used occasionally in East Africa to assess the chances of expecting a given amount of rainfall or absence of rainfall (dry spell) at a given and time (Mungai, 1985; Woodhead, 1970; and Dennett ***et.al.***, (undated); and Braun, 1977).

In this study, probabilities of having dry spell of 15 days after date of onset were computed for each season category, and graphs were plotted (**Figures 4.10–4.17**). Again the plots start at zero when the probability of dry spell is zero (since the first day is wet). There is a sharp rise from day zero to day 15, since it is an extrapolation from day one to day 15. The subsequent plots from day 15 shows the calculated probabilities joined from one plot (point) to the other, up to the end of the dry season.

FIG. 4·10: PROBABILITY OF DRY SPELL.

KAMPI–YA–MAWE LONG RAINS

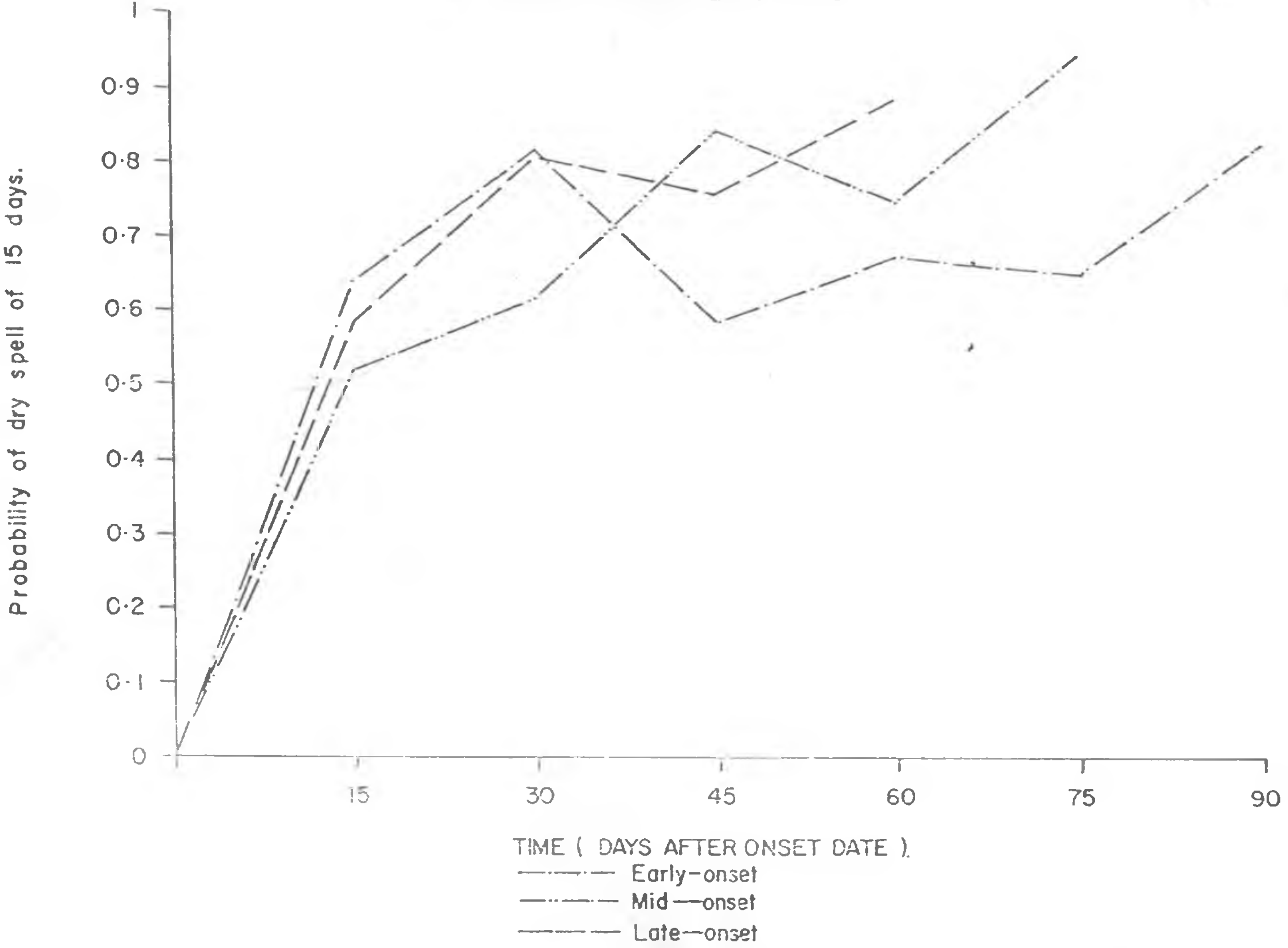


FIG. 4·11: PROBABILITY OF DRY SPELL.

KAMPI-YA-MAWE SHORT RAINS.

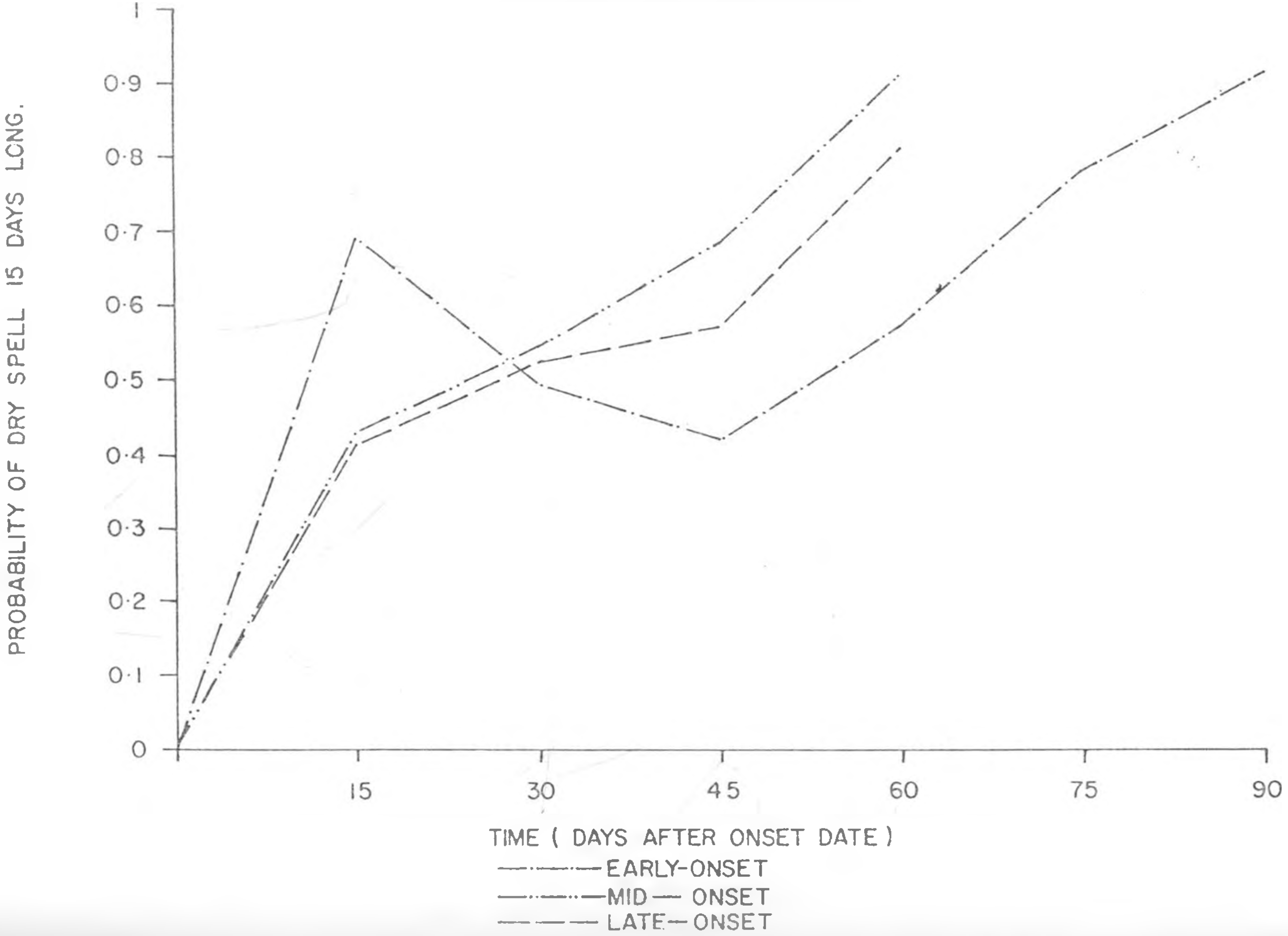


FIG. 4·12: PROBABILITY OF DRY SPELL.
KATUMANI-LONG RAINS.

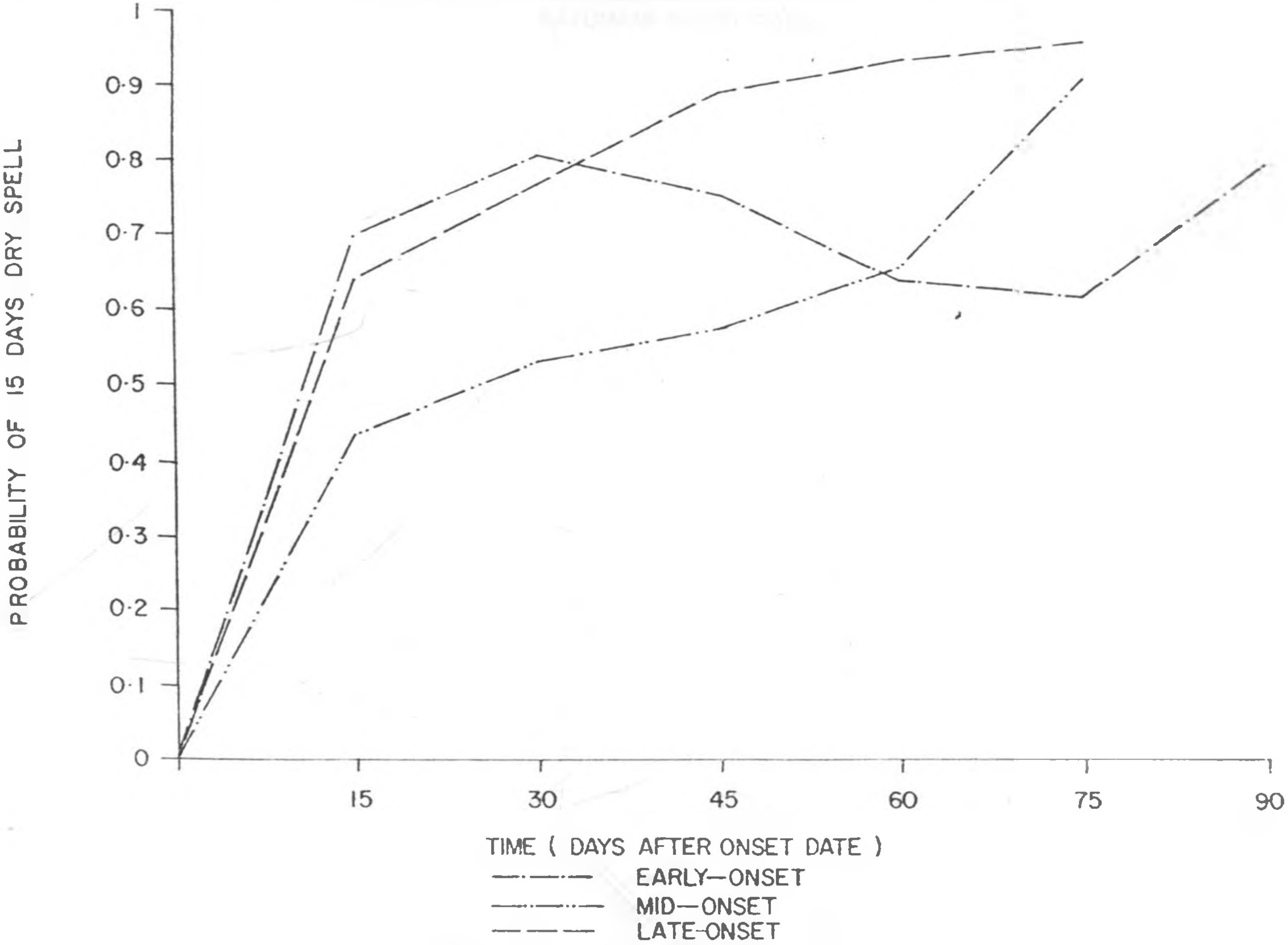


FIG. 4·13 PROBABILITY OF DRY SPELL.

KATUMANI–SHORT RAINS.

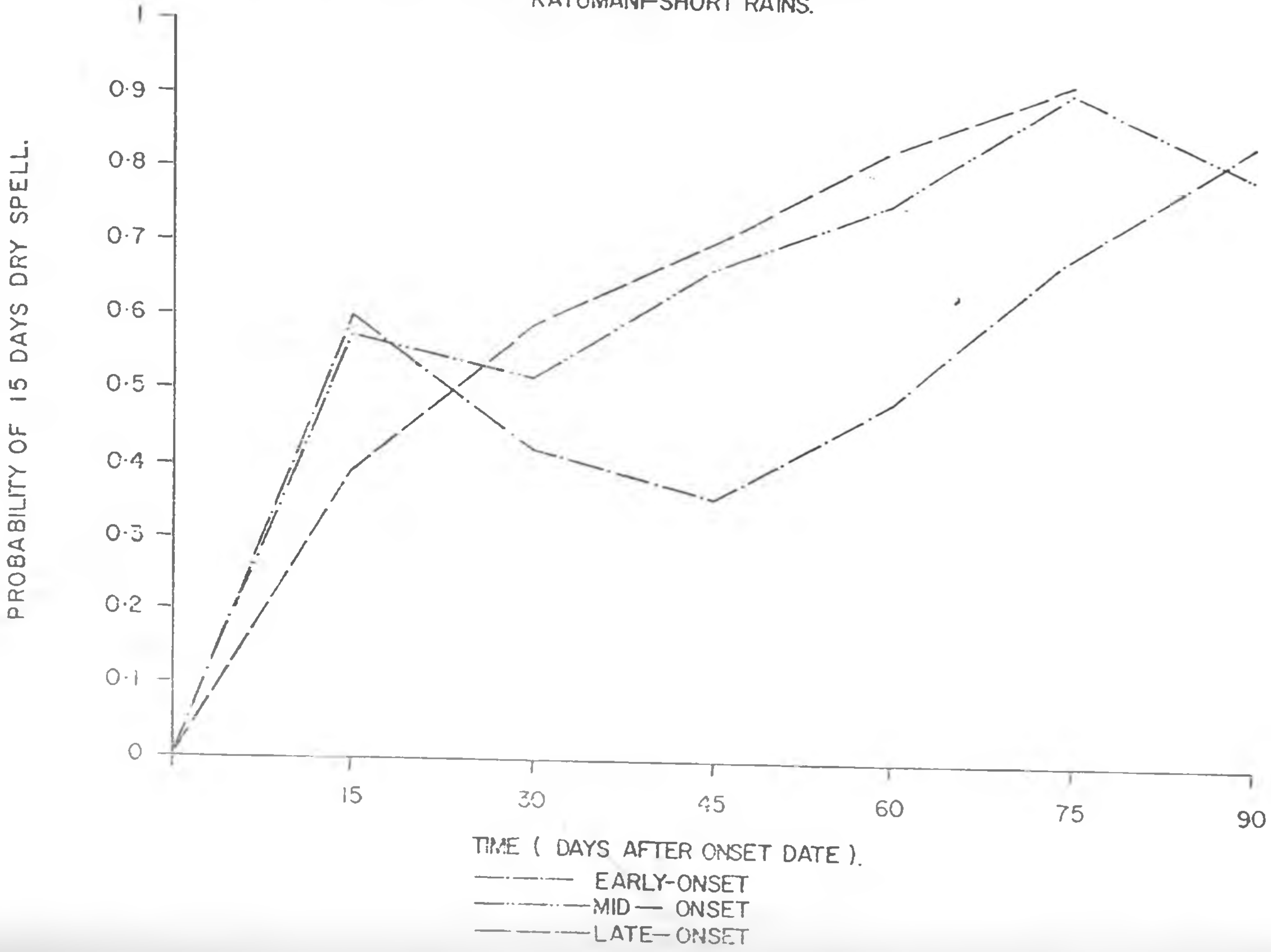


FIG. 4.14 : PROBABILITY OF DRY SPELL

MAKINDU – LONG RAINS

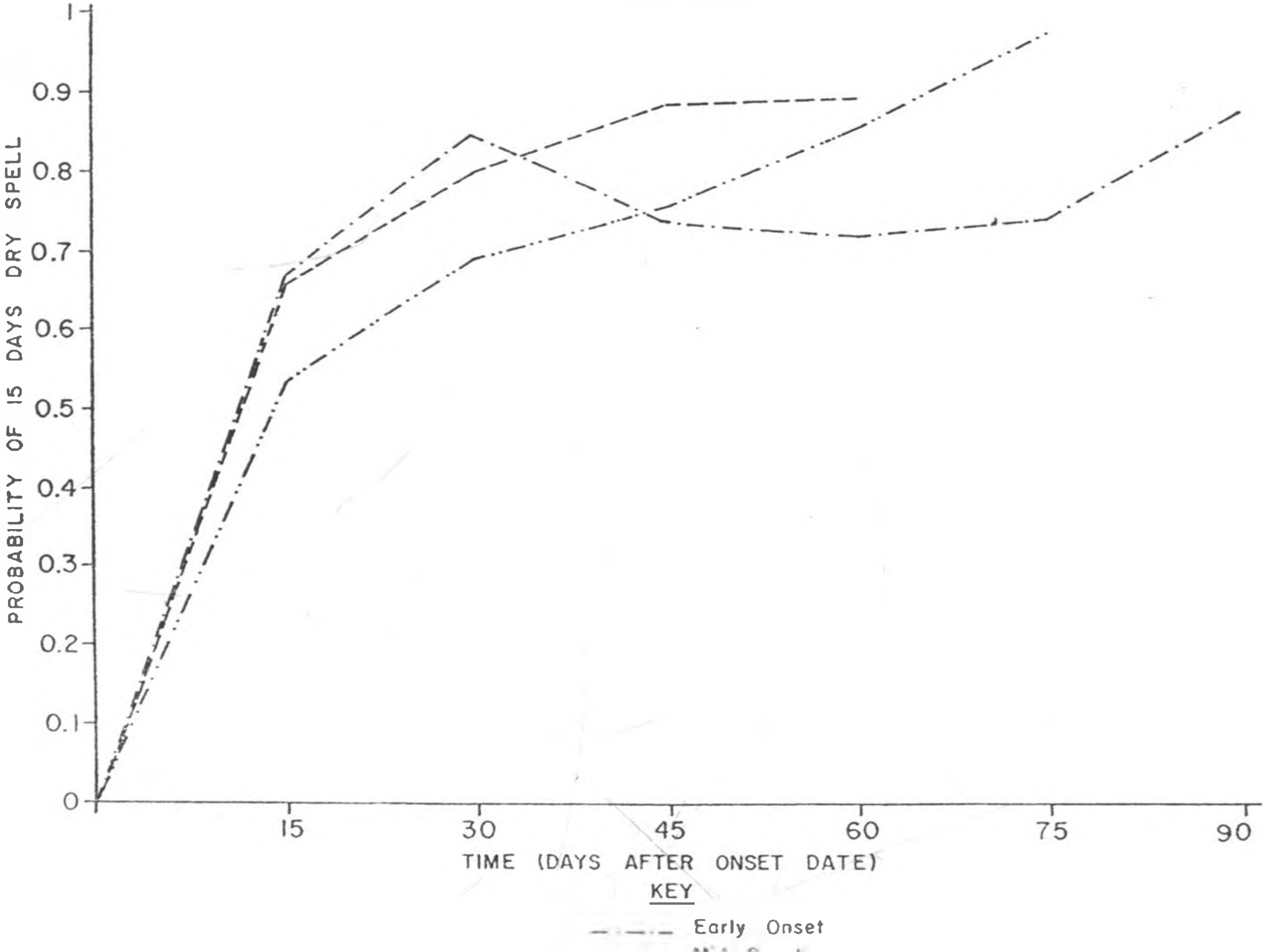
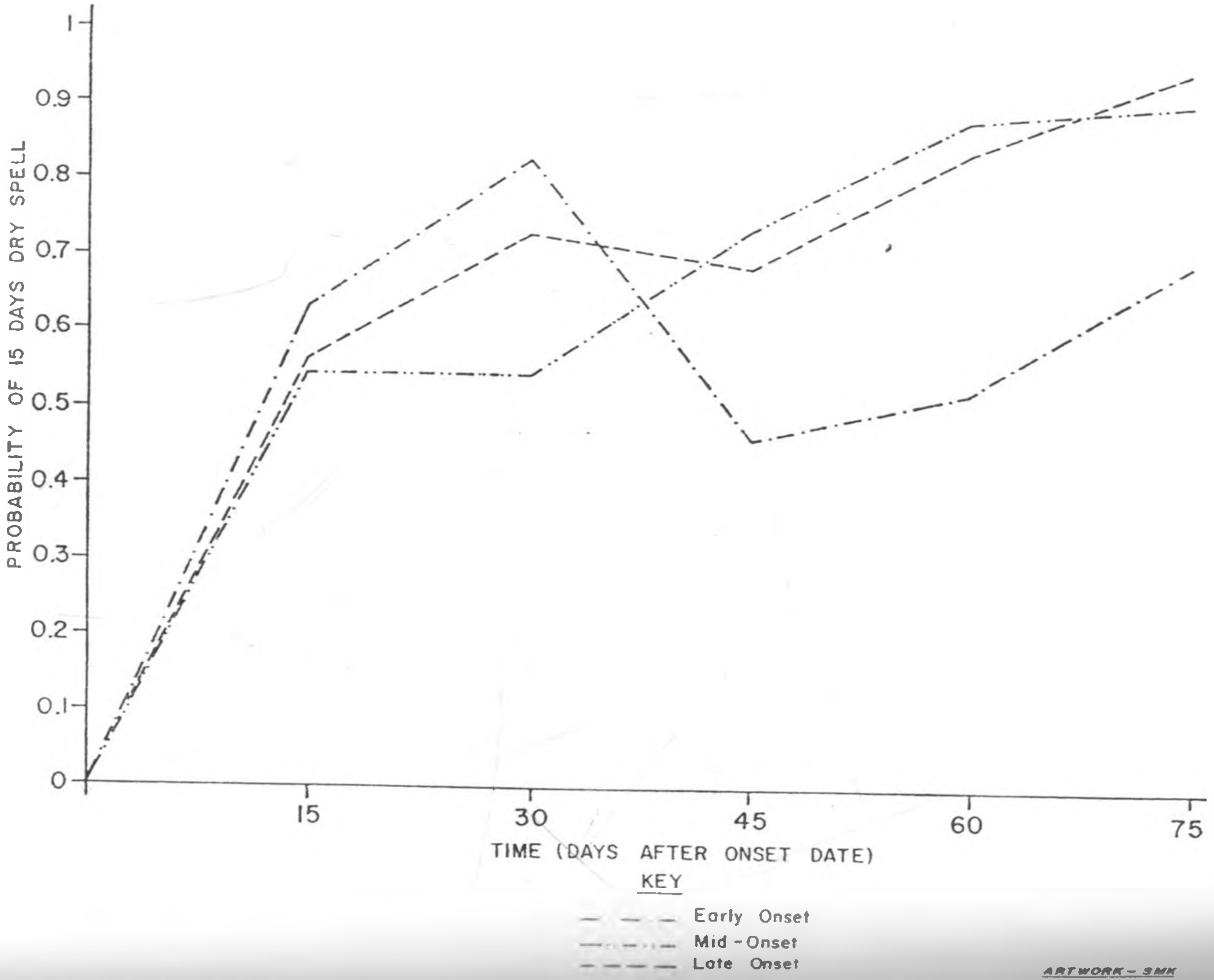
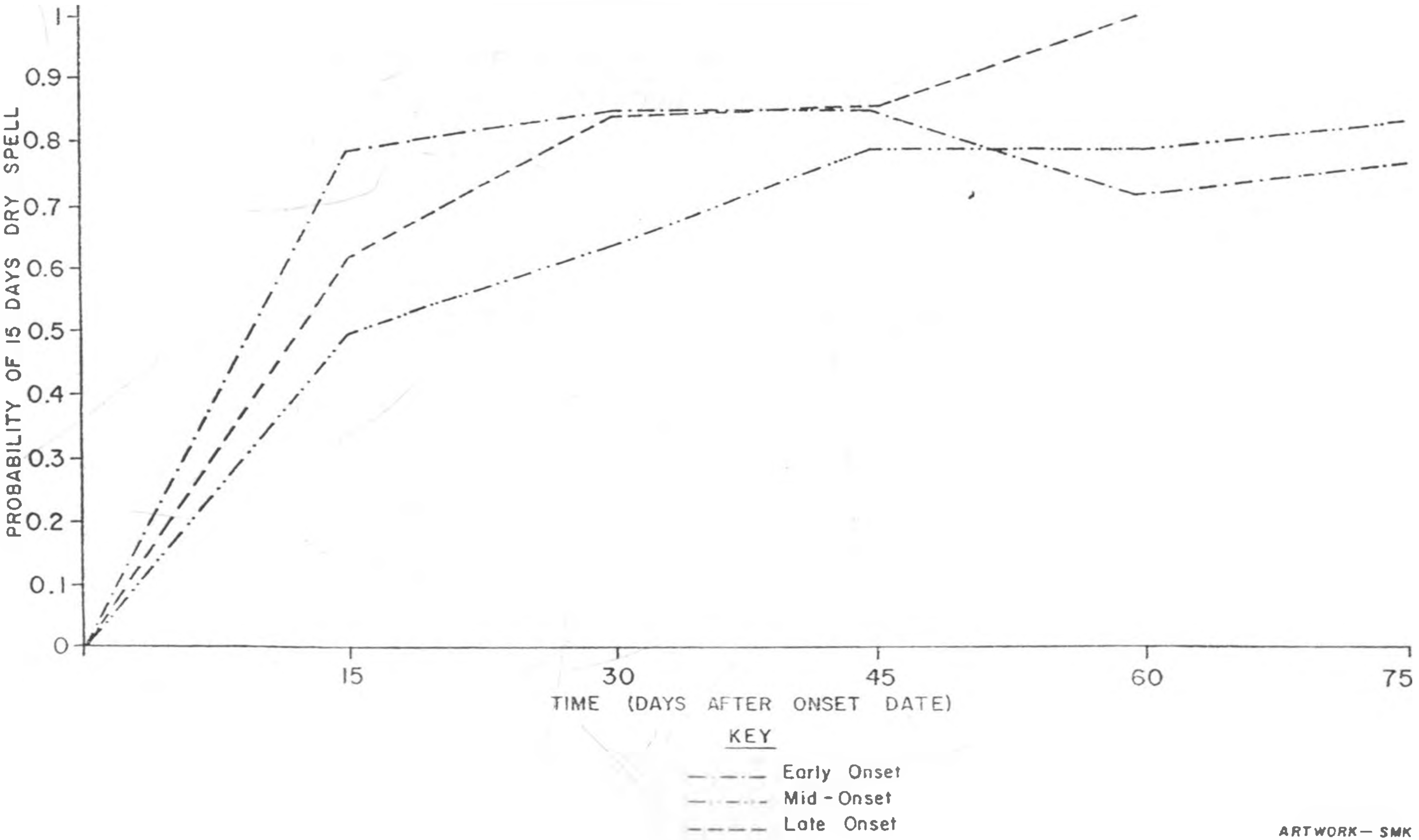


FIG. 4.15 : PROBABILITY OF DRY SPELL
MAKINDU - SHORT RAINS



ARTWORK - SMK

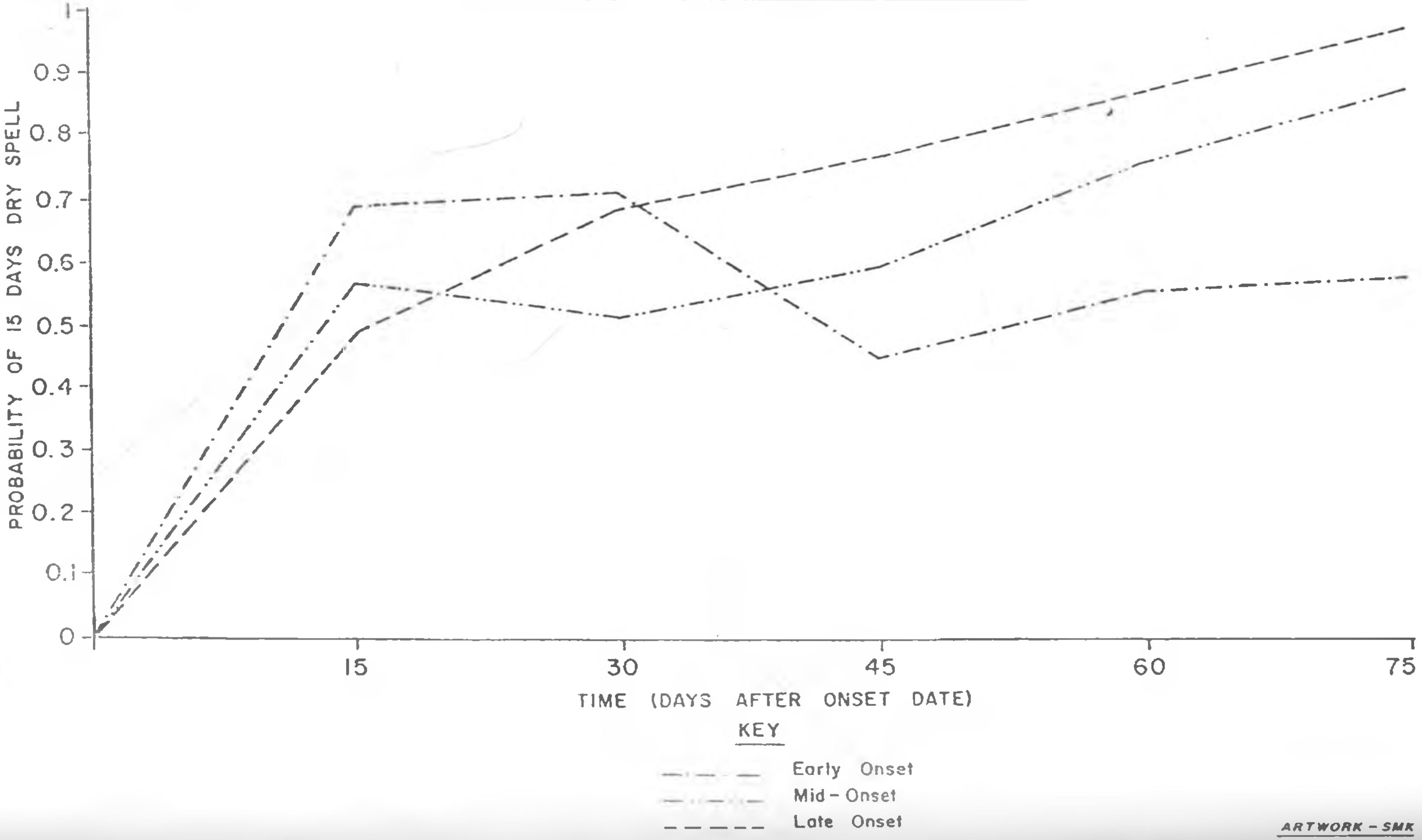
FIG. 4.16 PROBABILITY OF DRY SPELL
KIBWEZI D.W.A PLANTATION – LONG RAINS



ARTWORK – SMK

FIG. 4.17 : PROBABILITY OF DRY SPELL

KIBWEZI D.W.A PLANTATION - SHORT RAINS



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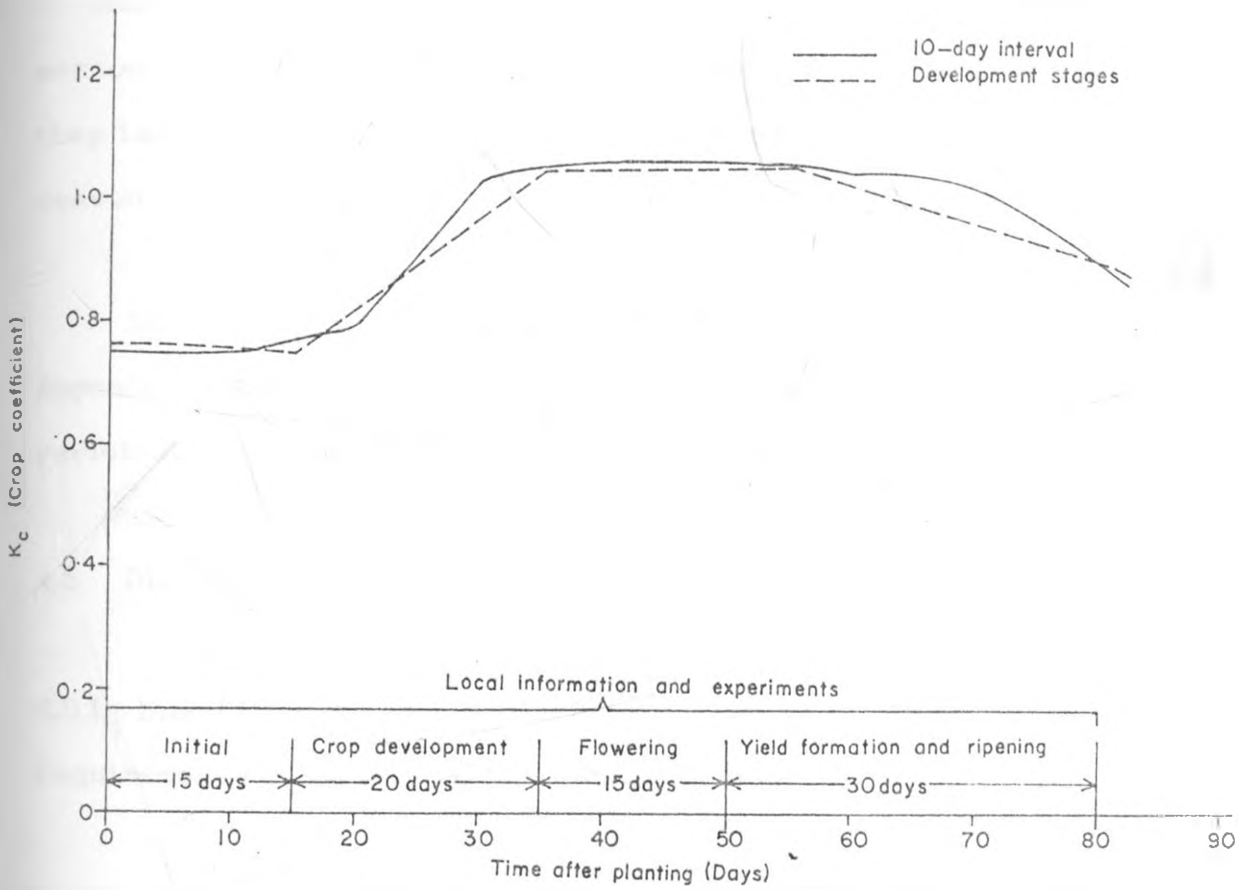

FIGURE 4·18 : PLOTTED CROP COEFFICIENT CURVE FOR BEAN I AND MWEZI MOJA VARIATIES AT KATUMANI.

Source: Field data.

Also in some season categories, the complete season lasted for only 60 days while in others it was 90. The end of the season was taken as the time when less than 1 mm of fall or no fall was registered for at least 15 days after 1st December during the short rains or after 1st April during the long rains.

Thus 15 days dry spell during the mentioned period marked the end of the season. This definition is supported by Dennett *et. al.,* (undated) pp. 42, though they take the last ten days in the named period to indicate the end of the season.

The method of calculating probabilities of dry spells is shown in **Appendix IIb**. The derived crop coefficient curve for **Bean 1** and **Mwezi Moja** varieties at Katumani is given in **Figure 4.18**.

4.5 DISCUSSION

4.5.1 Discussion on the Evaluation of the Crop Water Requirements of Bean 1 and Mwezi Moja Varieties:

Crop water requirements for the two varieties did not show any marked difference. They took approximately same period of time to complete their life stages (of 80 days) and hence same $ET_{(bean)}$ over the season.

The water requirements $ET_{(bean)}$ rises from the initial stage, which took about 15 days, showing highest rise in water requirement $ET_{(bean)}$ during crop development stage, when the crop has started flowering and hence reached full maturity, then levels out during the late flowering and pod filling only to drop at the end of the 8th decade (10 day period) when the crop is reaching senescence and hence with some leaves dropping (**Table 4.1**). This trend has also been observed by Mwanje (1981) on some plant species in Kenya rangelands, with reference to their spectral reflectance.

The seasonal $ET_{(bean)}$ is 281 mm as calculated from 8th November to 26th January 1988/1989 under rainfed conditions during the short rain season. One notices here that the calculated (281 mm) (**Table 4.1**) ET (bean) and that by Mugah ***et al,***. (1984) for Mwezi Moja variety grown at the Kenya Agricultural Research Institute (K.A.R.I.), Muguga, differs by a wide margin. The latter workers calculated $ET_{(bean)}$ to be 407, 379, 358 and 362mm using modified Penman Formula, Radiation Formula, Pan evaporation Formula and Lysimeter Method respectively.

This discrepancy is explainable. While Muguga is rather cool and wetter (altitude 2095 metres, and rainfall 954mm per annum), Katumani stands at an altitude 1575m, with rainfall of 661 mm per annum). Further the possibilities discussed below could contribute the anomaly as one would expect $ET_{(bean)}$ in Katumani to be higher than in Muguga.

The experiment carried out at Muguga was conducted from 7th September to 30th November (Mugah ***et. al.***, 1984 **pp.** 88). This is a rather dry period when temperatures and windrun are expected to be high in most parts of Kenya. The relative humidity is bound to be low and the sky overcast (especially in the month of September), thus enabling evapotranspiration to be high. The experiment conducted by the present worker at Katumani was set from 8th November to 26th January, a period covering the short rains season within the study area. Temperatures were moderate as compared to the month of September for the case in Muguga. Advected energy was not a major problem since most of the vegetation appeared green due to the rainy conditions. **Table 4.3** gives some of the meteorological conditions during the time of the two experiments (at Muguga and Katumani) which could explain the apparent differences in $ET_{(bean)}$ between the two places. **Table (4.3)** indicates why the evaporative demand of the atmosphere was higher in Muguga during the time of the experiment than that prevailing at Katumani when the current study was conducted (refer to contrasts in windrun and relative humidity in Katumani and Muguga). This difference in meteorological conditions may therefore result in raising the $ET_{(bean)}$ at Muguga as compared to that at Katumani.

Secondly the question of source of water for the crop is crucial in determining crop coefficients. Smaller intervals of water supply will certainly give high crop coefficients (Doorenbos and Pruitt 1977, **pp** 38) and this would affect the $ET_{(bean)}$. In the trials carried out at Muguga, the application interval was 2 days (Mugah *et. al.*, 1984) while at Katumani, the recurrence interval of significant rain at Katumani after onset date for 26 years (1962-1987) was calculated as 4 days (**Fig. 4.1**). Higher crop coefficients increase $ET_{(crop)}$ as indicated by **equation (3.1)**. Hence this could have reinforced the difference between the two stations.

In conclusion, differences in soil type, texture depth, among other factors, could also have a profound effect on evaporation, and hence even any two rather closer stations in distance could experience different evaporation readings depending on the background surrounding the pan (Kaila, 1983). Certainly Muguga and Katumani do not have same type of soils, besides other environmental conditions.

The results show that the crop water requirements ($ET_{(bean)}$) is higher from the 3rd to 6th decade (10 days). This could be attributed to the fact that the Leaf Area Index (L.A.I.) is expected to be high during this time when there is high metabolic activities from development stage to pod filling (Mugah and Stewart, 1984). It then drops from 7th to 8th decade as the metabolic activities drop with declining Leaf Area Index.

4.5.2 Discussion on the Evaluation of the Effective Rainfall

The result on effective rainfall (Pe) for the study area shows wide variation after onset date, with a mean of 24.8 mm and a standard deviation of 16.2 over the whole bean crop season (**Table 4.2**). The deviation could affect bean production especially if this occurs during germination, development and pod filling stages (Doorenbos and Kassam, 1979 **pp.**78). However a reduction of rainfall during ripening stage will be welcome.

According to the results of this study, total seasonal effective rainfall **(Pe)** as compared to $ET_{(bean)}$ was approximately 70% (**Table 4.2**). Thus the $ET_{(bean)}$ deficit is only about 30%. With this deficit, a yield of 0.871 and

Table 4.3 Some Sample Meteorological conditions during the time of the two Field Trials (Mugah *et al*,. 1984 and current study, 1988)

Days after 7th Sept. 1980 (Mugah *et al*), (01-85)	Days after 8th Nov. 1988 (Current study) (01-80)	Muguga RH(%)	Katumani RH(%)	Muguga wind-run (Km/day)	Katumani wind-run (Km/day)
01-10	01-10	65	69	239	104
11-20	11-20	57	74	296	123
21-30	21-30	55	65	325	126
31-40	31-40	79	73	307	118
41-50	41-50	63	82	364	116
51-60	51-60	68	68	358	98
61-70	61-70	74	66	337	82
71-80	71-80	76	68	304	89
81-85	-	69	-	368	-
Mean (x)	-	67.3	71	322	107

0.874 **ton/ha.** for Mwezi Moja and Bean 1 was received respectively. This is quite a good harvest under rainfed agriculture in marginal lands. The total amount of rainfall received during the experimental trials was 392mm. It is therefore reasonable to assume that with the said rainfall amount and if it is well distributed (i.e temporal distribution), a good yield would be expected. This allows for prediction of the production level using rainfall totals and the spread for other stations in the study area (as the effective rainfall increases with increasing total rainfall). Reference to **Tables I–IV** in, **Appendix I** and and **Table 4.2**, clearly indicates that in most of the years, seasonal rainfall will be enough to produce reasonable bean yields for the two varieties mentioned earlier if the timing is done properly and land preparation done at a suitable time. This aspect is discussed in the next section.

As for the total effective rainfall (**Pe**) only 51% of the total amount of rainfall is effective as per the field trials. The rest is lost either through deep drainage or runoff or both (**Table 4.2**).

4.5.3 DISCUSSION ON THE THE EVALUATION OF RAINFALL VARIABILITY BY THE USE COEFFICIENT OF VARIATION.

4.5.3.1 Long Rains Variability After Onset Date:

During the long rains, variability appears to be minimal if the season is of late-onset category. Thus we expect minimal variation from onset date to the end of the season and if the season takes enough time for beans to reach the 6th and the 7th decades (10-day groups), then one expects a satisfactory yield. However this kind of season (late-onset) shows the lowest seasonal total rainfall (**Figures. 4.2, 4.4, 4.6 and 4.8**) ranging from 136mm in Katumani to 177 mm in Kampi-ya-mawe. The other short fall is that the season hardly lasts over 60 days and thus a short delay in planting after onset date could mean a total failure in crop yield.

The mid-onset and the early onset seasons lasts for more than 60 days after the onset date. They have higher rainfall totals over the entire season and this will certainly imply higher effective rainfall (**Fig. 4.2-4.10**). Consequently this implies that most of the time the bean crop water requirements deficit (if any) will be low due to the high total rainfall received which is hardly below 122 mm.

As for variability after onset date, the two types of seasons named above show contrasting trends. Apart from Kampi-ya-mawe where at day 45 into the season the mid-onset season show a rise in variability, all the other stations show a falling variability at day 45. The variability is further lower if the season is of mid-onset category as compared to the early onset season. During the early days of the season however (from day 15 to 30), variability of rain is higher in the mid onset season than in the latter case. This implies that, if the onset is early, (during the long rains), variability is lower in the early days of the season and higher in the later days. This, however is the opposite if the season is of mid-onset.

In concluding this subsection, the two types of seasons (early and mid) show higher variability throughout the season compared to the late-onset season. Thus it is more difficult to predict temporal rainfall changes after onset date than the latter case.

4.5.3.2 Variations of Rainfall After Onset Date During the Short Rains.

As in the long rains, variability is lowest if the season is of late-onset category. The rainfall totals are also reasonably higher (compared to same season category during the long rains). This season could be considered to be desirable for a crop that needs shorter intervals of wetting such as beans (**Figures 4.3, 4.5, 4.7, and 4.9**) and hence a good harvest would be expected due to the probability of expecting higher effective rainfall.

The mid-onset season shows a declining variability from day 30 into the season (except in one case, Kibwezi Fig.4.12 where the decline is at day 45). This season takes longer period of time as compared to the late-onset season. The advantage of this is obvious in that it gives farmers enough time to plant and weed.

The early-onset season shows the highest variability after onset date compared to the "mid"and "late" onset. This is undesirable to the bean farmers due to the reasons already mentioned elsewhere. However the season has advantage of taking the longest time and has reasonably higher rainfall totals.

In conclusion, the locally designated" short rains" have less variations after onset date and thus the deference between early, mid and late-onset as termed in this work are not as distinct as is the case during the" long rains".

4.5.4 DISCUSSION ON THE EVALUATION OF THE RAINFALL VARIABILITY BY THE USE OF PROBABILITY ANALYSIS

Rainfall probability were calculated for the next 15 days being dry (dry spell of 15 days after onset date). The plots to show the trend observed are given in **Figures 4.2–4.17** and discussed in the subsections below.

4.5.4.1 The Long Rains.

There is a geheral trend portrayed by the plots of each category of season suggesting that the early-onset gives a wider gap from day 15 to 30 after onset date. Thus if the rain season is of this category, it continues (after onset) for sometime (about 15 days) and stops and gives a longer gap of dry spell before it resumes again. This gap is what Stewart and Kashasha (1984) observed and referred to as a "window" after onset. After the dry spell gap, the probability of the next 15 days being dry drops so that it hardly goes above 70%. The other feature of this season is that, it stretches over a long period, an advantage to the farmers as discussed earlier and revisited in **Chapter Five.**

The other interesting trend is portrayed by the mid-onset season. After onset date, the probability of having the next 15 days dry rises but very slightly. This implies short intervals of dry spells from day 1 to 45 (**Figure 4.10, 4.12, 4.14 and 4.16**). There is then a steady rise in the probabilities after day 45 up to the end of the season. The implications of this rise is discussed in **Chapter Five**. However it is important to note that this type of season lasts for about 75 days.

The late-onset season shows a steady rise in probability from day 15 and continues to rise slightly and almost smoothly (except in a few cases) up to the end of the season which lasts for about 60 days. The steady increase confirms the results discussed in **section 4.4.3.1**, where coefficients of variations were found to be lower than in the other seasons.

4.5.4.2 Short Rains

The early-onset season during the short rains shows some similarities in trend with the same season during the long rains. However, the fall in probability at day 30 is drastic. There is trough shape from day 30 into the season up to day 60 with the lowest dry spell probability being at day 45. The probability curve then rises steadily up to the end of the season which takes between day 75 to 90. The lowest probability is 40%, which is a rather small value compared to the other category of seasons (**Figures 4.11, 4.13, 4.15 and 4.17**).

The mid onset-season probability curve shows a similar trend with the late-onset in that after day 30 the two probability curves are parallel. Occasionally, however, the probability curve of mid-onset season shows (after day 15) a declining trend which continues up to day 30 (except for Kampi-ya-mawe station). In general, the mid-onset season has less chances of getting dry spells of 15 days after onset date than the late-onset season.

Finally, the late-onset season portrays the smoothest rise in probability (comparatively) from the onset date to the end of the season. This season could last for 60 days or less, a disadvantage noted later in this **Chapter.**

4.5.5 DISCUSSION ON THE EVALUATION OF RAINFALL VARIABILITY USING SIMPLE LINEAR REGRESSION:

Simple linear regression analysis was used to establish the relationship between the days following onset and the frequency of rainfall (calculated in terms of probability of occurrence of 15 days dry spell). The essence of this computation was to find out if the frequency of rainfall after onset date can be predicted. A strong relationship would indicate that the frequency of rainfall can be relatively predicted using the developed equations, while a weak one would indicate that rainfall frequency after onset date is uncertain.

The computed correlation coefficients and F-test were used to investigate the significance of the established relationship. The relevant results are shown in **Tables 4.4-4.9.** The significant equations may be used for predictions in future, for example, equations shown in **Table** 4.5 and 4.8 are suitable towards this goal.

The importance of being able to predict rainfall variability is obvious.This could provide a guideline to farmers (if well informed) to know when and what to plant, and in addition what they should expect in terms of harvests. Consequently would provide mechanisms for adjusting their farming schedule so as to maximize the opportunities offered in each season. This is of particular significance to crops such as beans which have a short growth period. A wider gap of dry spell, especially during germination and flowering could mean a failure in crop yield.

The results of the regression analyses (**Table 4.4 and 4.7**)clearly indicates that if the season is of early-onset category, we are unable to predict the frequency of rainfall after onset date. In this category of season, the relationship between the variables considered in this study is not significant. This is demonstrated by the computed **F-statistic**.

On the contrary, the mid and the late-onset seasons can be predicted with higher degree of accuracy (**Table 4.5, 4.6, 4.8 and 4.9) at p = 0.05**). The correlation coefficients for the two seasons are high so is the **F-statistic** values.

In conclusion, it is observed that one could predict rainfall variations (or frequencies) if the season is of "mid" or "late" onset(s). For "early"-onset season, rainfall variations after onset could not be predicted using the statistical methods utilized in this study.

Table 4.4 A summary for the linear regression equations characterizing the relationship between mean probabilities of rainfall occurrence (MPR) and days after onset of rainfall(DOR) for Kampi-ya-mawe (Equation 4.1); Katumani (Equation 4.2); and Makindu (Equation 4.3) during the Long Rains: Early onset (of the rains)

Equation Number	Regression	Estimated Parameters n = sample size
4.1	$MPR = 0.648 + 0.00099DOR$	$r^a = 0.276846$ $s^b = 0.10786$ $s.e^c(\beta_1) = 0.001718$
$F^d = 0.332023$, Not significant ($p < 0.05$)		$n = 6$, $df = 4$
4.2	$MPR = 0.738666 - 0.00034DOR$	$r^a = 0.120566$ $s^b = 0.090210$ $s.e^c(\beta_1) = 0.001437$
$F^d = 0.059002$, Not significant ($p < 0.05$)		$n = 6$, $df = 4$
4.3	$MPR = 0.696666 + 0.001333DOR$	$r^a = 0.462438$ $s^b = 0.080208$ $s.e^c(\beta_1) = 0.001278$
$F^d = 1.088082$, Not significant ($p < 0.05$)		$n = 6$, $df = 4$
Kibwezi no Equation - Insufficient degrees of freedom		

a = Simple regression coefficient
b = Standard error of Y-estimate
c = Standard error of estimate for the regression coefficient
d = F-statistics and,
df = Degrees of freedom

Table 4.5: A summary for the linear regression Equations characterizing the relationship between mean probabilities of rainfall occurrence (MPR) and day after onset of rainfall(DOR) for Kampi-ya-mawe (Equation 4.4); Katumani(Equation 4.5); Makindu(Equation 4.6) and Kibwezi D.W.A Plantatio (Equation 4.7) during the Long Rains: "Mid" onset

Equation Number	Regression	Estimated Parameters n = sample size
4.4	$MPR = 0.443 + 0.006466DOR$	$r^a = 0.913631$
		$s^b = 0.078803$
		$s.e^c(\beta_1) = 0.001661$
$F^d = 15.15136$, Significant ($p < 0.05$)		
		$n = 5$, $df = 3$
4.5	$MPR = 0.299 + 0.007177DOR$	$r^a = 0.945544$
		$s^b = 0.067667$
		$s.e^c(\beta_1) = 0.001426$
$F^d = 25.31642$, Significant ($p < 0.005$)		
		$n = 5$, $df = 3$
4.6	$MPR = 0.4454 + 0.007093DOR$	$r^a = 0.9993381$
		$s^b = 0.022461$
		$s.e^c(\beta_1) = 0.001487$
$F^d = 224.3847$, Significant ($p < 0.05$)		
		$n = 5$ $df=3$
4.7	$MPR = 0.467 + 0.0054DOR$	$r^a = 0.927913$
		$s^b = 0.059413$
		$s.e^c(\beta_1) = 0.001252$
$F^d = 18.58640$, Significant ($p < 0.05$)		
		$n = 5$ $df = 3$

Table 4.6: A summary for the linear regression Equations characterizing the relationship between mean probabilities of rainfall occurrence (MPR) and days after onset of rainfall (DOR) for Kampi-ya-mawe (Eqn. 4.8); Katumani (Eqn. 4.9); Makindu (Eqn. 4.10) and Kibwezi D.W.A Plantation (4.11), during the Long Rains: \`Late´ onset.

Equation No.	Regression	Estimated Parameters n = Sample size
4.8	$MPR = 0.5455 + 0.002705DOR$	$r^a = 0.933165$
		$s^b = 0.072755$
		$s.e^c(\beta 1) = 0.009933$
$F^d = 13.47965$, significant ($p < 0.05$)		n = 4, df = 2
4.9	$MPR = 0.599 + 0.005346DOR$	$r^a = 0.911528$
		$s^b = 0.045617$
		$s.e^c(\beta 1) = 0.000961$
$F^d = 30.90939$, Significant ($p < 0.05$)		n = 4, df =2
.10	$MPR = 0.615 + 0.0052DOR$	$r^a = 0.926996$
		$s^b = 0.049899$
		$s.e^c(\beta 1) = 0.001487$
$F^d = 12.21686$, Significant ($p < 0.05$)		n = 5, df = 3
4.11	$MPR = 0.592 + 0.005866DOR$	$r^a = 0.905150$
		$s^b = 0.075454$
		$s.e^c(\beta 1) = 0.001590$
$F^d = 13.60187$, Significant ($p < 0.05$)		n = 5, df = 3

Table 4.7: A summary for the linear regression Equations characterizing the relationship between mean probabilities of rainfall occurrence (MPR) and days after onset of rainfall (DOR) for Kampi-ya-mawe (Eqn.4.12); Katumani (Eqn. 4.13) during the short rains:` Early´ onset.

Equation No.	Regression	Estimated Parameters n = sample size
4.12	MPR = 0.429333 + 0.003980DOR	$r^a = 0.584130$
		$s^b = 0.173552$
		$s.e^c(\beta 1) = 0.002765$
$F^d = 2.071727$; Not Significant ($p < 0.05$)		
		n = 6, df = 4
4.13	MPR = 0.352666 + 0.004076DOR	$r^a = 0.637194$
		$s^b = 0.154684$
		$s.e^c(\beta 1) = 0.002465$
$F^d = 2.734198$; Not Significant ($p < 0.05$)		

Makindu and Kibwezi no Equations - due to low degrees of freedom.

Table 4.8: A summary for the linear regression Equations characterizing the relationship between mean probabilities of rainfall occurrence (MPR) and days after onset of rainfall (DOR) for Kampi-ya-mawe (Eqn. 4.14); Katumani (Eqn. 4.15); Makindu (Eqn. 4.16) and Kibwezi D.W.A Plantation (Eqn. 4.17) during the Short Rains: `Mid´onset.

Equation No.	Regression	Estimated Parameters n = sample size
4.14	$MPR = 0.25 + 0.010733DOR$	$r^a = 0.988362$
		$s^b = 0.039179$
		$s.e^c(\beta1) = 0.001168$
$F^d = 84.43322$; Significant ($p < 0.05$)		
		n = 4, df = 2
4.15	$MPR = 0.464 + 0.004590DOR$	$r^a = 0.877524$
		$s^b = 0.078703$
		$s.e^c(\beta1) = 0.001254$
$F^d = 13.39506$; Significant ($p < 0.05$)		
		n = 6, df = 4
4.16	$MPR = 0.41 + 0.007066DOR$	$r^a = 0.956236$
		$s^b = 0.059217$
		$s.e^c(\beta1) = 0.001248$
$F^d = 32.04182$; Significant ($p < 0.05$)		
		n = 5, df = 3
4.17	$MPR = 0.408 + 0.005733DOR$	$r^a = 0.908946$
		$s^b = 0.072018$
		$s.e^c(\beta1) = 0.001518$
$F^d = 14.25964$; Significant ($p < 0.05$)		
		n = 5, df = 3

Table 4.9: A summary of linear regression Equations characterizing the relationship between mean probabilities of rainfall occurrence (MPR) and days after onset of rainfall (DOR) for Kampi-ya-mawe (Eqn.4.18); Katumani (Eqn. 4.19); Makindu (Eqn.4.20) and Kibwezi D.W.A Plantation (Eqn. 4.21) during the Short Rains: `Late´ onset.

Equation No.	Regression	Estimated Parameters n = sample size
4.18	MPR = 0.225 + 0.009933DOR	r[a] = 0.933165
		s[b] = 0.090746
		s.e[c]($\beta 1$) = 0.002705
F[d] = 13.47966; Significant ($p < 0.05$)		n = 4, df = 2
4.19	MPR = 0.296 + 0.008666DOR	r[a] = 0.98945
		s[b] = 0.034253
		s.e[c]($\beta 1$) = 0.000722
F[d] = 144.0340; Significant ($p < 0.05$)		n = 5, df = 3
4.20	MPR = 0.491 + 0.005933DOR	r[a] = 0.947237
		s[b] = 0.054984
		s.e[c]($\beta 1$) = 0.001159
F[d] = 26.19955; Significant ($p < 0.05$)		n = 5, df = 3
4.21	MPR = 0.416 + 0.0076DOR	r[a] = 0.984516
		s[b] = 0.037058
		s.e[c]($\beta 1$) = 0.000781
F[d] = 94.63106, Significant ($p < 0.05$)		n = 5, df = 3

CHAPTER: FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION:

This **Chapter** gives a conclusion of salient findings arrived at in this study and their implications to farmers of the two bean varieties, namely, **Mwezi Moja** and **Bean 1**. The conclusion is given basically on the three major objectives of the study namely, calculations of crop water requirements of the two bean varieties, effective rainfall, and rainfall variability, after onset date.

5.2 CONCLUSION ON THE CROP WATER REQUIREMENTS:

Crop water requirements ($ET_{(bean)}$) for both **Mwezi Moja** and **Bean 1** varieties were calculated using the pan evaporation formula to **281 mm** (**Table 4.1 section 4.2**) over the season. The $ET_{(bean)}$ fluctuated from one stage of development to the other. It was lowest during the initial stage and highest during the mid-season stage when the crop attains maturity and starts flowering and producing pods. The highest rate of increase in $ET_{(bean)}$ however is noted during the crop development stage (**Fig.4.18**). The increase at this stage could be associated with the high Leaf Area Index expected at this stage of development as reported by Stewart and Hash, 1981; Mwanje, 1981;Kashasha, 1982; and Stewart, 1984.

5.3 CONCLUSION ON THE EVALUATION OF SEASONAL EFFECTIVE RAINFALL (Pe)

Seasonal effective rainfall was found to vary with the total rainfall. Effective rainfall calculated during the time of the trials was 51% of the total rainfall (**Table 4.2**). However, the effective rainfall deficit was 30% of the crop water requirements.

The small deficit of rainfall to attain the crop water requirements makes us conclude that, with good timing of onset of the rains, and thus planting at suitable time, a farmer is assured good yield if other management factors are taken care of. At the site of the trials which depended solely on rainfall and with the said $ET_{(bean)}$ deficit, a yield of **0.871** and **0.874 ton/ha.** of grain bean for **Mwezi Moja** and **Bean 1** varieties was recorded, respectively.

5.4 CONCLUSION ON THE EVALUATION OF THE SEASONAL LENGTH, TOTAL SEASONAL RAINFALL AND SEASONAL VARIABILITY

5.4.1 Seasonal Length

Late onset season hardly lasts over 60 days. However if the season is of mid or early onset, the length in average stretches for not less than 75 days. This gives adequate time for the farmers to plant their crop and weed while the season lasts. The two latter seasons are desirable in the study area where planting is done by animal drawn plough or by hoe, thus in most of the time, the first two weeks after onset are set for sowing (planting) (Stewart, 1984). A short season like the late-onset may not allow the mentioned activities to take place in time and hence exposes bean farmers to higher risk of crop failure. It is not surprising that the late-onset season is manifested in all the lean years when rainfall amounts were low leading to crop failure **(Table III Appendix 111).**

5.4.2 Total Seasonal Rainfall:

Total seasonal rainfall is important for it gives the required amount of moisture that is likely to be available for the crop during its development stages. Also, total effective rainfall over the entire season is based on the total seasonal rainfall received in a given place (Stewart and Faught, 1984). In this study, total seasonal rainfall was found to vary from one type of season category to the other. In general, early-onset season we expect the highest seasonal total rainfall followed by mid-onset and late-onset season (**Figures 4.2-4.9,** and **Appendix III Tables I and II**). This confirms findings by Stewart and Kashasha (1984). However, during the `short rains´, rainfall totals were not found to be distinct as in the `long rains´ (Fig.4.3); an aspect unreported by other researchers.

5.4.3 Seasonal Variability:

Seasonal variability of rainfall after onset date was computed using coefficient of variation and probability analysis to estimate the chance of dry spells of 15 days long (which was thought to be adequate time to cause adverse effects on bean crop development). Variability was found to be minimal if the season is of late-onset category. This implies that if the season is of this category, there is a higher continuity in rainfall from the date of onset up to the end of the season and thus shorter incidence of dry spell. The seasonal variations of rainfall after onset can fairly be predicted. This conclusion is enhanced by the rainfall frequency analyses by the use of linear regression equations (**Table 4.6 and 4.9**). The derived equations were highly significant ($p = 0.05$).

The late-onset season during the `short rains´ has higher rainfall totals compared to the same season during the `long rains´ and thus gives some hope of a fair bean yield.

The mid-onset season (both during the long and the short rains) shows reasonably higher rainfall totals which are desirable for the bean farmers of the two varieties. The variability is however higher during this season than in late-onset season. Its advantage over the latter is that it stretches over a longer duration. Variability during the mid-onset season can be predicted over the season as shown in **Table 4.5 and 4.8.**

Early onset season has the highest total amount of seasonal rainfall for the three seasons. It also lasts for a longer duration compared to the others but its rainfall frequency after onset date can not be predicted at least using the methods adopted in this study(i.e the simple correlation coefficient shows strong association between the two variable under investigation(Table 4.4 and 4.7).

In conclusion, the mid onset season exposes farmers of the two bean varieties to a lesser risk of crop failure than early and the late-onset seasons and should be adopted as the official onset time in the study area.

5.4.4 Recommendations to Extension Officers and Bean Farmers.

(a) Crop water requirements for **Mwezi Moja** and **Bean 1** varieties was found to be **281 mm** over the growth period. The seasonal effective rainfall was consequently **50%** of the total rainfall received during the time of field trials. A yield of **0.871** and **0.874 ton/ha.** of grain harvest for **Mwezi Moja** and **Bean 1** was realised, respectively, with a spacing of **50** and **30 cm** within and between rows accordingly. The recommendation is that if planting is done in time and weeding performed efficiently the two varieties of beans can give good yield.

(b) Planting before onset of the season is not necessary if the season is of early-onset category (before or on 20th October during the `short rains´, and on or before 10th March in the case of `long rains´). This is because the season is normally long enough to allow the crop to complete its life stages. Variability of rainfall during this season have not been predicted and thus, farmers should expect surprises. The rainfall during this season is expected to meet the crop water requirements.

(c) The most suitable season is the mid-onset season (i.e onset season between 10th March and before 1st April during the `long´rains) for it caries lesser risk of bean crop failure due the higher rainfall amount compared to crop water requirements and has lesser rainfall variability. During this season farmers should plant immediately after onset. This applies to both the long and the short rains.

(d) Late-onset season (i.e onset after 1st April during the "long" rains) is risky in that, crop failure is much more likely due to the low rainfall amounts expected during this season compared to known bean crop water requirements (ET(bean)). However, during the "short rains", the chances of a good harvest are higher than the case during the "long" rains with total rainfall over the season being slightly over the ET(bean). In both cases, sowing should not wait for the onset. Dry sowing is likely to bear more fruits so that immediately after the onset, germination can take place during the first few days of the season. Weeding should be done early to avoid moisture competition with the crops and if possible wider spacing of the crops should be emphasized.

5.4.5 Recommendations to Researchers.

As indicated in the conceptual crop (production) model, production depends on many factors interacting favourably to bring out a good result (Fig.1.0). This involves bio-physical, social-cultural, genetic and other factors. The complex interaction call for multi-disciplinary research. Once a new hybrid of bean is produced, research is needed to assess the acceptability of the "new" crop to the people before much investment on it is undertaken. The nutritional values should also be computed and documented before further promotion is commisioned. A study is needed to establish the critical number of weeding times required and the appropriate method to be used without minimizing crop yield. The crop-soil interactions should be investigated to zone-out areas where the two bean varieties can thrive well given arid conditions. This can be achieved by the analysis of soil texture, pH, water holding capacity and soil depth. This zonation and with the assistance of agricultural extension officers, will minimize the non-deterministic methods, sometimes applied by farmers before they learn about a suitability of a crop for given environmental conditions.

Research on mixed cropping is inadequate although the practice is popular (mixed cropping) among farmers in the study area. Finally, there is need to investigate the critical biomass needed by beans (and other crops) before a satisfactory grain yield is achieved and relate this to water application.

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Appendix I

Table I: KAMPI-YA-MAWE MONTHLY TOTALS AND MEAN ANNUAL RAINFALL (1962-1987)

Year	Year	Jan.	Feb.	Mar.	April	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1962	1962	62	13.2	91.2	69.9	80.5	2.8	0	3.4	3	23.1	194	93.3	647
1963	1963	3.51	39.7	119.7	66.5	74.6	28	2.1	2.3	10.1	5.6	302.2	160.1	833.9
1964	1964	38.4	28.2	109.6	123.9	6.8	117.6	2.8	2.3	3.6	24.9	176.8	228.8	863.7
1965	1965	74.4	0	12.2	220.3	24.7	6.1	0	6.3	0.5	73.9	166	77.5	661.9
1966	1966	10.4	129	211.3	101.6	26.2	1.5	0	0	0	5.6	71.3	43.6	601
1967	1967	0.0	25.3	37.7	281.7	73.4	4.6	1	17	32	178.9	226.5	0	878.1
1968	1968	0.0	78.3	257.7	298.3	37.5	37.4	3.6	0.5	0	21.4	293.5	125.3	1153.5
1969	1969	70.9	74.9	121.2	36.1	41.2	0	0	16.7	0	31.6	214.6	27.5	634.7
1970	1970	90.5	0	111.2	57.2	31.9	0	0	4.7	3.3	4.1	78.9	82.7	464.5
1971	1971	51.5	0	37.3	236.9	72.7	10.4	3.3	3.5	2.8	3.5	68.4	128.3	619
1972	1972	50.5	42.3	11.1	1.2	30.2	0.3	0	0.4	5.3	211.7	155.3	79.7	588
1973	1973	135.6	51.5	8.1	68.2	17.5	1.6	1.6	0	2.5	0.5	167.1	17.5	471.7
1974	1974	1.8	16.3	112.9	223.3	26.4	8.8	5.5	21.7	4.6	8.1	84.7	69.8	583.9
1975	1975	1.1	12.8	6.2	110.9	49.4	0	6	0.8	12.2	1.5	13.9	-	214.8
1976	1976	0.0	13.4	2.8	183.5	11.2	13.8	-	-	17.3	3.5	227.1	123.4	536
1977	1977	15.1	22.9	88.9	226.9	10.6	10	0.7	20.1	7.2	22.1	-	-	420.2
1978	1978	11.4	76.9	188.7	107.9	30	0.7	-	-	-	-	129.6	205.1	750.3
1979	1979	299	32.2	-	202.6	-	18.3	8.7	-	9.5	-	308.2	102.2	980.7
1980	1980	-	-	-	136.9	40.8	0	0.6	13.3	0	0	176.1	57.7	425.4
1981	1981	0.0	0.4	295.5	224.4	71.2	2.3	3.2	1	0.6	50.4	63.9	67.3	780.2
1982	1982	0.6	0	12.5	142.7	131.7	3.1	4.5	1.5	17.1	14.4	247	125.5	7000.6
1983	1983	1.2	46.5	11.9	172.4	47.2	1.6	0.8	1	1	0.8	73.3	170.1	529.8
1984	1984	33.2	0	44	71	4.6	0	2.2	0	2.3	160.2	296	76	689.5
1985	1985	15.3	14.9	75.8	193.2	86.2	0.8	2.9	0	1.6	74.4	175.4	88.3	728.8
1986	1986	44.6	0.7	77.8	178.7	53.2	5.4	1.1	5.4	3.7	26.6	341.4	125.6	864.2
1987	1987	6.5	0	22.7	81.9	28.5	23.6	2.4	20.3	0	2.4	197.5	41.3	427.1
Mean	Mean	40.7	28.9	86.1	147.5	44.3	11.5	2.2	6.4	5.7	39.5	178	96.7	658
Std	Std	63.1	32.2	80.6	76.8	29.6	23.3	2.2	7.5	7.3	58.7	88.1	55.4	197.5

Appendix I

Table II: KATUMANI TOTALS AND MEAN ANNUAL RAINFALL (1962-1987)

Year	Jan	Feb.	Mar.	April	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1962	91.4	91.1	60	107.3	131.3	7.8	0	0.3	17.5	35.1	125.2	93.5	676.4
1963	94.3	71	103.1	101.2	150.9	13.5	0	0	3.3	0.0	462	262.1	1262.3
1964	57.9	36.3	88.6	284.5	11.8	25.4	9.9	11.2	0	4.6	63.9	121.3	715.4
1965	86.3	24.6	33.8	86.4	17.1	0	0	1	0	136.2	149.4	35.5	570.3
1966	22.9	66.9	119	141.4	20.5	0.8	0	0	0	1.5	178.5	33.6	585.2
1967	0	4.3	49.1	256.2	141.6	11.7	0	6.1	12.2	99.8	121.1	38.6	742.7
1968	0	76.4	215.8	162.5	64.2	17	0	0	0	19	275.6	149.7	980.2
1969	11.4	62.5	60.1	26	61.3	0	0	8.3	0	12.2	193.2	12.7	447.7
1970	50.3	0	139.9	138.1	93.2	1	1.7	4.7	0	0.0	34	59.8	522.7
1971	94.2	0	27.7	200.7	48.8	6.2	0	0	0	0.0	87.4	134.1	599.1
1972	46.2	39.5	63.2	20.2	74.1	16.7	0	0	8.0	113.5	146.1	24.3	552.8
1973	129.8	52	0	65.1	10.7	7.3	0	2.7	30.5	9.3	137.6	42.4	487.4
1974	17.8	60.6	145.9	235.2	34.9	35	36.3	20.4	3.2	31.4	154.7	38	813.4
1975	12.5	19.6	32.4	102.1	36.5	0	12.7	0	42.5	23.8	118.2	48.9	449.2
1976	-	-	13.5	111.9	29.1	27.3	1.6	0.5	13.3	0.6	94.1	117.3	409.2
1977	10.7	30.9	99.7	314.7	87.5	11.5	9.1	10.2	3.1	7.3	197.7	86.8	869
1978	92.8	-	144.5	204.6	23.5	1.1	0.1	0.4	0	61.6	120.8	123.8	773.2
1979	190.4	116.9	77.7	213.5	91.4	12.8	14.6	7.7	6.4	14.7	136.2	61.9	944.2
1980	38.7	0.8	113.2	107.6	88.9	0	6	6.4	0	1.5	151.4	27.2	541.7
1981	10.7	10.7	171.7	182.4	87.4	0	0.5	1.6	7.2	57.5	55.3	63.3	648.3
1982	0.1	1.6	68	93..1	39.4	3.6	8.5	4	9.5	111.7	252.2	99.2	750.9
1983	12.9	120.3	4.4	116.8	7.2	10.3	4.2	7.4	1.2	4.0	43.2	158.6	490.5
1984	24.2	0	3.4	51.4	0.6	0	7	6.4	15.7	154.4	211.2	43.2	517.5
1985	5.3	110.5	78.7	278.3	84.6	0	1.4	1.9	0.2	56	75.1	121	813
1986	59	0	59.4	192.4	72.7	5.7	0.4	0.3	0.0	2.6	180.8	127.2	700.5
1987	22.7	0	23.3	56.7	39.4	61.9	3.6	11.6	0.0	0.3	93.5	12	325
Mean	47.3	38.1	76.8	148.2	61.9	10.6	4.5	4.4	6.7	36.9	148.4	82.2	661.1
Std	46.9	38.3	54.7	80.7	41.8	13.9	7.7	5.0	10.2	46.5	86.4	56.8	203.3

Appendix I

Table III : STATION NO.923700
MAKINDU RAINFALL TOTALS & MEANS (1962-1987)

	MONTH												
YEAR	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPT.	OCTOBER	NOV.	DEC.	TOT. ANNUAL RAINFALL
1962	56.8	22.6	94	51.8	36.1	2.1	2.8	1	0	23.1	169.8	129.9	590
1963	55.3	58.7	116.7	60.4	16.6	4.8	0	0	3.8	6.6	466.8	241.1	1030.8
1964	39.9	51.6	35.5	137.6	2	31.7	1.1	0	0	0.7	67.9	317.7	685.7
1965	42.2	0.3	22.2	60.7	17.7	0.2	0	1.4	2.9	20.7	198.6	17.4	384.3
1966	36.3	56.8	135.6	145.6	6.5	0.3	0	0	0	2.9	46.5	55.3	485.8
1967	0	22	29.2	283.2	54.4	1.8	4.1	22.5	32.2	95.3	263	10	817.7
1968	0	134.8	205.1	291.6	14	5.7	0	0	0	16.6	416.8	161.6	1246.2
1969	113.8	59.4	106.2	24.4	4.8	0	0	0.4	0	8.6	224.6	27.6	569.8
1970	24.9	0	163.7	40.3	21.4	0	0	2	0	0	38	89.5	379.8
1971	24.6	5	14.8	243.6	29.7	2.3	0.6	0.4	0.9	2.2	173.5	92.9	590.5
1972	24.5	24.1	0.6	9.4	13.6	0.7	0	0	2.4	33	234.9	74.5	417.7
1973	59.4	70.9	1.1	102.9	19.3	0	0	0	1.5	8.8	143.3	3	410.2
1974	13.6	8.2	122.5	94.9	4.8	2.2	0.3	0.3	0.6	15.1	96.7	45	404.2
1975	10.1	12.1	0.8	133.7	9.9	0	5.2	0	4.2	4.3	210.1	42.7	433.1
1976	0	4.1	0	132.1	1	0	0	0	12.8	0.8	98.8	114.8	364.4
1977	16	34.3	41	140.4	98.2	14.6	0	6.2	3.7	3.4	205.6	160	723.4
1978	44.5	21.6	160.3	91.9	1.1	0	0	0	1.1	174.8	205.6	-	700.9
1979	234.2	48.3	21.5	127	61.8	1.5	5.5	0	2.3	19.5	138.5	117.3	777.4
1980	48.4	20.7		66.7	21.2	0	0	7.1	0.1	0.6	137.1	37.8	339.7
1981	0	0	104.9	287.3	80	0	0	0.4	2.4	42.9	45.5	97.9	661.3
1982	1	0	7.4	176.2	34.6	0.5	1.6	1.2	11.3	147.6	397.7	158.4	937.5
1983	0.5	36.9	3	40.8	12	0.1	0.5	0	2.3	0.3	15.8	147.2	259.4
1984	2.7	0	6	86.9	0	0	1.2	0	0.4	85.6	358.9	122.4	664.1
1985	53.3	83.3	34.1	81.9	16.8	0.2	1.6	0	1.6	67.4	125.6	89.3	555.1
1986	19.7	1	36.3	159.5	22.4	6.5	0	3	0	20.4	181.8	169.6	620.2
1987	16.5	0	16.1	62.9	70.4	19.5	1	2	0	0.5	108.9	10.4	308.2
MEAN	36.08461	29.87307	59.144	120.5269	25.78076	3.642307	0.980769	1.842307	3.326923	30.83461	183.4730	101.332	590.6692
STD	47.49481	32.46023	61.00823	78.91080	25.75764	7.264517	1.598080	4.509918	6.575687	45.57516	116.6979	74.23101	232.5230
VAR	2255.757	1053.666	3722.004	663.4561	52.77321	2.553860	20.33936	43.23965	2077.095	2077.095	13618.41	5510.242	54066.97

Appendix I

Table IV: KIBWEZI D.W.A PLATANTION
MONTHLY TOTALS
AND MEAN ANNUAL RAINFALL (1962-1987)

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1962	55	18	152	63	22	0	0	0	0	2	169	144	626
1963	30	20	129	76	17	14	0	0	7	19	295	253	860
1964	69	27	60	192	0	21	0	0	6	1	125	53	956
1965	44	0	9	33	35	0	0	4	0	74	124	53	375
1966	24	51	184	102	10	3	0	0	0	0	25	111	509
1967	3	22	22	266	19	0	1	20	45	75	337	15	825
1968	0	183	209	225	45	9	0	0	2	20	351	173	1215
1969	5	36	105	106	2	0	0	4	5	14	248	42	566
1970	5	0	158	71	29	0	0	0	1	0	100	139	502
1971	10	0	7	304	17	5	0	0	0	0	178	145	666
1972	40	24	17	7	13	8	0	2	4	39	289	105	548
1973	53	25	9	143	31	0	0	1	1	9	301	18	591
1974	11	43	204	124	0	2	0	1	1	15	117	58	576
1975	26	8	10	16	17	0	2	0	3	12	171	40	302
1976	0	1	21	140	14	0	0	0	30	2	166	117	491
1977	29	51	50	233	167	1	0	3	4	-	583	178	1298
1978	36	128	169	76	2	0	0	1	1	66	218	289	986
1979	372	26	71	191	55	5	2	2	1	54	220	196	1194
1980	29	22	76	35	1	0	0	8	0	0	273	91	535
1981	1	1	205	181	30	0	0	4	8	34	160	96	722
1982	1	0	39	163	186	0	149	2	13	135	383	175	1245
1983	9	69	82	29	11	0	1	0	8	0	78	145	431

1984	38	1	20	26	1	0	2	0	2	88	362	88	633
1985	6	110	75	43	27	0	1	0	2	82	141	131	619
1986	16	1	11	169	65	0	0	5	0	112	199	121	697
1987	14	0	12	56	68	8	1	5	0	1	143	36	342
Mean	36	33	81	118	34	3	6	2	6	34	220	133	704
Std	70	44	70	82	45	5	28	4	10	39	119	99	281

Appendix II

Artical a: Coefficient of Variation as a Measure of Dispersion.

To calculate Coefficient of Variation (C.V), or the relative dispersion, we need to firstly compute:

1) Standard deviation (s) and,

2) The mean ($\bar{X}$)

The standard deviation is given as:-

$$S = \frac{\sum_{i=1}^{n} (Xi - \bar{X})}{N}$$

and the sample mean as:

$$\bar{X} = \frac{\sum_{i=1}^{n} (Xi)}{N} = \frac{\sum_{i=1}^{n} X}{N}.$$

where:

S = standard deviation

Xi = the deviation of each of the X entry cells from the mean

$\bar{X}$ = the mean

$\sum X$ = summation of all the entries in X cell from i=1 to n

N = a set of numbers X1, X2,------XN.

Coefficient of variation is therefore given as

$$C.V = \frac{\sum_{i=1}^{n}(Xi-\bar{X})}{N} \Big/ \sum_{i=1}^{n}(Xi) \quad \text{or simply} \quad \frac{S}{\bar{X}}$$

where: S = standard deviation
$\bar{X}$ = the mean

Appendix II

Artical b: Probability of dry spell.

Given a record of "n" years and that a particular event ocurred in "m" out of these years, the possibility of that event ocurring in any given years is simply m/n.

This can be also denoted by

$p = pr(m) = m/n$

and the probability of non-ocurrence "q" is

$q = pr(m) = n-m/n = 1 - m/n = 1 - p = 1 - pr(m)$

thus, $p + q = 1$

The mean probability (Pm) of a dry spell after onset date in each season was computed for each 15 days interval, grouped from i = 1st to nth. This can be given as:

$$Pm = \sum_{i=1}^{x} Pi/N$$

Pm = mean probability

Pi = probability of the ith group

N = total count of the groups

x = xth group, maximum value of x = n

Appendix III

Table I: Years when the season was of early onset category (onset before 10th March during the long rains and before 20th October during the short rains)

STATION	Long-rains	Seasonal length (days after onset)	Total Rainfall (mm)
Kampi-ya-mawe	1963	75	327
	1964	75	240
	1966	75	454
	1967	75	385
	1968	75	677
	1969	75	263
	1973	75	134
	1977	75	313
	1978	75	359
	1983	75	252
	1985	75	504
Katumani	1963	75	281
	1964	75	404
	1966	75	334
	1967	75	449
	1968	75	510
	1969	75	204
	1972	75	185
	1973	75	129
	1974	75	416
	1977	75	500
	1979	75	512
	1980	75	310
	1983	75	241
	1985	75	552
	1986	75	318
Makindu	1963	75	245
	1964	75	225
	1966	75	333
	1967	75	367
	1968	75	602
	1969	75	190
	1973	75	193
	1977	75	311
	1978	75	339
	1983	75	090
	1985	75	216

continued ....

Makindu						
				1957	60	119
	1962	60	176	1967	60	366
	1965	60	84	1972	60	395
	1970	60	222	1984	60	561
	1974	60	201	1963	60	740
	1981	60	465	1965	60	198
	1986	60	183	1966	60	93
				1968	60	575
				1969	60	249
				1973	60	146
				1974	60	132
				1977	60	402
				1979	60	241
				1980	60	169
				1985	60	291
				1986	60	365
Kibwezi						
	1968	75	620	1962	75	316
	1962	75	231	1963	75	615
	1970	75	256	1965	75	252
	1979	75	321	1967	75	414
	1981	75	404	1968	75	521
	1982	75	388	1970	75	239
				1972	75	474
				1973	75	319
				1974	75	213
				1977	75	799
				1978	75	623
				1979	75	454
				1980	75	357
				1985	75	362
				1986	75	438
				1987	75	179

KIBWEZI D.W.A PLANTATION	1969	75	284
	1963	75	242
	1964	75	279
	1966	75	289
	1967	75	310
	1972	75	046
	1973	75	291
	1974	75	367
	1977	75	500
	1978	75	373
	1980	75	133
	1983	75	186
	1985	75	224
	Short-rains (Year)	Seasonal Length(days)	Total seasonal rainfall (mm)
KAMPI-YA-MAWE	1962	75	316
	1965	75	311
	1972	75	567
	1982	75	453
KATUMANI	1965	75	317
	1982	75	446
	1984	75	407
MAKINDU	1981	75	186
	1982	75	698
KIBWEZI D.W.A PLANTATIION	1981	75	289
	1982	75	692
	1984	75	543

Table II: Years when the season was of category Mid-Onset (after 10th March but before 1st April, during the long rains and after 20th October but before 10th November, during the short rains).

STATION	Long rains (year)	Seasonal length (days)	Total rainfall (mm)	Short rains (year)	Seasonal length (days)	Total rainfall (mm)
Kampi-ya-mawe	1962	60	231	1966	60	112
	1970	60	178	1967	60	339
	1971	60	347	1968	60	412
	1974	60	352	1969	60	219
	1981	60	579	1970	60	157
	1984	60	119	1973	60	185
				1974	60	145
				1980	60	232
				1981	60	131
				1984	60	506
				1985	60	281
				1986	60	492
				1987	60	228
Katumani	1962	75	281	1967	75	203
	1965	75	134	1968	75	400
	1970	75	370	1974	75	235
	1978	75	333	1978	75	292
	1981	75	436	1981	75	153
	1982	75	251	1985	75	304
				1968	75	416
				1969	75	197
				1973	75	198
				1977	75	375
				1979	75	192
				1980	75	183
				1983	75	211
				1986	75	308
				1987	75	106

continued ....

Appendix III

Table III Years when the onset was late (on or after 1st April (long rains) and after or on 10th November (short rains)

Station	Long rains (year)	Seasonal length (days)	Total rainfall (mm)	Short rains (year)	Total length of season	Total rain-fall (mm)
Kampi-ya-mawe	1965	60	193.7	1963	60	478.6
	1975	60	145.7	1964	60	473.1
	1976	60	192.7	1971	60	191.0
	1982	60	257.9	1976	60	312.8
	1987	60	101.4	1983	60	231.3
Katumani	1975	60	137.0	1962	60	303.0
	1976	60	136.0	1963	60	766.0
	1971	60	223.5	1964	60	262.0
	1984	60	040.6	1970	60	154
	1987	60	143.8	1971	60	238.0
				1975	60	152.0
				1976	60	168.0
Makindu	1971	60	267	1962	45	237.0
	1975	60	132	1964	45	420.0
	1976	60	132	1971	45	291
	1979	60	189	1975	45	150
				1976	45	237
	1982	60	190	1983	45	176
	1984	60	77			
	1987	60	133			