EVALUATION OF THE WATER BUDGET TECHNIQUE FOR THE DETERMINATION OF THE EFFECTIVE LENGTH OF THE GROWING SEASON UNDER DIFFERENT CLIMATIC CONDITIONS IN MALAWI

BY

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ABSTRACT

A study was conducted in Malawi, with the objective of evaluating the potential of the water budget technique, for the determination of the effective length of the growing season under different soil and climatic conditions. Two criteria were used to achieve the objective. One was the rainfall criterion, where rainfall was the only input and the other was the water budget criterion, where climatic data, soil and plant characteristics were major inputs.

Historical rainfall data were tested for homogeneity and statistical distribution using RAINBOW computer programme. All the stations, except Dedza, were homogeneous ($P = 0.05$). The coefficient of determination (R^2) suggested that the onset and end of the growing season can be approximated by normal distribution whilst the annual rainfall can be approximated by lognormal distribution.

Three years of historical rainfall data were used to calibrate IRSIS as a predictor of daily runoff. Very good and consistent performance ($R^2=0.86$) was obtained in predicting runoff. The calibration of the rainfall criterion using the water budget criterion indicated that the onset of the growing season could be defined as, a day when a running total of 30mm of rain is accumulated in a decade with no dry spell of more than 10 days occurring in the following 30 days. The results of the start and end of the growing season indicate that the rainfall criterion used in this study can be adapted for Chitedze and Makoka. The water budget criterion predicted onset dates closer to when farmers usually plant maize than the rainfall criterion. Both criteria revealed that Mangochi, Ngabu, Makhanga and Chileka have short growing seasons and high occurrence of dry spells within the growing season. Water conservation measures and / or supplemental irrigation should be advocated in these areas for sustainable crop production.

Using runoff plots, the study also showed that the Curve Number (CN) value in plain plot was higher than in contour plot.

It is recommended that the rainfall criterion which does not require a lot of input data should be calibrated using a more accurate approach (water budget) to establish appropriate threshold and conditions for different stations.

DECLARATION

I, Majamanda, I. I., hereby declare to the Senate of Sokoine University of Agriculture, Morogoro, that the work presented here is my own, and that, to the best of my knowledge, has not been submitted for a higher degree in any other University.

Date 25th NOV. 1998

Signature..............................

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DEDICATION

To the three noble men; Ives, Rhoben and Gomire for passing away before witnessing the fruits of their respective effort.

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ABREVIATIONS AND SYMBOLS

ΔG	Water storage change beyond root range
ΔS	Water storage change within root range
θ_v	Volumetric Soil Water Content
AMC	Available Moisture Content
CN	Curve Number
CRBD	Complete Randomised Block Design
D	Deep percolation
DoI	Department of Irrigation
E	Evaporation
ET	Evapotranspiration
FAO	Food and Agriculture Organisation
FC	Field Capacity
GDP	Gross Domestic Product
I	Infiltration
IRSIS	Irrigation Scheduling and Information Systems
ITCZ	Inter-Tropical Convergence Zone
L	Inflow/Outflow
MoA	Ministry of Agriculture
MORECS	Meteorological Office Rainfall and Evaporation Calculation Scheme
OPC	Office of the President and Cabinet
P	Precipitation
PET	Potential Evapotranspiration
PWP	Permanent Wilting Point
Q	Streamflow

r	Correlation coefficient
R	Runoff/Rainfall
R^2	Coefficient of determination
RAW	Readily Available Water
RWH	Rain Water Harvesting
S	Soil storage capacity
SWD	Soil Water Deficit
SWEAT	Soil Water Energy And Transpiration
TAW	Total Available Water
W_n	Water budget for the soil
$Z\Delta\theta$	Change of soil water storage

1 INTRODUCTION

1.1 Rainfall and agriculture in Malawi

Agriculture is the mainstay of Malawi's economy accounting in 1990 for 33.3% of the gross domestic product (GDP), 91.2% of the total domestic export earnings and 45.6% of the wage employment (OPC, 1991). The agricultural sector also supports 89% of the total population who derive their livelihood mainly from farming.

Most of the food production in Malawi is by smallholder farmers under rainfed conditions. Notwithstanding the great importance of irrigation for the production of foodstuffs and raw materials, the sustainability of irrigation farming in developing countries, including Malawi, is seriously at stake. Wolff and Hubener (1996) intimate that country-wide, regional and seasonal water scarcity in developing countries poses severe problems for national governments and the international development community. The challenges of growing water scarcity are exacerbated by the increasing costs of new water, wasteful use of already developed water supplies, degradation of soils in irrigated areas and the depletion of ground water.

Malawi has an irrigation potential of 240,000 hectare of which only 14% has been fully utilised (DoI-MoA, 1992). Although irrigation offers a means of increasing agricultural production and can ensure the survival of a crop in a drought year, its impact in Malawi is limited. Irrigation in Malawi faces major challenges in the coming decades. On one hand, it has to provide a major share of the required increases in food to meet the objectives of poverty alleviation and development. On the other hand, it is threatened by water shortages arising from accelerated competition of domestic, industrial and other water users. This means that rainfed agriculture will continue to dominate Malawi's economy. The critical nature of water resources in much of the tropics, for example, the fluctuations in the supply of rainfall have great significance and receive more attention than in some other regions. In addition, the economic situation in many tropical areas makes it difficult to cope with variability. Because most of the agricultural activities in Malawi depend on rainfall, any significant variation in the temporal and spatial distribution of rainfall usually results in serious food availability problems and a worsening poverty trap for most of the farmers.

The foregoing discussion stresses the need for an in depth study of rainfall in order to address the conditional questions which the majority of farmers face. Despite the importance of weather on the food supply and demand equation, the climatic element has not been carefully described in relation to crop performance so as to assist farmers in their day to day management strategies. Based on the same premise, the research reported herein was geared to address the conditional questions about rainfall and suggest strategies to answer those questions.

1.2 Rainfall analysis and water balance studies

Although rainfall criteria provide satisfactory results in determining the length of the growing season, a measure of water storage is needed to define for example, the end of the growing season more realistically (Mavi, 1986). Unlike the rainfall and modelling criteria which are solely based on rainfall, the water balance criteria involve the interaction of several factors such as rainfall, evapotranspiration and the moisture holding characteristics of the soil. This is an important element in that crop growth is not only affected by rainfall but a combination of rainfall, evapotranspiration and the water holding capacity of the soil.

Water balance studies showing, the relationship between rainfall and crop water requirements can provide valuable information to the farmer and the agricultural planner. They indicate the agricultural possibilities of an area, as far as water supply by rainfall is concerned, show the times and dimensions of water deficits, which allows an estimate of irrigation requirements and give an estimate of the right times for the most important agricultural operations (Nieuwolt, 1978). Therefore, an understanding of the frequency and magnitude of the recharge and drying cycles within the rainy season would quantitatively define the most viable traditional land use practice for sustainable growth of crops in regions with erratic and unreliable rainfall.

Furthermore, water-balance studies provide a general overview of water in an area; form part of a model for investigating rainfall-runoff relationships and stream flow prediction from climatic data; assess suitability of an area for a particular crop (analysing water requirement of the crop) and assessing favourable planting and harvesting dates; and finally, can be used to assess man's impact on the system. For example, the effects of irrigation, changing land use and changing cultivation practices can be analysed (Jackson, 1989).

1.3 Objectives

The main objective of the study was to assess the potential of the water budget technique for determination of the effective length of the growing season under different soil and climatic conditions in Malawi.

The specific objectives were as follows:

(i) to test the homogeneity of rainfall data for the representative stations between 1965 - 1992.

(ii) to fit different statistical distributions for the beginning and end of the growing season and annual rainfall amount.

(iii) to validate the IRSIS model by using the measured runoff depths.

(iv) to determine the start and end of growing season for the representative stations using both the rainfall and water budget criteria.

(v) to determine the risk of dry spells and their frequency.

2 LITERATURE REVIEW

2.1 Start and end of the growing season

To estimate the effect of rainfall on agriculture on an event like the start and end of a growing season, analysis of rainfall data is very important (Nieuwolt, 1989). A number of approaches based on some criteria have been proposed in analysing rainfall data for the purpose of determining the start and end of the growing season and hence the effective length of the growing season.

2.1.1 Rainfall Criteria

Several definitions of the start of the growing season based on rainfall have been suggested by different researchers. Davey et al. (1976) defined the start of the growing season as being that 10 day period which first received 20mm or more of rainfall. Virmani (1975) defined the start of the growing season as being that week which had more than 20mm of rain in one or two consecutive days provided that the probability of at least 10mm of rain in the subsequent week was greater than 0.7. This definition attempted to rule out early starts of the rains resulting from occasional heavy rainfalls. Frere (1982), defined the start as the date on which 75mm of rainfall is accumulated after the peak of the growing season. This definition is suspect in that the peak of the growing season is not defined.

To use rainfall criterion, as with other criteria, a threshold below which a day is considered dry must be defined. The smallest amount of rain usually recorded is 0.1mm

(Stern et al., 1982). Smaller amounts are considered to be of doubtful value both to a crop and in terms of the reliability with which they are recorded. Rao et al. (1980) defined a rainy day as a period of 24hrs in which 0.2mm or more rainfall is recorded. Any threshold, however can be used depending on the objective of the analysis. A great deal of agronomical analyses have been devoted to data grouped over several days (Da Mota and Da Silva, 1980Hay, 1981) because of ease of analysis and that plant water requirements for periods of about 10 days can easily be met by stored soil moisture reserves. However, Jackson (1989), Kingamkono (1993) and Mzengeza (1994) observed that the use of monthly values of any kind to define seasonal regimes is suspect, not only because rainfall conditions during short time periods are critical to agriculture but also the start and end of the growing season is based solely on rainfall amount.

Kingamkono (1993) used daily rainfall to derive the onset and cessation of the growing season. Cumulative rainfall was derived from the mean daily data and was plotted against day number with 1 January as day one. Using the graphs, the earliest possible dates, taken as points of maximum positive and negative curvature were used as guides to derive the start and end of the growing season respectively. The start of the growing season was taken as the date on which a running total of at least 20mm of rain was reached in 4 consecutive days with at least 2 days being wet and that no dry spell of at least 10 days occurred in the following 30 days.

However, Mzengeza (1994), used the pentade approach to define the start and end of the growing season in rice growing areas of Malawi. The percent annual rainfall occurring at each pentade was derived and accumulated. The accumulated percentages were plotted and the earliest possible onset and end dates were then determined as the points of maximum positive and negative curvature respectively. He then defined the start of the growing season as the first occasion that the 5-day running total exceeded 40mm and at least 3 of the days were rainy. A rainy day was defined as one having 0.85mm or more of rainfall. The end of the growing season was taken as the first occurrence of 15 consecutive dry days after the earliest possible end date. The problem with this criterion was that, in some years, the growing season did not end (the negative curvature was not reached). The meaning of this is that the condition set for determining the end of the growing season in some years, was not satisfied.

Dennett et al. (1983) defined the start of the growing season at three stations in Nigeria as the first occasion after 9 April when a total of at least 20mm of rains falls within a five day period and there is no dry spell of 10 or more days beginning within the next five days. These conditions are likely to allow sowing and successful emergence of a crop. The end of the growing season was defined as the first date after 15 August when the amount of water in the soil becomes zero and remains at zero for more than five days.

In a 100 year rainfall analysis at Davis, California, Stewart (1988) defined onset of rain as the date when 30mm of water had stored from the new rains in the surface soil. Depending on the early rainfall pattern and evaporation losses between rains, this amount of storage could accrue in one day, few days or a longer period. This required a small water balance program for determination of the date in each year of record.

The pentade approach has been widely adopted to define the growing season. Torrance (1967) used pentades to examine the progress of the mean rainy season occurrence of rainy and dry spells in the growing season in Central Africa. Stern et al. (1982) observed that the flexibility to choose the start event is useful where experience shows that successful planting rarely occurs by a particular date.

Jackson (1989) reported that in the Lilongwe plain, Malawi, the season is marginal in terms of water requirements of maize and it is therefore essential to make full use of the season. Therefore, in areas where rainfall seasons are comparatively short, forecasting the onset of rains is of great importance, especially since the planting is done or should be done before the rains begin.

The rainfall criterion requires longer records of historical data and this presents difficulties in comparing stations that may have different years of records. However, the criterion makes few assumptions in analysis and is simple. If this criterion is well calibrated, it could be of use to many farmers.

2.1.2 Soil-Water balance Criteria

Through water balance studies, the start and end of the growing season for different soils can be estimated. The use of simple water balance as input instead of rainfall has been discussed by Stern et al. (1982). Although a number of researchers have defined potential start and end of rains on such basis (Cocheme and Franquin, 1967; Berry et al., 1972), the approach is too simplistic and general. Different species vary greatly in their ability to withstand water shortage before their photosynthetic rate is seriously reduced. They also differ in their ability to recover when the water shortage ceases. Other experiments have shown that photosynthesis declines when the soil-water content is very high. Kramer (1963) however, points out problems in design of experiments to assess the relation between soil moisture and plant growth. Also, it is the plant-water deficit, not soil moisture, which influences plant growth and this involves both the rate of moisture absorption from the soil and transpiration. Overall, the relationships between water stress, plant growth and transpiration are rather complex and some aspects are not fully understood.

In Kenya, Wallis (1963) examined the use of water balance methods to estimate soil-water deficit and crop water use. He assessed the impact of water deficit on yield and also related this to irrigation needs. He then used his findings as a basis for an ecological grouping of different crops according to their probable water balance.

In Uganda, Rijks and Harrop (1969) used a water balance approach in an experiment concerning irrigation and fertilizer use on cotton. For irrigation control, the water balance, including rainfall, irrigation and crop-water requirement was used to determine the occurrence of moisture deficit. An important conclusion was that the use of a water balance approach reduced water expenditure, lowered labour cost and gave similar yields to a pre-set pattern of irrigation at regular intervals.

Agroclimatic models using soil-water balance data are usually set up on the basis of water budget, in which the difference between precipitation and runoff is added to the water store which is depleted by deep drainage and evapotranspiration. However, attempts to predict these factors under different conditions require many assumptions which simplify the process and are likely to introduce errors. Slatyer (1968) observed that this is the problem with which the agroclimatologist is confronted in predicting the length and characteristics of the growing season in many regions.

Computer simulation models to describe soil water recharge and depletion patterns (water balance) have been developed by crop modelling experts based on the simplified continuity equation on soil-plant-atmosphere continuum (Phillip, 1966). The continuity equation (Hillel, 1979), which constitutes the law of conservation of matter and energy in an ecological system can be represented as follows:

$$\theta_v = (P + I) - (R + ET + D) \tag{1}$$

Where θ_v is the volumetric soil water content, P is precipitation sources (which could be rainfall, irrigation, dew or frost), R is runoff, ET is evapotranspiration, D is deep drainage below the root zone and I is infiltration.

Campbell (1975) advocated the use of the Meteorological Office Rainfall and Evaporation Calculation Scheme (MORECS) in order to estimate weekly and monthly evapotranspiration, soil water depletion pattern and other components of the water balance. The MORECS soil water depletion term is represented as:

$$SWD_{i+1} = SWD_i + E_i - P_i \qquad \text{for } SWD > 0 \tag{2}$$

$$SWD_{i+1} = E_i - P_i \qquad \text{for } SWD < 0 \tag{3}$$

Where SWD_i is soil water depletion on day i, E_i is evaporation on day i and SWD_{i+1} is soil water depletion for day i+1.

Similarly, Campbell (1975), Bristow et al. (1986) and Choudhurry and Monteith (1988) used the Soil Water Energy and Transpiration (SWEAT) model to estimate soil water under different soil management practises. Lack of flexibility in the models to accommodate the variations in rainfall intensity and subsequent distortions in the infiltration and runoff relationship with time, limits the use and adaptability of such models.

Jackson (1989) presented a water balance equation as follows:

$$R = E_t \pm \Delta S \pm \Delta G + Q \ \pm L \tag{4}$$

Where, R is rainfall, E_t is evapotranspiration, ΔS is water storage change within root range, ΔG is water storage change beyond root range, Q is streamflow or runoff and L is outflow/inflow other than past streamflow measurements points. However, accurate assessment of R and Q are necessary and because of problems in assessing ΔS and ΔG, it is desirable to adopt a yearly period such that they are negligible. In its simplest form, where ΔS, ΔG and L are assumed to be zero, then,

$$R = E_t + Q \tag{5}$$

A common assumption in equation 5 is that all the precipitation infiltrates into the soil and therefore, strictly speaking, there is no surface runoff, a water surplus occurring only when the soil-moisture storage capacity has been exceeded. A second frequent assumption is that the rate of evaporation (transpiration) does not change with change in the amount of available water. Karnieli and Ben-Asher (1993) presented a model which proposes that runoff begins when the soil initial water deficit has been filled to saturation. Therefore, the assumptions of no runoff and no change in transpiration render the model presented in equation 5 weak in assessing the soil moisture within the rootzone.

On an annual basis, the components involved in Water Balance Equation (WBE), as suggested by Karnieli and Ben-Asher (1993), are as follows:

$$P = Q + E_t + D + Z\Delta\theta \tag{6}$$

Where P is the precipitation, Q is the runoff, E_t is the evapotranspiration, D is the deep percolation through the lower boundary of the soil profile (assumed to be positive in arid and semi-arid areas), and $Z\Delta\theta$ is the change of soil water storage. All the WBE components have length units (L). Although the only input data required for the WBE are actual daily rainfall depths over a long period of time, associated with the respective storm dates and the initial soil water content, there is no explicit solution to solve the equation for daily runoff. The other disadvantage of the WBE is that the term deep percolation is very difficult to quantify.

Dennett et al. (1983) and Stern et al. (1982) used the soil-water balance or water budget criterion as follows: Two constants, a soil moisture storage capacity, S, and daily evapotranspiration (E) were chosen. A water budget for the soil, W_n, was evaluated taking the value S and zero as upper and lower limits, rainfall, R, as input and E as output. So, on any day, n,

$$W_n = W_{n-1} + R_n - E. \tag{7}$$

This means that the value of W_n on day n is evaluated by taking its value on the previous day, adding rainfall on day n and subtracting the evapotranspiration. A result less than zero is set to zero and greater than S is set to S; corresponding to soil at field capacity. This technique was used by Stern et al. (1982) to define the end of the rains for Kano, Nigeria, as the first date after a pre-specified date on which the value dropped to zero.

The foregoing is based on assumptions that are too simplistic. An alternative, would be to use water balance approaches, based on conceptual type soil water flow models which consist of a numerical solution of the soil water flow equations for example Richards equation. This approach is very accurate when compared to analytical solutions (Belmans et al., 1983). The disadvantage of these models is however their small time step, which is of the order of minutes or hours. Their use will result in excessive calculation time which appears to be prohibitive for simulation programs that cover an entire or even several growing seasons. Furthermore, the precise results obtained with such an explanatory soil water flow model will often be in contradiction with what is usually desired in practice. And finally, the associated boundary conditions needed for the solution of the flow equation, have to be described at every time step with which the explanatory model is advancing in time (Raes, 1982). Consequently the climatological parameters which determine the flux across the soil surface (infiltration, evaporation), should be supplied to the simulation model with an accuracy corresponding to the magnitude of the time step. This is unrealistic since a tremendously vast computer memory would be needed to enter the continuously changing climatological parameters.

The last decade, starting from 1980, saw the development of field water balance and crop growth computer simulation models that allow the quantification of water in the soil (Belmans et al., 1983; Feddes et al., 1988; Muchow and Bellamy, 1990). For example, field water balance models like WAVE (Vanclooster et al., 1994) and MIKE-SHE (DHI, 1995) allow the estimation of actual evaporation, transpiration, soil moisture status, runoff and percolation losses for the season and previous years under different climatic conditions. The problem with WAVE and MIKE-SHE computer models is the difficulty in obtaining the required physical and hydraulic properties of the soils.

To avoid the inconvenience of a conceptual model, Raes (1982) developed a simplified solution which can be employed especially when the model has to be used for routine purposes. The procedure used consisted of an incorporation into a so-called summary model of the simulation results of an explanatory model through multiple entry tables or analytical expressions. By this the use of the summary model is restricted to those specific cases which were described by the conceptual model and which were subsequently incorporated into the summary model. Therefore a summary soil water flow model is composed of a series of summary submodels, each describing a specific process involved in soil water movement.

There have been recent developments on the water budget approach as applied to irrigation scheduling (e.g. Raes et al., 1988). This approach can easily be extended to rainfed agriculture for purposes of determining appropriate planting strategies and as a tool for early warning and crop yield prediction under prevailing and forecasted weather conditions.

BUDGET (Raes, 1982), which is a computer programme describing the soil water movement employing the "summary" approach, has been incorporated in IRSIS to simulate the soil water balance (Raes et al., 1988).

Water conservation for drylands in arid and semi arid regions, where, nearly two thirds of the world's food is produced from rainfall despite the inherent risk of food production in these regions, requires a critical analysis of water regimes in the soil. Water balance studies will therefore help to develop systems of production for these regions that will help to capture and retain a greater portion of rainfall, reduce soil water evaporation, use crops better suited to the rainfall distribution and seasons and eventually reduce runoff.

2.1.3 Modelling Criteria

One of the best examples of the modelling approach to rainfall analysis is by Stern et al. (1982). They fitted simple probabilistic models of daily rainfall for Kano, Nigeria and Sholapur, India. The models consisted of two parts. The first described the probability of rain throughout the year by fitting curves to observed proportions of rainy days. The second part of the model described the frequency of daily rainfall amounts on rainy days using gamma distributions.

Dennett et al. (1983), in a detailed study of three sites in arid West Africa, used probabilistic models to examine the independence of rainfalls through the rainy season. They observed weak relationships between monthly rainfall totals and the rainy days. These monthly attributes were treated as being effectively independent of each other. The start and end of the rains were also found to be independent.

The use of models provides more precise estimates than the other criteria and can be used with shorter periods (Stern et al., 1982). The other advantage of the model approach is that it provides quick and consistent comparisons between stations. However, fitting such models is not easy unless specialised computer packages are used.

2.2 Effective length of the growing season

The effective length of the growing season is usually defined as the duration between the start and end of the growing season. Stern et al. (1982) noted that it is useful to assess whether there is any correlation between the dates of the start and end of growing season. If there is a correlation, it becomes easy to answer conditional questions about the length of the season.

There are great variations in the amount of rainfall and rainfall distribution in Malawi. Some areas receive a mean annual rainfall as low as 600mm with a length of growing period of 105 days, while others receive mean annual rainfall over 2,000mm with a length of growing period up to 330 days (Eschweiler and Nanthambwe 1990).

In an analysis of rainfall data in Tanzania, Mhita (1984) observed that the start and end of rains are independent while correlation existed between the length and the start of the growing season. Alusi and Mushi (1974) in their analysis of onset and cessation of rains in East Africa, reported that although some stations have uni-modal type of rainfall and others bi-modal, the total average length of the growing season appeared to be the same.

In most instances, rainy period duration correlates with date of onset much better than does rainfall amount. Sivakumar (1989) quantified the duration relationship for 57 gauged stations in Niger and Burkina Faso. In each case, the rainfall records used were more than 25 years, ranging from 26 to 78 years. The correlations were excellent with coefficients (r) ranging from 0.81 to 0.95.

Stewart (1988) found virtually the same correlation between duration and date of onset at Niamey in Niger as did Sivakumar. This is of interest because Sivakumar used somewhat different criteria for both dates of onset and final rain date.

2.3 Dry Spells

Rao et al. (1980) defined a dry spell as period of at least 15 consecutive dry days to none of which is credited 1mm or more of rain. Crop moisture stress, due to occurrence of dry spells, is an interaction of rainfall variability, moderate to high evapotranspiration and low moisture holding capacity of most soils. A sequence of 15 consecutive dry days might not be appropriate where soils are mostly sandy and shallow, or a crop variety is drought susceptible. Fewer days might then be taken to constitute a dry spell. In the computation of dry spells at 4 stations in Tanzania, Nieuwolt (1978) defined dry spells as periods longer than 4 days each with less than 0.25mm of rain.

It is useful to know the occurrence of consecutive dry periods during the rainy season. Prolonged dry spells may affect crop development especially when they coincide with a sensitive phenological stage, for example, reproductive stage.

Munthali and Ogallo (1986) analysed annual rainfall time series for a few selected locations from 1897 to 1983. They observed that drought conditions are not uncommon in Malawi. They noted that wet years were generally followed by dry years but there was no fixed return period of dry or wet years.

In Singapore, dry spells of more than 6 days each with less than 0.25mm rain occurred in every month except November over the period 1962 - 1966 with the longest dry spell lasting 20 days (Jackson, 1989).

2.4 Extension of the growing season through rainwater retention techniques.

Different water retention techniques have been found to maintain yield stability during drought and to extend the growing season. Kampen (1976) evaluated the effects of different land treatments on runoff, erosion and yields in the semi arid tropics of India. They observed that yields obtained from hydrologically monitored, field size units (0.4 ha) on vertisols illustrated the superior yield performance of ridged cultivation system. The yield from the flat planting and narrow ridges were 2740 and 3240Kg/ha while the runoff was 141 and 77mm respectively.

The use of ridges on which the crop is planted running across the slope provides an excellent barrier to water running down the slope and forces the water to move slowly along the furrows to be discharged, hopefully, into a safe waterway. This slowing down of water flow was shown to reduce runoff losses from 23% for ridges up and down the slope to 14% for ridges on a 1:250 gradient. This difference could amount to 50 to

100mm of water during the life of the crop, a quantity that could make a considerable difference in seasons and areas with inadequate rainfall (FAO, 1987).

Contour ridges have been found to reduce surface runoff and erosion from a field (Lal, 1983). This is because contour ridges increase the infiltration opportunity time for surface runoff as it travels across the furrow thus allowing more water to infiltrate into the soil. The effectiveness of contour ridges is greater if the ridges are truly on a contour, the field slopes are flatter and the soils are more permeable (FAO, 1993).

Tie-ridging is also effective in reducing soil erosion, surface runoff and increasing soil water storage. Early and recent research in East Africa (Faulkner, 1944, Peat and Prentice, 1949), Zimbabwe (FAO, 1993), Burkina Faso (Hulugalle et al., 1990) and USA (Khrishna, 1989) have generally shown that tie-ridging is effective in reducing surface runoff, increasing soil water storage and crop yield especially in dry years. In severe storms however, research in Africa as reviewed by El-Swaify et al.(1985) has shown that tie-ridging can lead to overtopping, ridge failure and water logging and total loss of the crop.

There exists throughout the world a body of evidence showing the effectiveness of various on-field soil and water conservation techniques on the field soil water status and crop yield. Simalenga, et. al., (1992) noted that tie ridging increased soil water content, soil water retention and available water capacity and decreased surface runoff. Many studies have shown that tie ridging increases yields probably due to the high water retention associated with tie ridging (Hatibu, et al., 1995; Dick et al., 1991). With the exception of Lungu (1971), very few studies done in Malawi have focused on soil water status of field crops. He observed that there was a marked difference in soil moisture status between early planted and late planted maize. His pioneering work was, however, limited in that he only considered one rainwater retention technique (contour ridging) and the soil moisture data was limited to one depth. Research in Rain Water Harvesting (RWH) techniques in Tanzania has shown that there is a significant mean yield benefit of about 3.22 t/ha and of about 2.95 t/ha for maize and sorghum respectively due to runoff harvested from different catchments (Lameck, 1994).

2.5 Response farming as a means to avert crop failure.

The benefits of early planting of maize in East Africa have been indicated by a number of researchers (Gray, 1970; Gwynne, 1964). Planting at the start of the rains or even before the rains was found to give the highest yields. With early planting, maize developed a better root system and was therefore able to use soil water more effectively (Gwynne, 1964). Turner (1965) at Iloga, Tanzania, found that late planted maize received much less rainfall from the tasselling stage to harvest than early planted maize, and therefore suffered from lack of water during grain formation with resultant low yield.

Dagg (1965) used a simple water-balance approach to test the suitability of marginal area in Kenya for growth of two varieties of maize and reported that the imported variety of maize, which had a shorter growing season than the local variety, but higher water demand at certain stages of its growth, was more suited to the rainfall season. The local variety with longer season, was likely to be subjected to moisture stress towards the end.

In general, yields are markedly and progressively reduced the longer the planting date is delayed after the start of the rains. Trials at Ikiriguru, Tanzania cited by Wrigley (1969), for example, showed that delaying planting from 6 to 27 January reduced cotton yields by 47%. Groundnut yields at Gezira (Sudan) were reduced by 40% by delaying planting from early August to September (Wrigley, 1969).

3.0 METHODOLOGY

3.1 Description of the study area

In this study, a total of sixteen stations were selected from different parts of Malawi for data collection. The major criteria in the selection of the stations was the availability of sufficient rainfall data to undertake the study. Fig. 3.1 shows the location of stations used in the study.

Rainfall in Malawi is seasonal, erratic and variable. The seasonal character is associated with the movement of the South East Trade moist Zaire air and the North East Monsoon air masses which meet at the Inter-Tropical Convergence Zone (I.T.C.Z.). Nevertheless, monthly rainfall totals for particular stations are related to local influences.

The runoff plots were located at Bunda College of Agriculture (Agricultural Engineering field) with an altitude of 1118m above sea level . Bunda soils (latosols), are a representative of the latosols found extensively in the Lilongwe plains. The Lilongwe plains, where the College is located, is an important maize producing area in Malawi.

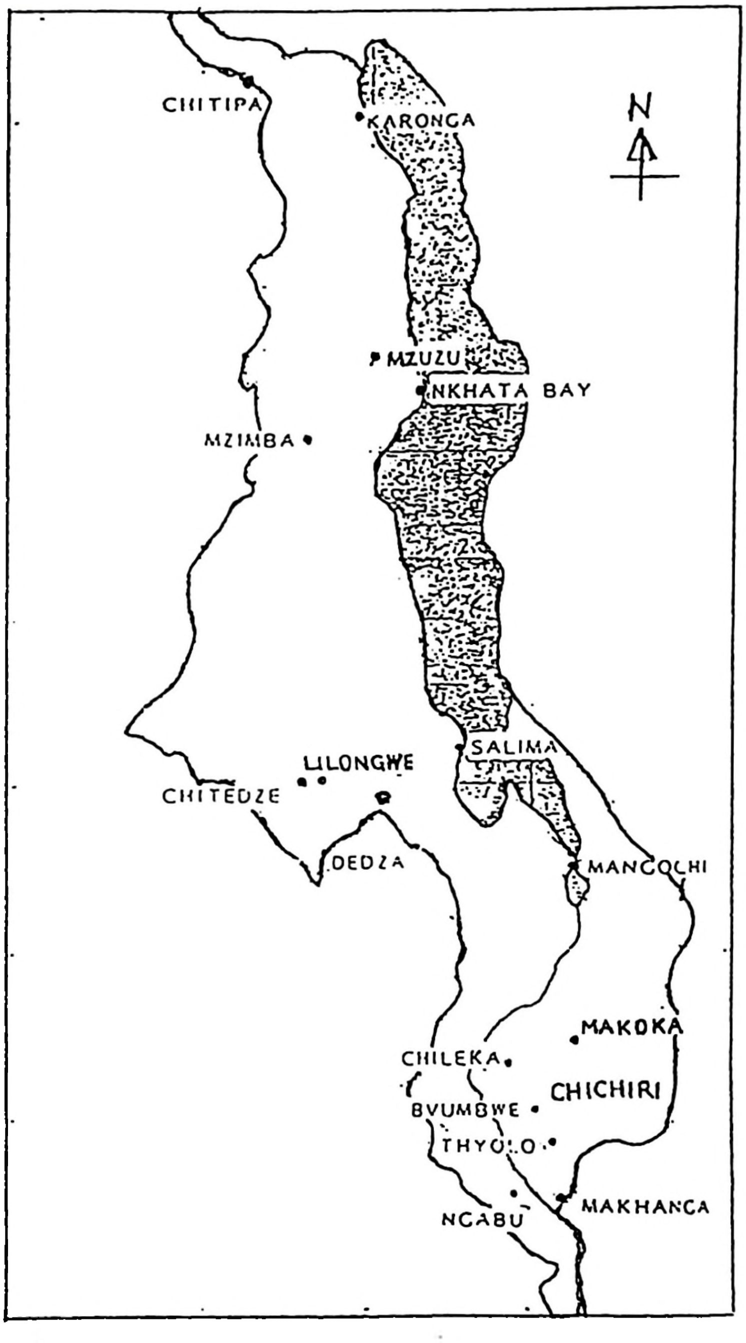


Figure 3.1: Map of Malawi showing the locations of the stations used in the study.

Source: Department of Surveys (1991)

3.2 Data Collection

3.2.1 Climatological Data

Historical rainfall, minimum and maximum temperature, relative humidity, sunshine hours and wind speed data (1965-1993) were collected for sixteen representative meteorological stations from the Directorate of Meteorology in Blantyre. The 1996/97 rainfall data were collected from a recording rain gauge located at Bunda College of Agriculture.

3.2.2 Soils data

The following soil physical parameters for different soils from selected meteorological stations were determined as per standard methods and procedures by Klute (1986): infiltration rate, bulk density, particle density, texture, and hence the type of soil, field capacity (FC) and permanent wilting point (PWP) to determine total available water (TAW).

3.2.3 Experimental Data

To validate the IRSIS model, a maize field trial consisting of three rainwater retention techniques namely, contour ridging contour ridging plus tie-ridging and contour ridging without ridging as a control (Shaxton, 1977) and two replications was laid out in a complete randomised block design (CRBD).

Surface runoff generated from the 2 rainwater retention techniques for selected storms throughout the 1996/97 rainy season was measured. The runoff from runoff plots was channelled to containers and runoff depth was measured using stage recorders. For the contour bund block without ridges, surface runoff was collected from a smaller 5m by 4m plot instead of 12m by 12m experimental unit to reduce the size of runoff collection containers. From the contour ridge block, surface runoff from a single ridge furrow (10m by 1m) was collected.

3.3 Data Analysis

3.3.1 Rainfall patterns in Malawi

(a) Homogeneity of rainfall data

Homogeneity of rainfall between 1965-1992 for the selected stations was done by testing the cumulative normalised deviation from the mean at 95% confidence levels (Raes et al., 1990; Haan, 1977). This, including the annual dependable rainfall at 20, 50 and 80% probability of exceedance was done by using RAINBOW computer software (Raes et al., 1990).

(b) Rainfall statistical distribution

Statistical distributions, namely, normal, lognormal and gumbel (Extreme value 1) were fitted to the onset, end of the growing season (as derived in section 3.2.2) and the annual rainfall using RAINBOW computer program (Raes et al., 1990).

(c) Annual, seasonal and monthly rainfall variability

Coefficients of variation were computed for annual and seasonal rainfall to find out the variability of rainfall in the studied areas. Variability of annual, seasonal and monthly rainfall was highlighted by a 5-year moving average and rainfall graphs.

3.3.2 Validation of IRSIS model

Apparently, an important element of using any computer model is model validation. Model validation involves the testing and evaluation of the performance of the model using a set of data other than those used in the model identification and parameter estimation. The model is considered to be conditionally acceptable if the results of the model on the independent set of test data prove to be acceptable for the intended purposes and within the desired accuracy. If this is not the case, the model parameters will need to be updated or the basic model structure will need to be modified altogether.

Daily rainfall amounts collected at Bunda were input into IRSIS computer program for model validation to find out if IRSIS could be adapted for Malawi conditions.

3.3.3 Derivation of the start and end of the effective growing season

For each station and each rainy season, the date of the onset of rains, the length of the growing season and total seasonal rainfall were determined.

(a) Rainfall criterion

The threshold rainfall amount used by different researchers in Malawi (Munthali, 1986, 1996; Hay, 1981; Mpata, 1973; Mzengeza, 1994 and Mkandawire, 1987) to derive the start of the growing season ranged from 20 - 40mm of rainfall. Simulation runs with IRSIS programme were made using historical rainfall data for Bunda and Chitedze, during 1982/83 and 1981/82/83 growing seasons respectively in order to establish the respective threshold values for the start and end of the growing season. Different running totals ranging from 20 - 40mm of rainfall were tried to find the best threshold for Malawi.

(b) Water balance criterion

The field, climatological and crop data were input into the IRSIS computer model that was used to derive the start and end of the effective growing season. IRSIS is a computer programme incorporating a water balance simulation model.

A day was, therefore, considered the potential start of the growing season when the soil moisture was equal to or above readily available water (RAW), a suction at which plants can easily take up water from the soil to sustain good growth, with no dry spell of 10 days or more within the next five days. The end of the growing season was taken as the day when the soil moisture was below RAW followed by a dry spell of 10 days or more.

3.3.4 Determination of dry spells and their frequency

To find the probability of having a dry spell of N days (where N varies from 1 to maximum observation for the station) frequency analysis of historical dry days data (1965 -1992) for each station and for each year during the rainy season (Haan, 1977) was carried out. The probability of the dry day versus time was plotted to show the time when it is likely to be dry and the time when it is likely to be wet for each station.

4 RESULTS AND DISCUSSION

4.1 Review of rainfall in Malawi

4.1.1 Homogeneity of annual rainfall data

Frequency analysis of hydrologic data and their potential use in agrometeorological decision making process, require that the data be homogeneous and independent. The restriction of homogeneity assures that the observations are from the same population (Raes et al., 1990). The results of this study clearly demonstrate that the annual rainfall data for the stations studied are homogeneous. It frequently occurs that rainfall data over different periods are not comparable since the measured amount of rainfall depends on such factors as; type, height and exposure of the raingauge. Buishand (1982), noted that it is often not possible to specify the nature of changes in the mean amount of rainfall from the station documentation. This is partly because it is not always known how a change in the instrument or in the raingauge site may influence the measured amount of rainfall, and partly because it is highly questionable whether the station information gives a complete picture of a raingauge site during the period that the station has been in operation.

Because of the uncertainty about possible changes, graphical methods are often used in climatology and hydrology to obtain some insight into the homogeneity of a record. Though graphs are useful for the detection of shifts in the mean, it is usually not obvious how real changes can be distinguished from purely random fluctuations. Therefore, in this study, statistical methods were used to test the significance of departures from homogeneity. Table 4.1 shows that all the stations under study except Dedza were homogeneous at the 5% level of significance. It was observed that the raingauge station at Dedza was shifted to a new site (Chilemba, J. M, personal communication, 1997). The non homogeneity of Dedza can, therefore, be attributed to the change in raingauge site.

Table 4.1 Summary of findings of annual rainfall homogeneity based on cumulative normalized departures ($P < 0.05$)

			Probability distribution			
Station	Duration of rainfall data (yrs)	Homogeneity	Normal	Lognormal	Gumbel graphical assessment	overall best fit choice
Bvumbwe	27	yes	0.92	0.96	poor	lognormal
Chichiri	26	yes	0.97	0.98	poor	lognormal
Chileka	27	yes	0.97	0.99	poor	lognormal
Chitedze	24	yes	0.96	0.98	poor	lognormal
Chitipa	24	yes	0.96	0.98	fair	lognormal
Dedza	24	NO	0.90	0.94	fair	lognormal
Karonga	25	yes	0.89	0.97	fair	lognormal
Makhanga	26	yes	0.96	0.78	fair	normal
Makoka	24	yes	0.96	0.98	fair	lognormal
Mangochi	27	yes	0.97	0.98	fair	lognormal
Mzimba	27	yes	0.92	0.96	poor	lognormal
Mzuzu	26	yes	0.98	0.97	poor	normal
Ngabu	21	yes	0.98	0.93	very poor	normal
Nkhatabay	26	yes	0.94	0.89	poor	normal
Salima	27	yes	0.92	0.98	good	lognormal
Thyolo	27	yes	0.94	0.97	poor	lognormal

4.1.2 Rainfall statistical distribution

The general visual gumbel observation and the coefficient of determination (R^2), for normal and log-normal, suggested that the onset and end of the growing season can best be approximated by normal with gumbel distribution showing the weakest distribution (Table 4.2). Kingamkono (1993), Mhita (1984) in Tanzania and Stern et al. (1982) for Kano, Nigeria, made similar observations. However, the analysis in this study shows that the annual rainfall can best be predicted by the lognormal distribution. Gregory (1969) suggests that for annual rainfalls of more than 750mm normality is a reasonable assumption and this is often true for wet season rainfalls. For rainfalls less than 750mm, the possibility of non-normality is greater and Griffiths (1961) found that for annual rainfalls less than 635mm there was a 45% chance of data being non-normal. Mooley and Appa Rao (1971) found that whilst the normal distribution gave a good fit to seasonal and annual rainfall at stations in some parts of India, it did not give a good fit over the major part of the country, instead, a gamma distribution was more suitable. Manning (1956) and Griffiths (1961) showed that a square-root transformation was best but Gregory (1969) showed that neither square-root nor logarithmic transformation is necessarily a better fit. The advantage of fitting the distributions to the start and end dates of the growing season is that a concise summary of the data is possible. With the assumption of normality, this summary consists of parameters like, the mean, standard deviations of the dates of start and end of the growing season, and the correlation coefficient between the start and end. Furthermore, any required percentage points of the start, end and length of the rains can be derived from these parameters.

Table 4.2 Measure of fit (R^2) for normal and log normal distributions for onset and end day at different stations.

Station	Onset		End	
	Normal	log normal	Normal	log normal
Bvumbwe	0.99	0.98	0.94	0.96
Chichiri	0.99	0.99	0.97	0.94
Chileka	0.99	0.99	0.98	0.94
Chitedze	0.98	0.97	0.94	0.90
Chitipa	0.87	0.88	0.97	0.96
Dedza	0.98	0.98	0.95	0.92
Karonga	0.98	0.98	0.97	0.96
Makhanga	0.98	0.98	0.97	0.93
Makoka	0.92	0.91	0.95	0.85
Mangochi	0.96	0.96	0.95	0.87
Mzimba	0.96	0.96	0.95	0.85
Mzuzu	0.98	0.98	0.97	0.98
Ngabu	0.95	0.95	0.97	0.85
Nkhatabay	0.94	0.95	0.98	0.98
Salima	0.96	0.96	0.96	0.98
Thyolo	0.97	0.97	0.97	0.98

4.1.3 Annual, seasonal and monthly rainfall variability

This study has also shown that most of the rains in Malawi are received in January (Table 4.3). The high amounts of rainfall received in January is probably due to the general migration of the Inter-Tropical Convergence Zone. Van der Velden (1979), in an analysis of rainfall in Malawi from 1947 -1967, reported similar results. However, this study has revealed a large year to year seasonal variation within a station. For example, in 1982 the seasonal recorded rainfall for Salima station was 711.1mm while in 1971, the station recorded 1580.2 mm. Similarly, Mzuzu station recorded seasonal rainfall of 792.4mm in 1987 and 1263.6mm in 1979. Fig.4.1 shows the annual variations for Salima. Stewart (1988), reported that seasonal rainfall amount is notoriously variable in most locations in the world. Typically, it may range from a low of around 0.33 of the long term mean to a high of approximately double the mean. Munthali (1996) noted that many subtropical climates including Malawi, have high rainfall variability even on annual or seasonal level and that a change in rainfall variability could be more important than a change in the mean amount over the year. In this study, monthly variations were also apparent as evidenced by Table 4.3. Variation of this magnitude is both doubting and confusing to farmers whose very lives depend on their making rational decisions about types of crops to be planted, level of inputs to purchase and specific practices to follow. This trend indicates that mean values are of little significance in analysis of rainfall as a tool to guide agricultural planning. Primault (1979) reported that since an average is the quotient of the sum total of a certain number of observations divided by that number, it provides no indications concerning the possible fluctuations and the frequency of such fluctuations. The mean deviation and standard deviation are though commonly used to express variation but as the case of arithmetic mean, they suffer from disadvantages with a skew distribution by forcing the results towards one direction of the distribution . Consequently, the average, and even the standard variation accompanying that average, would not fulfill the requirements of agriculture. Hence, median values have been used in this study for both rainfall and water balance criteria.

Table 4.3 Summary of mean, annual seasonal and monthly rainfall (mm)

Station	Relief	Annual	Seasonal	Oct-Dec	Jan-Feb	Mar-Apr
Bvumbwe	plateau	1085.0	1051.2	338.8	417.7	255.8
Chichiri	highlands	1107.3	1083.2	349.8	454.2	250.9
Chileka	rolling	500.0	859.5	297.1	375.9	198.9
Chitedze	plains	877.6	857.0	288.8	363.4	195.3
Chitipa	hills	926.9	929.0	282.8	386.2	247.1
Dedza	hills	920.6	887.0	283.2	433.2	181.5
Karonga	rift valley	1092.5	1082.5	249.3	325.3	483.4
Makhanga	rift valley	680.2	640.2	234.8	252.8	136.3
Makoka	plains	986.2	958.1	319.3	411.7	226.7
Mangochi	rift valley	816.6	784.4	243.0	374.4	39.0
Mzimba	plateau	896.4	869	265.3	418.9	199.6
Mzuzu	plateau	1226.0	1161.9	320.1	348.1	424.1
Ngabu	rift valley	798.0	719.2	368.5	293.2	73.6
Nkhatabay	rift valley	1576.4	1508.2	335.1	379.6	649.0
Salima	rift valley	1249.1	1238.0	289.2	616.7	330.6
Thyolo	plateau	1227.8	1137.5	385.5	425.8	305.6

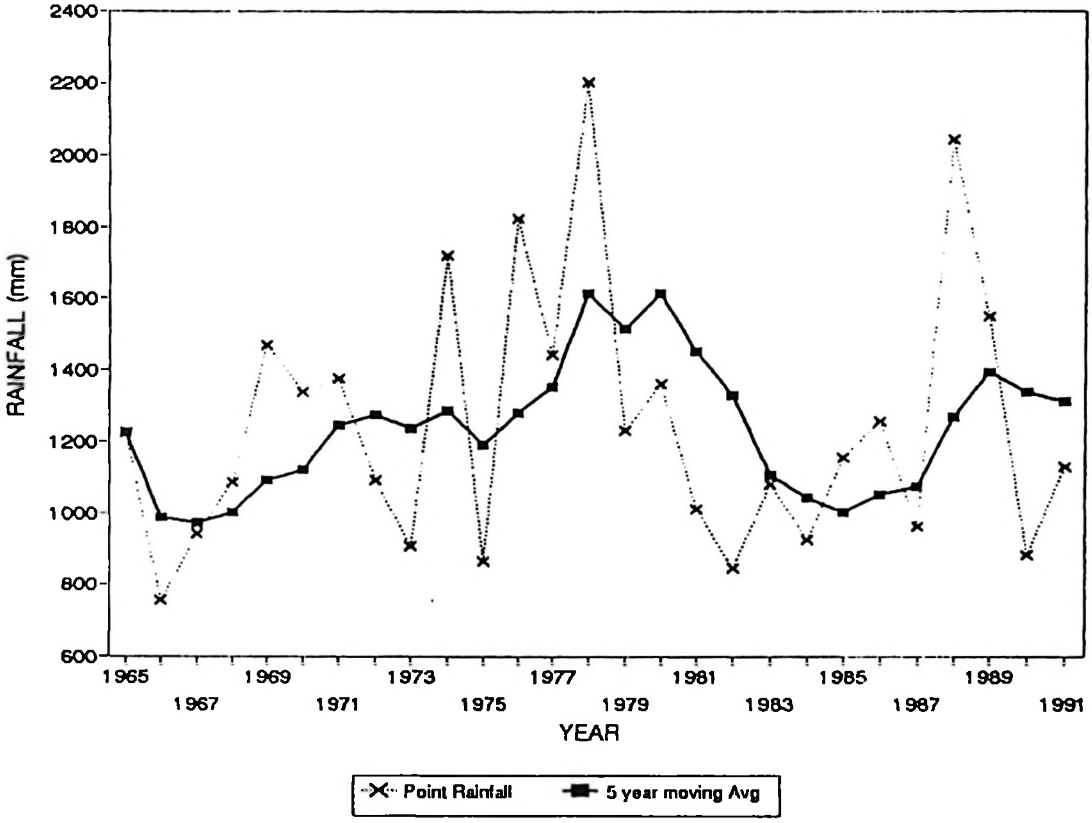


Figure 4.1: Salima annual rainfall long-term trend.

In Malawi, rainfall distribution is strongly influenced by orographic effects and that windward slopes on steep topography which face the prevailing south easterly winds like Thyolo, may receive twice the rainfall of the low lying areas like Makhanga. Rainfall totals and their geographical distribution correlates closely with relief, such that the highlands and escarpment exposed to the full force of the northeast monsoon experience greater precipitation rates than do the lowlands and rain shadow areas. Thus, whereas 90% of the country has a mean annual rainfall of more than 800 mm, the plateaus of Bvumbwe, Mzuzu and Thyolo; the lake shore at Nkhatabay which is backed by the steep slopes of the rift valley escarpment, together with the highlands of Chichiri, receive in excess of 1000mm per year. Conversely, as reported by the Government of Malawi (1983), and as found in this study, low annual rainfall rates are experienced along hinterland as in Mangochi and in the Shire Valley lowland, for example Ngabu and Makhanga.

Table 4.4 shows the 20, 50 and 80 probability level of annual rainfall for all the stations. While the mean annual rainfall for Salima was 1249.1mm, (Table 4.3), Table 4.4 shows that the annual rainfall was equal to or greater than 1547.8mm in one out of five years, equal to or greater than 1202.2mm in one out of two years and equal to or greater than 933.7mm in four out of five years. Huke (1966), stated that all other factors being equal, theory dictates that stations with large total volume of rainfall have the least annual percentage variation and the driest stations have the greatest variations. Interestingly, many authors such as Dale (1969), Dick (1968) and Huke (1966) point out that there are exceptions in Huke's theory within the area of study. Table 4.4 also shows that some stations under this study obeyed Huke's theory, for example, Mzuzu station recorded one of the highest seasonal rainfall amount of greater than or equal to 1242.1mm in 1 out of

2 years and registered the least seasonal variation of 17%. It is also true that drier areas had high variations. Ngabu station recorded one of the lowest amount of seasonal rainfall of equal to or greater than 767.0mm in 1 out of 2 years and registered a high variation of 29%. Exceptionally, though Salima had one of the highest average seasonal rainfall equal or greater than 1202.2mm in 1 out of 2 years it had the highest seasonal variation percentage of 31. The high rainfall in Salima can be due to the prevailing south easterly winds.

If data are approximately normal, Gregory (1969) suggests that the relative variation is not only related to the mean value but also, contrary to general opinion, it is no greater in the tropics than in the higher latitudes. Gregory (1969) cites variability values of 10 - 20 percent in Britain, similar to those of northern Nigeria and Sierra Leon. In Ghana, 25% is the highest value, most being less than 20%. In Mozambique, seasonal variability is somewhat higher, but exceeds 35% only in very limited dry areas. In this study, as indicated in Table 4.4, seasonal variations ranged from 17% for Mzuzu to 31% for Salima. As was observed in Mozambique, this study also shows high rainfall variations in dry areas of Mangochi, Chileka, Makhanga, Ngabu and Salima.

Table 4.4 Expected annual rainfall (mm) at different stations based on log normal distribution

	Annual rainfall equal or greater than				
Station	20%	50%	80%	Annual CV	Seasonal CV
Bvumbwe	1281.1	1062.0	880.5	0.21	0.23
Chichiri	1341.3	1077.7	865.9	0.23	0.18
Chileka	1098.2	803.0	678.7	0.25	0.23
Chitedze	1033.3	861.2	717.8	0.20	0.21
Chitipa	1092.6	909.3	756.8	0.20	0.19
Dedza	1076.7	904.1	759.1	0.20	0.19
Karonga	1379.3	1043.1	788.8	0.32	0.26
Makhanga	906.5	632.4	441.2	0.33	0.25
Makoka	1139.2	972.2	829.6	0.17	0.19
Mangochi	1002.2	791.1	624.5	0.25	0.25
Mzimba	1034.7	882.8	753.2	0.18	0.18
Mzuzu	1455.9	1242.1	1059.6	0.22	0.17
Ngabu	1007.5	767.0	584.1	0.26	0.29
Nkhatabay	1884.5	1538.7	1256.3	0.21	0.22
Salima	1547.8	1202.2	933.7	0.29	0.31
Thyolo	1485.2	1193.9	959.6	0.24	0.23

4.2 Calibration of the IRSIS model

A t-test was performed for different simulated runoff volumes with IRSIS using different CN (AMC II) values and the measured runoff. A probability of 0.1 for significance was chosen for the T-test because at lower probabilities e.g. 0.05 the simulated runoff was no significant change in the simulated runoff. The results showed that the simulated runoff from a maize field at CN (AMC II) 62 and 54 was not significantly different ($P < 0.1$) from the measured runoff from plain and contour field respectively.

Regression analysis showed that the simulated runoff at CN (AMC II) 64 and measured runoff from the plain field agrees reasonably well ($r^2 = 0.86$). There was also a high correlation ($r^2 = 0.86$) between the simulated runoff at CN (AMC II) 54 and collected runoff from the contour field. Figs. 4.2 and 4.3 show the comparison between the measured and simulated runoff from plain and contour fields at CN (AMC II) 64 and CN (AMC II) 54 respectively.

The CN values found in this study could be used to improve computer model predictions of runoff, erosion and water quality and provide more accurate estimates of runoff volume for use in designing conservation structures, water supply, flood control and numerous other uses in soil and conservation.

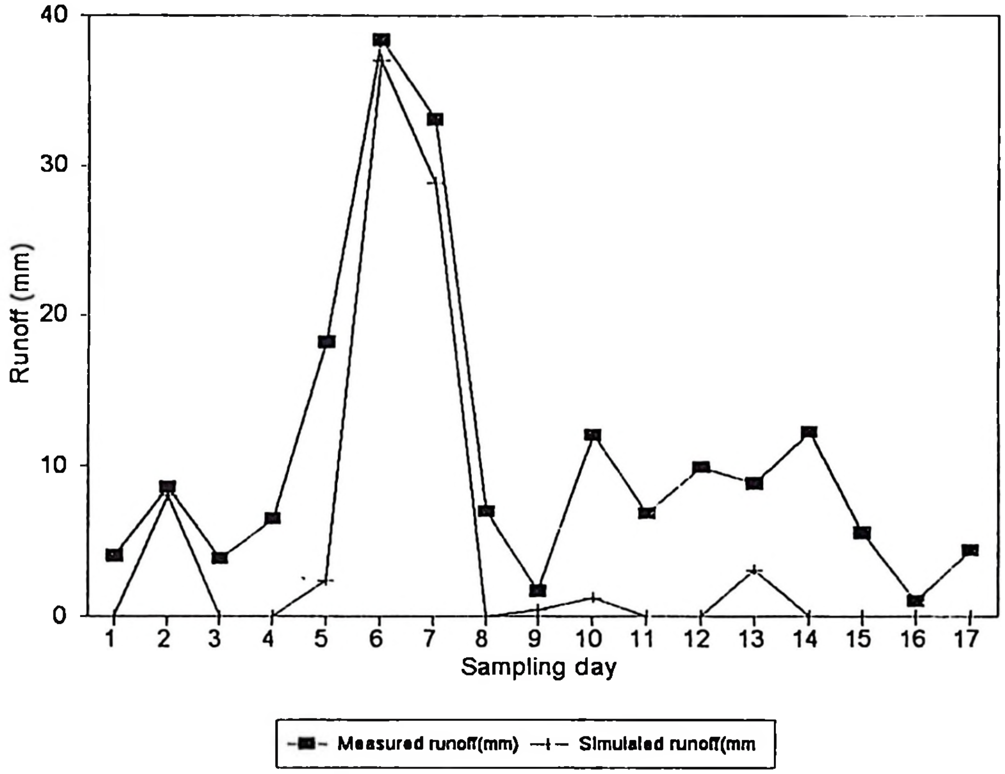


Figure 4.2: Comparison between measured runoff from plain field and simulated runoff from IRSIS at CN (AMC II) 64.

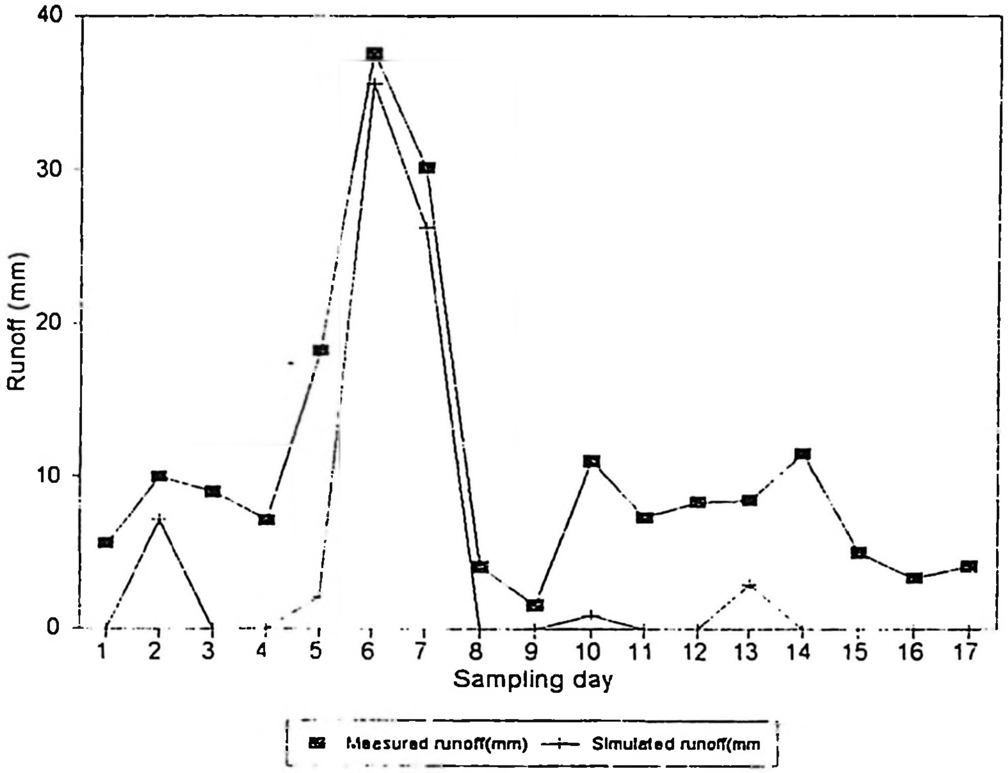


Figure 4.3: Comparison between measured runoff from contour field and simulated runoff from IRSIS at CN (AMC II) 54.

4.3 Start, end and length of effective growing season

4.3.1 Start and end of effective growing season

4.3.1.1 Rainfall criterion

The running total of at least 30mm of rainfall reached in 10 days and 25mm not exceeded in 15 days agreed reasonably well with the water budget criterion for the onset and end of the growing season respectively. An effective growing season in this study was, therefore, considered to start if a running total of at least 30mm of rain was reached in a decade with no dry spell of more than 10 days occurring in the following 30 days.

Table 4.5 summarizes the start and end of the effective growing season at three levels of probability of exceedance. Reference to the table shows that the start of the growing season at Bvumbwe occurs on or after 16 October in 4 out of 5 years, and on or after 6 November in 1 out of 2 years and finally, on or after 19 November in 1 out of 5 years. The end of the growing season for Bvumbwe occurs on or after 9 May in 4 out of 5 years and on or after 27 April in 1 out of 2 years and finally, it occurs on or after 14 April in 1 out of 5 years. The results for other stations are summarized in Table 4.5.

Table 4.5 Percentage points for which the growing season can be expected to start and end at a given probability of exceedance (Rainfall criterion)

	Start date				End date			
Station	20%	50%	80%	CV	20%	50%	80%	CV
Bvumbwe	16 Oct	6 Nov	19 Nov	0.04	14Apr	27Apr	9 May	0.12
Chichiri	21 Oct	3 Nov	15 Nov	0.04	7 Apr	21 Apr	5 May	0.14
Chileka	27 Oct	10 Nov	24 Nov	0.05	18 Mar	2 Apr	17 Apr	0.17
Chitedze	7 Nov	18 Nov	30 Nov	0.04	29 Mar	14 Apr	29 Apr	0.16
Chitipa	9 Nov	28 Nov	27 Nov	0.03	8 Apr	17Apr	25 Apr	0.09
Dedza	15 Nov	23 Nov	1 Dec	0.03	25 Mar	8 Apr	22 Apr	0.16
Karonga	19 Nov	28 Nov	8 Dec	0.03	21 Apr	1 May	10 May	0.09
Makhanga	1 Nov	16 Nov	30 Nov	0.05	22 Mar	10 Apr	28 Apr	0.20
Makoka	2 Nov	13 Nov	26 Nov	0.04	15 Mar	3 Apr	22 Apr	0.21
Mangochi	15 Nov	25 Nov	7 Dec	0.04	12 Mar	29 Mar	15 Apr	0.20
Mzimba	15 Nov	25 Nov	3 Dec	0.03	25 Mar	9 Apr	24 Apr	0.16
Mzuzu	6 Nov	18 Nov	29 Nov	0.04	23 Apr	6 May	19 May	0.11
Ngabu	15 Oct	28 Oct	10 Nov	0.05	18 Feb	11 Mar	2 Apr	0.33
Nkhatabay	11 Nov	23 Nov	5 Dec	0.04	1 Jun	22 Jun	12 Jul	0.10
Salima	17 Nov	27 Nov	6 Dec	0.03	4 Apr	15Apr	27 Apr	0.12
Thyolo	30 Oct	13 Nov	26 Nov	0.05	11Apr	25Apr	9 May	0.13

The most desired food crop in Malawi is maize despite the rather low rainfall and the worldwide reputation maize has for suffering greater yield loss from a given water stress than most other crops. A mitigating factor in Malawi should, therefore, be the development by breeders of a maize variety which has particular adaptations fitting rainfall conditions. Stewart (1988) records that in Kenya, Katumani Composite B maize, was bred to adapt to both low temperature and rainfall conditions in Eastern Province. Katumani maize is capable of delaying tasseling and silking if stressed for water, and of maturing early if stress is later in the season. The normal maturity for Katumani maize is 120 days but experience under different temperature and rainfall conditions, has shown a range from 85 to 137 days.

Table 4.5 also summarizes the variability in the start and end dates for the studied stations. Ngabu, Chileka, Makhanga and Thyolo had the highest variability of 5% in the start dates while Chitipa, Mzimba, Karonga, Dedza and Salima registered the lowest (3%). Ngabu registered the highest variability in the end dates while Bvumbwe and Chichiri exhibited the lowest variability. Table 4.5 also shows that all the stations had higher variability in the end dates than the start dates. The implication is that start dates in Malawi can be predicted more accurately than end dates. The date of onset is of particular interest because, by definition, it occurs at the beginning of the season before on-farm decisions are finalized. Table 4.5 further exhibits high rainfall variability in rift valley districts especially the Lower Shire and Lake shore areas and low variability values in highlands, plateaus and plains.

4.3.1.2 Water balance criterion

Water balance simulation was done for Bvumbwe, Chileka, Chitedze and Makoka for a maize crop for a period of 10 years. Table 4.6 shows a summary of the start and end dates of the effective growing season for four stations. Reference to the table shows that the effective growing season for Bvumbwe started on or after 5 November in 4 out of 5 years, on or after 21 November in 1 out of 2 years and on or after 6 December in 1 out of 5 years. The effective growing season at Bvumbwe ended on or after 14 March in 1 out of 5 years, on or after 4 April in 1 out of 2 years and on or after 24 April in 4 out of 5 years. Interestingly, the start and end dates of the growing season at Chitedze (Table 4.6), the station used in the calibration of rainfall criterion, coincided well with the results of the rainfall criterion (Table 4.5).

Table 4.6 Percentage points for which the growing season can be expected to start and end at given probability of exceedance. (Water balance criterion) for selected stations.

	Start date				End date			
Station	20%	50%	80%	CV	20%	50%	80%	CV
Bvumbwe	5 Nov	21 Nov	6 Dec	0.06	14 Mar	4 Apr	24 Apr	0.25
Chileka	29 Oct	20 Nov	12 Dec	0.08	21 Feb	17 Mar	30 Mar	0.32
Chitedze	9 Nov	28 Dec	27 Dec	0.04	25 Mar	8 Apr	22 Apr	0.42
Makoka	7 Nov	24 Nov	11 Dec	0.06	10 Mar	9 Apr	8 May	0.39

In a separate study, Munthali (1996) found that the mean planting date for Bvumbwe was on 24 November. This date coincided well with results of a separate approach based on evapotranspiration (PET) and rainfall. Comparatively, Mpata (1973) found the mean planting date for Bvumbwe to be 17 November with standard deviation of 10 days. The results for Bvumbwe of water balance criterion are, therefore, in agreement with the findings of Munthali (1996) and Mpata (1973). On the basis of these results, it can therefore be said that while the threshold values used in this study are adaptable for Chitedze and Makoka, other stations, for example Bvumbwe, should be calibrated using the water budget approach. Notwithstanding the advantages of the water budget approach, calibration of the rainfall criterion will help to establish the rainfall database in Malawi to a less labour intensive, time saving and less costly analysis.

Table 4.6 further shows the variability of start and end dates. Chitedze exhibited the lowest variability (0.04) while Chileka exhibited the highest variability (0.08) in start dates. Chitedze registered the highest variability (0.47) and Bvumbwe showed the lowest variability (0.25) in end dates.

4.3.2 Effective Length (days) of the growing season

4.3.2.1 Rainfall criterion

The duration between the start and end of the effective growing season was taken as the length of the growing season. The year to year variation in lengths were evident. Table 4.7 shows the effective length (days) of the growing season at three levels of probability. Nkhatabay has the longest growing season with 194 days or more in 1 out of 5 years, 174 days or more in 1 out of 2 years and 153 days or more in 4 out of 5 years.

Interestingly, though some stations appear to have longer growing seasons, they are not necessarily the recipients of larger amounts of rainfall. For example, the median length of the growing season for Chileka is 143 days while that of Dedza is 135 days. But Dedza receives a median annual rainfall of 904.1 mm compared to Chileka of 803.0 mm. Length cannot, therefore, be used as a criterion to judge the quality of the growing season. Rather, the distribution in time should be used and the length be used only as a guide in selecting long or short maturing varieties. Since seasonal length appears to be influenced by the date of the onset of rains, farmers could be advised, in a late starting season, to grow short duration cultivars or alternatively, to grow other more tolerant crops such as cassava. From the foregoing discussion, it will be improper to advise farmers in Mangochi to grow long maturing and high water demanding varieties like hybrid maize, Katswiri PAN 6479 which takes 150 days to mature in warmer areas (according to PANNAR seed (Malawi) Limited, 1996). Drought resistant varieties or crops like millet and sorghum should be advocated in stations like Mangochi.

Table 4.7 Effective length (days) of the growing season at three levels of probability of exceedance (rainfall criterion)

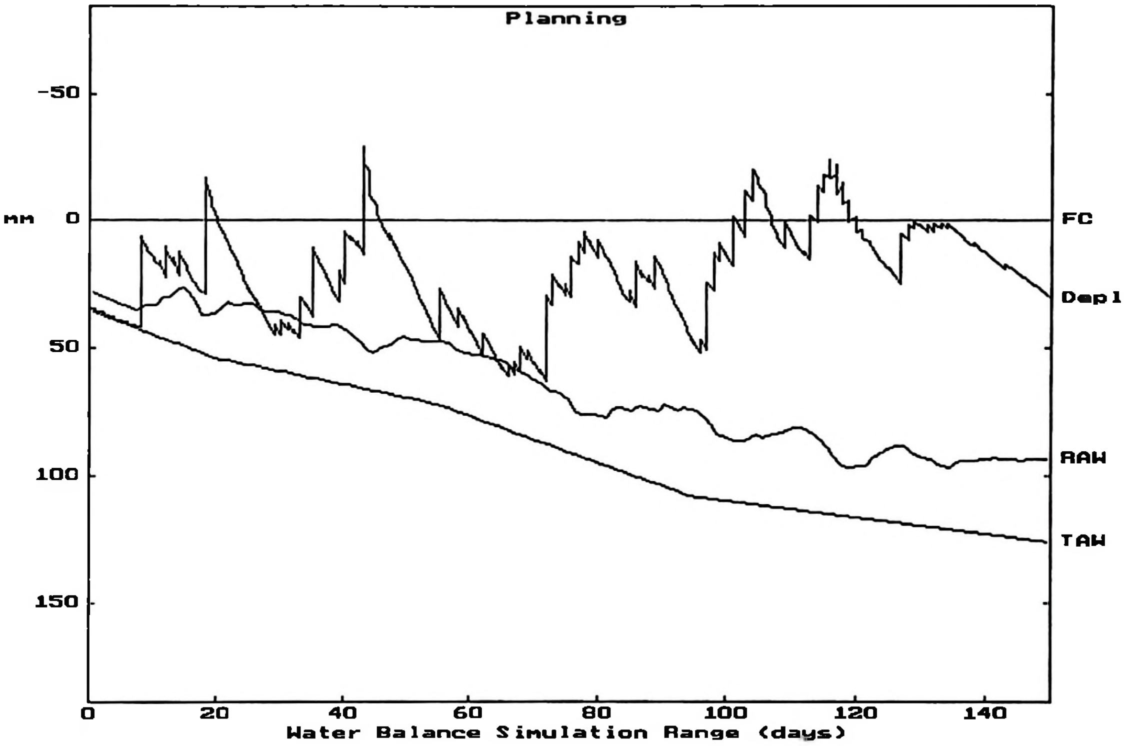
	Effective length of the growing season (days) level of exceedance			
Station	20%	50%	80%	CV
Bvumbwe	187	172	156	0.09
Chichiri	184	170	155	0.09
Chileka	164	143	123	0.15
Chitedze	164	146	127	0.14
Chitipa	164	150	136	0.10
Dedza	153	135	118	0.14
Karonga	168	154	140	0.10
Makhanga	162	144	125	0.14
Makoka	164	141	117	0.18
Mangochi	146	125	103	0.19
Mzimba	149	135	120	0.12
Mzuzu	186	169	153	0.10
Ngabu	161	135	109	0.20
Nkhatabay	194	174	153	0.13
Salima	154	138	122	0.12
Thyolo	183	163	144	0.13

4.3.2.2 Water balance criterion

Results of the water balance criterion given in Table 4.8 give estimates of the length of the effective growing season at three levels of probability for four selected stations. In terms of variation in length of the growing season, Bvumbwe exhibited the lowest variability and Chitedze exhibited the highest variability. The lengths and the coefficients of variation of the effective growing season computed using the water balance criterion provide a general idea of the long term moisture availability. Climate water balance studies help in the evaluation of the soil moisture storage and the amount of crop-available water on a daily basis. The length of the growing season computed from the analysis should help in the choice of crops and varieties to fit well within the moisture availability period and the technologies to be followed depending on the moisture status in the area. For example, the maize root zone depletion graph (Fig. 4.4) shows that the soil moisture availability at Bvumbwe is adequate to support long-duration maize varieties. It is also not prudent to advise farmers in Chileka to grow maize varieties which take more than 100 days to mature. Rainfall flags, depicting less than 100 days of effective growing season (Fig. 4.5), are common in Chileka. The knowledge of water balance studies provides information on the occurrence of an after-sowing or mid-season drought. This can have an effect on farming practices as well as on the selection of suitable varieties. Where an early season drought is a regular feature, one may select a variety with a slow early leaf development. The knowledge may also help to plan the farming system so that the peak water requirements of a crop occur at a time of optimum water availability hence the optimum sowing dates for a given location.

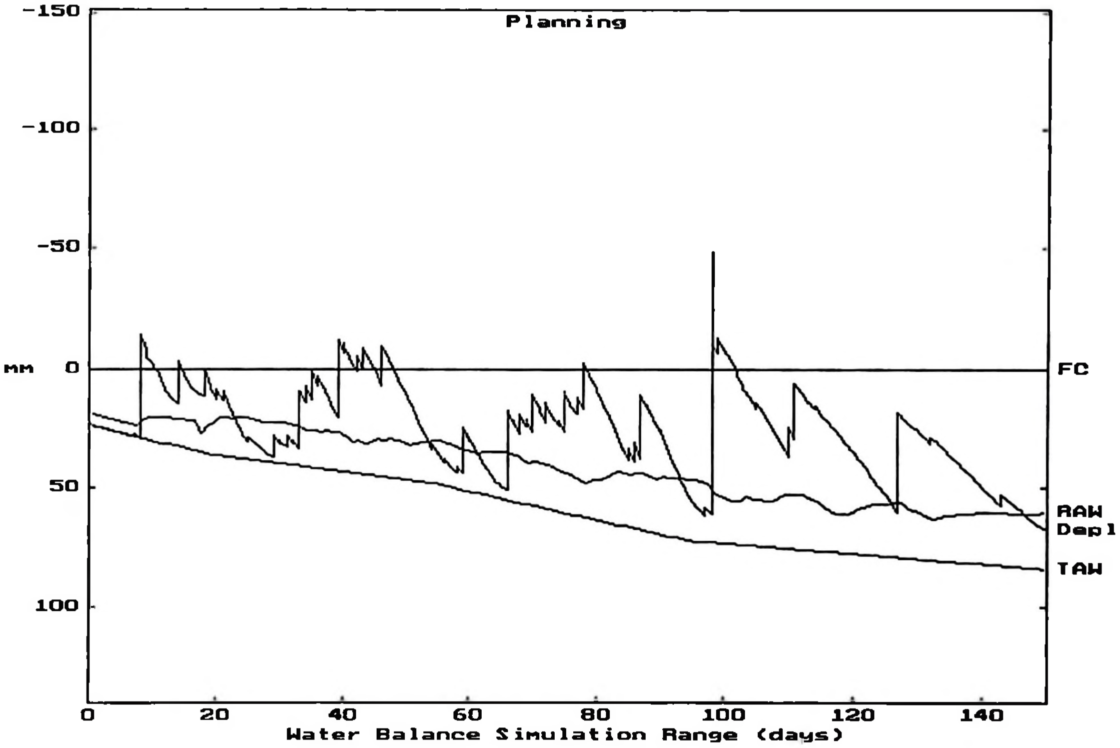
Table 4.8 Effective length (days) of the growing season at three levels of probability of exceedance (water balance criterion) for selected stations.

	Effective length of the growing season (days) level of exceedance			
Station	20%	50%	80%	CV
Bvumbwe	180	152	124	0.22
Chileka	143	112	82	0.32
Chitedze	148	114	81	0.34
Makoka	176	137	98	0.34



Day 1 = 1 November

Figure 4.4: Bvumbwe rootzone depletion for 1990/91 growing season - Maize crop.



Day 1 = 1 November

Figure 4.5: Chileka root zone depletion for 1990/91 growing season -Maize crop

4.3.3 Comparison between the two criteria

Long term rainfall probabilities computed in both criteria are of particular interest when agriculture is being developed in a region. Designers of dams and drainage structures rely heavily on these types of data to ensure that their works will withstand the strains of designed rainfall events. Stewart (1988), reported that development of a region for agriculture and of individual farms in a region, is in essence a one-time activity which must consider all the long term variability in climate. Caution should be taken, however, with long term probabilities in that, by their nature, they do not satisfactorily address farmers' questions about how to maximize production and returns per unit of rainfall in the approaching season. Raes, et al. (1990) noted that for management and planning purposes the information on the amount of rainfall which one can expect in a specific period under dry, normal and wet conditions is important. A period is dry if the rainfall received during that period will be exceeded 4 out of 5 years, i.e. having a probability of exceedance of 80%. This information, as noted by many researchers, is of importance to ascertain if the rainfall is sufficient to support rainfed agriculture or if supplemental irrigation is needed. When calculating the capacity of storage reservoirs and main canals, the rainfall amount with a 80% of probability of exceedance is generally used. The rainfall in a period is normal when the probability of exceedance is equal to 50% and this corresponds to the average or mean rainfall. A wet period is when the rainfall received during that period is exceeded 1 out of 5 years, i.e. having a probability of exceedance of 20%. The three values, (20, 50 and 80%), are useful for programming of irrigation supply and simulation of irrigation management conditions. As noted by Stewart (1988), the information on probabilities is also useful in the field in two fold: the first is simply to present the farmer with the pertinent prediction and let him react to the situation however he wishes, as dictated by his own experience, resources and knowledge. Although the rainfall variation is not the major factor in credit disbursement, the same information could be supplied to credit sources, who today in the third world, including Malawi, generally find the risk of lending to smallholders too great, hence credit is not available.

The rainfall probabilities computed in both criteria could also be used to demarcate the risk associated with dry seeding of rainy-season crops. The dry seeding period for rainy-season crops will be a couple of weeks ahead of the onset of rainy season. A farmer equipped with knowledge of rainfall probabilities would want to alter his farm activities to conform with the onset of the rains. He might wish to forget maize production and fallow his land, or change to an alternative crop if the onset of rains is late. If he plants maize, he would likely reduce his seed rate and certainly should reduce his fertilizer usage. FAO (1987), in a study of rainfed agriculture in the Near East region, describes how wheat and barley farmers in Jordan delay planting after they have prepared their farms until they have assessed the early rains, then adjust the planted area accordingly. With high rainfall, they expand the planted area and with low rainfall, they contract it. Likewise in Malawi, if farmers are provided with information on rainfall probabilities, they can make similar rational decisions.

Comparison of the two criteria discussed in section 4.3.1 and 4.3.2 depicts that there are significant differences in start and end dates for Bvumbwe and Chileka. For example, the start dates for Bvumbwe using rainfall criterion at 20, 50 and 80 percentage points are 16 Oct, 6 Nov and 19 Nov respectively. Corresponding start dates derived using water balance criterion are 5 Nov, 21 Nov and 6 Dec. The experience is that farmers in the Southern region plant maize earlier than farmers in the Central region. Munthali (1996) and James (1988) observed that most farmers in the Southern region plant maize as early as 20 November whilst those in the Central region plant in the first or second week of December. The emerging trend is that the rainfall criterion predicts the start dates earlier than the water balance criterion. In 1 out of 2 years, the rainfall criterion predicts the start date for Bvumbwe on or after 6 Nov and the corresponding date for water balance criterion is on or after 21 Nov, 15 days later than the rainfall criterion. On the contrary, the rainfall criterion predicts the end dates later than the water balance criterion. Expectedly, the length of the effective growing season is longer in rainfall criterion than in water balance criterion. The longer lengths in rainfall criterion is probably due to three major reasons; firstly, the definition of onset of the growing season adopted in rainfall criterion often gives rise to false starts forcing many researchers to add various qualifying criteria to overcome the difficulty; secondly, it does not take into consideration the soil characteristics, for example the field capacity, wilting point, hence the water holding capacity of the soil; the type of crop, for example the depth of root system as does the water balance criterion; and thirdly, the threshold amount used in this study, is not appropriate for Bvumbwe and Chileka. Basing on the experience of the farmers and other researchers, the water balance criterion gives a better measure for the onset and end of the growing season than the rainfall criterion for Chitedze and Makoka stations. The date of the onset of the growing season is of prime importance because critical decisions in agriculture e.g. the amount of labour, seeds, fertilizer, land and any other scarce input to be used are usually made at the beginning of the growing season.

The results of the end of the growing season simulated by water balance criterion could also be deemed more accurate than those derived by the rainfall criterion. Many researchers, (Mavi, 1986; Stewart, 1988; Stern et al., 1982; Dennett et al. 1983; Kingamkono, 1993 and Silvakumar, 1979) intimate that a measure of soil water storage, climatic conditions and crop characteristics are needed to define the end of the growing season more realistically.

Similarly, both the rainfall and water balance criteria showed lower variability in start dates and higher variability in end dates. This underscores the fact that start dates in Malawi can easily be predicted than end dates. The variability in length under the rainfall criterion is lower than those observed under water balance criterion.

Regression analysis was performed to find the relationship between length and start of the effective growing season; the length and end of the effective growing season and start and end of the effective growing season. A summary of the results studied under rainfall criterion for four stations is shown in Table 4.9. The results show high dependence between the length and both the start and end of the growing season. The start of rains was significantly and negatively correlated ($r = 0.6$) with length of the growing season for twelve out of sixteen studied stations. However, the end of the effective growing season was significantly and positively associated with the length of the effective growing season ($r = 0.6$) for all the stations. This is expected since both the start and end dates are used in the derivation of the length of the effective growing season. The implication is that the length of the effective growing season decreases with late start dates while the length increases with late end dates. However, the results generally show that there is no correlation between the start and end of the effective growing season. Mkandawire (1987) combined a seven year data from 1980 - 1987 with those of the seven years (1969 - 1976) used by Hay (1981) for Bunda in a correlation analysis and found that over the fourteen years, there was no significant correlation (r = 0.147), between the start and end of the effective growing season. The implication is that a farmer cannot strategically address the problem of a late start or early start of rains in terms of choice of varieties. If there was a positive correlation, a farmer would be safe planting crops that are normally planted because season length may stay the same. On the other hand, if there was a significant negative correlation, a farmer would be compelled to plant an earlier maturing variety because the delay of rains will reduce the length of the effective growing season due to an earlier end of the rains. Similar results were reported by Stewart (1988) in Niger, Sivakumar (1989) in Burkina Faso, Kingamkono (1993) in Tanzania and Dennett et al. (1983) in West Africa.

Table 4.10 shows a summary of results for the correlation of length (L), start (S) and end (E) of the effective growing season studied under water balance criterion. As was the case with the rainfall criterion, the start and end dates are completely independent in all the stations. However, it was observed that the length of the effective growing season at Bvumbwe and Chitedze does not depend on whether the start date is early or late. Bvumbwe and Chileka also showed that the length is independent of the end of the effective growing season.

Table 4.9 Correlation between the length (L), start (S) and end (E) of the effective growing season (Rainfall criterion)

Station	Linear equation	Correlation coefficient
Bvumbwe	L = 382.79 - 0.679S	- 0.584
	L = 91.37 + 0.680E	0.578
	S = 272.71 + 0.328E	0.324
Chileka	L = 459.09 - 1.003S	- 0.684
	L = 50.04 + 1.003E	0.732
	S = 314.96 - 0.003E	- 0.003
Chitedze	L = 449.49 - 0.937S	- 0.582
	L = 44.54 + 0.964E	0.785
	S = 320.46 + 0.036E	0.048
Makoka	L = 506.73 - 1.149S	-0.614
	L = 39.92 + 1.068E	0.847
	S = 325.08 - 0.068E	- 0.101

Table 10 Correlation between the length (L), start (S), and end (E) of the effective growing season (Water balance criterion)

Station 2	Linear equation	Correlation coefficient
Bvumbwe	L = 244.9 - 0.286S	- 0.15
	L = 122.34 + 0.354E	0.48
	S = 294.87 + 0.324E	0.44
Chileka	L = 455.44 - 0.06S	- 0.77
	L = 86.39 + 0.44E	0.42
	S = 329.25 - 0.06E	- 0.05
Chitedze	L = 287.48 - 0.52S	- 0.16
	L = 26.53 + 1.17E	0.94
	S = 329.30 + 0.04E	0.09
Makoka	L = 553.65 - 1.29	- 0.57
	L = 30 + 1.078E	0.89
	S = 336.94 - 0.078E	- 0.14

4.4 Dry Spell Analysis

In the semi-arid tropics, mid-season risks to crops often arise due to prolonged rainless spells. Hence, frequency analysis of dry and wet spells was worked out to pinpoint the most critical time when a dry spell is likely to occur.

Table 4.11 shows that the start and end of wet period ($P_{dry} \leq 0.5$) for most stations in Malawi is in December and March respectively. This period coincides with the growing season. However, Chileka, Makhanga, Mangochi and Ngabu exhibited no wet spells. That is, the probability of dry spells in these stations go up to and above 0.5 within the growing season. For example, Fig. 4.6 shows the probability of dry spells for Makhanga station which is a typical example of a dry station. Fig. 4.7 shows the probability of dry spells for Chichiri which is a good example of a wet station. The probability of a dry spell in Chichiri for the whole of the growing season is mostly less than 0.5. Mzengeza (1994) found that the risk of 5-day dry spell for Nkhatabay, which is an example of a wet area, from onset of the growing season to 1 March does not go beyond 0.4. On the contrary, the dry area of Makhanga depicted a high risk (>0.6) of a 5-day dry spell between onset and 6 January. The risk at Makhanga was never below 0.7 from 6 January to the end of the season. In fact, 37 days before the end of the season, the risk of a 5-day dry spell was 100%. He then concluded that, it is imperative to incorporate drought tolerance in varieties targeted for Salima, Mangochi and Makhanga. Figs 4.6 and 4.7 can be used successfully to select the best planting date of a crop though this statement is not conclusive in that other factors, for example the type of soils, water holding capacity of a soil and variety of a crop have to be taken into account. The water balance simulation for Chileka for a period of one year (Fig. 4.8), also shows that the occurrence of dry spells within the growing season at Chileka is not a remote phenomenon. For the same year, Bvumbwe, Fig. 4.9, depicted less dry spell within the growing season.

Table 4.11 Summary of wet periods ($P_{dry} \leq 0.5$), decade likely to be wet, maximum length of dry spell (days) and probability of maximum dry spell

Station	Wet period			Month and decade dry spell is likely				Max length of a dry spell (days)	Max probability of dry day during a dry spell
	Start	End (days)	length (days)	Month	Decade				
					1	2	3		
Bvumbwe	Dec 12	Mar 12	90	Feb	-	+	+	11	0.63
Chichiri	Dec 10	Mar 13	93	Dec	-	+	+	14	0.29
Chileka	No likely	wet period	0	Dec	-	+	+	10	0.66
Chitedze	Dec 13	Mar 10	87	Jan	+	+	-	20	0.54
				Feb	+	+	-	20	0.54
Chitipa	Dec 10	Mar 21	101	None	-	-	-	None	None
Dedza	Dec 13	Mar 12	89	Dec	-	+	-	7	0.54
				Jan	+	-	-	9	0.50
Karonga	Jan 5	Apr 18	103	None	-	-	-	None	None
Makhanga	No likely	wet period	0	Dec	-	+	+	14	0.72
				Feb	-	-	+	10	0.73
Makoka	Dec 10	Mar 11	91	Dec	-	+	+	14	0.72
				Jan	-	+	-	9	0.56
				Feb	+	-	-	10	0.54
Mangochi	No likely	wet period	0	Feb	+	-	+	25	0.66
Mzimba	Dec 25	Mar 13	78	Mar	+	-	-	12	0.52
Mzuzu	Dec 22	Apr 27	126	Mar	-	+	-	8	0.51
Ngabu	No likely	wet period	0	Jan	+	-	-	8	0.73
Nkhatabay	Dec 20	Apr 23	124	Jan	-	+	+	8	0.54
				Feb	-	+	+	17	0.65
Salima	Jan 5	Feb 14	40	Jan	-	+	-	5	0.52
Thyolo	Dec 15	Mar 22	97	Feb	+	+	-	16	0.55
				Mar	+	-	-	10	0.64

Legend: ($P_{dry} \geq 0.5$) = probability of a dry day equal to or more than 0.5; + = decade likely to be dry
- = decade likely not dry.

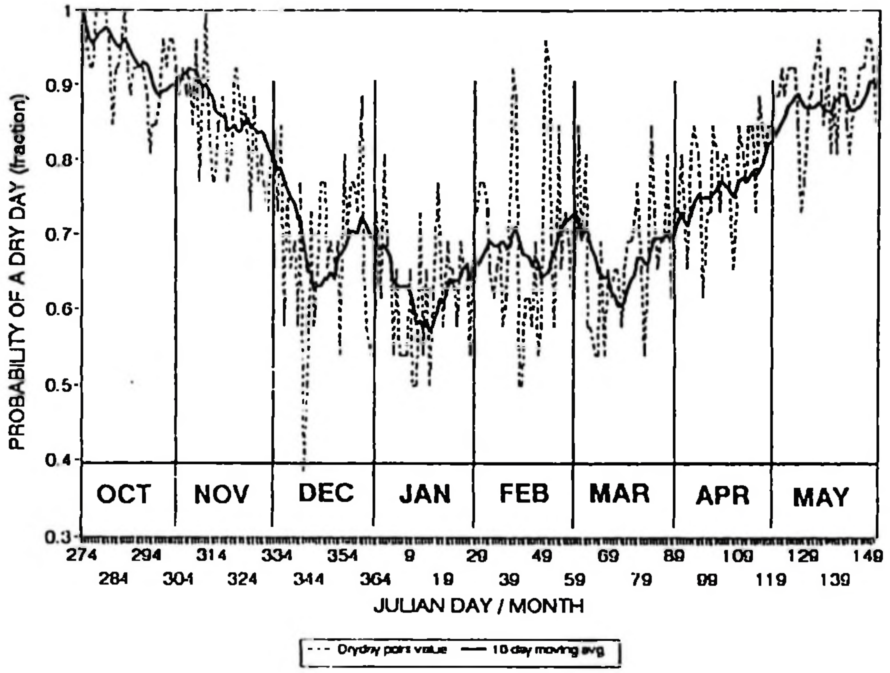


Figure 4.6: The probability of a dry day for Makhanga.

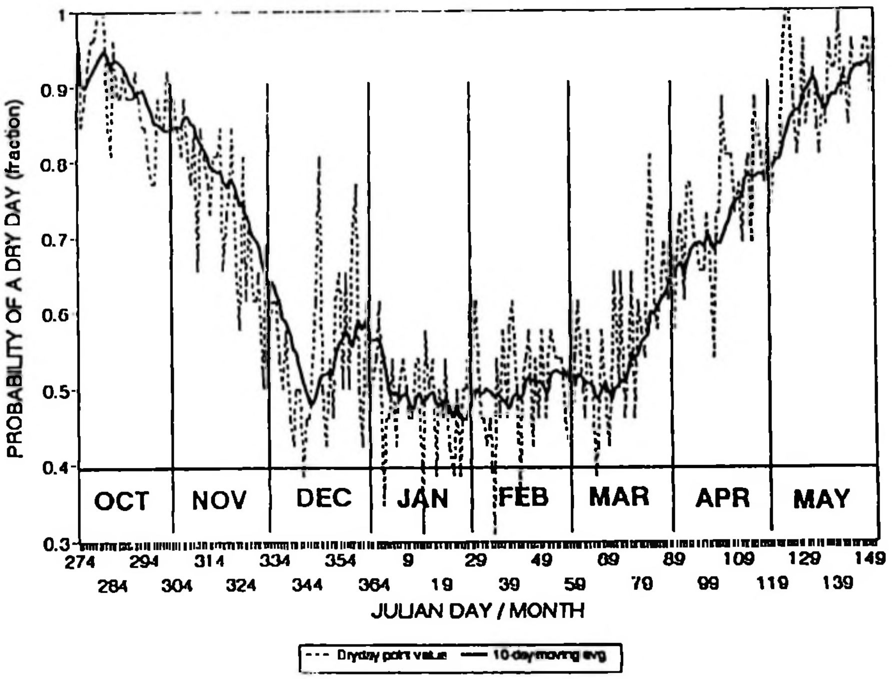
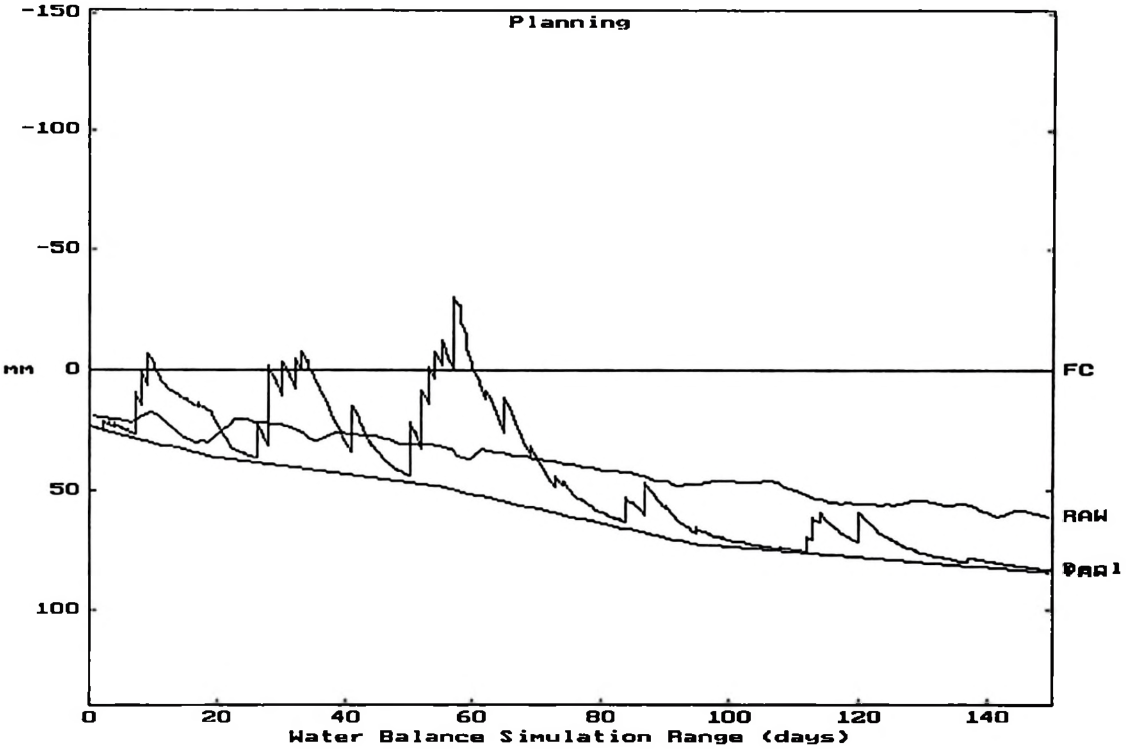
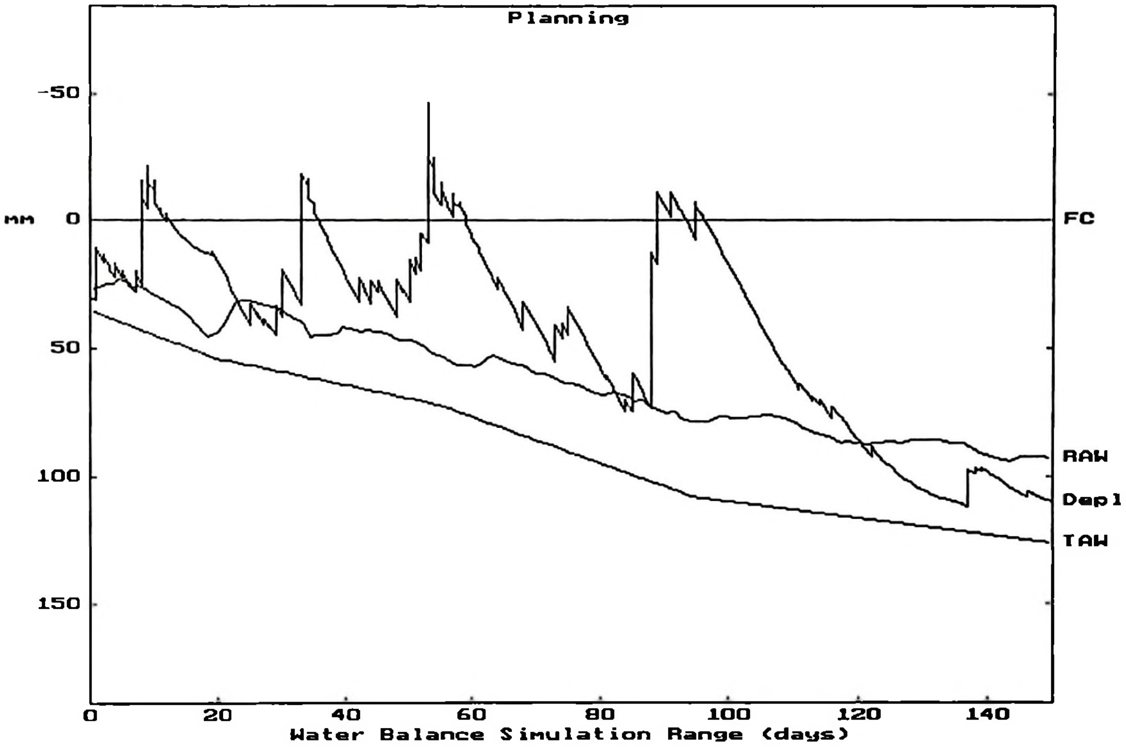


Figure 4.7: The probability of a dry day for Chichiri.



Day 1 = 1 November

Figure 4.8: Chileka root zone depletion for 1986/87 growing season - Maize crop.



Day 1 = 1 November

Figure 4.9: Bvumbwe rootzone depletion for 1986/87 growing season - Maize crop

There are certain periods during the growing season when moisture stress reduces yield. Glover and Gwynne, (1962); MoA (1996) reported that maize is apparently more drought resistant in the early stages of growth than when fully developed. Severely wilted young maize leaves, which unfold when moisture conditions improve, recover completely and assimilate carbon dioxide normally, whilst maize subjected to drought at a later stage does not recover completely. This may explain why the practice, which is common in drought areas in East Africa, of sowing maize early, is desirable despite the danger of wilting during periods between light showers which precede the rainy season. The early sown maize has the advantage of a longer growing season than later sown maize, though the latter is sown under more favorable conditions of moisture. Critical analysis of the water balance displays could help to know whether a particular phenological stage of maize is coinciding with a period of moisture deficit. This study has however shown that in dry places of Mangochi, Chileka, Ngabu and Makhanga, not only should the early sowing be encouraged but should be accompanied by simple technologies which farmers can afford e.g. water retention techniques for improving *in situ* infiltration namely; contour ridges constructed across the slope, tie-ridges, terraces etc. and incorporation of crop residues because the dry spells are common throughout the growing season.

The displays in water budget criterion shows that given a maize crop of less than 100 days to maturity, multiple cropping is possible in most of the years for places like Bvumbwe because the length of the growing season is equal to or more than 150 days and that throughout the growing season, dry spells are a rare occurrence. The water balance criterion together with dry spell analysis can enhance decision making on planting strategies.

The advent of hybrid varieties with a notion of high yielding under low rainfall amounts and short rainy season ought to be taken with care. The hybrid is of value only if environmental conditions make it possible to exploit this advantage. When the hybrids are grown with traditional low input methods or under adverse growing conditions, they may be inferior to well-adapted open-pollinated varieties. When pollination coincides with unfavorable climatic conditions such as hot dry winds and deficient soil moisture, the hybrid is at a disadvantage (Glover and Gwynne, 1962; Moore, 1982). Local varieties, being more heterogeneous, continue producing pollen for a longer period. The prospect that at least part of this period will enjoy more favorable conditions is greater than for the hybrid, which completes fertilization within a few days. It is therefore apparent that in places like Ngabu, Chileka and Mangochi where the probability of dry days is above 0.5, hybrid maize varieties should only be grown under careful agronomic practices, for example, ridging across the slope to conserve the moisture to avoid critical periods coinciding with shortage of moisture.

Maize generally displays tolerance to appreciable moisture stress except during grain filling and the growth period from tassel emergence to completion of pollination. Therefore, moisture stress that results in significant wilting during tasseling, silking, and pollination periods may reduce grain yield significantly. Stress strong enough to desiccate the lower or the tender top leaves during this interval, may cut grain yield in half (Robins and Domingo, 1953; Freez, 1981; James, 1988). Therefore, according to this study, in places with maximum length of dry spell of more than 5 days within the growing season, farmers should be encouraged to practice water conservation measures especially during the critical stages of plant growth.

Response of grain sorghum to moisture stress is similar to that of maize (Musick et al., 1963; Hudson, 1987). Even though sorghum is considered a highly drought resistant crop, stress sufficient to cause leaf desiccation results in significant yield reduction both of vegetative portions and grain. Severe stress during the boot to flowering stage results in pollination failure similar to that of corn. The implication is that each crop should be studied in its own right in relation to moisture requirements and that even drought resistant crops need supplemental irrigation at one point or the other. Furthermore, it appears that for a particular crop, response can differ depending upon the variety.

Field beans appear to withstand considerable moisture stress without major reproduction yield reduction (Howe and Rhoades, 1961). Visible stress symptoms evidenced by foliar colour change and wilting for periods of up to 5 days or more reduce vegetative growth but do not significantly reduce seed yield. Longer stress periods any time during the flowering period reduce both the number of pods and the number of seeds developed per pod. These yield component losses are only partially offset by increased bean weight. Consequently, dry spell analysis can assist farmers deciding on the type of crop to grow and the extent they can allow moisture stress to affect their crop depending on the type of yield component they are interested in.

Chang (1968), and Salter and Goode (1967) noted that not only yield but quality of the crop is important and the two in some cases respond differently to moisture conditions. The necessity for drier conditions at certain times for sugar cane is a good example. Some moisture stress during ripening would seem to have beneficial effects in the case of rubber and tobacco.

Table 4.11 also shows the length in days when it is likely to be wet. Karonga, Mzuzu and Nkhatabay had wet days of more than 100 whilst Chileka, Makhanga, Mangochi and Ngabu depicted no wet day at $P_{dry} \leq 0.5$. This does not mean that these places have no wet season. At a higher dry spell probability, a wet season can be depicted at Chileka, Makhanga, Mangochi and Ngabu. Regression analysis between the length of the effective growing season using rainfall criterion at 80% probability of exceedance and the length of the wet period was significant ($r = 0.71$). This shows that stations with longer effective growing seasons have longer wet periods. The length of a wet period can be used to select the type and variety of a crop to grow in an area. Farmers in areas with short or no wet period can be advised to grow drought resistant crops and should they grow crops with high water requirements, conservation methods, water harvesting techniques, supplemental irrigation among other drought amelioration methods should definitely be advocated.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusins

The main objective of this study was to evaluate the potential of the water balance technique for determination of the effective length of the growing season under different climatic conditions. Two criteria were used to define the events of interest, *inter-alia*, rainfall, based purely on rainfall, and water budget, based on rainfall, crop and soil factors. Sixteen stations were selected for the rainfall criterion and four stations for the water balance criterion.

The annual rainfall data was first tested for homogeneity at 5% level of significance to find if the data were from the same population. The results showed that annual rainfall data in the selected areas except Dedza is homogeneous ($P < 0.05$). The non-homogeneity at Dedza was attributed to the change in the raingauge site. It can probably be concluded that the site, type, height and exposure of the raingauge in the studied stations has been the same or the data collection has been consistent over the years.

Different statistical distributions were fitted to the annual rainfall, start and end of the growing season. The results showed that the annual rainfall can best be described by the lognormal distribution. However, the start and end of the growing season can best be approximated by normal distribution.

An overview of rainfall in the selected areas showed that year to year, seasonal and monthly variability was evident. However, there was no discernible trend in the variability and Huke's theory, that dry areas exhibit higher variation than wet areas, was not consistent with the results.

Evaluation of IRSIS indicated that there was a good agreement between the measured and the simulated runoff ($R^2=0.86$) rendering IRSIS adaptable to Malawi conditions. Three years of historical rainfall data were used to calibrate the rainfall criterion. The calibration, using water budget criterion gave 30mm of rainfall reached in a decade with no dry spell of more than 10 days occurring in the following 30 days as the start of the growing season. The end of the growing season was designated as the first occasion when an accumulation of 25mm of rainfall was not exceeded in 15 days. The general trend is that the rainfall criterion predicted start dates earlier than water budget criterion. The rainfall criterion also predicted the end dates later than the water budget criterion making the length in rainfall criterion longer than in water budget criterion. Both criteria showed lower variability in start dates than in end dates underscoring the fact that start dates in the studied areas are easier to predict than end dates. However, the onset date of the growing season predicted by the water balance criterion agreed reasonably well with the dates when farmers usually plant maize. It can, therefore, be concluded that using the water balance approach, onset dates of the growing season can be predicted close to farmers expectations with a small data set. The onset and end dates of the growing season indicate that the threshold values used in rainfall criterion can be adapted for Chitedze and Makoka.

Results of the correlation indicated high dependence between the length and both the start and end of the growing season in case of rainfall criterion. The water budget criterion depicted that the length at Bvumbwe and Chitedze is independent of start dates.

Bvumbwe and Chileka also exhibited independence of the length and end dates in the water budget criterion.

Results of dry spell analysis indicated that, Chileka, Ngabu, Makhanga and Mangochi stations had high probabilities of dry spell ($P_{dry} \geq 0.5$) within the growing season. Drought amelioration methods, e.g. water harvesting or water conservation practices, and or supplemental irrigation are the only solutions for optimal crop growth in these areas. It can also be concluded that stations with longer growing season had longer wet periods.

5.2: Recommendations

In Malawi, farming is less sophisticated and climate is unpredictable. Most farmers farm primarily for survival, even if they include a few crops for sale. The meteorologist, hydrologist and the agriculturist have, therefore, key roles to play in helping to break the "survival only" mentality. Obviously, data on the expectation or probability of rainfall throughout the season provide a much simpler, less laborious and more accurate means of assessing optimal planting dates. In the same vein, the potential of the water balance criterion in pinpointing the start, end of the growing season and more importantly, the ability of IRSIS in showing the dry spells in time and space by considering soil, climate and crop characteristics, can be utilised by planners to help farmers in decision making.

Data on dry spell length could be used as a guide for the various maturity duration of varieties when breeding at different locations. Breeding strategies should be oriented towards maturity in less than 100 days at Chileka, Makhanga, Mangochi and Ngabu, in more than 100 days for Bvumbwe and other wet areas.

This study has also shown the great potential of water balance criterion in selecting the type and probably, the variety of a crop in relation to the water requirements for a particular area. There is need to carry out water balance studies in other stations with simulations of different crops and varieties to establish threshold values for different stations based on the rainfall criterion, which, apparently, is less costly and less labour intensive. A data base can be established in this line with the aim of earmarking places that are suitable for a particular crop and variety. This information is not only important to policy makers, but also agricultural scientists, investors and more importantly, the smallholder farmer.

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APPENDIX A: Rainfall long-term trend for selected areas.

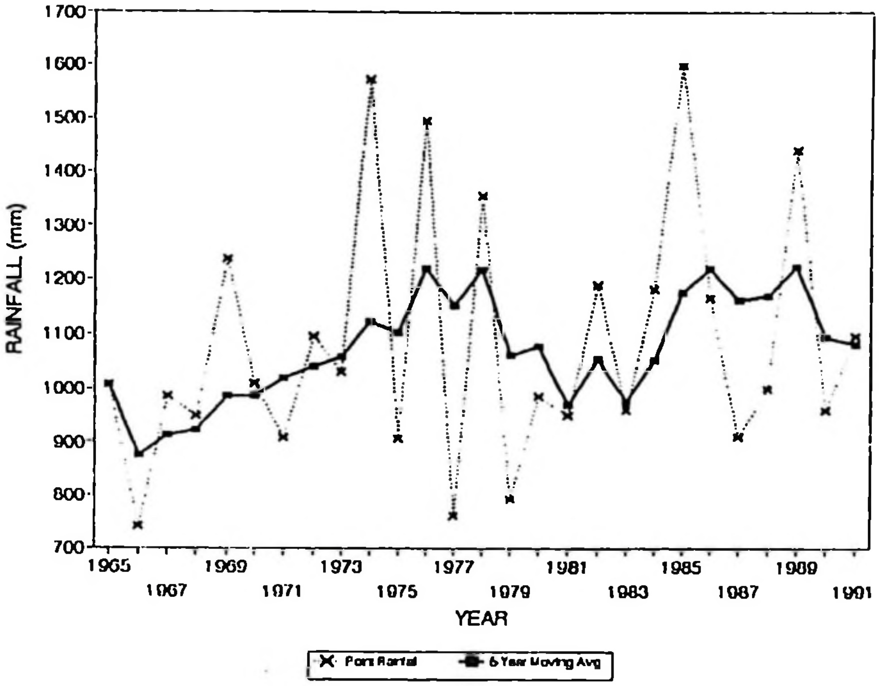


Figure A1: Bvumbwe annual rainfall long-term trend.

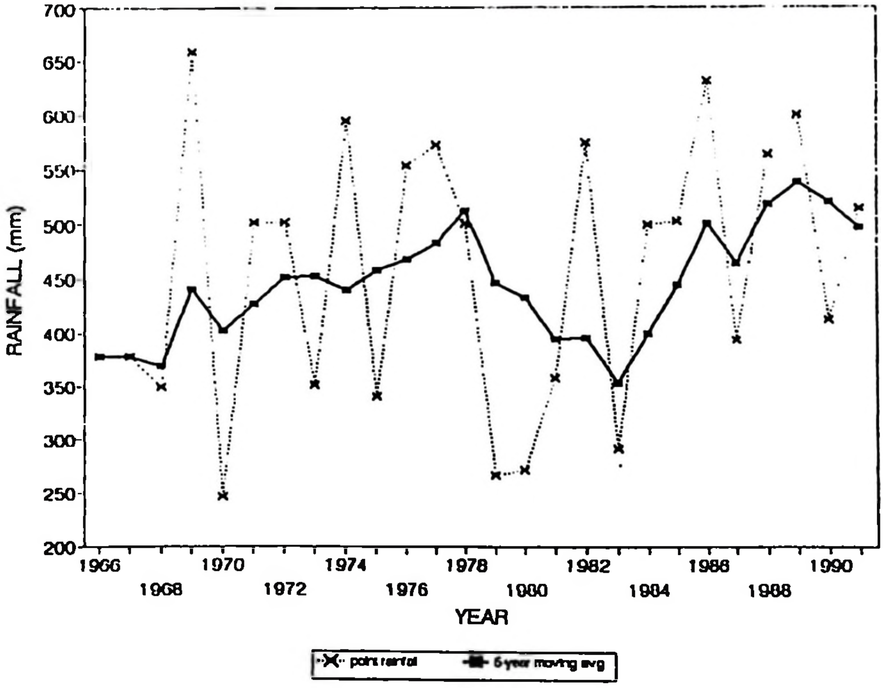


Figure A2: Chichiri annual rainfall long-term trend.

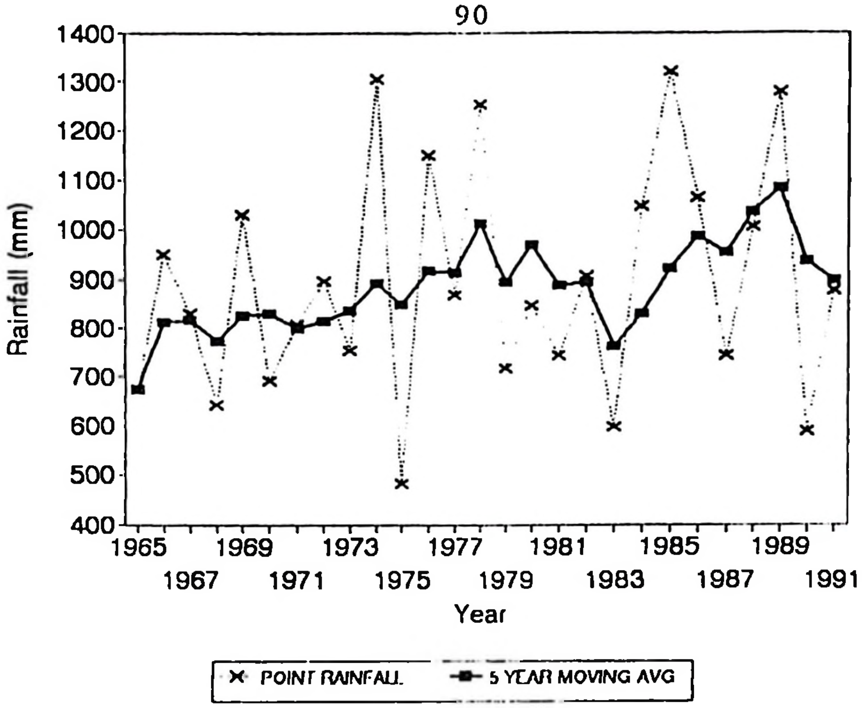


Figure A3: Chileka annual rainfall long-term trend.

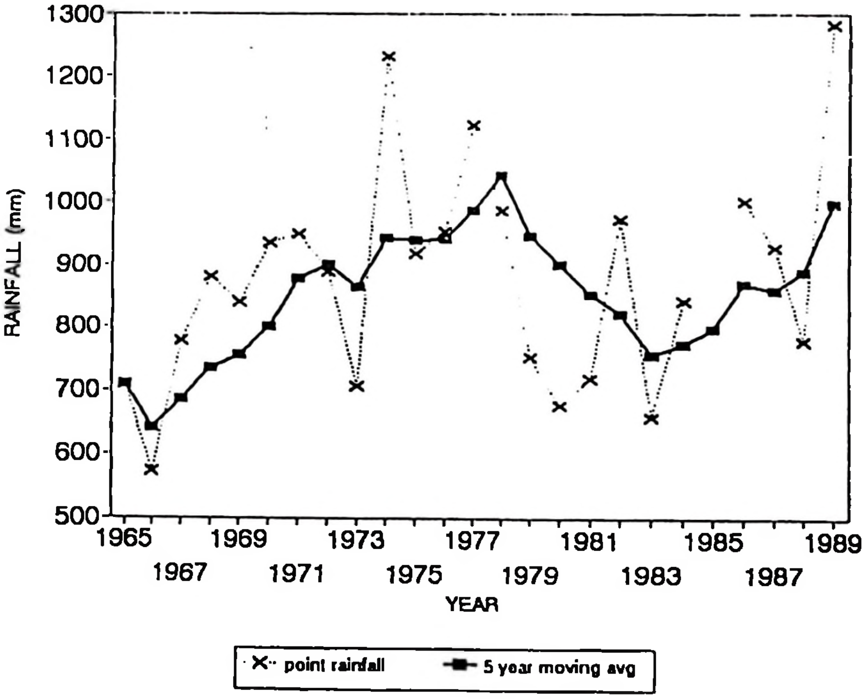


Figure A4: Chitedze annual rainfall long-term trend.

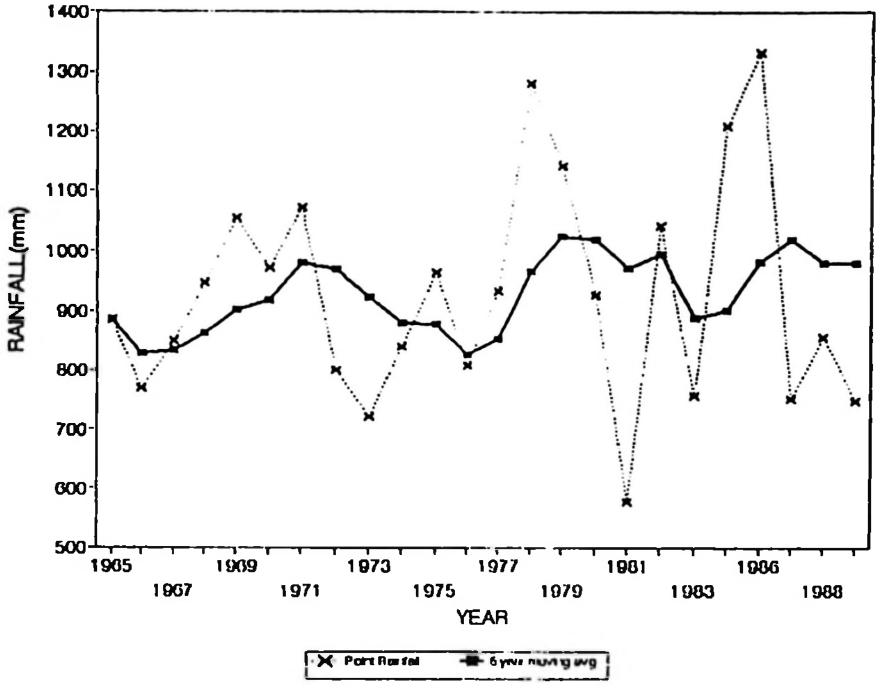


Figure A5: Chitipa annual rainfall long-term trend.

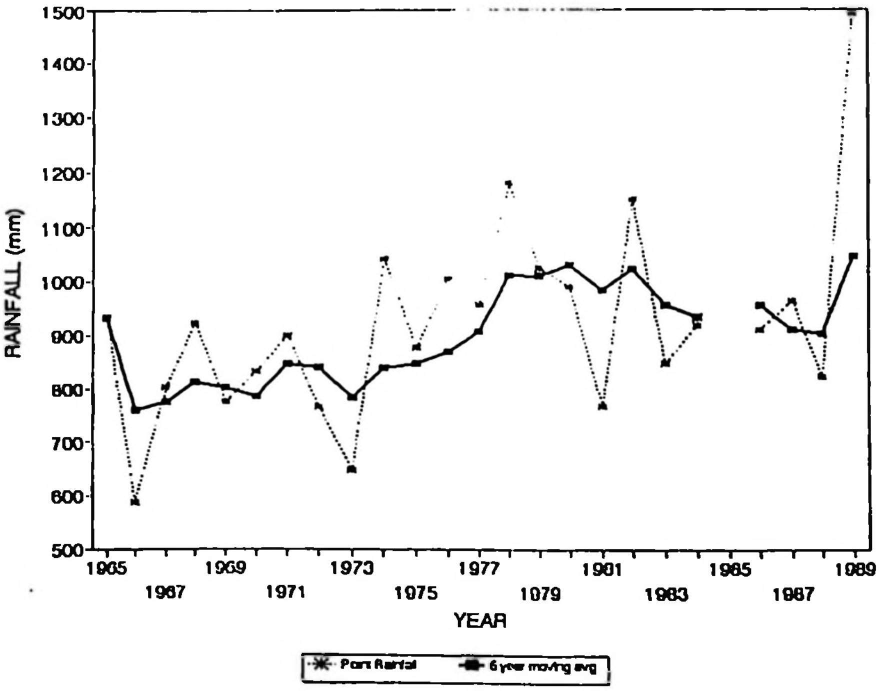


Figure A6: Dedza annual rainfall long-term trend.

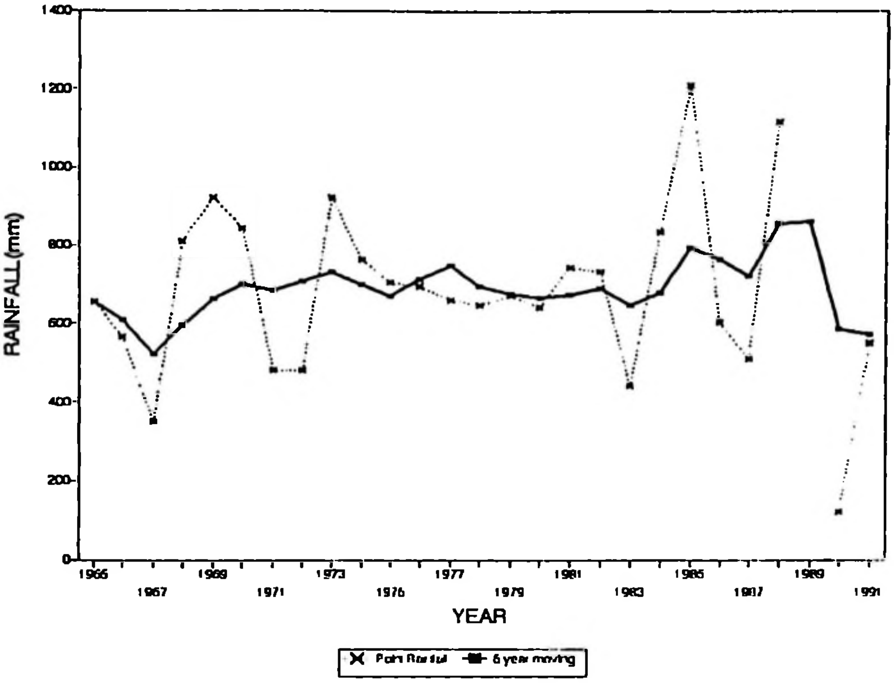


Figure A7: Makhanga annual rainfall long-term trend.

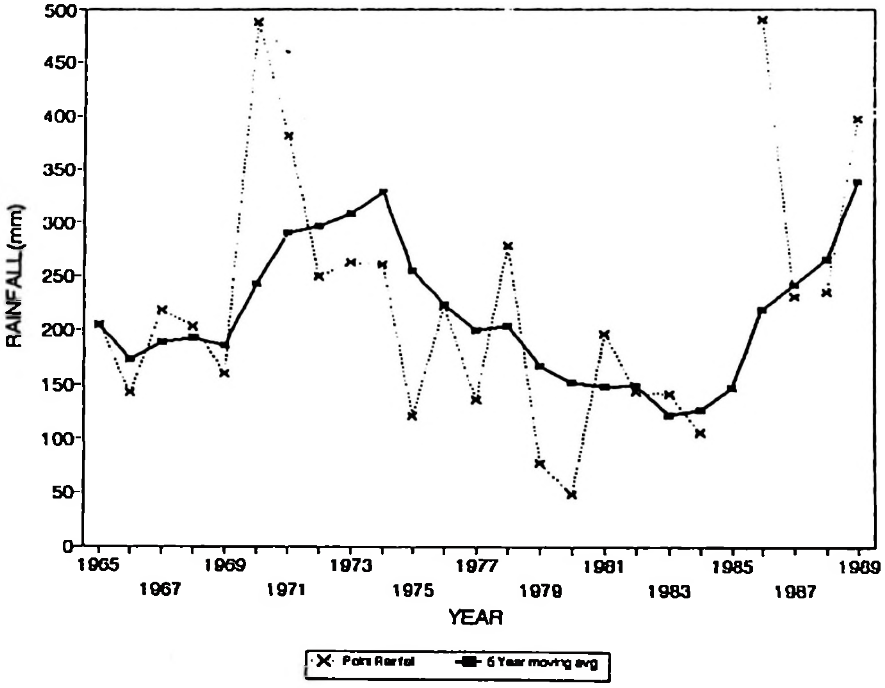
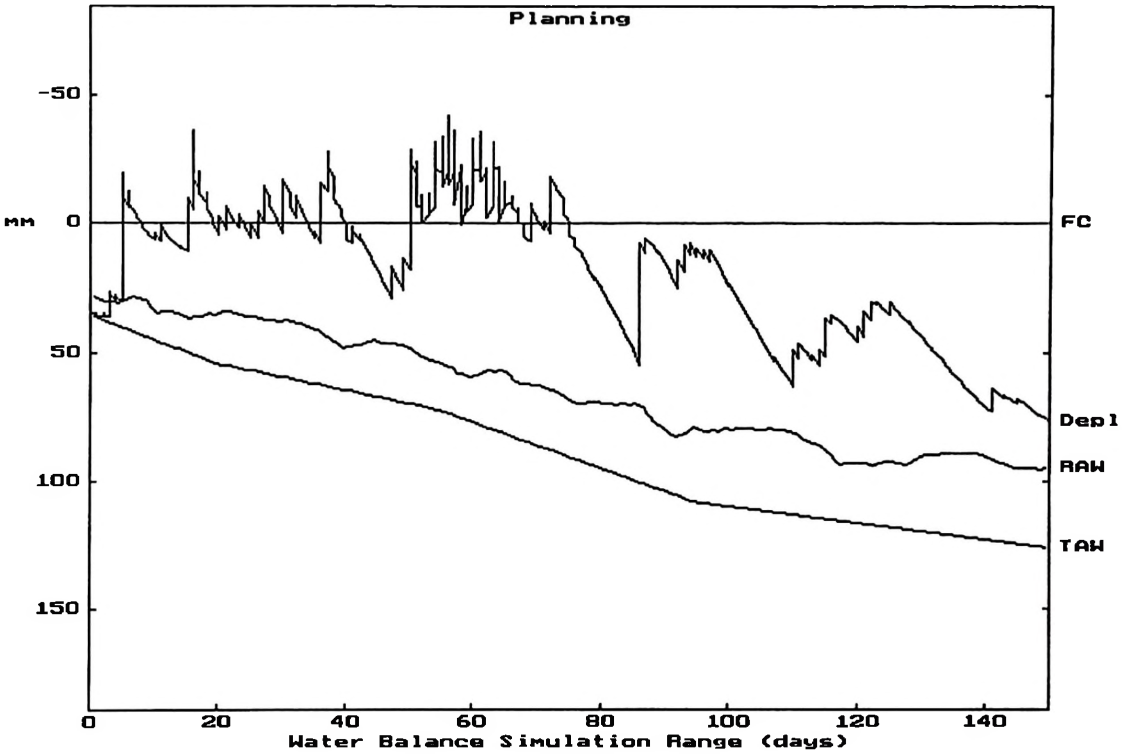


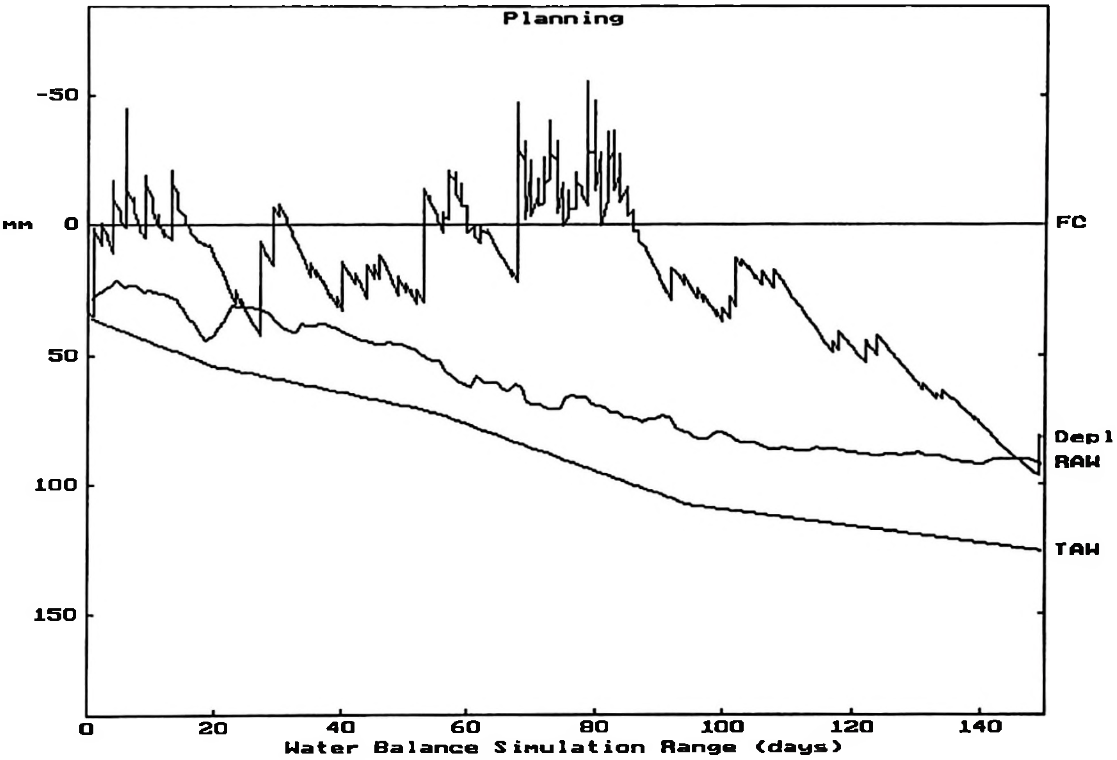
Figure A8: Makoka annual rainfall long-term trend.

APPENDIX B: Rootzone depletion for maize for selected years.



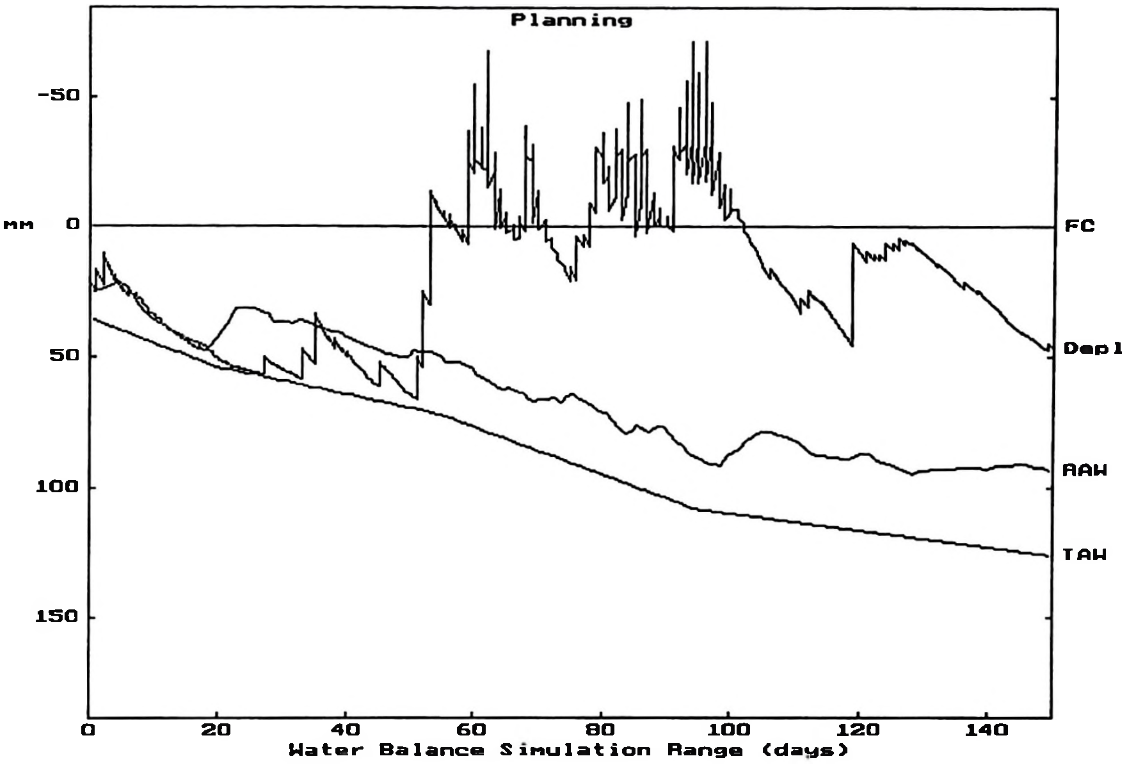
Day 1 = 1 November

Figure B1: Bvumbwe rootzone depletion for 1985/86 growing season - Maize crop



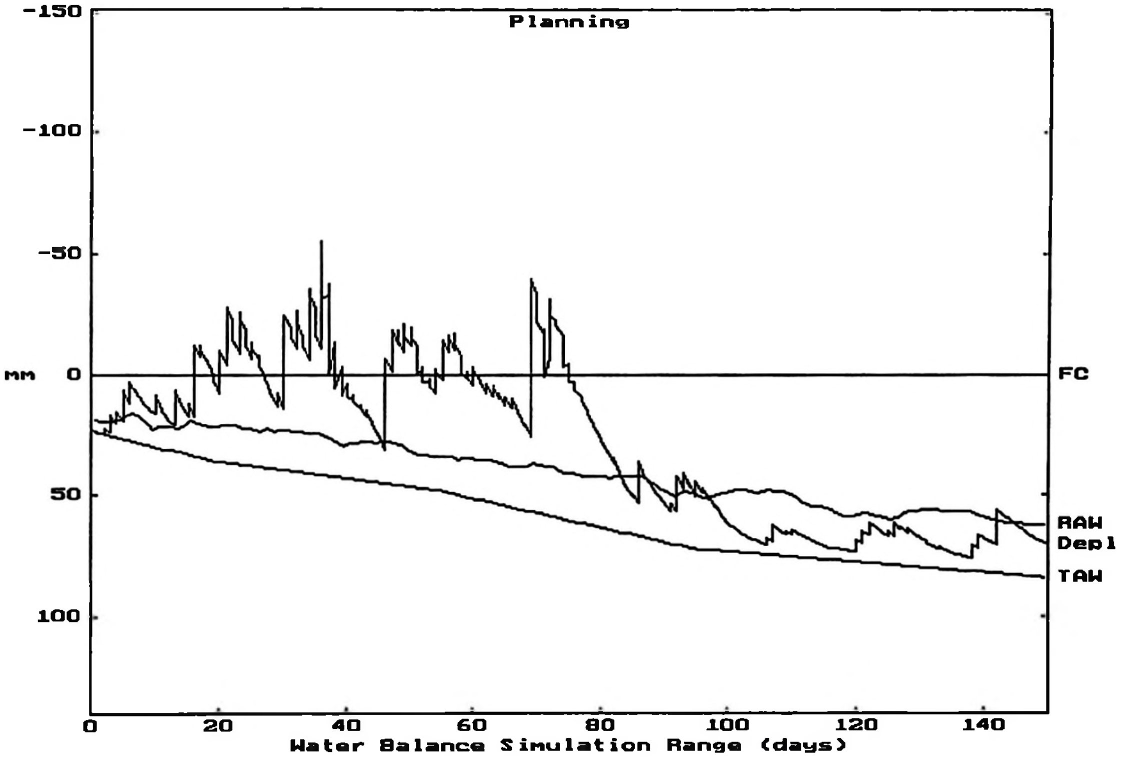
Day 1 = 1 November

Figure B2: Bvumbwe rootzone depletion for 1987/88 growing season - Maize crop



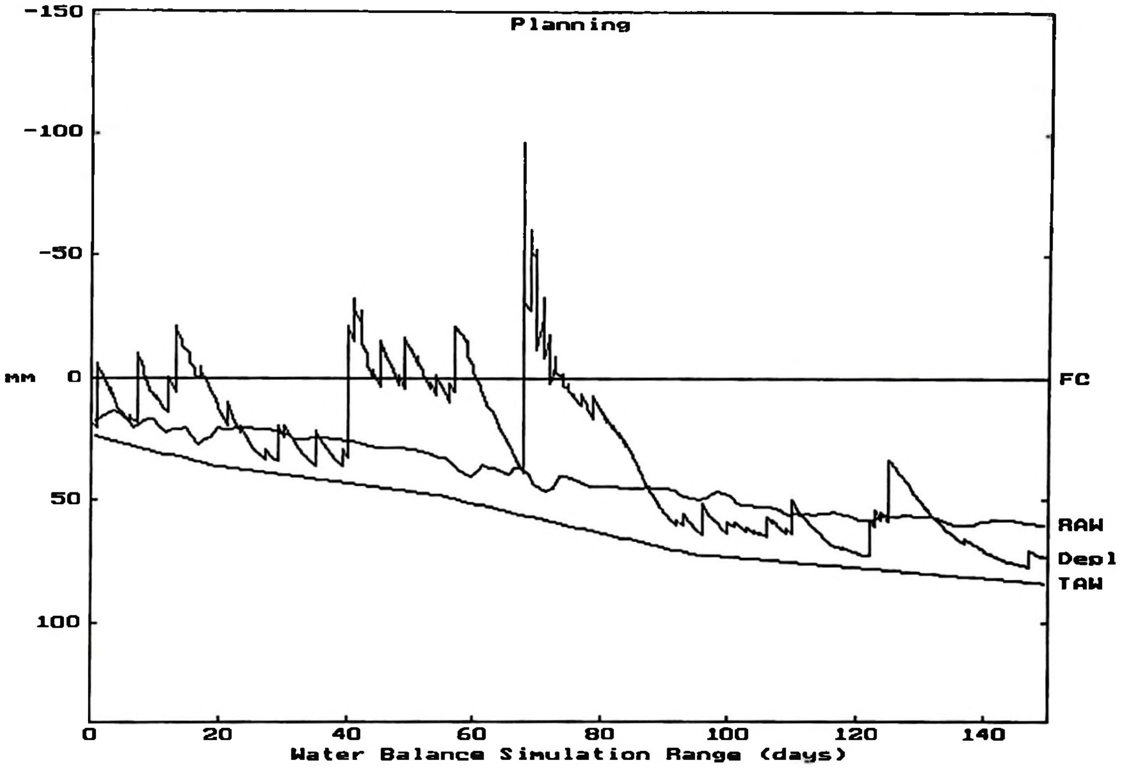
Day 1 = 1 November

Figure B3: Bvumbwe rootzone depletion for 1988/89 growing season - Maize crop



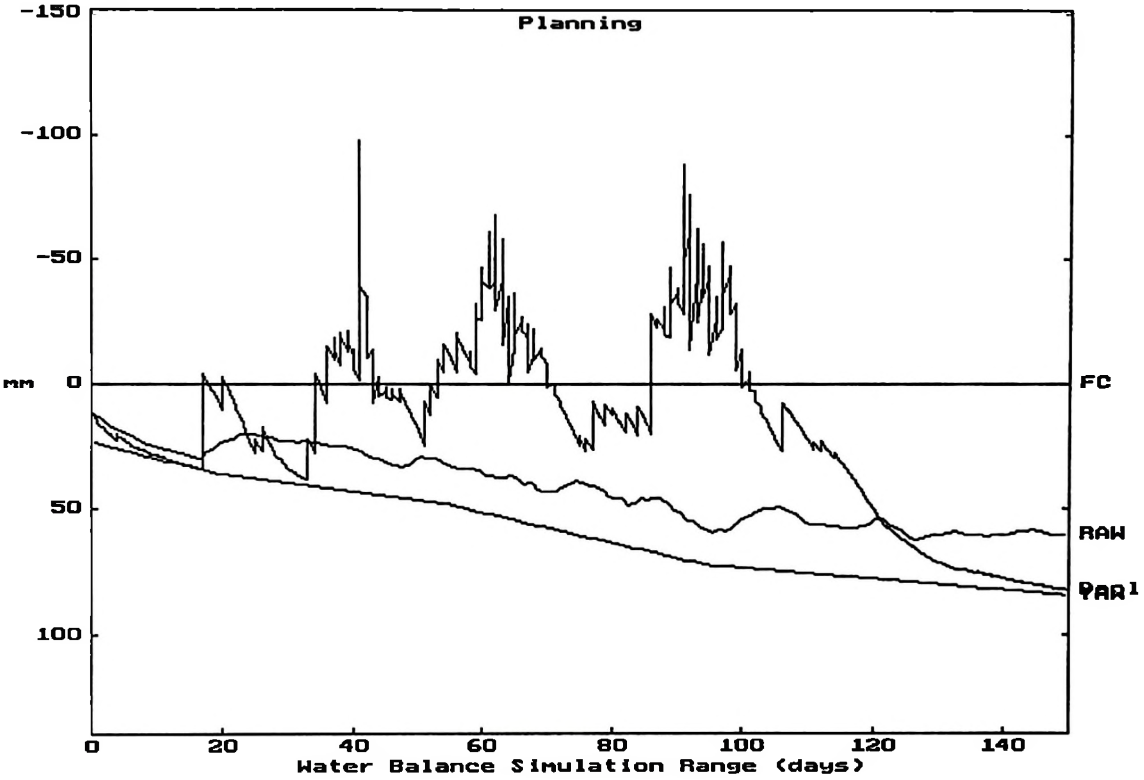
Day 1 = 1 November

Figure B4: Chileka rootzone depletion for 1985/86 growing season - Maize crop



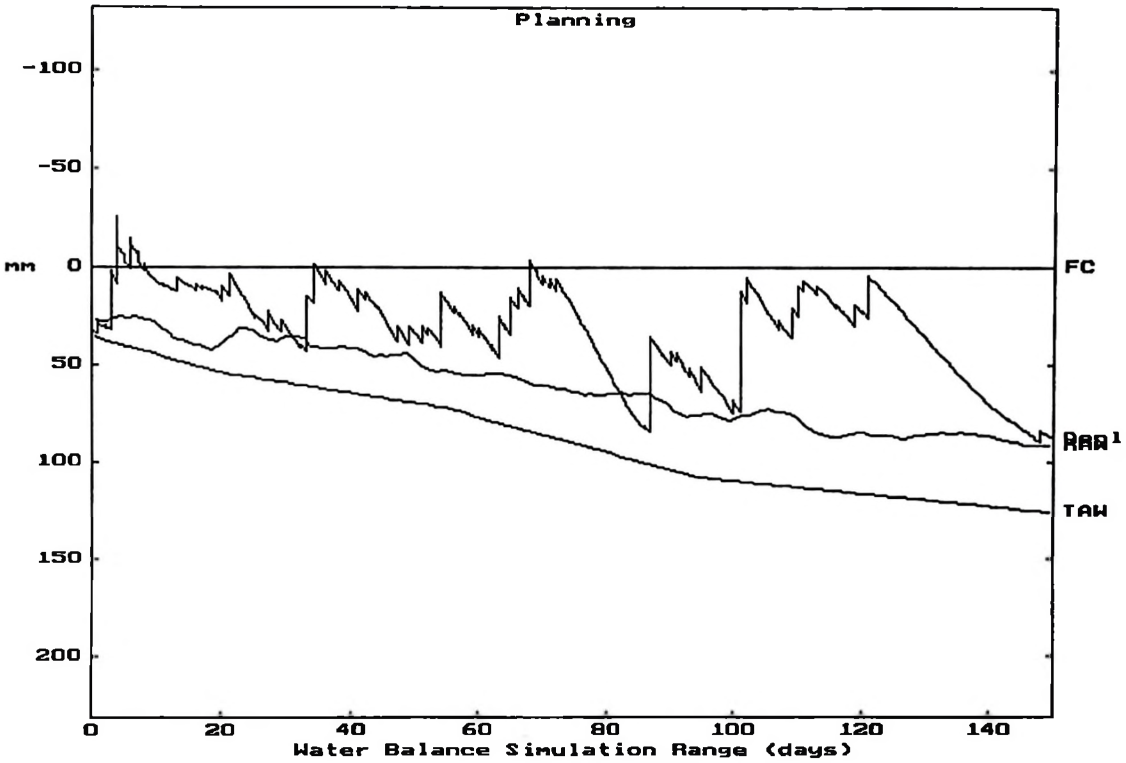
Day 1 = 1 November

Figure B5: Chileka rootzone depletion for 1987/88 growing season - Maize crop



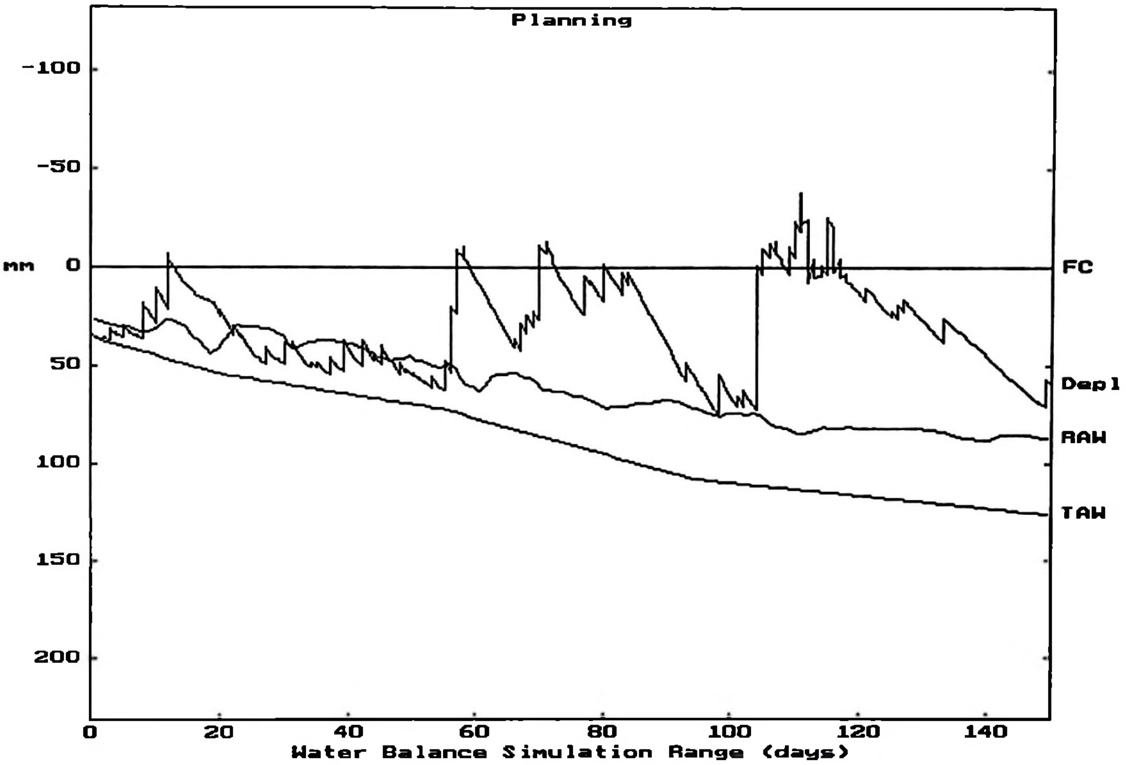
Day 1 = 1 November

Figure B6: Chileka rootzone depletion for 1988/89 growing season - Maize crop.



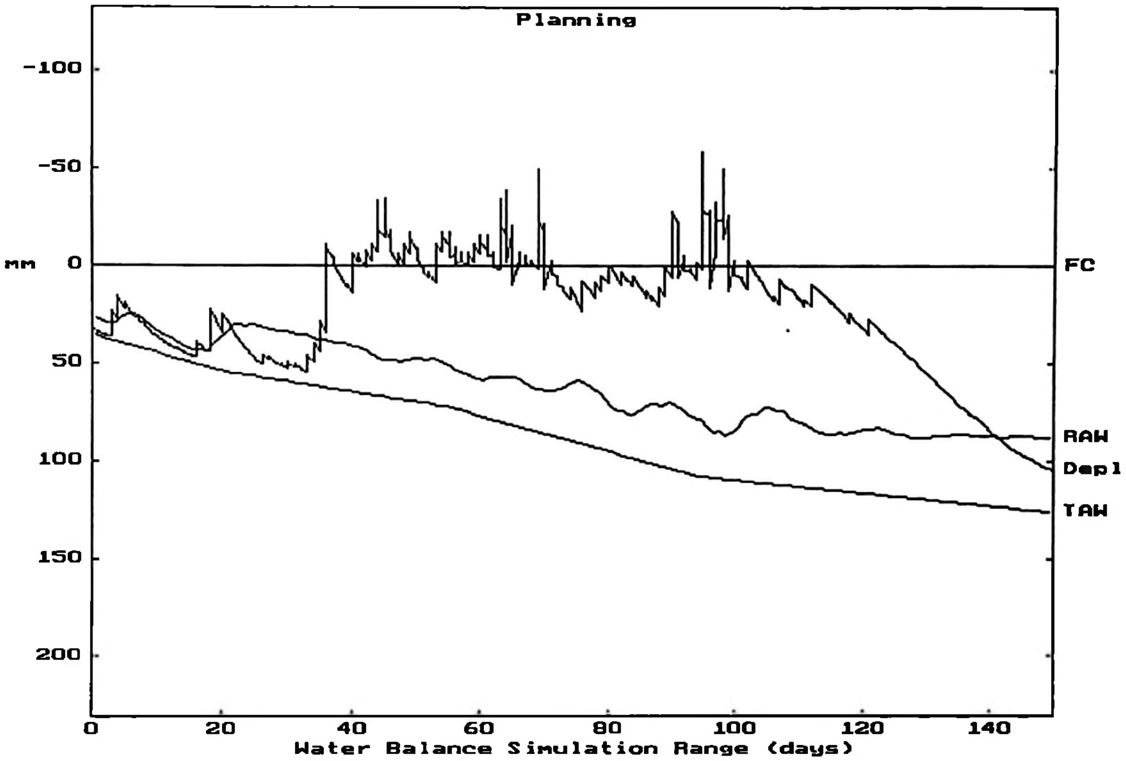
Day 1 = 1 November

Figure B7: Chitedze rootzone depletion for 1985/86 growing season - Maize crop.



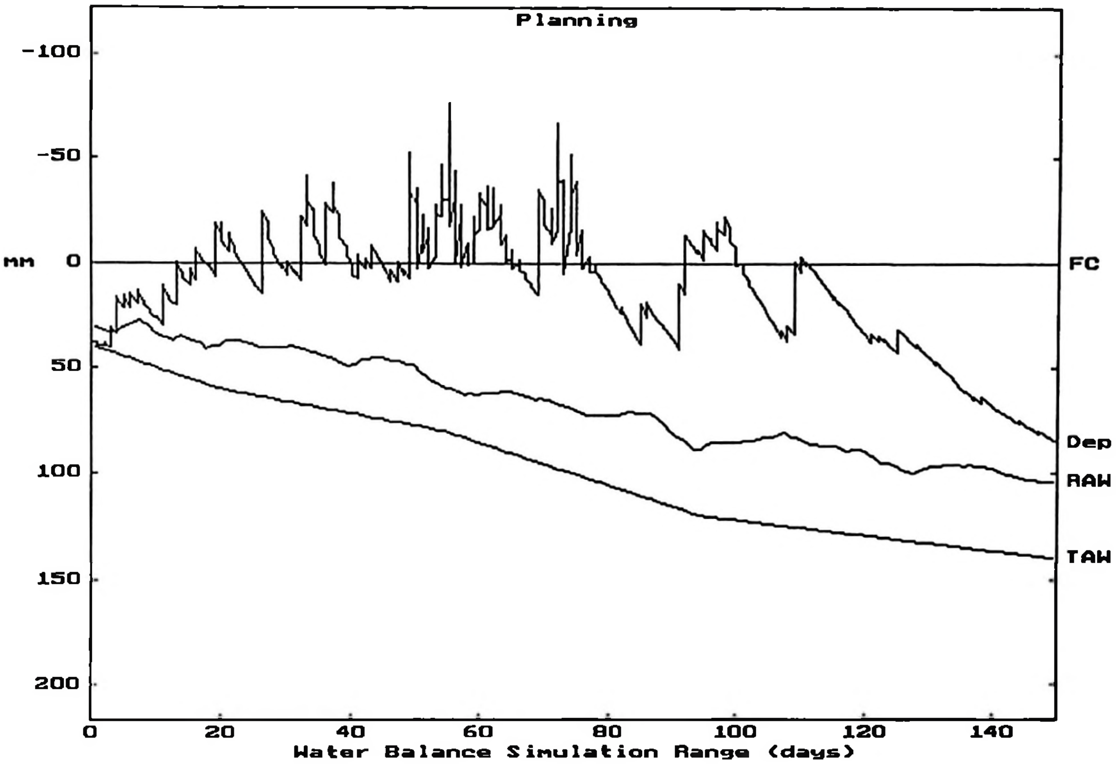
Day 1 = 1 November

Figure B8: Chitedze rootzone depletion for 1987/88 growing season - Maize crop



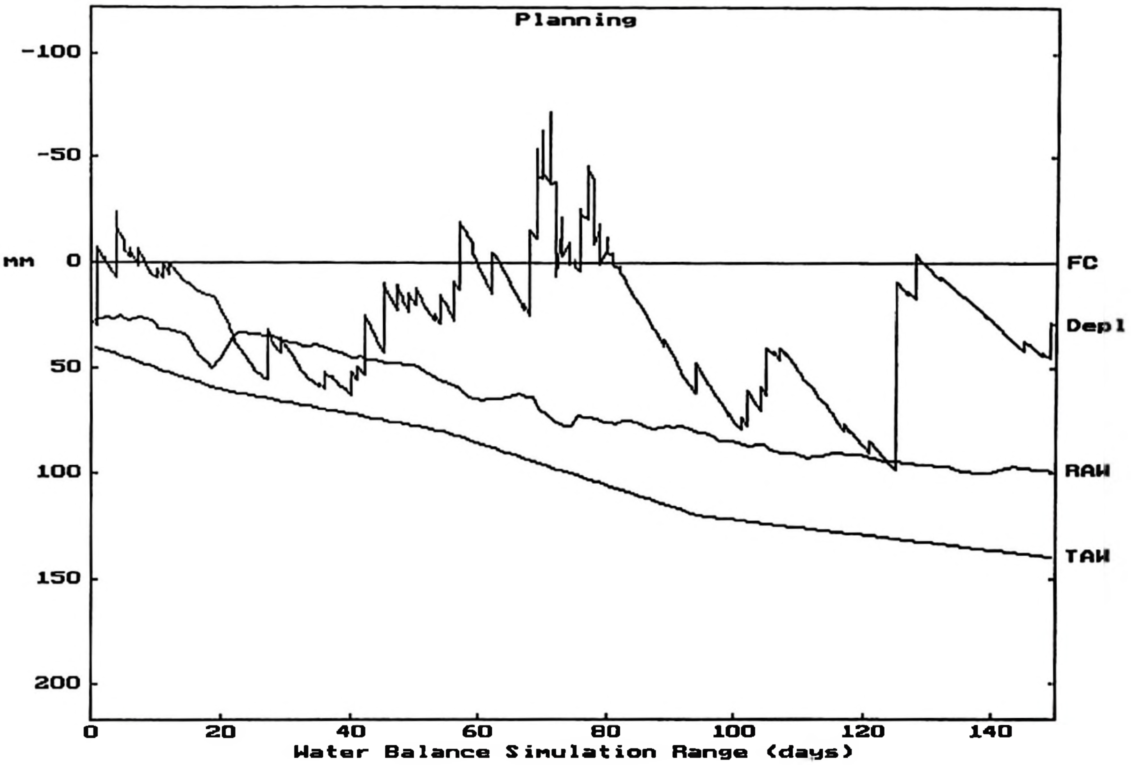
Day 1 = 1 November

Figure B9: Chitedze rootzone depletion for 1988/89 growing season - Maize crop.



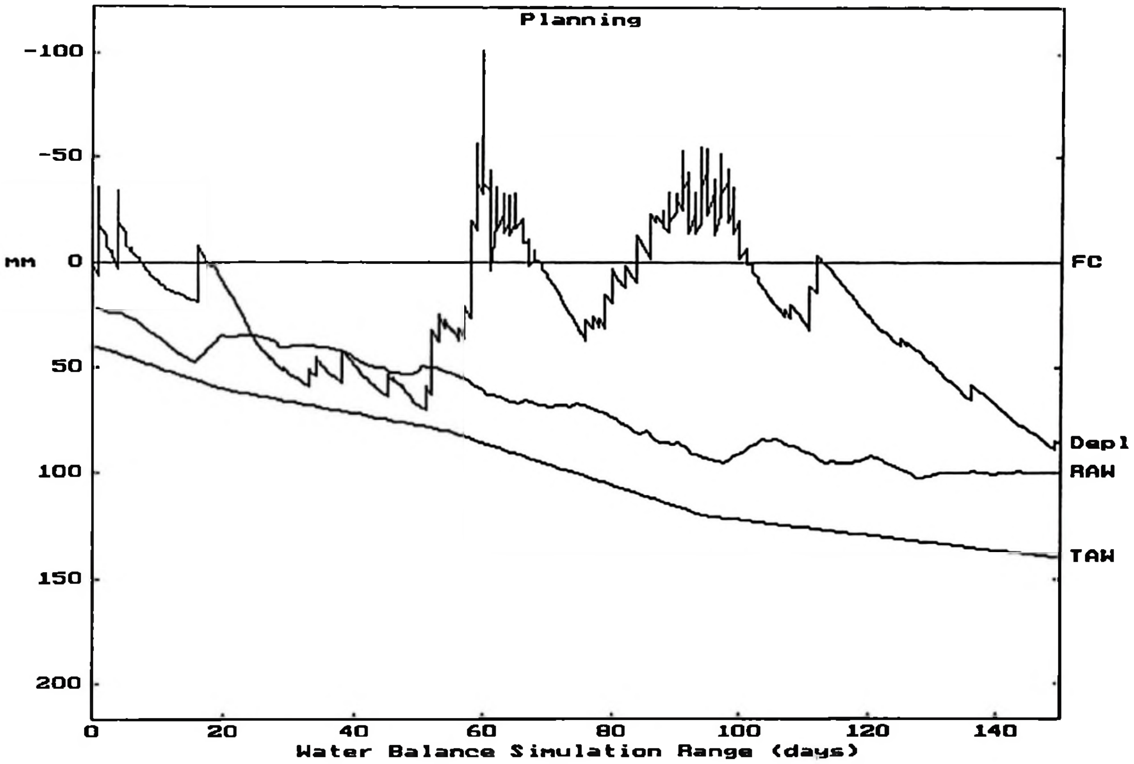
Day 1 = 1 November

Figure B10: Makoka rootzone depletion for 1985/86 growing season - Maize crop.



Day 1 = 1 November

Figure B11: Makoka rootzone depletion for 1987/88 growing season - Maize crop.



Day 1 = 1 November

Figure B12: Makoka rootzone depletion for 1988/89 growing season - Maize crop

APPENDIX C: The probability od a dry day for selected areas.

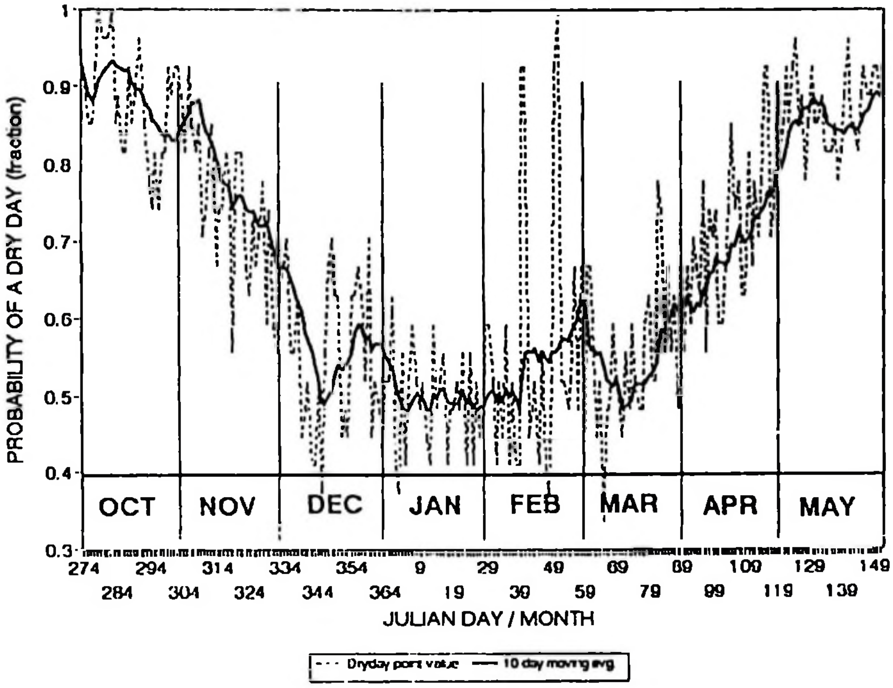


Figure C1: The probability of a dry day for Bvumbwe.

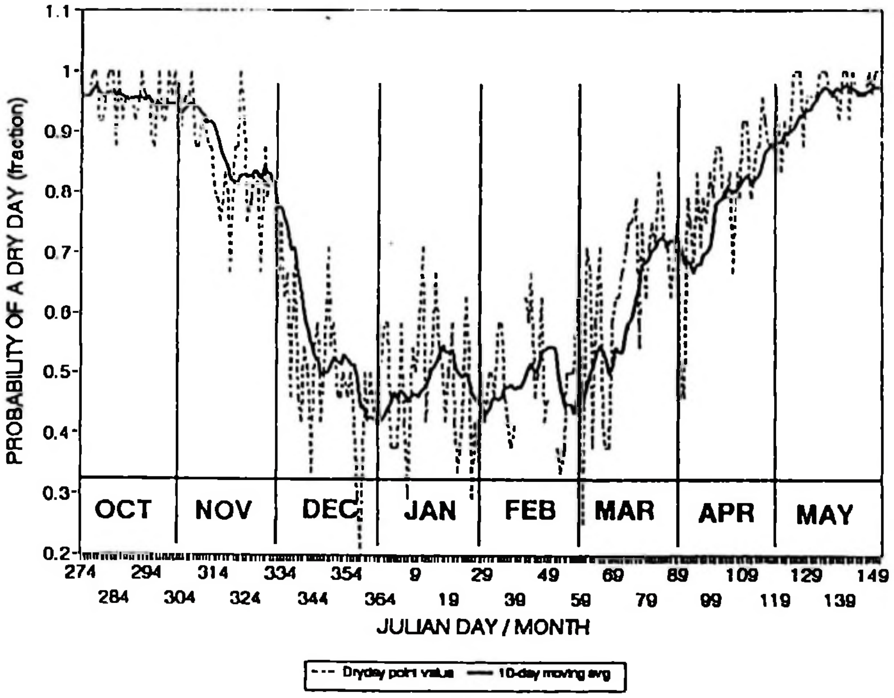


Figure C2: The probability of a dry day for Chitedze.

APPENDIX D

Table D1: Measured and simulated runoff

	MEASURED RUNOFF		SIMULATED RUNOFF	
DATE	Plain field	Contour field	CN64	CN54
12/12/96	4.04	5.64	0	0
13/12/96	8.56	9.97	8.00	7.2
15/12/96	3.83	8.98	0	0
21/12/96	6.48	7.16	0	0
30/12/96	18.14	18.18	2.4	2.1
31/12/96	38.31	37.52	37.0	35.6
10/01/97	33.06	30.11	28.8	26.2
17/01/97	6.94	4.04	0	0
18/01/97	1.66	1.53	0.4	0
19/01/97	11.99	10.96	1.2	0.9
20/01/97	6.80	7.29	0	0
21/01/97	9.87	8.28	0	0
22/01/97	8.79	8.42	3.1	2.9
23/01/97	12.25	11.45	0	0
26/01/97	5.54	4.99	0	0
29/01/97	1.03	3.35	0	0
31/01/97	4.41	4.10	0	0

APPENDIX E

Table D2: Day numbers (starting from 1st January) for the days of the year

Month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Day												
1	1	32	61	92	122	153	183	214	245	275	306	336
2	2	33	62	93	123	154	184	215	246	276	307	337
3	3	34	63	94	124	155	185	216	247	277	308	338
4	4	35	64	95	125	156	186	217	248	278	309	339
5	5	36	65	96	126	157	187	218	249	279	310	340
6	6	37	66	97	127	158	188	219	250	280	311	341
7	7	38	67	98	128	159	189	220	251	281	312	342
8	8	39	68	99	129	160	190	221	252	282	313	343
9	9	40	69	100	130	161	191	222	253	283	314	344
10	10	41	70	101	131	162	192	223	254	284	315	345
11	11	42	71	102	132	163	193	224	255	285	316	346
12	12	43	72	103	133	164	194	225	256	286	317	347
13	13	44	73	104	134	165	195	226	257	287	318	348
14	14	45	74	105	135	166	196	227	258	288	319	349
15	15	46	75	106	136	167	197	228	259	289	320	350
16	16	47	76	107	137	168	198	229	260	290	321	351
17	17	48	77	108	138	169	199	230	261	291	322	352
18	18	49	78	109	139	170	200	231	262	292	323	353
19	19	50	79	110	140	171	201	232	263	293	324	354
20	20	51	80	111	141	172	202	233	264	294	325	355
21	21	52	81	112	142	173	203	234	265	295	326	356
22	22	53	82	113	143	174	204	235	266	296	327	357
23	23	54	83	114	144	175	205	236	267	297	328	358
24	24	55	84	115	145	176	206	237	268	298	329	359
25	25	56	85	116	146	177	207	238	269	299	330	360
26	26	57	86	117	147	178	208	239	270	300	331	361
27	27	58	87	118	148	179	209	240	271	301	332	362
28	28	59	88	119	149	180	210	241	272	302	333	363
29	29	60	89	120	150	181	211	242	273	303	334	364
30	30		90	121	151	182	212	243	274	304	335	365
31	31		91		152		213	244		305		366