# TOWARDS MAIZE YIELD PREDICTION IN THE KATUMANI AREA OF KENYA

BY

MARTIN FRANCIS LUKANDO

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This thesis is my original work and has not been presented for a degree in any other University

Signature .................................. 30/9/80

This thesis has been submitted for examination with our approval as University Supervisors

Signature.................................. 30/9/1980

Signature.................................. 30/9/80

Department of Crop Science
University of Nairobi
P.O. Box 30197
Nairobi, Kenya

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## ABSTRACT

In this study, attempts were made to relate yield of maize grown at Katumani Agrometeorological Station to rainfall and air temperature variables by two approaches.

In the first approach, yield was regressed on interphase rainfall totals. The results indicate that the flowering to wax ripeness interphase period is the most sensitive to unit changes in rainfall. They also indicate that the approach cannot be used to predict yield till end of the season when the best combination of variables, SER, ELR and FWR, can be obtained. A relatively large error was found presumably due to the use of data for a short run.

In the second approach, the yield was regressed on rainfall alone, then on rainfall and temperature combinations employing Fisher's (1924) regression technique as modified by Hendricks and Scholl (1943). The seasons were divided into 3, 5, 7 and 10-day periods. First and second degree equations were tried. The results were much improved. Out of all the combinations of variables and periods, rainfall and temperature range in 3-day periods in second degree equation was best, giving a high coefficient of determination and minimum error. Unlike the best equation in the first approach this equation can at any time of the season be used to assess the effect of weather variables on maize yield. Much of the yield variability seems to be

due to little and/or bad distribution of rainfall.

In using this equation, it was noted that the maize is affected differently during its different stages of growth and development. Above average 3-day totals of rainfall had a favourable effect up to about tasseling/ flowering time, thereafter the effect was reduced, and negative up to maturity. Above average 3-day temperature range had a similar effect, being favourable up to about tasseling time and then a progressively reduced and negative effect up to maturity.

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# LIST OF SYMBOLS AND ABBREVIATIONS

| Symbol | Meaning of symbol |
|---|---|
| E | Expected |
| Z | Dependent variable |
| $x, y$ | Independent variables |
| $\alpha, \beta, \gamma$ | Regression coefficients |
| $a_0, a_1, a_2$ | Regression coefficients |
| $b_0, b_1, b_2, D$ | Regression coefficients |
| $A_0$ | Constant |
| T | Dummy variable |
| R | Multiple correlation coefficient |
| $R^2$ | Coefficient of multiple determination |
| $^oC$ | Degrees Centigrade |
| $^oF$ | Degrees Fahrenheit |
| % | Percentage |
| $\Sigma$ | Summation |
| RF0 | Level of rainfall variable |
| RF1 | Linear component of rainfall variable |
| RF2 | quadratic component of rainfall variable |
| TP0 | Level of temperature variable |
| TP1 | Linear component of temperature variable |
| TP2 | Quadratic component of temperature variable |

## Abbreviations

Dum - Dummy variable

C.V - Coefficient of variation

Ha - Hectare

kg - Kilogramme

mm - Millimetre

WMO - World Meteorological Organization

PSR - Pre-sowing rainfall

SER - Rainfall total in the period between sowing and emergence

ELR - Rainfall total in the period between emergence and appearance of the 9th leaf

LTR - Rainfall total in the period between the appearance of the 9th leaf and tasseling

LFR - Rainfall total in the period between the appearance of the 9th leaf and flowering

TFR - Rainfall total in the period between tasseling and flowering

FWR - Rainfall total in the period between flowering and wax ripeness

WFR - Rainfall total in the period between wax ripeness and full ripeness

SFR - Rainfall total in the period between sowing and full ripeness

PFR - Rainfall total in the period between pre-sowing and full ripeness time

## Abbreviations

AMSL - Above Mean Sea Level

EAMD - East African Meteorological Department

DF - Degrees of freedom

FC - Field capacity

WP - Wilting point

# CHAPTER I

## INTRODUCTION

Maize is the most important cereal crop in Kenya, being the staple food for a large proportion of the population. Today it is estimated that slightly over one million hectares are under this crop annually, mainly on smallholdings.

As a crop, maize is found in a wide ecological zone, being grown in areas with as little as 250 mm of rainfall per annum to areas with as much as 5000 mm, and from sea level to altitudes of 4000 metres above sea level in the Andes (Duncan, 1975). However, individual varieties of the crop generally exhibit adaptation to a narrow band of latitude or altitude (Palmer, 1973). Here in Kenya it is grown from sea level to about 2500 metres above sea level and in rainfall regimes ranging from about 300 mm in the Machakos District to about 2000 mm in Kakamega District. Despite this apparently large adaptability, there are seasons when production either falls below the potential or the crop fails completely. The main reason being insufficient, or excess, rainfall which is at times coupled with high temperatures during certain stages of growth and development or during the whole growing season.

The crop's water demands during the growing season are varied; rising to a peak in the period between maximum elongation of the stem to flowering and then tapering off to maturity (Glover, 1948; Salter and Goode, 1967). The plant is therefore variably sensitive to either moisture stress or excess, both of which ultimately depress the yield to an extent depending on the magnitude and duration of their effect and on the stage of growth and development affected. For instance, the young maize plant which is moderately drought resistant up to the 5th leaf stage due to a covering of wax platelets in the leaves cannot withstand excess soil moisture conditions because its growing point is at this time below the soil surface. Excess moisture is known to reduce yield in a number of ways some indirectly like delayed planting after the onset of the rains (Evans, 1962; Goldson, 1963; Dowker, 1963; Akehurst and Sredhakan, 1964; Turner, 1968; Gray, 1970; Allan, 1972; Cooper, 1975; Cooper and Law, 1976) and directly by reducing availability of nitrogen by creating anaerobic conditions (Shaw, 1976).

As the plant grows a moisture deficit may progressively reduce growth rate i.e. net photosynthesis due to stomatal closure which directly leads to impending carbondioxide supply and indirectly to high leaf temperatures (Slatyer, 1967). At the start of the peak water demand a deficit seems to reduce the rate of floral primordia initiation while at anthesis and fertilization a deficit may dehydrate pollen grains and impair pollen germination or growth of the pollen tube from the stigma to the ovules (Robins and Domingo, 1953). Excess rain during anthesis may wash away pollen grains in addition to creating anaerobic conditions. During the grain filling period, a deficit leads to reduced photosynthetic rates, reduced and prolonged translocation of assimilates, even of those manufactured prior to flowering, out of the leaves. The role of temperature at any stage is to influence the atmospheric demand for water vapour and to affect the rate of the bio-chemical processes.

There have been numerous attempts to quantify the crop-weather relationship for forecasting purposes so as to be able to plan for any eventuality. However, the efforts have only met partial success for a variety of reasons, the basic one being that the plant's response to a given moisture and/or temperature value or to any other weather variable is complex and therefore difficult to quantify.

Besides this basic limitation, improved success requires overcoming the following problems, some of which are related to the main analytical tool - statistics. For a meaningful analysis and subsequent interpretation of the results, reliable and continuous data for many years are very essential. The reason for reliability is obvious. A continuous long run of data on the other hand is necessary for having many explaining variables and for getting representativeness where there are cyclic trends. When data for a short run are used the analysis may just show the random effects of explaining variables as the systematic effects may be low.

For the sake of analytical simplicity many workers have had to assume linear relationships between crop yields and explaining variables even where such relationships are not the best. For example, regressing final yield on total seasonal rainfall for a season which had little rain during the first half and excess during the second is inappropriate as the relationship can be curvilinear for a given area within a given range of the rainfall observed (Glover, 1957; Geslin and Bouchet, 1966). The best thing to do is to analyse by a number of methods and to test the results in future work. While analysing it is better to subdivide the growing season into reasonably small periods so as to account for the different responses of the crop to the weather variable. The length of the subperiods however, should be such that noise in the data is reduced without losing much information.

It has also been shown that a given weather variable might not be the only or the most important yield determinant. Consideration should also be given to the effect of other weather variables and agrotechnical advancements such as increases in rates of fertilizer application, use of high yielding varieties, application of herbicides, pesticides etc. (Glover, 1957; Geslin and Bouchet, 1966; Thompson, 1964; Brown and Cohemé). Agrotechnical advancements are known to account for a large proportion of positive trends in yields (Benci and Runge, 1976; Thompson, 1976; Swanson and Nyankori, 1979). It is therefore important that proper methods are used to discern agrotechnological trends from those due to weather in cases where they are significant.

In formulating models, errors have also been made in using explaining variables which show multi-collinearity (Katz, 1977). In cases of multi-collinearity, the effect of each variable is difficult to separate because the least square method is either difficult to perform or is not the most efficient way of estimating parameters as it gives unbiased estimators. To avoid this, one can try to use the squared departures rather than the actual weather variables (Thompson, 1976) or to use ridge regression (Katz, 1979) which gives biased estimators where the intercorrelation is not very high. If these two alternatives fail then the problem can be avoided by discarding one of two highly intercorrelated variables.

Quite often when relating rainfall alone or with other variables to yield, the pre-sowing soil moisture status is not incorporated into the model. This reduces the efficiency of the model because as it has been mentioned in the preceding paragraphs, a plant's response to additional rainfall/ soil moisture is dependent on what is already in the soil. Pengra (1952) obtained high correlations between yield and pre-sowing moisture.

The effects of the weather variables and the limitations of analysis in mind in this study attempts are made to relate maize grain yield to rainfall, and rainfall and temperatures, for Katumani by two approaches. In the first approach the maize yield is regressed on rainfall totals during interphase periods. In the second the yield is regressed on rainfall and temperature variables obtained from the complex rainfall distribution in 3, 5, 7 and 10-day periods using Fisher's (1924) regression technique as modified by Hendricks and Scholl (1943) and as adopted by Stacy *et al* (1957), Runge and Odell (1958) and Huda *et al* (1975,1976). Whereas these workers used data for one season per year, we have used data for two seasons per year.

Though the data is reliable, being for just 13 seasons, for the reasons given above it is inadequate for conclusive statistical analysis. Nevertheless, it is assumed sufficient to explain some of the variability in yield due to the weather conditions and therefore enabling some preliminary findings to be pointed out.

# CHAPTER II

## LITERATURE REVIEW

The task to quantify the relationship between weather and crops might have started just before the turn of the last century, but the qualitative effect of some of the weather variables, particularly rainfall, seem to have been known from time immemorial. For instance, Kautilya (321-291 B.C.) quoted by Stanhill (1973), wrote the following: "According as the rainfall is more or less, the super intendent shall sow the seed which require either more or less water". In China according to ancient literature, the measurement of precipitation dates back to the Eastern Han Dynasty (A.D. 25-200). A network of precipitation observations may have come into existence as early as 1424 when the Third Emperor of the Ming Dynasty ordered that reports on rainfall at various places be sent to him. Whereas this was probably done, none of these precipitation records have ever been discovered (Peiyuan and Gaofa, 1980). During the course of research on documents of the Ching Dynasty kept in the Imperial Palace in Beijing (Peking), a set of rain and snow records submitted by governors of different provinces were found. It is likely that such records were used for advisory services on farming.

Abbe (1905), also quoted by Stanhill (1973)concluded that in a dry climate the harvests are to an extraordinary degree dependent on rainfall. On the other hand, in moist climates crops are diminished by extremely large quantities of rain. Stanhill illustrated Abbe's point by quoting work done by Geslin and Bouchet (1966) and Lomas and Shashoua (1973) who respectively related wheat yields and total seasonal rainfall for two contrasting climatic regions- a moist Paris basin of France and an arid region of Israel. While the data of Geslin and Bouchet suggest a negative relationship between seasonal rainfall and yield with maximum yields occuring during years of below normal rainfall, that of Lomas and Shashoua suggest a positive relationship of maximum yields being associated with maximum rainfall. These observations are in agreement with Abbe's and are an indication that different models of the rainfall - yield relationship are likely to be appropriate in different climatic regions.

Over the years so much has been done to relate weather to maize yield that a review of all the work can form a separate topic for a thesis. Much of the work looked at the influence of weather variables acting jointly or independently on the yield of maize grown at single or various stations using different techniques.

Smith (1914) used simple linear regressions to relate average maize yield for Ohio State with average June, and August rainfall in 10-day periods for sixty years (1854-1913). He noted that the rainfall from flowering to ripeness was the most important and that the rainfall for the ten days following the date of flowering had an almost dominating effect upon the yield of corn. During this period yield was proportional to rainfall amount. If the rainfall was low during this period, high temperature had a very unfavourable effect on yield. He also observed that 12.5mm of rainfall were critical. Amounts equal to or greater than this had a larger effect on the development of corn than falls of less amounts.

The observations by Smith (1914) that rainfall about flowering time as the most critical factor in maize production in the corn belt was confirmed by Wallace (1920) and Houseman (1942), both quoted by Thompson (1969). Houseman developed curvilinear equations which indicated that 25 mm of rain occuring in any 5-day interval had the greatest benefit to corn about flowering time. The critical nature of moisture about flowering time has also been noted by other authors who demonstrated the relative importance of rainfall amounts during different growth periods of maize. Grain yield reductions greater than 40% as a result of four to eight days of wilt at silking have been observed (Robins and Domingo, 1953; Denmead and Shaw, 1960; Barnes and Woolley, 1969; Claasen and Shaw, 1970). For comparable stress periods, reductions in yield from water deficits during the ear stage have ranged from 21% (Denmead and Shaw, 1960) to 48% (Barnes and Woolley, 1969). Claasen and Shaw (1970) observed a significant grain reduction (12 to 15%) after stress during the vegetative period at early ear shoot and ovule development. These observations show that sensitivity to short periods of water stress is greatest at silking followed by the early ear and vegetative stages in order of decreasing vulnerability.

Houseman's and Smith's work and that of some of the authors above show, inter alia,the importance of subdividing the growing season into smaller periods in order to reduce noise in the data and to identify critical periods.

Davis and Pallesen (1940), used a method developed by Fisher (1924) to relate 5-day rainfall data to maize yields at Wooster, Ohio, and concluded that, "although the total rainfall for the season is not significantly correlated with yield, the distribution of the seasonal rainfall is correlated with yield". Fisher (1924) examined the influence of rainfall distribution and amount on the yield of wheat at Rothamsted by fitting the rainfall data of each year which was subdivided into 61 periods of six days each, with a 5th-degree polynomial on time. He then related the yield to the corresponding co-efficients of the polynomial in a linear multiple regression equation including trend variables to allow for slow changes in yield due to non-weather causes. The equation gives the yield to be expected in any year for which the rainfall distribution is known, and thus allows estimation of the effect on final yield of a unit change in rainfall during any particular period. His analysis showed that rainfall distribution accounted for, on the average, one third of the total variation in yield, with the importance of rainfall variations differing greatly from one experimental area to another.

Fisher's approach has since been used by other workers with or without modification on various crops with some success. For instance, Hendricks and Scholl (1943) used the approach after modifying it slightly to allow for the measurements of joint effects of rainfall and temperature on maize yields in Indiana, Ohio and Iowa States. Their results showed varying effects of high temperatures on yield depending on amount of available soil moisture. With adequate available soil moisture supply, high temperatures were found to have a beneficial effect proportional to amount of moisture while a detrimental effect was noted at times of deficiency.

Stacy *et al* (1957) looked at the joint effects of maximum temperatures and rainfall averaged over 5-day periods for 18 periods during each growing season of a 38 year period on corn yields at Experiment, Georgia by using 2nd degree equations. The results indicated that none of the individual regression constants was significant at the 5% level or above but the multiple correlation coefficient was highly significant. A coefficient of determination of 71.0% was obtained. The results like those of Hendricks and Scholl also showed higher than normal temperatures towards the end of the season to be beneficial to the crop by increasing yield if rainfall was adequate. A detrimental effect was noted in absence of adequate rainfall. The value of 25 mm of rainfall was shown to decline for a time after the usual planting date and then to increase sharply during the later part of the growing season especially when associated with the higher temperatures which are normal for that period.

Runge and Odell (1958) used the same technique as Stacy _et al_ (1957) to relate precipitation and temperature to the yield of maize on the Agronomy South Farm, Urbana, Illinois. Unlike their predecessors they subdivided the growing season into 2-day, 4-day and 8-day periods and instead of using a second-degree polynomial alone, they tried 1st, 2nd, 3rd and 4th-degree polynomials. They found that the 4th-degree polynomial explained more of the variability than the rest. The results indicated that yields were influenced most markedly by precipitation preceding anthesis and maximum temperatures during anthesis.

Runge (1968) did similar work to above by looking at the effects of rainfall and temperature interactions during the growing season on maize yield. The difference between their 1958 work and this being that the previous work's emphasis was to document the percentage of year to year maize yield variability that was due to differences in rainfall and temperature under constant management and soil conditions while the emphasis in the later work was to show relationships between rainfall and temperature during various intervals of the growing season and to show how the various combinations affected maize yield. Similar results to those of the previous work were obtained.

Maximum daily temperatures and rainfall had a large effect on yield from 25 days before to 15 days after anthesis. The maximum effect of temperature and rainfall on yield occured approximately one week before anthesis and remained at a high level one week to either side of the maximum. The models solved indicated that high temperatures, maximum daily temperatures between 32.2°C and 37.8°C were beneficial to maize yield in the presence of adequate available moisture as fourd by Hendricks and Scholl (1943) and Stacy et al (1957).

Huda et al (1976) adopted Hendricks and Scholls' (1943) approach in an attempt to quantify the relationship between maize yield and weekly rainfall totals, average daily minimum and maximum temperatures and daily minimum and maximum relative humidities over the same period. They found the yield to be affected differently by each variable during the different stages of growth of the crop. Above average weekly rainfall totals had a favourable effect on yield during emergence but a markedly reduced effect during silking and from tasseling to maturity. The second-degree equation had a co-efficient of determination of 67.6%. Above-average daily maximum temperatures had a favourable effect on yield during a 4-week period prior to silking, while higher than average daily maximums depressed yields during maturation. A co-efficient of determination of 49.4% was obtained. Above-average daily minimum temperatures on the other hand gave a favourable effect during tasseling and silking. The equation had a co-efficient of determination of 53.2%. As a whole, the crop was noted to be more sensitive to deviations of all the climatic variables mentioned above during the 3-week period to silking and tasseling, during maturation and during the 3-week period following maturation.

Prior to this work, Huda et al (1975) did similar work on rice and concluded that a second-degree multiple regression equation can profitably be employed in quantifying the relationship between rice yield and weather variables. The results showed that the crop reacts differently to the weather variables during the different stages of development, with the ripening phase being the most susceptible to excess rainfall.

Das (1974) used 20 years data for 9 stations in Zambia to evolve a maize yield forecasting model using multiple regression equation with daily rainfall, daily maximum temperature ($^{\circ}$F), daily minimum temperature ($^{\circ}$F), daily available period of sunshine, number of crop rainy days and a technological trend term as predictors. He observed that for better maize yield a rainfall of 58 mm during land preparation and sowing is essential. An excess might reduce yield by washing away seeds. He also found that some rain was essential during the growth period and that yield increased with number of crop rainy days. Each crop rainy day increased yield by 95.4% kg/ha. A higher daily average range of temperature during maturation period was conducive to grain formation and for each 5/9$^{\circ}$C (1$^{\circ}$F) rise in temperature, yield increased by 106.8 kg/ha. The equation had a coefficient of determination of 99.0%.

Benci and Runge (1976) caution modelers using historical data to discern the technlology trend from the weather trend if the interactions of weather events are to be determined clearly, otherwise a bias may be introduced in the models when assuming that the observed trend is strictly due to the technology. Thompson (1969) was much aware of this as he separated the influence of weather from that of technology on the yield of maize by using time trends for technology and multiple curvilinear regression for weather variables in five corn belt state of the USA. A time trend from 1930 to 1960 indicated an average annual increase of 51 kg of grain per hectare while a time trend from 1960 to 1967 indicated an average annual increase of 201 kg of grain per hectare. Meanwhile, weather variables accounted for most of the variation from the time trends. In earlier studies (Thompson, 1964) he looked at the unfluences of weather on corn yields by using multiple curvilinear regression along with a time trend for the evaluation. With such a technique the number of observational years may be insufficient to provide a desirable number of degrees of freedom. So in this (1969) study he pooled data from five states for a period of 38 years, providing 190 observations of yield on weather variability. A good account of how to separate time trends of different slopes in multiple regression is given by the same author (Thompson, 1976).

In Kenya and East Africa as a whole little has been done to quantify crop weather relationships. Some of the early attempts were by Glover (1957) who related maize yield from large scale farms in western Kenya to seasonal rainfall for April to August and obtained a curvilinear relationship with 750 mm as the optimum rainfall. In using the curve for estimating yield at the optimum rainfall amount, a yield of 2130 kg/ha is obtained. The pattern of the yield-rainfall curve obtained is similar to that of Geslin and Bouchet (1966). However Brown and Cocheme (1973) point out the need for confirmatory evidence that higher rainfall decreases yield. They site as examples some of the agricultural research stations in the same area like Kakamega where management is optimum and rainfall is about 1845 mm per annum and yet yields of about 9000 kg/ha are not uncommon. They suggest that the seemingly adverse effect of excessive rainfall is complex and could be due to concomitant factors like excessive cloudiness and subnormal temperatures, waterlogging and promotion of weed growth and diseases.

In earlier work on water demands by maize and sorghum Glover (1948) observed that the critical demand period for cereals to be from maximum stem elongation to flowering with the peak demand at heading and flowering times. Similar results were obtained by Simango (1976) who used average locational three year data for Embu, Katumani and Kitale to relate rainfall totals during estimated interphase periods with maize yield.

Special attention has been paid to the marginal areas of East Africa. Dowker (1963) on the rainfall reliability and maize yields in Machakos district, noted that crop failures are frequent normally following a succession of low rainfall seasons. He showed that yield reliability can be increased by either low plant populations or quick maturing varieties which can utilize the rainfall fully. The latter was found most satisfactory, provided there is good husbandry. He also noted that within the rainfall range experienced, the yields fit a linear relationship.

Dagg (1965) in a study of the rational approach to the selection of crops for areas of marginal rainfall in East Africa pointed out that in these areas total annual rainfall or total seasonal rainfall are poor guides in relating rainfall with maize yield. Periods of light rains from flowering to maturity, partly through the catchment effect of the maize plant as described by Glover and Dwynne (1962) were found critical for crop survival and production.

Much of the other work in East Africa in this field has been qualitative, centered on investigating causes for low yields of late planted maize after the onset of the rain (Evans, 1962; Goldson, 1963; Dowker, 1964; Akehurst and Sredhakan, 1964; Turner, 1968; Gray, 1970; Allan, 1972; Cooper, 1975). With time, different theories were advanced, a new one superceding or augmenting a previous one(s), but no definite explanation given. The break through seem to have been attained after the work of Cooper and Law (1976) who after detailed studies of the effect and importance of soil temperature in determining the early growth vigour and final grain yields of hybrid maize in the highlands of Kenya showed that soil temperature at 7.5 cm and to a lesser degree soil moisture are the major factors controlling early growth of maize up to five weeks (12th leaf stage).

Soil temperature controls growth by affecting the apical meristem which is below the ground during this period. It controls leaf primordia initiation rate and final leaf number. The warmer the temperature the higher the initiation rate and more leaves per plant are produced. The effect of the soil temperature on leaf number is only up to the 9th leaf stage when tassel initiation occurs. The effect of soil moisture is on cell expansion and thus leaf expansion and final leaf size, both of which are sensitive to moisture stress.

A strong relationship between dry matter at five weeks and final grain yield was found. Fitting soil temperature and soil moisture during this time in a regression equation gave a co-efficient of determination of 81.6%.

From the literature cited it is noted that both rainfall and temperature are closely related in affecting maize growth, development and yield. And that rainfall at about flowering time is critical. Relating yield to the variables in small subperiods of a growing season rather than a whole season is better but the relationship is by no means simple.

# CHAPTER III

# MATERIALS AND METHODS

## 3.1 DATA USED

The data used in this study are those recorded by the Kenya Meteorological Department (KMD).

The department runs a network of agrometeorological stations, see Fig. I and Table I, at which concurrent observations of surface weather variables and crops are made.

The surface weather variables observed include: Rainfall, maximum, minimum and mean air temperatures, soil temperature, grass minimum temperature, sunshine hours,cloud cover, radiation, pan evaporation, wind speed, wind run and relative humidity. All these are observed daily and recorded in the observation register.

In order to obtain crop observations, the department uses commercial/non experimental fields belonging to agricultural institutions like research and/or training centres. At such places the department builds and equips an enclosure within the farm premises. In making observations at such places, the department is assured of their continuity on crops grown under standard recommended cultural practises.

The fields where crop observations were made during the period covered by this study varied in area. Ideally they were supposed to be of 1 hectare. However, if the whole field was larger than this, then a 1 hectare field was delineated for the observations for each crop. If the area was less, still the observations were carried out

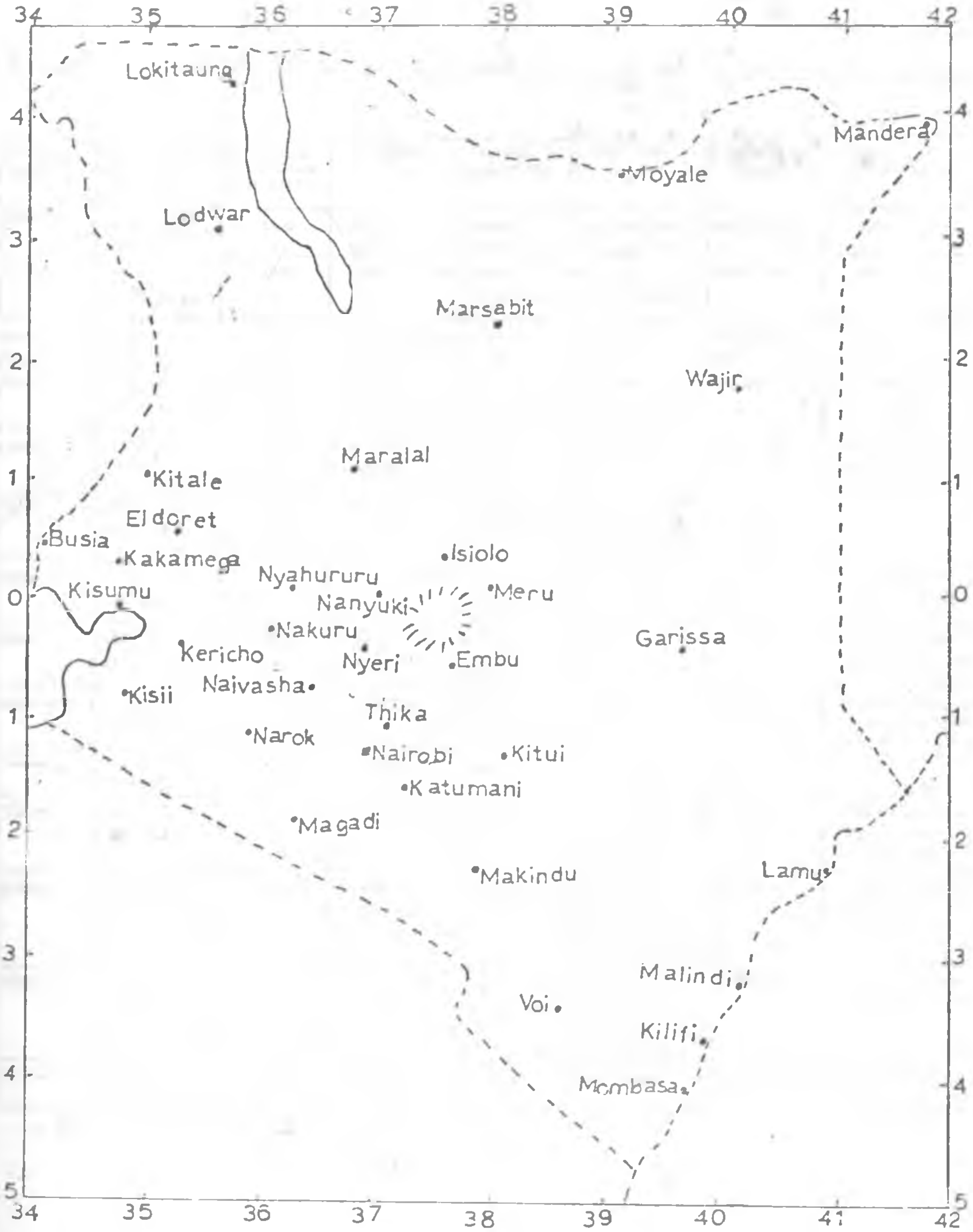

Fig. 1: Geographical locations of the agrometeorological stations in Kenya.

Table 1: Description of Agrometeorological stations in Kenya

| STATION NAME | GEOGRAPHICAL CO-ORDINATES | ALTITUDE (M), GRADE OF STATION * | TOPOGRAPHY | NATURAL VEGETATION | SOIL TYPE | BEGINNING OF RECORDS | RECORD INTERRUPTION |
|---|---|---|---|---|---|---|---|
| Katumani | 01°35'S<br>37°14'E | 1600<br>A | Gentle Rolling Land | Wooded Grassland | Gravelled Red Friable Clays | April 1973 | NIL |
| Kitale | 01°01'N<br>35°00'E | 1890<br>A | Sloping Land | Wooded Grassland | Dark-red and Red Friable Clays | April 1975 | NIL |
| Wambugu F.T.C. | 00°26'S<br>36°58'E | 1790<br>A | Rolling Land | Wooded Grassland | Red Friable Clays | September 1975 | 1977 |
| Kisii | 00°41'S<br>34°48'E | 1700<br>A | Sloping Broad Flat-Topped Ridges | Wooded Grassland | Dark-red Friable Clays | May 1973 | Intermittent Up to Sept. 1975 |
| Kabete | 01°15'N<br>36°44'E | 1940<br>A | Gently Rolling Land | Bushed Grassland | Red Friable Clays | April 1973 | Intermittent Up to end of 1976 |
| Thika | 01°01'S<br>37°06'E | 1460<br>B | Mainly Level Land | Wooded Grassland | Red to strong Brown Friable clays with Laterite Horizon | December 1973 | 1976 |
| Embu | 00°37'S<br>37°36'E | 1490<br>A | Sloping Ridge | Wooded Grassland | Dark-red Friable Clays | August 1973 | Intermittent Records up to end of 1975 |
| Meru | 00°05'N<br>37°39'N | 1550<br>A | Sloping Broad Flat Topped Ridges | Wooded/ Bushed Grassland | Dark-red Friable Clays | May 1976 | Proper Reporting Started in 1977 |
| Nyahururu | 00°02'N<br>36°17'E | 2340<br>A | Sloping | Wooded Grassland with Forest | Dark-red Friable Clays | April 1976 | Proper Reporting Started in 1977 |
| Kakamega | 00°17'N<br>34°45'E | 1560<br>A | Gently Undulating | Wooded Grassland | Dark-brown Sandy Loams | April 1977 | NIL |
| Njoro | 00°20'S<br>35°56'E | 2160<br>A | Mainly Level Land | Wooded Grassland with Bushland | Dark-brown Loams with Ash and Pumice Soils | October 1973 | Reporting of Yield Data Intermittent |
| Bukura | 00°13'N<br>34°37'E | 1460<br>B | Gently Rolling | Bushed Grassland | Red Friable Clays with Light Yellow Brown Sandy Loams with Laterite Horizon | May 1976 | Yield Reporting Started in 1977 |
| Eldoret | 00°34'N<br>35°18'E | 2130<br>B | Low Lying Level land | Wooded Grassland | Red to Strong Brown Friable Clays with Laterite Horizon Grey Mottled Clays | June 1976 | Yield Reporting Started in 1977 |
| Masbaha | 03°16'S<br>40°03'E | 90<br>B | Coastal Low-Lying | Wooded Grassland | Coral Rag | June 1976 | Yield Reporting Started in 1977 |

* No soil moisture observations at a Grade B station.

** Instruments installed according to WMO recommendations.

provided the area was not less than 0.2 hectare.

The crop data observed were:

1. PHENOLOGICAL

This involved recording of the stages of development/ phenological phases of 40 representative plants of a crop from emergence to ripeness, every monday, wednesday and friday or daily if deemed necessary. The information was noted in Form Agro I.

For maize, six phases were observed. These were: Emergence of the plant above the soil surface, appearance of the 9th leaf, appearance of the tassel, flowering of the tassel, wax ripeness and full ripeness.

2. STATE AND YIELD OBSERVATIONS

These observations were made while considering all plants in a field for the phenological observations. The information was entered in a Form Agro 4. The observations included:

a. A general assessment of the state of the plants every ten days.

b. Determination of the plant density at the beginning and at the end of the season.

c. The height of 40 representative plants every ten days.

d. Assessing weed infestation every ten days.

e. Recording any damage due to adverse meteorological phenomena, pests and diseases when such damage occured in the course of the season.

f. Recording the final yield at harvesting.

3. SOIL MOISTURE OBSERVATIONS

These were made on 7th, 17th and 27th day of each month in the same fields for the phenological and state and yield observations. Depending on the homogeneity of the soil, samples were taken in 4 or 5 replications for the depth 0 - 100cm at 10cm intervals [0(10) 100cm] and the moisture in each sample calculated and recorded in a Form Agro 5.

For details of procedure for making the agrometeorological observations, the reader is referred to a guide - book for Agrometeorological Observations by Dr. A. V. Todorov (1977).

## 3.2 SELECTION OF STATIONS

The Kenya Meteorological Department has at present a total of 14 agrometeorological stations ( Table I and Fig. I), but only 4 had either an uninterrupted record of observations since inception or had a relatively long record of observations. These 4 are Katumani, Wambugu F.T.C. (Nyeri), Kisii and Kitale. These are the stations which were initally earmarked for this study. Initial data collection which included determination of the agrohydrological properties of the soils, was done at all four. However, when it came to analysing the data, Wambugu, Kisii and Kitale stations were dropped because of a shorter run of yield data compared to Katumani.

### 3.3.1 LOCATION

The station is situated approximately 1600m above sea level at latitude I$^{o}$ 35's and longitude 37$^{o}$ 14'E, near Machakos town in Machakos district of Eastern Province. The Meteorological enclosure is within the farm premises.

### 3.3.2 SOILS

The soils are mainly gravelled red friable days which are well drained. The bulk density and field capacity for the

Table 2: Agrohydrological properties of the soils at Katumani Agrometeorological station.

| SOIL DEPTH (cm) | WILTING POINT (% of the wt. of dry soil) | FIELD CAPACITY (% of the wt. of dry soil) | BULK DENSITY ($g/cm^3$) |
|---|---|---|---|
| 10 | 7.0 | 19.6 | 1.23 |
| 20 | 7.6 | 20.3 | 1.41 |
| 30 | 10.1 | 19.5 | 1.34 |
| 40 | 10.6 | 20.5 | 1.32 |
| 50 | 11.0 | 21.9 | 1.33 |
| 60 | 11.2 | 22.6 | 1.32 |
| 70 | 11.5 | 22.9 | 1.32 |
| 80 | 11.9 | 23.2 | 1.28 |
| 90 | 12.9 | 23.7 | 1.29 |
| 100 | 13.0 | 23.7 | 1.44 |

Table 3: Rainfall and Temperature statistics for Katumani Agrometeorological Station.

| MONTH | RAINFALL (1958 - 70) | | | | | TEMPERATURES (1965 - 70) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | MEANS | | | | EXTREMES | |
| | MEAN | HIGHEST | LOWEST | MAX. 24 HOURFALL | NUMBER OF RAIN DAYS | MAX. | MIN. | MEAN | RANGE | HIGHEST | LOWEST |
| | mm | mm | mm | mm | ≥1 mm | °C | °C | °C | °C | °C | °C |
| JANUARY | 37 | 94 | 0 | 52.8 | 4 | 26.5 | 13.8 | 20.2 | 12.7 | 30.0 | 8.9 |
| FEBRUARY | 44 | 76 | 0 | 31.5 | 3 | 28.1 | 14.5 | 21.3 | 12.6 | 31.1 | 10.0 |
| MARCH | 96 | 216 | 34 | 63.5 | 7 | 26.0 | 16.0 | 21.0 | 10.0 | 31.1 | 10.0 |
| APRIL | 137 | 285 | 26 | 82.5 | 11 | 24.7 | 15.6 | 20.2 | 9.1 | 28.3 | 10.0 |
| MAY | 74 | 151 | 12 | 58.2 | 7 | 24.7 | 14.2 | 19.5 | 10.5 | 30.3 | 7.8 |
| JUNE | 8 | 25 | 0 | 19.3 | 1 | 23.6 | 12.1 | 17.8 | 11.5 | 28.9 | 6.7 |
| JULY | 4 | 10 | 0 | 1.6 | 1 | 22.2 | 11.8 | 17.0 | 10.4 | 27.8 | 6.1 |
| AUGUST | 3 | 11 | 0 | 7.6 | 1 | 22.9 | 11.7 | 17.3 | 11.2 | 30.0 | 5.6 |
| SEPTEMBER | 4 | 17 | 0 | 17.5 | 0 | 25.5 | 12.2 | 18.8 | 13.3 | 30.6 | 6.3 |
| OCTOBER | 40 | 136 | 0 | 86.9 | 3 | 26.5 | 13.9 | 20.2 | 12.6 | 31.1 | 6.7 |
| NOVEMBER | 184 | 463 | 34 | 186.9 | 14 | 23.9 | 14.9 | 19.4 | 9.0 | 28.9 | 11.1 |
| DECEMBER | 95 | 262 | 12 | 46.7 | 8 | 24.6 | 14.1 | 19.3 | 10.5 | 29.4 | 10.0 |
| YEAR | 726 | 1263 | 450 | 186.9 | 60 | 24.9 | 13.7 | 19.3 | 11.2 | 31.1 | 5.6 |

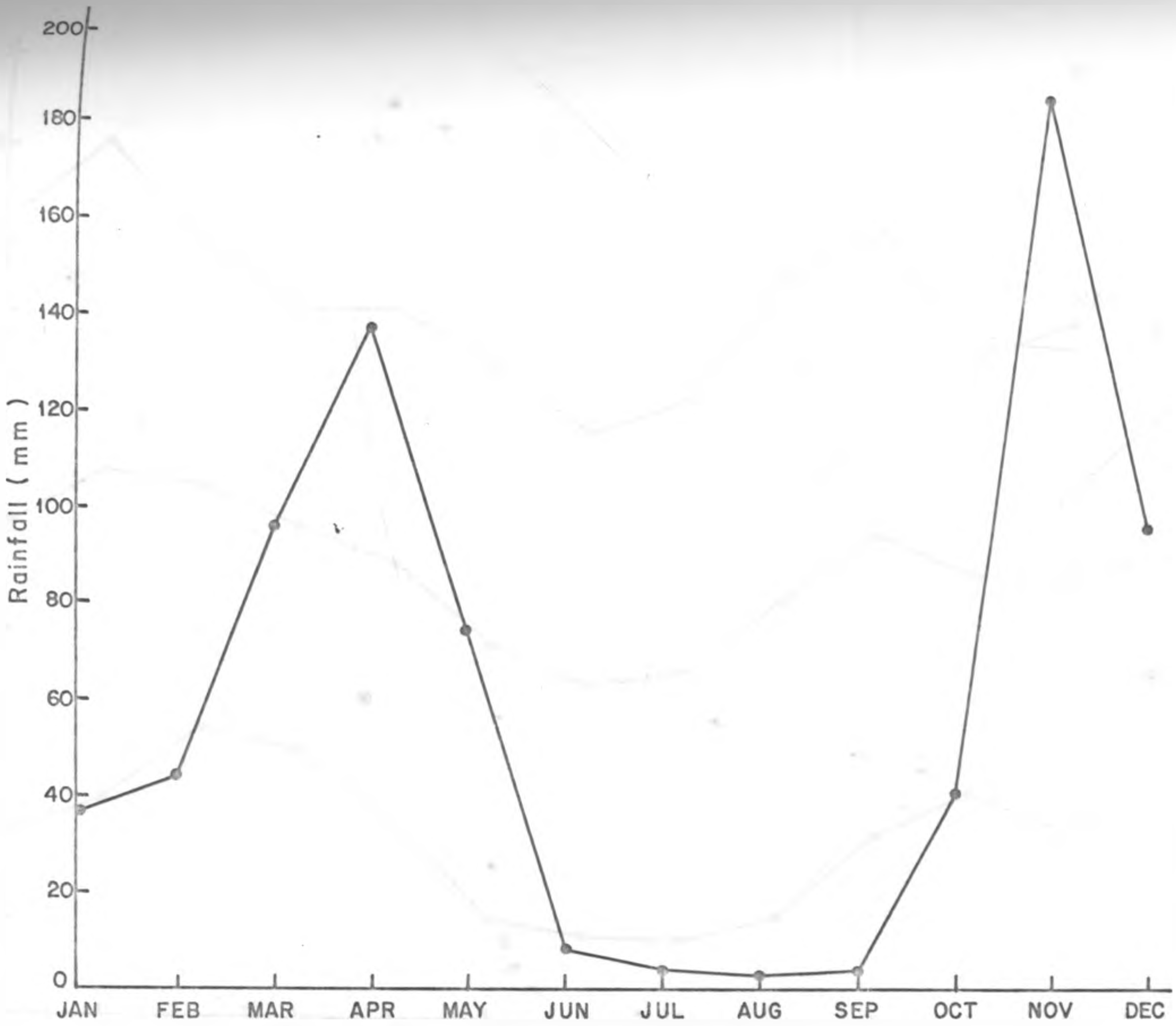

Fig. 2 : Mean monthly rainfall for Katumani agrometeorological station, 1958-70.

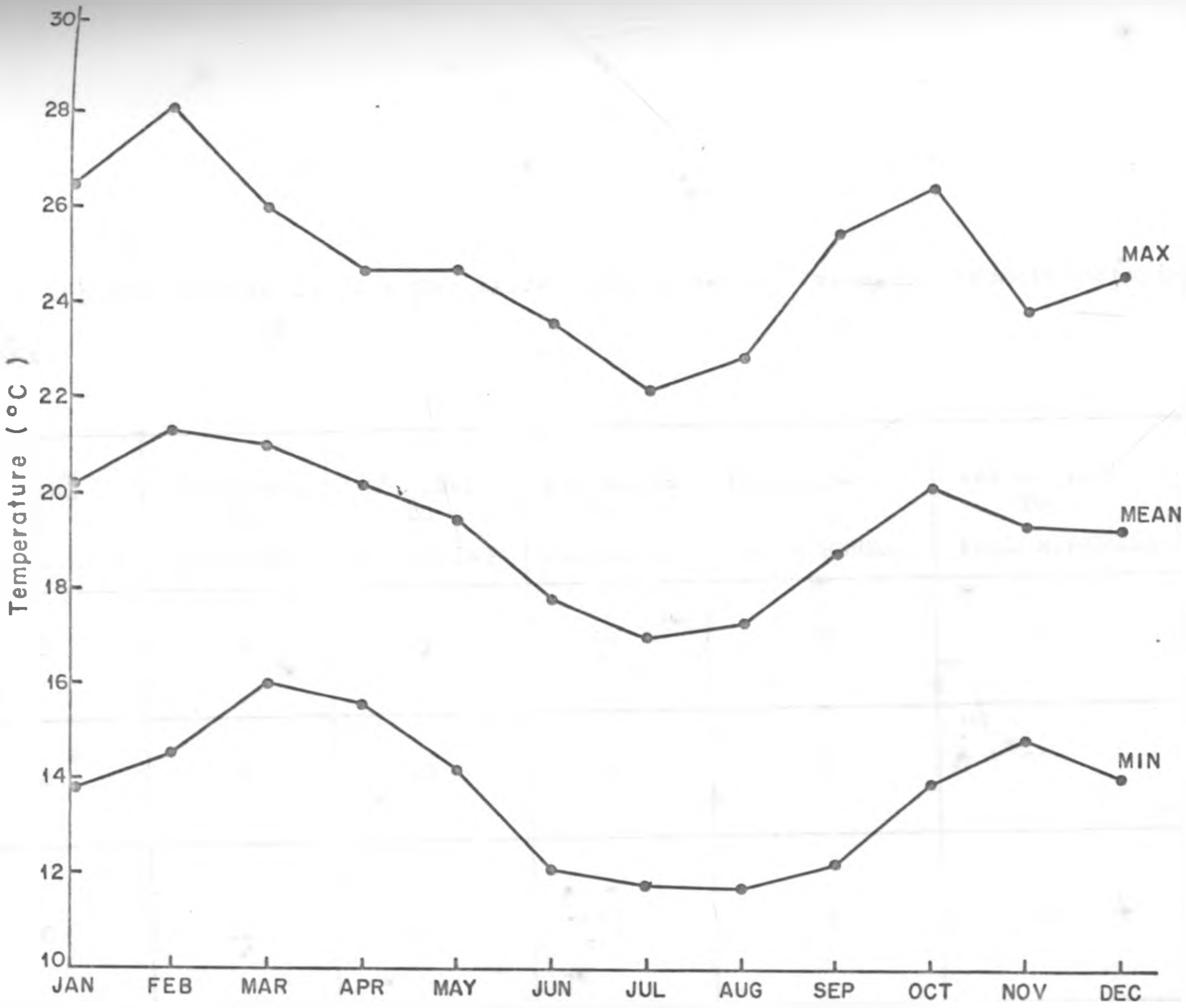

Fig. 3 : Average monthly maximum, mean and minimum temperatures for Katumani agrometeorological station, 1965-70.

Table 4: Mean Interphase periods in days for maize (KCB) grown at Katumani Agrometeorological station.

| INTERPHASE<br>SEASON | SOWING TO EMERGENCE | EMERGENCE TO 9TH LEAF | 9TH LEAF TO TASSELING | TASSELING TO FLOWERING | FLOWERING TO WAX RIPENESS | WAX RIPENESS TO FULL RIPENESS | SEASON |
|---|---|---|---|---|---|---|---|
| First season | 8 | 20 | 24 | 14 | 25 | 19 | 110 |
| Second season | 12 | 25 | 25 | 11 | 22 | 17 | 112 |
| Average | 10 | 22 | 25 | 13 | 23 | 18 | 111 |

## 3.4 METHOD OF ANALYSIS

In chapter I, some of the problems associated with statistical analysis were highlighted. Here a mention of a number of these problems is repeated with a little elaboration to serve as an introduction of the methods used in the analysis.

In relating yield to meteorological data, for example rainfall (x) and temperature (y) over a number of subperiods during the growing season, the expected yield E(Z) is a function of $x_1, \ldots\ldots, x_m, Y_1, \ldots\ldots, Y_m$. If the function is estimated, knowledge of the values of the predictors $x_1, \ldots\ldots\ldots, x_m, Y_1, \ldots\ldots\ldots, Y_m$ will enable the prediction of the expected yield. However, restrictions have to be made in chosing the function and the number of predictor variables as yields for a few seasons can be perfectly fitted by many types of functions provided the meteorological factors are many. For instance in Katumani, the yields of 13 seasons can be perfectly tested by many functions if the meteorological factors are measured in say 20 subperiods. In such a situation, one possibility is a linear function of rainfall only. Different functions will give totally different predictions. For purposes of simplicity and understanding of the prediction method, a simple regression function and a small number of predictors is best.

A simple regression function and a small number of predictors in itself is not the solution to all problems. We have mentioned in chapter I that even if the number of predictors is so small that identification problems are not likely, it may occur that the predictors are highly correlated. In that case we have nearly multicollinearity. Then, the estimation of the parameters is difficult as there is computational inaccuracy and the standard errors of the estimates are large. Some methods, for example ridge regression, have been developed to construct biased estimators with a lower mean squared error than that of the least squares estimates. More often a solution is sought in reducing the number of predictors. Such a reduction is based on all the correlation coefficients, partial and multiple, between the response and predictor variables. Even then, with the available techniques and programmes (selection procedures, cluster analysis, principal component analysis) the results are often subjective. In this work this process is often done intuitively, supported by simple correlation coefficients. When the regression equation is reasonably simplified it is possible to select a sequence or a set of predictors by a selection method. This is the basis of one of the two methods used in this work.

With this method, the predictors are combined in certain phases of growth. It is likely that for each season there is a different combination and the same phases have different lengths. The phase length is again a potential predictor. The easiest way of combining is addition over fixed periods, e.g. 3, 5, 7 or 10 day periods. The total or average of a given variable is maintained as a predictor, while its variation with the period is disregarded. So, if the length of the period is too long the smoothing of the data may lead to loss of relevant and important information.

Another method for combining and deleting predictors was initiated by Fisher (1924) and later reformed by Hendricks and Scholl (1943). It is this approach which forms the basis of the second method of analysis in this work. This approach also considers predictor variables in periods of fixed duration. These variables are then substituted for new ones and from the new set the least important are deleted. For instance, if we have rainfall in 3 subperiods $x_1$, $x_2$ and $x_3$, these are replaced by $x_1 + x_2 + x_3$, $x_3 - x_1$ and $x_1 - 2x_2 + x_3$. These replacements are the level, linear and quadratic components of the rainfall. The simplification may be obtained by leaving out the quadratic term.

In this work, the analysis of the relationship between the weather variables and the yield is done by two approaches, hinted at above, both having the assumption of additive contributions of the weather variables during different periods of a season. With this assumption, the form of the function used which disregards the interaction of variables can be presented thus:

$$E(Z) = \alpha_0 + \alpha_1 x_1 + \dots\dots\dots\dots + \alpha_n x_n + \beta_1 y_1 + \dots\dots\dots\dots + \beta_n y_n \qquad (1)$$

where $x_1 \dots\dots x_n$; $y_1 \dots\dots y_n$ are the quantities of the independent variables in different subperiods, $Z$ the expected yield, $\alpha_0$ the general level, $\alpha_i = \frac{\partial E(Z)}{\partial x_i}$, $\beta_i = \frac{\partial E(Z)}{\partial y_i}$.

Two crucial assumptions of this model may be stated:

1. The effect on maize yield of x and y in each period i is additive to the effects in other periods. The form of interaction in cases where the effects are not additive is rather difficult because the interaction will be related to growth stages than to fixed periods.
2. The effect of a unit change in $x_i$ leaving the other x's and y's unchanged is $\alpha_i$. If the change is positive, the interaction between x and y in the same period will probably be more important than the interaction between periods. The model can then be extended by including the interaction term: $\gamma_i x_i y_i + \ldots\ldots + \gamma_n x_n y_n$. In that case

$$\frac{\partial E(Z)}{\partial x_i} = \alpha_i + \gamma_i y_i$$

Prior to the actual analyses some of the data was examined and processed.

### 3.4.1 EXAMINATION AND PROCESSING OF DATA

#### 3.4.1.1 TREATMENT OF THE SOIL MOISTURE DATA

The soil moisture data used in this study is the total available soil moisture, in millimetes, in the depth 0(10) 100cm. The term available soil moisture was used here in its original sense as advanced by workers like Veihmeyer and Hendrickson (1927, 1949, 1950, 1955). It is the amount of water available throughout a definable range of soil wetness from an upper limit (Field Capacity) to a lower limit (the Permanent Wilting Point) both of which are characteristic and constant for any given soil.

From studies over the years it is now evident that the field capacity is dynamic and therefore not a unique value that always recur in the soil. Its value is approached slowly, if at all, as the surface tension forces adhering moisture to soil particles tend towards an equilibrium with the gravitational forces which cause moisture drainage. For this reason, it is regarded as a narrow interval of soil wetness and not a strict value.

Likewise, the permanent wilting point is dynamic and is considerd as a range of soil wetness over which the rate of water supply to plants is not great enough to prevent wilting.

Despite the developments which have led to the discarding of the classical concept of available water in its original sense, the field capacity and permanent wilting point are, respectively, still considered useful criteria for the upper and lower limits of soil water content which can more or less be depended upon in the field. It is for this reason that in this study the term available moisture was used in its original sense.

During the period of study, the moisture as observed was expressed as a mass wetness ratio (W), which is the mass of water ($M_w$) relative to the mass of dry soil particles (at 105°C) in a soil sample, expressed thus:

$$W = \frac{M_w}{M_s} \qquad (2)$$

For convinience of computations there was need to convert the mass wetness ratio to volume wetness ratio ($\theta$). These two are related as follows:

$$\Theta = \frac{M_w}{\rho_w} \cdot \frac{\rho_s}{M_s} \tag{3}$$

or

$$\Theta = W \frac{\rho_s}{\rho_w} \tag{4}$$

Where $\rho_s$ is the dry bulk density of the soil

$\rho_w$ is the density of water

as

$$\text{Volume} = \frac{\text{Mass}}{\text{Density}} \tag{5}$$

But we were interested in the total volume of water ($H_T$) per cross sectional area present in a soil profile of depth D. Knowing that the water concentration in the profile varies with depth, then in order to obtain an approximation of $H_T$, the total profile D was divided into n sublayers.

Fo the $i^{th}$ sublayer of depth $(\Delta D)_i$ the mass wetness ratio $W_i$ and the bulk density $\rho_{si}$ were calculated.

Then $H_T$ was obtained by the formula:

$$H_T = \sum_i \frac{\rho_{si}}{\rho_w} \cdot W_i \cdot (\Delta D)_i \tag{6}$$

To obtain the volume of available water per cross sectional area in the same profile of depth D, the volume of water at wilting point was subtracted from the total ($H_T$ - $H_{wp}$) thus:

$$H_T - H_{wp} = \sum_i \left(\frac{\rho_{si}}{\rho_w}\right) \left(W_{iT} - W_{iwp}\right) (\Delta D)_i \tag{7}$$

Where $D = 1m$

$(\Delta D)_i = 10cm$

$\rho_w \approx 1g/cm^3$

$n = 10$

### 3.4.1.2 TREATMENT OF THE RAINFALL DATA

Rainfall totals were found for the periods: 10 days prior to sowing (PSR), sowing to emergence of the first green parts of the plant above the soil surface (SER), emergence to appearance of the 9th leaf (ELR), 9th leaf to appearance of the tassel (LTR), tasseling to flowering of the tassel (TFR), flowering to wax ripeness (FWR) and wax ripeness to full ripeness (WFR). The abbreviations in brackets are later used as a short form for their respective interphase rainfall totals. The 10-day period before sowing was chosen because according to the data, it is about the period allowed from the onset of the rains to planting.

### 3.4.1.3 SCRUTINY OF THE YIELD DATA

Reasons were found for crop failures (zero yield) and low yields and on this regard the yields for 1975 and 1976 need special mention. Low yields or crop failures at Katumani, a low rainfall area, are frequent and mainly due to moisture deficit. The report that accompanied the yield record of 1975 reads and I quote: "Drought at tasseling and flowering caused the abortion of most cobs. Only good cobs were harvested and the rest were given to people. The yield record is therefore not precise", unquote. The report for the yield of 1976 says that the crop was affected by drought in the middle of the season, therefore animals were let in the field to feed. A scrutiny of the rainfall totals and distributions for the seasons of study, 1973 through 1979, 13 in total, indicate that there is a chance that there is a chance that this crop (1976) could have survived to give a low yield in lieu of the zero value reported. The yields of these two seasons were therefore used only up to intermediate stages of the analysis to see their effect in the error.

### 3.4.1.4 TEST OF DEPENDENCE

The dependence between yields and two of the potential explaining variables - available soil moisture at different phenological phases and rainfall during different interphase periods was tested by a nonparametric method, the Spearman's rank correlation method. This method was used instead of the normal correlation because it does not require rigorous assumptions about a population distribution, nor does it require to have a hypothesis stated in terms of specified parameter values. The normal correlation method on the other hand assumes that the two variables to be tested have a joint normal distribution and same conditional variance.

### 3.4.1.4.1 COMPUTATION OF RANK CORRELATION COEFFICIENTS ($r_s$)

Each of the two variables to be correlated were arranged in order of ranks, then the formula for Spearman's coefficient of rank correlation to find $r_s$ was applied as follows:

$$r_s = 1 - \frac{6 \sum_{i=1}^{n} d_i^2}{n(n^2 - 1)} \qquad (8)$$

where $d_i$ is the difference between ranks of the ith pair and n is the number of pairs. After obtaining $r_s$ the hypothesis of dependence was tested.

### 3.4.1.4.2 RESULTS AND DISCUSSION

The rank correlation coefficients between available soil moisture and yield, and between interphase rainfall totals and yield are given in tables 5 and 6 respectively.

The coeficients between available soil moisture and yield contrary to the findings of Pengra (1952) indicate no existence of a significant dependence at sowing and emergence times. They however suggest a high level of dependence from the 9th leaf stage, the start of floral primordia (Cooper and Law, 1976), through full ripeness. While the level of significance at the 9th leaf, tasseling and flowering stages are in conformity with established relationship (Glover, 1948; Salter and Goode, 1967; Robins and Domingo, 1953; Denmead and Shaw,1960) that the plant's demand for water rises to a peak at flowering, the high correlations at the end of the season contradict the fact that the demand declines at this time. These high correlations could be due to intercorrelations of the predictors or may be due to rainfall at this time which should have a negative effect on yield. Instead they imply that a high available soil moisture content at the end of the season is conducive to high yield. These correlations are therefore meaningless and the data could be skeptical. For this reason, the yield was not regressed on the soil moisture data.

The correlations between interphase rainfall and yield on the other hand were only significant from emergence through flowering, the coefficients being highly significant during the emergence to 9th leaf interphase period (ELR). These results are in agreement with these of the authors mentioned above and therefore rainfall was used instead of available soil moisture.

Table 5: Rank correlations ($r_s$) of available soil moisture and yield for Katumani at different phenological phases.

| SOWING | EMERGENCE | 9TH LEAF | TASSELING | FLOWERING | WAX RIPENESS | FULL RIPENESS |
|---|---|---|---|---|---|---|
| 0.21 | 0.43 | 0.93** | 0.88** | 0.85** | 0.80** | 0.78** |

Table 6: Rank correlations ($r_s$) of rainfall during different interphase periods with yield at Katumani.

| 10-DAYS PRE-SOWING | SOWING EMERGENCE | EMERGENCE 9TH LEAF | 9TH LEAF TASSELING | TASSELING FLOWERING | FLOWERING WAX RIPENESS | WAX RIPENESS FULL RIPENESS |
|---|---|---|---|---|---|---|
| 0.05 | 0.36 | 0.78** | 0.60* | 0.71* | 0.32 | 0.17 |

### 3.4.2 ANALYSIS BY FIRST APPROACH: REGRESSION OF YIELD ON INTERPHASE RAINFALL TOTALS

#### 3.4.2.1 CHECKING FOR MULTI-COLLINEARITY

In this approach rainfall during different interphase periods was related to the yield. Prior to this a correlation matrix for the interphase rainfall totals (PSR, SER, ELR, LTR, TFR, FWR, WFR, PFR, SFR) and final yield was produced to check for multi-collinearity and to note the degree of correlation of each interphase rainfall total with final yield.

There were some high intercorrelations between some of the potential explaining variables. Under such circumstances, as explained in Chapter I, the least square method is inefficient. In order to permit efficiency some of the variables were either discarded or pooled. The discarding of variables may be done by using a selection procedure (multiple correlation method) while analysing, clustering methods or principal component analysis (Jolliffe, 1973), but with few variables it may simply be done by scanning of a correlation matrix. The latter option was adopted.

The variables LTR and TFR had a correlation coefficient of 0.68. These were pooled to form one variable - 9th leaf to flowering rainfall (LFR). A correlation coefficient of 0.85 was obtained for FWR and WFR. FWR and final yield had a correlation coefficient of 0.47 while WFR and final yield had a coefficient of

0.28, low as expected. Therefore, WFR was dropped. The highest intercorrelation was 0.98 between PFR and SFR. PFR and final yield had a correlation coefficient of 0.67 while SFR and final yield had a coefficient of 0.72. PFR was therefore dropped. The final explaining variables chosen were: SER, ELR, LFR, FWR and SFR.

#### 3.4.2.2 REGRESSION

The yield was first regressed on SER then, progressively, the other variables, except SFR on which yield was regressed seperately, were added. Each equation had a dummy variable to distinguish the seasons. Later the same explaining variables, except LFR which was entered in its square form $(LFR)^2$, were related to the yield in a similar way but without the dummy variables.

#### 3.4.2.3 MEASURING AND TESTING THE SIGNIFICANCE OF EXPLAINING VARIABLES

While regressing the yield on the rainfall totals, it was necessary to measure and test the contribution of each explaining variable as it was added to an equation.

The contribution was obtained by calculating the coefficient of multiple determination, $R^2$, which is a measure of the relative importance of all the variables in an equation as it indicates the proportion of the variance in the dependent variable which has been mathematically accounted for. The larger it is, the better a fitted equation explains the variation in the dependent variable. To obtain $R^2$ first the multiple correlation coefficient, R, defined as:

$$R = \frac{\text{The standard deviation of the estimated values}}{\text{The standard deviation of the original values}} \qquad (9)$$

was calculated and then squared.

While regressing the yield on interphase rainfall totals, comparison was made of the value of $R^2$ as each variable was added, for example:

| Variables in equation | $R^2$(%) |
|---|---|
| $E(Z) = f(SER)$ | 52.67 |
| $E(Z) = f(SER, ELR)$ | 75.30 |
| $E(Z) = f(SER, ELR, LFR)$ | 75.72 |
| $E(Z) = f(SER, ELR, LFR, FWR)$ | 75.96 |

It can be noted that after the addition of ELR, the gain in $R^2$ as more variables are added is very small. This would mean that the addition of more than two variables contributes little towards explaining the variation in yield. The variable added after the second may not have a significant contribution and therefore are included in the equation at the expense of degrees of freedom. In fact the value of $R^2$ will keep on increasing with increase in explaining variables till $R^2 = 1$. Because of this, the significance of the contribution of a variable as it was added, was tested by both the F test and t-test; but in this case $(t_{cal})^2 = F_{cal}$. Therefore only the t values are given and discussed.

F is the variance ratio defined as:

$$F_{cal} = \frac{\dfrac{SS\begin{pmatrix}\text{Error Restricted}\\\text{Model}\end{pmatrix} - SS\begin{pmatrix}\text{Error General}\\\text{Model}\end{pmatrix}}{\text{Error d.f. Restricted Model} - \text{Error d.f. General Model}}}{\dfrac{\text{SS(Error General Model)}}{\text{d.f. of General Model}}} \qquad (10)$$

while $$t_{cal} = \frac{\text{Value of regression coefficient}}{\text{Its standard Error}} \qquad (11)$$

$$= \frac{\beta}{\text{Standard Error } (\beta)}$$

A significant $R^2$ indicates how reliable or how good an equation is in estimating or reproducing the yield values, but for information on their relative variation another statistic, the coefficient of variation, C.V, often expressed as a percentage, defined as:

$$C.V = \frac{\text{Standard deviation of residuals}}{\text{Mean of observed values}} \qquad (12)$$

was calculated.

Standard deviation of residuals

$$= \sqrt{\frac{SS(\text{Error})}{d.f.(\text{Error})}} \qquad (13)$$

$$= \sqrt{\text{Error Mean Square (EMS)}}$$

therefore

$$C.V = \frac{\sqrt{EMS}}{\text{Mean of observed values}}$$

### 3.4.3 ANALYSIS BY SECOND APPROACH: REGRESSION OF YIELD ON RAINFALL AND AIR TEMPERATURE VARIABLES - A MODIFICATION OF FISHER'S TECHNIQUE.

This approach was followed to see if the yield - explaining variable relationship could be improved and to see if prediction can be carried out at any time during the growing season.

#### 3.4.3.1 VARIABLES

The explaining variables used are rainall totals, mean maximum temperature, mean temperature and temperature range in 3, 5, 7 and 10-day periods of the growing season. These divisions were made to compare the smoothing effect of the different durations on the data as there is no established reasonable length.

However, the act of subdividing the growing season into smaller periods increases the number of independent variables with respect to the observational seasons. Depending on the length of the subperiod, the number of the independent variables may be so large that establishing and interpreting the regression coefficients is difficult. With the need to use the above four lengths of subperiods, the following assumption had to be made: that the explaining variable(s) used is regular and can therefore be described by a smooth function which can be characterized by a small number of parameters. In view of this assumption, it was decided to analyse the data using Fisher's (1924) technique as modified by Hendricks and Scholl (1943).

### 3.4.3.2 FISHER'S TECHNIQUE

Fisher (1924), while investigating the relationship between wheat yield (Z) and rainfall (x), $E(Z) = \alpha_0 + \alpha_1 x_1 + \ldots + \alpha_n x_n$, suggested a relationship with the rainfall figures in polynomial structure. He assumed that the rainfall distribution can be described by a polynomial:

$$x_i = \xi_0 + \xi_1 t_i + \ldots\ldots + \xi_k t_i^k .$$

By fitting this polynomial of degree k to the rainfall variable, the estimated values of the $\xi$s may be obtained for each year or season. Then, by regressing the series of the $\xi$ s to the corresponding yields of the crop, the values $\alpha_0, \alpha_1 \ldots\ldots \alpha_n$ are obtained.

Fisher completed the calculations by replacing 1, t, $t^2 \ldots\ldots t^k$ by orthogonal polynomials the values of which, in equally spaced points, are tabulated in statistical tables by Fisher and Yates. The first step in the whole calculation can be done manually.

### 3.4.3.3 THIS STUDY

Now, according to this study, there was need to extend the model to include temperature, and rainfall and their interaction. Such work was first done by Hendricks and Scholl (1943) who did not use orthogonal polynomials. Their modification has since been adopted by several authors (Stacy et al, 1957; Runge and Odell, 1958; Runge, 1968; Huda et al, 1975, 1976).

In this study the available data limited the degree of the polynomial. Therefore, only the main effects of the independent variable on yield were investigated to the second degree. The second degree multiple regression equation for the joint effect of rainfall and temperature is:

$$E\ (Z) = A_0 + a_0\left(\sum_{i=1}^{n} t_i^0 x_i\right) + a_1\left(\sum_{i=1}^{n} t_i^1 x_i\right) + a_2\left(\sum_{i=1}^{n} t_i^2 x_i\right) + b_0\left(\sum_{i=1}^{n} t_i^0 y_i\right) + b_1\left(\sum_{i=1}^{n} t_i^1 y_i\right) + b_2\left(\sum_{i=1}^{n} t_i^2 y_i\right) + c_0\left(\sum_{i=1}^{n} t_i^0 x_i y_i\right) + c_1\left(\sum_{i=1}^{n} t_i^1 x_i y_i\right) + c_2\left(\sum_{i=1}^{n} t_i^2 x_i y_i\right) + DT \qquad (14)$$

where

Z is the maize yield in kg/ha.

$x_i$ is total rainfall in the ith 3, 5, 7 or 10-day periods.

$y_i$ is either average maximum temperature, mean temperature, or average temperature range in °C in the ith 3, 5, 7 or 10-day period.

$t_i$ is the number of each of the subperiods. For example, if the season is 30 days long it can be divided in 3, 10-day subperiods. The first subperiod will be t = 1, the second t = 2 and the third t = 3.

n is the total number of the subperiods for the season. In the hypothetical 30-day season above with 10-day subperiods, n = 3.

T is a dummy variable (Dum) to distinguish the seasons.

$A_0$; $a_0$; $a_1$; $a_2$; $b_0$; $b_1$; $b_2$; $c_0$; $c_1$; $c_2$; and D are regression coefficients.

With respect to the present study, the coefficients in this equation (14) are too many. These were reduced by disregarding the interaction terms. The equation for the main effects alone becomes:

$$E\,(Z) = A_0 + a_0\Big(\sum_{i=1}^{n} t_i^0 x_i\Big) + a_1\Big(\sum_{i=1}^{n} t_i^1 x_i\Big) + a_2\Big(\sum_{i=1}^{n} t_i^2 x_i\Big) + b_0\Big(\sum_{i=1}^{n} t_i^0 y_i\Big) + b_1\Big(\sum_{i=1}^{n} t_i^1 y_i\Big) + b_2\Big(\sum_{i=1}^{n} t_i^2 y_i\Big) + DT \qquad (15)$$

The relationship between yield and rainfall alone was found by using this equation (15) without the temperature terms.

The relationship between yield and all explaining variables was also found by the first degree equations and the results were compared with those of the corresponding second degree equations.

Later on it was desired to find the effect on yield of 1 mm of rainfall and 1°C of temperature range, above or below average for any subperiod as the season unfolded. This was done by taking a partial derivative of equation (15) above with respect to either rainfall or temperature and then substituting the t values.

The partial derivative of yield (Z) with respect to rainfall (x) is as follows:

$$\frac{\partial z}{\partial x} = a_0 + a_1 t + a_2 t^2 \qquad (16)$$

And that of yield (Z) with respect to temperature range (y) is as follows:

$$\frac{\partial z}{\partial y} = b_0 + b_1 t + b_2 t^2 \qquad (17)$$

# CHAPTER IV

# RESULTS AND DISCUSSION

## 4.1 FIRST APPROACH

### 4.1.1 RESULTS

The results are presented in tables 7, 8, 9, 10 and 11. It can be seen that for the equations with a dummy variable (table 7) the coefficients of multiple determination, $R^2$, ranges from a low value of 22.4% when yield was regressed on SER alone, to a value of 73.3% when the yield was regressed on SER, ELR, LFR and FWR.

The inclusion of ELR is shown by the t-test to be significant at the 5% level, whilst the subsequent addition of LFR and FWR were not significant. The t value is particularly low for LFR, comparable only to that for the dummy variable. A combination of all the variables but without LFR boosted the significance of both ELR and FWR. The ELR being highly significant while FWR was just significant. The combination had a coefficient of determination of 73.3, the same value as when LFR was included. This suggests that LFR has a negligible effect. The total seasonal rainfall, SFR, had a coefficinet of determination of 53.6% and was highly significant.

For the equations without a dummy variable (table 8) the coefficients of determination rose from a low value of 18.6% when SER was the only explaining variable to 72.2% when all variables were included. ELR

Table 7: Statistics for interphase rainfall - yield relationship, with a dummy variable, for Katumani.

| VARIABLE NAME IN REGRESSION EQUATION | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | $100R^2$ | 100 C.V | REGRESSION ERROR SUM OF SQUARES |
|---|---|---|---|---|---|---|
| CONST | 552.1722 | 401.562 | 1.38 | 22.4 | 95.8 | 6992670 |
| SER | 7.8437 | 4.6284 | 1.69 | | | |
| DUM | -348.2283 | 492.004 | 0.71 | | | |
| CONST | -242.6021 | 434.050 | 0.56 | 56.7 | 75.4 | 3899550 |
| SER | 6.1730 | 3.6966 | 1.67 | | | |
| ELR | 8.9959 | 3.3669 | 2.67* | | | |
| DUM | -175.8931 | 392.622 | 0.45 | | | |
| CONST | -343.2063 | 460.762 | 0.74 | 59.9 | 77.0 | 3612780 |
| SER | 7.3185 | 4.0384 | 1.81 | | | |
| ELR | 7.7552 | 3.7735 | 2.06* | | | |
| LFR | 2.3144 | 2.9043 | 0.80 | | | |
| DUM | -243.6544 | 409.754 | 0.59 | | | |
| CONST | -637.8735 | 431.921 | 1.48 | 73.3 | 67.2 | 2408460 |
| SER | 4.4141 | 3.8517 | 1.15 | | | |
| ELR | 9.3859 | 3.4071 | 2.75* | | | |
| LFR | 0.4113 | 2.7315 | 0.15 | | | |
| FWR | 10.0847 | 5.3903 | 1.87 | | | |
| DUM | 193.3543 | 427.177 | 0.45 | | | |
| CONST | -631.3053 | 402.610 | 1.57 | 73.3 | 62.9 | 2416260 |
| SER | 4.1517 | 3.2183 | 1.29 | | | |
| ELR | 9.6247 | 2.8254 | 3.41** | | | |
| FWR | 10.3869 | 4.6871 | 2.22* | | | |
| DUM | 216.8246 | 372.640 | 0.58 | | | |
| CONST | -330.4426 | 451.152 | 0.73 | 53.6 | 74.1 | 4184600 |
| SFR | 4.1234 | 1.2154 | 3.39** | | | |
| DUM | 84.6799 | 363.032 | 0.23 | | | |

Table 8: Statistics for interphase rainfall - yield relationship, without a dummy variable, for Katumani.

| VARIABLE NAME IN REGRESSION EQUATION | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | $100R^2$ | 100 C.V | REGRESSION ERROR SUM OF SQUARES |
|---|---|---|---|---|---|---|
| CONST | 433.2103 | 356.325 | 1.22 | 18.6 | 93.3 | 7342970 |
| SER | 6.7778 | 4.2761 | 1.59 | | | |
| CONST | -322.9615 | 379.127 | 0.85 | 55.8 | 72.3 | 3986510 |
| SER | 5.6013 | 3.3292 | 1.68 | | | |
| ELR | 9.2436 | 3.1856 | 2.90** | | | |
| CONST | -348.6443 | 407.030 | 0.86 | 56.2 | 75.9 | 3947980 |
| SER | 5.9854 | 3.7229 | 1.61 | | | |
| ELR | 8.9161 | 3.5197 | 2.53* | | | |
| $(LFR)^2$ | 0.0027 | 0.0093 | 0.30 | | | |
| CONST | -522.5151 | 352.973 | 1.48 | 72.2 | 64.1 | 2500770 |
| SER | 5.2113 | 3.1633 | 1.65 | | | |
| ELR | 9.0868 | 2.9722 | 3.06** | | | |
| $(LFR)^2$ | 0.0019 | 0.0078 | 0.24 | | | |
| FWR | 9.0377 | 4.2003 | 2.15* | | | |
| CONST | -506.1135 | 327.554 | 1.55 | 72.1 | 60.6 | 2518520 |
| SER | 4.9477 | 2.8039 | 1.76 | | | |
| ELR | 9.3098 | 2.6692 | 3.49** | | | |
| FWR | 9.0899 | 3.9687 | 2.29* | | | |
| CONST | -274.4353 | 365.164 | 0.75 | 53.3 | 70.9 | 4207370 |
| SFR | 4.0862 | 1.1519 | 3.55** | | | |

Table 9: Statistics for interphase rainfall - yield relationship with a dummy variable for Katumani with 1975 and 1976 yield data omitted.

| VARIABLE NAME IN REGRESSION EQUATION | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | $100R^2$ | 100 C.V | REGRESSION ERROR SUM OF SQUARES |
|---|---|---|---|---|---|---|
| CONST | -595.3019 | 415.546 | 1.43 | 76.5 | 52.9 | 1742860 |
| SER | 4.8784 | 3.5676 | 1.37 | | | |
| ELR | 8.6217 | 2.9616 | 2.91 | | | |
| FWR | 11.0770 | 4.6571 | 2.38 | | | |
| DUM | 330.4748 | 414.822 | 0.80 | | | |

Table 10: Statistics for interphase rainfall - yield relationship without a dummy variable for Katumani with 1975 and 1976 yield data omitted.

| VARIABLE NAME IN REGRESSION EQUATION | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | $100R^2$ | 100 C.V | REGRESSION ERROR SUM OF SQUARES |
|---|---|---|---|---|---|---|
| CONST | -495.0173 | 385.549 | 1.28 | 73.9 | 51.5 | 1927220 |
| SER | 6.3071 | 3.0025 | 2.10 | | | |
| ELR | 8.6270 | 2.8833 | 2.99 | | | |
| FWR | 9.2702 | 3.9599 | 2.34 | | | |

and FWR were the only significant variables, being significant at 1% and 5% respectively. The t-value for $(LFR)^2$ was not only insignificant but also the lowest. This is a further sign of the insignificance of the variable LFR. The total seasonal rainfall, SFR, was again highly significant, with almost the same coefficient of determination, 53.3%. It can be seen that the coefficients of determination were slightly low for equations without a dummy variable than for the same equations with a dummy variable.

The coefficients of variation both for equations with and without a dummy variable were highest when the explaining variable was only SER. The values were 95.8 and 93.3 respectively. These values gradually decreased with the inclusion of more variables, except for SER and LFR whose values are third highest. All along, the equations without a dummy variable had slightly lower values. The lowest values were 62.9 for a combination of SER, ELR, FWR and Dum and 60.6 for a combination of SER, ELR and FWR. The seasonal total rainfall, SFR, had coefficients of 74.1 and 70.9 respectively with and without a dummy variable.

The error sum of squares took a similar trend of variation to that for $R^2$ and C.V. The values were generally high, decreasing with the inclusion of more variables. The values were however slightly greater for equations without a dummy variable.

Tables 9 and 10 show the results of the analysis which excluded data of 1975 and 1976 seasons, for the reasons given in section 3.4.1 under scrutiny of the yield data, and the exclusion of LFR. Only the combinations with highest coefficients of determination, least coefficients of variation and minimum error are presented.

The trend of values is the same as in the previous case for equations with and without a dummy variable.

Comparing these results with the previous ones for the same combination of variables but with 1975 and 1976 data included, it can be seen that these have higher coefficients of determination, lower coefficients of variation and appreciably lower error sum of squares. The results show an improvement.

### 4.1.2 DISCUSSION

From these results it can be seen that the crop responds differently to rainfall during the different interphase periods and that the effects are manifested in the final yield. In order to identify the crop's relative sensitivities to rainfall during different phases, the relationship between each interphase rainfall with its corresponding average regression coefficient, obtained from all the equations tried in which it appears, was broken down and presented in table 11.

The sowing - emergence interphase period has an average duration of 10 days (table 4) and receives an average total rainfall of about 41.2 mm (table 47). Its

Table 11: Breakdown of the relationship between interphase rainfall with regression coefficient.

| VARIABLE NAME | AVERAGE INTERPHASE PERIOD-DAYS | AVERAGE INTERPHASE RAINFALL TOTAL-mm | AVERAGE RAINFALL PER DAY | AVERAGE REGRESSION COEFFICIENT | AVERAGE CHANGE IN YIELD PER mm |
|---|---|---|---|---|---|
| SER | 10 | 41.2 | 4.1 | 6.1 | 1.5 |
| ELR | 22 | 103.9 | 4.7 | 9.0 | 1.9 |
| LFR | 38 | 88.5 | 2.1 | 1.4 | 0.7 |
| $(LFR)^2$ | 38 | 88.5 | 2.1 | 0.002 | 0.009 |
| FWR | 23 | 27.9 | 1.2 | 9.6 | 8.0 |
| SFR | 111 | 283.4 | 2.6 | 4.1 | 1.6 |

average regression coefficient is about 6.1. This implies that during this interphase period a change in the rainfall amount received per day by 1 mm leads to a change in yield of about 1.5 kg/ha. By similar analysis a change in the rainfall amount by 1 mm leads to yield changes of 1.9 kg/ha during the emergence - 9th leaf period, 0.7 kg/ha during the 9th leaf - flowering period and 9g/ha during the same period but with the rainfall entered in the equation in its square form, 8.0 kg/ha during the flowering - wax ripeness period and 1.6 kg/ha during the whole growing season. These figures show that the period: flowering to wax ripeness is the most sensitive followed by the emergence - 9th leaf period, sowing-emergence period and 9th leaf - flowering period. These results, <u>inter alia</u> point out the critical nature of rainfall about flowering time as found by many workers (Wallace, 1920; Houseman, 1942; Glover, 1948; Salter and Goode, 1967 and Simango, 1976). They are also in agreement with the results found by Smith (1914) that the rainfall from flowering to ripeness, the grain filling period, is the most important.

The overall results suggest that at this place the crop very much depends on the rainfall from the sowing to the 9th leaf period, a period of about one month, which received an average of 145.1 mm (table 47), nearly half the average seasonal total. This amount appears to be essential for putting the crop into a good start by promoting good early germination and emergence of the plants, and for the proper initiation and differentiation of both the vegetative and reproductive primordia in the apical meristems. The tassel initiation starts at the 9th leaf stage (Cooper and Law, 1976), thus determining the potential grain number. After this stage at least the average rainfall received (table 47) appears essential up to flowering time when the degree to which the potential grain number set is fixed by fertilization. Thereafter, a rainfall amount slightly above average is important for good grain filling.

The low rate of change in the yield during the 9th leaf to flowering period when the rainfall is entered in its square form suggests that the relationship between yield and rainfall at this time is possibly more linear. However, the relationship between total seasonal rainfall with yield is not all that linear to the extent envisaged by Dowker (1963) as the coefficient of determination is only about 53%. It therefore appears that total seasonal rainfall alone, related in this way, is a poor guide in relating rainfall with maize yield in this area (Dagg, 1965). The relationship may be curvilinear during a certain part of the season, and other factors not incorporated in the equation could be having an important role (Glover, 1957; Geslin and Bouchet, 1966). In view of this it is good to relate the yield to the distribution rather than the total seasonal rainfall, and other factors as suggested by Davis and Pallesen (1940), Stacy et al (1957), Runge and Odell (1958), Gangopadhyaya and Sarker (1965), Runge (1968), Lomas and Shashoua (1973), Sreenivasan and Banerjee (1973), Huda et al (1975, 1976), to mention a few.

These results also show that the equations with a dummy variable have slightly higher values of coefficients of determination and variation and slightly lower values of error sum of squares. The dummy regression coefficients are not significant. These shortcomings are a suggestion that we discard the dummy variables, but with the run of data used there is need to get stronger evidence by working with a longer run of data.

With the exclusion of 1975 and 1976 seasons, there is an appreciable reduction in error, a slight increase in the coefficients of determination and a reduction in the coefficients of variation. This shows the importance of scrutinizing the data before it is analysed. The combination of SER, ELR, FWR and DUM is the best but the equation cannot be used to predict yield at any time of the growing season. Since one of the variables, FWR is obtainable at the end of the season, the equation is just important in explaining the history of rainfall - yield relationship. Furthermore, the error term is appreciable. For these reasons another approach had to be used to analyse the data.

## 4.2 SECOND APPROACH

### 4.2.1 RESULTS

The detailed results for each equation tried are given in tables 12 through 43 and a summary of the results in tables 44 and 45.

In all cases, the coefficients of determination increased from the first degree equation to the second, albeit slightly in some of the cases. Whatever the magnitude of the increase it is a sign that the relationship is not all linear as the second degree equation accounts for both the linear and quadratic contributions. Considering the subperiods, there is no definite pattern in which the coefficients of determination increased or decreased in both the first and the second degree equations. For the variable combinations in both the first and second degree equations, if their coefficients of determination are ranked starting with the lowest, on the average, the following order of increase is obtained: rainfall, rainfall and mean air temperature, rainfall and maximum air temperature, and rainfall and temperature range. The highest values were for the combination of rainfall and temperature range which had coefficients of 76.7 and 80.6 for the first and second degree equations respectively.

The coefficients of variation have, on the average, been slightly higher in the second degree equation than in their corresponding first degree equations. Like for

Table 12: Statistics for first degree equation for rainfall - yield relationship in 3-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V. |
|---|---|---|---|---|---|---|
| CONST | -47.9743 | 487.598 | 0.10 | 4666290 | 43.0 | 76.2 |
| RFO | 4.9063 | 3.299 | 1.49 | | | |
| RF1 | -0.0851 | 1.671 | 0.51 | | | |
| DUM | -111.6592 | 509.893 | 0.22 | | | |

Table 13: Statistics for first degree equation for rainfall - yield relationship in 5-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V. |
|---|---|---|---|---|---|---|
| CONST | -45.9737 | 482.105 | 0.10 | 4626280 | 43.4 | 75.8 |
| RFO | 4.9213 | 3.348 | 1.47 | | | |
| RF1 | -0.1409 | 0.277 | 0.51 | | | |
| DUM | -109.8210 | 507.170 | 0.22 | | | |

Table 14: Statistics for first degree equation for rainfall - yield relationship in 7-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | 100R$^2$ | 100 C.V. |
|---|---|---|---|---|---|---|
| CONST | 73.3130 | 488.229 | 0.15 | 5049400 | 38.3 | 79.2 |
| RFO | 4.7293 | 3.570 | 1.32 | | | |
| RF1 | -0.2197 | 0.414 | 0.53 | | | |
| DUM | -159.0134 | 532.060 | 0.30 | | | |

Table 15: Statistics for first degree equation for rainfall - yield relationship in 10-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | 100R$^2$ | 100 C.V. |
|---|---|---|---|---|---|---|
| CONST | 64.7721 | 513.059 | 0.13 | 457415 | 43.8 | 80.0 |
| RFO | 5.3299 | 3.884 | 1.37 | | | |
| RF1 | -0.3276 | 0.612 | 0.54 | | | |
| DUM | -111.7183 | 534.981 | 0.21 | | | |

Table 16: Statistics for first degree equation for rainfall and mean air temperature - yield relationship in 3-day periods, Katumani

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---:|---:|---:|---|---|---|
| CONST. | -1320.9278 | 10642.700 | 0.12 | 4643810 | 42.2 | 86.1 |
| RFO | 5.4094 | 4.941 | 1.09 | | | |
| RF1 | -0.1073 | 0.232 | 0.46 | | | |
| TPO | 5.9297 | 59.219 | 0.10 | | | |
| TP1 | 0.2118 | 3.153 | 0.07 | | | |
| DUM | -242.5703 | 1930.160 | 0.13 | | | |

Table 17: Statistics for first degree equation for rainfall and mean air temperature - yield relationship in 5-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -2862.6197 | 10501.900 | 0.27 | 4578340 | 44.1 | 85.6 |
| RF0 | 5.7513 | 4.990 | 1.15 | | | |
| RF1 | -0.1917 | 0.378 | 0.51 | | | |
| TP0 | -8.9614 | 98.915 | 0.09 | | | |
| TP1 | 1.1942 | 8.495 | 0.14 | | | |
| DUM | 147.4858 | 1929.670 | 0.08 | | | |

Table 18: Statistics for first degree equation for rainfall and mean air temperature - yield relationship in 7-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 719.6157 | 12124.400 | 0.06 | 5045330 | 38.3 | 89.8 |
| RFO | 4.5993 | 5.459 | 0.84 | | | |
| RF1 | -0.2097 | 0.589 | 0.36 | | | |
| TPO | 12.0129 | 176.078 | 0.07 | | | |
| TP1 | -1.5568 | 21.408 | 0.07 | | | |
| DUM | -315.3709 | 2260.850 | 0.14 | | | |

Table 19: Statistics for first degree equation for rainfall and mean air temperature - yield relationship in 10-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100C.V |
|---|---|---|---|---|---|---|
| CONST | -2179.3208 | 9619.810 | 0.23 | 4569800 | 44.1 | 85.5 |
| RFO | 5.8350 | 5.062 | 1.15 | | | |
| RF1 | -0.3886 | 0.743 | 0.52 | | | |
| TPO | 14.7546 | 186.074 | 0.08 | | | |
| TP1 | -0.9043 | 29.667 | 0.03 | | | |
| DUM | -160.7571 | 1670.090 | 0.10 | | | |

Table 20: Statistics for first degree equation for rainfall and mean maximum air temperature - yield relationship in 3-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 5516.1565 | 11232.200 | 0.49 | 4497410 | 45.0 | 84.8 |
| RFO | 3.2679 | 5.913 | 0.55 | | | |
| RF1 | -0.0493 | 0.239 | 0.21 | | | |
| TPO | -3.2733 | 27.481 | 0.12 | | | |
| TP1 | -0.1008 | 1.193 | 0.08 | | | |
| DUM | -221.6301 | 1223.290 | 0.18 | | | |

Table 21: Statistics for first degree equation for rainfall and mean maximum air temperature - yield relationship in 5-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 3017.2479 | 8422.310 | 0.36 | 3768750 | 53.9 | 77.6 |
| RFO | 7.5932 | 4.945 | 1.54 | | | |
| RF1 | -0.3874 | 0.375 | 1.03 | | | |
| TPO | 82.1054 | 67.533 | 1.22 | | | |
| TP1 | -6.9699 | 5.538 | 1.26 | | | |
| DUM | -2117.6035 | 1673.480 | 1.27 | | | |

Table 22: Statistics for first degree equation for rainfall and mean maximum air temperature - yield relationship in 7-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 6615.6491 | 8146.220 | 0.81 | 3604930 | 55.9 | 75.9 |
| RFO | 8.4322 | 5.039 | 1.67 | | | |
| RF1 | -0.7245 | 0.555 | 1.31 | | | |
| TPO | 170.3779 | 107.536 | 1.58 | | | |
| TP1 | -20.6296 | 12.489 | 1.65 | | | |
| DUM | -3134.8881 | 1863.980 | 1.68 | | | |

Table 23: Statistics for first degreee equation for rainfall and mean maximum air temperature - yield relationship in 10-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 1269.0681 | 8580.160 | 0.15 | 4057370 | 50.4 | 80.5 |
| RFO | 7.1265 | 5.290 | 1.35 | | | |
| RF1 | -0.6308 | 0.752 | 0.84 | | | |
| TPO | 124.3105 | 134.018 | 0.93 | | | |
| TP1 | -19.7991 | 20.432 | 0.97 | | | |
| DUM | -1444.4435 | 1472.970 | 0.98 | | | |

Table 24: Statistics for first degree equation for rainfall and temperature range - yield relationship in 3-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 1089.4465 | 3272.180 | 0.33 | 1909490 | 76.7 | 55.2 |
| RF0 | 12.1824 | 3.884 | 3.14** | | | |
| RF1 | - 0.4933 | 0.181 | 2.73* | | | |
| TP0 | 52.6204 | 21.018 | 2.50* | | | |
| TP1 | -2.6520 | 0.887 | 2.99** | | | |
| DUM | -1122.5787 | 488.522 | 2.30* | | | |

Table 25: Statistics for first degree equation for rainfall temperature range - yield relationship in 5-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 226.8282 | 3980.480 | 0.06 | 3083220 | 62.2 | 70.2 |
| RF0 | 11.1336 | 5.188 | 2.15* | | | |
| RF1 | -0.6130 | 0.369 | 1.66 | | | |
| TP0 | 82.8805 | 52.283 | 1.59 | | | |
| TP1 | -6.6645 | 3.736 | 1.78 | | | |
| DUM | -1022.8651 | 679.180 | 1.51 | | | |

Table 26: Statistics for first degree equation for rainfall and temperature range - yield relationship in 7-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | 100R$^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 2392.4880 | 4212.65 | 0.57 | 3611800 | 51.3 | 75.9 |
| RF0 | 9.7197 | 6.105 | 1.59 | | | |
| RF1 | -0.8644 | 0.622 | 1.39 | | | |
| TP0 | 97.4323 | 87.096 | 1.12 | | | |
| TP1 | -11.9759 | 8.885 | 1.35 | | | |
| DUM | -972.4043 | 798.033 | 1.22 | | | |

Table 27: Statistics for first degree equation for rainfall and temperature range - yield relationship in 10-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -78.1667 | 4318.090 | 0.02 | 3577700 | 56.2 | 75.6 |
| RF0* | 9.4523 | 5.413 | 1.75 | | | |
| RF1 | -0.9105 | 0.724 | 1.26 | | | |
| TP0 | 128.7239 | 109.390 | 1.18 | | | |
| TP1 | -19.6600 | 14.676 | 1.34 | | | |
| DUM | -678.0236 | 646.190 | 1.05 | | | |

Table 28: Statistics for second degree equation for rainfall - yield relationship in 3-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | 100R$^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 24.9553 | 587.005 | 0.04 | 4627540 | 43.4 | 80.5 |
| RFO | 6.0286 | 5.563 | 1.08 | | | |
| RF1 | -0.2239 | 0.564 | 0.40 | | | |
| RF2 | 0.0029 | 0.011 | 0.26 | | | |
| DUM* | -202.9977 | 643.861 | 0.32 | | | |

Table 29: Statistics for second degree equation for rainfall - yield relationship in 5-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | 100R$^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -9.5781 | 563.922 | 0.02 | 4612950 | 43.5 | 80.3 |
| RFO | 5.8743 | 7.201 | 0.82 | | | |
| RF1 | -0.3559 | 1.444 | 0.25 | | | |
| RF2 | 0.0083 | 0.055 | 0.15 | | | |
| DUM | -146.7388 | 589.474 | 0.25 | | | |

Table 30: Statistics for second degree equation forrainfall - yield relationship in 7-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 153.1783 | 522.023 | 0.29 | 4818250 | 41.1 | 82.1 |
| RFO | 8.3872 | 6.967 | 1.20 | | | |
| RF1 | -1.2983 | 1.793 | 0.72 | | | |
| RF2 | 0.0578 | 0.093 | 0.62 | | | |
| DUM | -267.4378 | 578.382 | 0.46 | | | |

Table 31: Statistics for second degree equation for rainfall - yield relationship in 10-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 62.1659 | 560.626 | 0.11 | 4468840 | 45.4 | 79.0 |
| RFO | 8.4455 | 7.669 | 1.10 | | | |
| RF1 | -1.7019 | 2.894 | 0.59 | | | |
| RF2 | 0.1047 | 0.210 | 0.50 | | | |
| DUM | -225.7112 | 577.545 | 0.39 | | | |

Table 32: Statistics for second degree equation for rainfall and mean air temperature - yield relationship in 3-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -10910.9245 | 25966.3 | 0.42 | 4436180 | 45.8 | 99.5 |
| RFO | 10.0849 | 11.487 | 0.88 | | | |
| RF1 | -0.5167 | 0.971 | 0.53 | | | |
| RF2 | 0.0071 | 0.017 | 0.41 | | | |
| TPO | 69.2490 | 185.337 | 0.37 | | | |
| TP1 | -7.4897 | 21.285 | 0.35 | | | |
| TP2 | 0.1767 | 0.515 | 0.34 | | | |
| DUM | 20.5237 | 2746.160 | 0.01 | | | |

Table 33: Statistics for second degree equation for rainfall and mean air temperature - yield relationship in 5-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -25574.8873 | 25169.900 | 1.02 | 3772630 | 53.9 | 91.8 |
| RFO | 17.5023 | 23.592 | 0.74 | | | |
| RF1 | -1.9622 | 4.261 | 0.46 | | | |
| RF2 | 0.0547 | 0.149 | 0.37 | | | |
| TPO | 237.8423 | 279.870 | 0.85 | | | |
| TP1 | -43.9969 | 55.718 | 0.79 | | | |
| TP2 | 1.7874 | 2.282 | 0.78 | | | |
| DUM | 937.0795 | 3291.470 | 0.28 | | | |

Table 34: Statistics for second degree equation for rainfall and mean air temperature - yield relationship in 7-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -27163.5197 | 27768.000 | 0.98 | 3888250 | 52.4 | 93.3 |
| RFO | 29.0930 | 22.566 | 1.29 | | | |
| RF1 | -5.7371 | 5.192 | 1.10 | | | |
| RF2 | 0.2502 | 0.241 | 1.04 | | | |
| TPO | 235.5627 | 381.295 | 0.62 | | | |
| TP1 | -40.6545 | 103.050 | 0.39 | | | |
| TP2 | 2.0203 | 5.990 | 0.34 | | | |
| DUM | -878.1716 | 3350.310 | 0.26 | | | |

Table 35: Statistics for second degree equation for rainfall and mean air temperature - yield relationship in 10-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -26540.5913 | 19946.900 | 1.33 | 3248780 | 60.4 | 85.3 |
| RFO | 33.0911 | 20.935 | 1.58 | | | |
| RF1 | -9.5371 | 6.993 | 1.36 | | | |
| RF2 | 0.6035 | 0.464 | 1.30 | | | |
| TPO | 346.1410 | 474.132 | 0.73 | | | |
| TP1 | -80.9720 | 166.913 | 0.49 | | | |
| TP2 | 5.4068 | 12.526 | 0.43 | | | |
| DUM | -973.2482 | 2104.310 | 0.46 | | | |

Table 36: Statistics for second degree equation for rainfall and mean maximum air temperature - yield relationship in 3-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 5720.2885 | 15774.200 | 0.36 | 4058530 | 50.4 | 95.2 |
| RFO | 5.6047 | 12.114 | 0.46 | | | |
| RF1 | -0.1161 | 0.978 | 0.12 | | | |
| RF2 | -0.0028 | 0.0192 | 0.14 | | | |
| TPO | 9.0527 | 35.287 | 0.26 | | | |
| TP1 | 1.4195 | 2.689 | 0.53 | | | |
| TP2 | -0.0782 | 0.108 | 0.73 | | | |
| DUM | -1900.4113 | 2676.930 | 0.71 | | | |

Table 37: Statistics for second degree equation for rainfall and mean maximum air temperature - yield relationship in 5-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -11614.8094 | 26128.800 | 0.44 | 3393690 | 58.5 | 87.1 |
| RFO | 22.5118 | 27.363 | 0.82 | | | |
| RF1 | -2.9534 | 4.673 | 0.63 | | | |
| RF2 | 0.0913 | 0.166 | 0.55 | | | |
| TPO | 192.7592 | 167.057 | 1.15 | | | |
| TP1 | -27.9175 | 29.393 | 0.95 | | | |
| TP2 | 0.8513 | 1.167 | 0.73 | | | |
| DUM | -1358.8129 | 2210.450 | 0.61 | | | |

Table 38: **Statistics for second degree equation for rainfall and mean maximum air temperature - yield relationship in 7-day periods, Katumani.**

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | 100R$^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -14685.9015 | 20602.700 | 0.71 | 2858290 | 65.1 | 80.0 |
| RF0 | 29.8018 | 20.428 | 1.46 | | | |
| RF1 | -5.6172 | 4.555 | 1.23 | | | |
| RF2 | 0.2399 | 0.219 | 1.09 | | | |
| TP0 | 294.4179 | 181.945 | 1.62 | | | |
| TP1 | -50.1428 | 48.966 | 1.02 | | | |
| TP2 | 1.8040 | 2.908 | 0.62 | | | |
| DUM | -2340.6814 | 2652.590 | 0.88 | | | |

Table 39: Statistics for second degree equation for rainfall and mean maximum air temperature - yield relationship in 10-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -19077.4603 | 18583.100 | 1.03 | 2614790 | 68.1 | 76.5 |
| RFO | 34.1507 | 21.893 | 1.56 | | | |
| RF1 | -9.6163 | 7.146 | 1.35 | | | |
| RF2 | 0.6129 | 0.488 | 1.25 | | | |
| TPO | 487.0557 | 264.974 | 1.84 | | | |
| TP1 | -144.4492 | 88.968 | 1.62 | | | |
| TP2 | 9.4311 | 6.445 | 1.46 | | | |
| DUM | -896.9564 | 1479.260 | 0.61 | | | |

Table 40: Statistics for second degree equation for rainfall and temperature range - yield relationship in 3- day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -1170.2604 | 4637.860 | 0.25 | 1589670 | 80.6 | 59.7 |
| RF0 | 19.3390 | 8.629 | 2.24 | | | |
| RF1 | -1.1397 | 0.705 | 1.61 | | | |
| RF2 | 0.01250 | 0.013 | 0.95 | | | |
| TP0 | 83.7015 | 39.554 | 2.12 | | | |
| TP1 | -5.8293 | 4.149 | 1.40 | | | |
| TP2 | 0.0692 | 0.095 | 0.73 | | | |
| DUM | -1306.6517 | 643.131 | 2.03 | | | |

Table 41: Statistics for second degree equation for rainfall and temperature range - yield relationship in 5-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | 100R$^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 503.7404 | 5316.920 | 0.09 | 2676010 | 67.2 | 77.4 |
| RFO | 15.8235 | 13.125 | 1.21 | | | |
| RF1 | -1.5351 | 2.354 | 0.65 | | | |
| RF2 | 0.0326 | 0.087 | 0.37 | | | |
| TPO | 137.1602 | 89.157 | 1.54 | | | |
| TP1 | -19.4837 | 15.755 | 1.24 | | | |
| TP2 | 0.5027 | 0.597 | 0.84 | | | |
| DUM | -806.3849 | 790.963 | 1.02 | | | |

Table 42: Statistics for second degree equation for rainfall and temperature range - yield relationship in 7-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -1524.1655 | 5195.600 | 0.29 | 2373010 | 71.1 | 72.9 |
| RF0 | 24.6209 | 11.548 | 2.13 | | | |
| RF1 | - 4.1620 | 2.509 | 1.66 | | | |
| RF2 | 0.1593 | 0.124 | 1.28 | | | |
| TP0 | 250.4016 | 116.766 | 2.14 | | | |
| TP1 | -48.8832 | 28.070 | 1.74 | | | |
| TP2 | 1.8475 | 1.528 | 1.21 | | | |
| DUM | - 997.2649 | 863.395 | 1.13 | | | |

Table 43: Statistics for second degree equation for rainfall and temperature range - yield relationship in 10-day periods, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | 469.7279 | 4819.840 | 0.10 | 2326710 | 71.6 | 72.1 |
| RFO | 22.2923 | 12.351 | 1.80 | | | |
| RF1 | - 5.9354 | 4.404 | 1.35 | | | |
| RF2 | 0.3564 | 0.319 | 1.12 | | | |
| TPO | 328.8524 | 160.623 | 2.05 | | | |
| TP1 | -111.6201 | 58.033 | 1.92 | | | |
| TP2 | 7.1349 | 4.357 | 1.64 | | | |
| DUM | -358.5034 | 653.759 | 0.55 | | | |

Table 44: Summary of statistics for first degree equations

| VARIABLE NAME | SUBPERIOD - DAYS | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|
| Rainfall | 3 | 4666290 | 43.0 | 76.2 |
| | 5 | 4626280 | 43.4 | 75.8 |
| | 7 | 5049400 | 38.3 | 79.2 |
| | 10 | 4574150 | 43.8 | 80.0 |
| Rainfall and Mean Air Temperature | 3 | 4643810 | 42.2 | 86.1 |
| | 5 | 4578340 | 44.1 | 85.6 |
| | 7 | 5045330 | 38.3 | 89.8 |
| | 10 | 4569800 | 44.1 | 85.5 |
| Rainfall and Maximum Air Temperature | 3 | 4497410 | 45.0 | 84.8 |
| | 5 | 3768750 | 53.9 | 77.6 |
| | 7 | 3604930 | 55.9 | 75.9 |
| | 10 | 4057370 | 50.4 | 80.5 |
| Rainfall and Temperature Range | 3 | 1909490 | 76.7 | 55.2 |
| | 5 | 3083220 | 62.2 | 70.2 |
| | 7 | 3611800 | 51.2 | 75.2 |
| | 10 | 3577700 | 56.2 | 75.6 |

Table 45: Summary of statistics for second degree equations

| VARIABLE NAME | SUBPERIOD - DAYS | ERROR SUM OF SQUARES | $100 R^2$ | 100 C.V |
|---|---|---|---|---|
| Rainfall | 3 | 4627540 | 43.4 | 80.5 |
| | 5 | 4612950 | 43.5 | 80.3 |
| | 7 | 4818250 | 41.1 | 82.1 |
| | 10 | 4468840 | 45.4 | 79.0 |
| Rainfall and Mean Air Temperature | 3 | 4436180 | 45.8 | 99.5 |
| | 5 | 3772630 | 53.9 | 91.8 |
| | 7 | 3888250 | 52.4 | 93.3 |
| | 10 | 3248780 | 60.4 | 85.3 |
| Rainfall and Maximum Air Temperature | 3 | 405853 | 50.4 | 95.2 |
| | 5 | 3393690 | 58.5 | 87.1 |
| | 7 | 2858290 | 65.1 | 80.0 |
| | 10 | 2614790 | 68.1 | 76.5 |
| Rainfall and Temperature Range | 3 | 1589670 | 80.6 | 59.7 |
| | 5 | 2676010 | 67.2 | 77.4 |
| | 7 | 2373010 | 71.1 | 72.9 |
| | 10 | 2326710 | 71.6 | 72.1 |

the coefficients of determination, there was no definite pattern in which the coefficients of variation varied with respect to the subperiods except for the second degree equation of rainfall and maximum temperature combination. In this equation the coefficients decreased with increasing subperiod length. Looking at the variable combinations in both the first and second degree equations, the coefficients decreased with the variables in the following order: rainfall and mean air temperature, rainfall and maximum temperature, rainfall, and rainfall and temperature range. The lowest values were 55.2 and 59.2 for the last combination for the first and second degree equations respectively.

The error sum of squares were lower in the second degree equations than in their corresponding first degree equations. As for the subperiods, for any variable combination, there was no definite pattern in which the error sum of squares varied except for the second degree equation of the rainfall and maximum temperature combination. For this equation the error sum of squares took a similar pattern as for the coefficients of variation, decreasing with increase in subperiod length. Considering the variable combinations, for both the first and second degree equations, on the average, the error sum of squares can be ranked starting with the combination with the highest value in the following order: rainfall, rainfall and mean temperature, rainfall and maximum temperature and, rainfall and temperature range. The lowest values for the last combination in 3-day periods were 1909490 and 1589670 respectively for the first and second degree equation.

### 4.2.2 CONCLUSION

From these results it can be concluded that there is no definite order in which the subperiods increase or decrease in superiority in their role of smoothing the data and in explaining the variation in yield. Notwithstanding this general picture, it can be stated that the 3-day subperiods with rainfall and temperature range in a second degree equation are superior to any other combination in either first or second degree equation. In the next chapter, further analysis based on this combination in a second degree equation is carried out.

# CHAPTER V

## FURTHER ANALYSIS

In view of the superiority of rainfall and temperature range in 3-day subperiods in a second degree equation, by having lowest error sum of squares (lowest coefficient of variation) and highest coefficient of determination, further investigations were based on this combination.

The relationship between yield and the variables can be presented in the following general form:

$$E\ (Z) = CONST + RF0 + RF1 + RF2 + TP0 + TP1 + TP2 + DUM \quad (18)$$

where Z is the yield in kg/ha.

CONST is a constant.

RF0 is the level of the rainfall.

RF1 the linear component of rainfall.

RF2 the quadratic component of rainfall.

TP0 the level of the temperature range.

TP1 the linear component of temperature range

TP2 the quadratic component of temperature range.

DUM is a dummy variable.

This equation (18) was slightly modified by removing its quadratic term in temperature range (TP2) because of its low and insignificant regression coefficient (table 40). The equation finally reduced to:

$$E\ (Z) = CONST + RF0 + RF1 + RF2 + TP0 + TP1 + DUM \qquad (19)$$

For the reasons given in section 3.4.1.3 this equation was used without the data of 1975 and 1976 seasons. It was differentiated with respect to rainfall and temperature range to note the effect of either 1 mm of rainfall or 1°C temperature above or below average in 3-day periods on yield. It was also used to predict yield.

## 5.2 RESULTS AND DISCUSSION

### 5.2.1 STATISTICS FOR THE EQUATION

The statistics for the equation are seen in table 46. It can be noted that all the regression coefficients were highly significant except RF2 which was significant at 5% only. The error sum of squares of 161384 represents a great reduction from the error sum of squares of 1589670, the lowest obtained when the 1975 and 1976 seasons were included. Likewise, the coefficient of variation is comparatively low while the coefficient of determination is high. The appreciable improvement in these values by the omision of the yield data for the 1975 and 1976 seasons confirms the suspicion that the data is not correct.

### 5.2.2 EFFECT OF THE DEPARTURE OF THE WEATHER VARIABLES FROM AVERAGE ON YIELD.

#### 5.2.2.1 DISTRIBUTION OF THE WEATHER VARIABLES

Changes in yield due to weather occur because of deviations of the weather variables from average.

Table 46: Statistics for second degree equation for rainfall and temperature range - yield relationship in 3-day periods, with 1975 and 1976 yield data omitted, Katumani.

| VARIABLE NAME | REGRESSION COEFFICIENT | STANDARD ERROR | t-STATISTIC | ERROR SUM OF SQUARES | $100R^2$ | 100 C.V |
|---|---|---|---|---|---|---|
| CONST | -3102.3465 | 1689.880 | 1.84 | 161384 | 97.8 | 19.6 |
| RF0 | 26.7650 | 3.228 | 8.29** | | | |
| RF1 | -1.4955 | 0.247 | 6.04** | | | |
| RF2 | 0.0139 | 0.004 | 3.10* | | | |
| TP0 | 93.3044 | 11.306 | 8.25** | | | |
| TP1 | -4.1899 | 0.448 | 9.35** | | | |
| DUM | -2540.6027 | 294.887 | 8.62** | | | |

Therefore, in order to monitor the changes during the season, the departure of these variables need to be known. Table 47 gives the average rainfall, average maximum temperature, average minimum temperature, average temperature range, and their coefficients of variation, in 3-day periods. These values are used in explaining the effect of departure from average on yield.

### 5.2.2.2 EFFECT OF 1 mm OF RAINFALL ABOVE OR BELOW AVERAGE 3-DAY RAINFALL TOTAL ON MAIZE YIELD

Table 47 shows that for the period of study, there were considerable fluctuations in the 3-day rainfall totals. The totals had coefficients of variation which ranged from 99.1% to 346.5%. Since the area is generally of low rainfall, it is seen from figure 4 that a departure of even 1 mm from the average 3-day totals was of critical importance.

If the rainfall amount was above average by 1 mm in any 3-day period from 10 days prior to sowing to about tasseling - flowering interphase period, a beneficial effect was observed. The increase in yield however progressively decreased from a figure of 25.3 kg/ha. On the other hand, 1 mm of rainfall below average in any 3-day period led to a yield decrease of the same magnitude. The above average rainfall during this period supplied the moisture required for proper germination, emergence and early growth. Evidence shows that the seasons which had at least the average rainfall at the beginning of the

Table 47: Rainfall totals and averages of daily maximum temperature, daily minimum temperature, daily temperature range and their coefficients of variation in 3-day period

| PERIOD NUMBER | RAINFALL (mm) | 100 C.V. | MAXIMUM TEMPERATURE (°C) | 100 C.V. | MINIMUM TEMPERATURE (°C) | 100 C.V. | TEMPERATURE RANGE (°C) |
|---|---|---|---|---|---|---|---|
| 1. | 11.7 | 200.0 | 26.7 | 6.1 | 14.5 | 7.4 | 12.2 |
| 2. | 7.4 | 174.3 | 26.4 | 6.3 | 14.3 | 8.4 | 12.1 |
| 3. | 1.2 | 200.0 | 26.6 | 6.2 | 14.1 | 10.8 | 12.5 |
| 4. | 7.3 | 193.1 | 26.3 | 5.1 | 14.5 | 8.5 | 11.8 |
| 5. | 9.4 | 131.9 | 25.7 | 5.3 | 15.0 | 7.8 | 10.7 |
| 6. | 24.5 | 151.8 | 25.5 | 7.4 | 15.1 | 6.9 | 10.[illegible] |
| 7. | 6.1 | 203.3 | 25.5 | 6.6 | 14.9 | 8.5 | 10.6 |
| 8. | 7.3 | 165.7 | 25.6 | 9.2 | 15.1 | 8.2 | 10.5 |
| 9. | 6.0 | 166.7 | 25.4 | 6.6 | 15.3 | 9.1 | 10.1 |
| 10. | 11.9 | 137.8 | 25.3 | 6.8 | 15.3 | 7.5 | 10.0 |
| 11. | 22.7 | 106.6 | 25.0 | 7.3 | 15.6 | 4.5 | 9.4 |
| 12. | 22.4 | 133.0 | 23.9 | 8.5 | 14.8 | 12.7 | 9.1 |
| 13. | 15.8 | 118.3 | 24.1 | 8.4 | 15.4 | 5.9 | 8.7 |
| 14. | 11.7 | 118.8 | 24.1 | 6.6 | 15.0 | 6.7 | 9.1 |
| 15. | 13.1 | 127.5 | 23.6 | 8.5 | 15.0 | 8.1 | 8.6 |
| 16. | 8.3 | 119.3 | 23.8 | 7.7 | 15.0 | 5.3 | 8.8 |
| 17. | 3.4 | 135.3 | 24.0 | 6.7 | 14.6 | 6.0 | 9.4 |
| 18. | 13.9 | 125.2 | 23.4 | 5.4 | 14.6 | 10.0 | 8.8 |
| 19. | 9.1 | 135.2 | 23.6 | 3.9 | 14.5 | 8.7 | 9.1 |
| 20 | 4.4 | 134.1 | 23.9 | 4.5 | 14.4 | 5.5 | 9.5 |
| 21 | 9.6 | 99.1 | 23.3 | 5.5 | 14.4 | 10.5 | 8.9 |
| 22. | 6.4 | 142.5 | 23.3 | 5.8 | 12.3 | 17.0 | 11.0 |
| 23. | 6.3 | 199.9 | 23.7 | 5.3 | 14.3 | 8.3 | 9.4 |
| 24. | 1.7 | 215.7 | 23.3 | 6.1 | 13.8 | 10.2 | 9.5 |
| 25. | 1.6 | 203.8 | 23.7 | 5.6 | 13.2 | 10.2 | 10.5 |
| 26. | 0.7 | 307.2 | 23.6 | 7.5 | 13.5 | 8.1 | 10.1 |
| 27. | 4.6 | 216.8 | 23.8 | 6.6 | 13.3 | 10.6 | 10.5 |
| 28. | 0.7 | 230.7 | 24.0 | 5.9 | 12.7 | 10.1 | 11.3 |
| 29. | 1.6 | 225.6 | 24.1 | 4.9 | 12.7 | 12.4 | 11.4 |
| 30. | 3.2 | 179.8 | 24.1 | 4.9 | 13.5 | 10.7 | 10.6 |
| 31. | 4.9 | 159.2 | 23.6 | 7.0 | 13.2 | 14.1 | 10.4 |
| 32. | 5.0 | 296.0 | 23.7 | 7.2 | 13.4 | 10.7 | 10.3 |
| 33. | 4.3 | 346.5 | 23.4 | 9.0 | 12.3 | 14.2 | 11.1 |
| 34. | 3.6 | 222.2 | 23.9 | 7.5 | 12.3 | 11.4 | 11.6 |
| 35. | 12.2 | 242.6 | 24.2 | 8.4 | 12.8 | 12.1 | 11.4 |
| 36. | 5.7 | 305.8 | 24.0 | 10.1 | 12.7 | 14.4 | 11.3 |
| 37. | 1.8 | 315.0 | 23.5 | 12.6 | 12.4 | 15.4 | 11.1 |
| 38. | 0.6 | 234.0 | 23.8 | 12.3 | 13.2 | 9.6 | 10.6 |
| 39. | 1.3 | 184.5 | 23.6 | 10.6 | 12.7 | 12.3 | 10.9 |
| 40. | 0.3 | 333.8 | 24.2 | 10.6 | 12.4 | 13.0 | 11.8 |

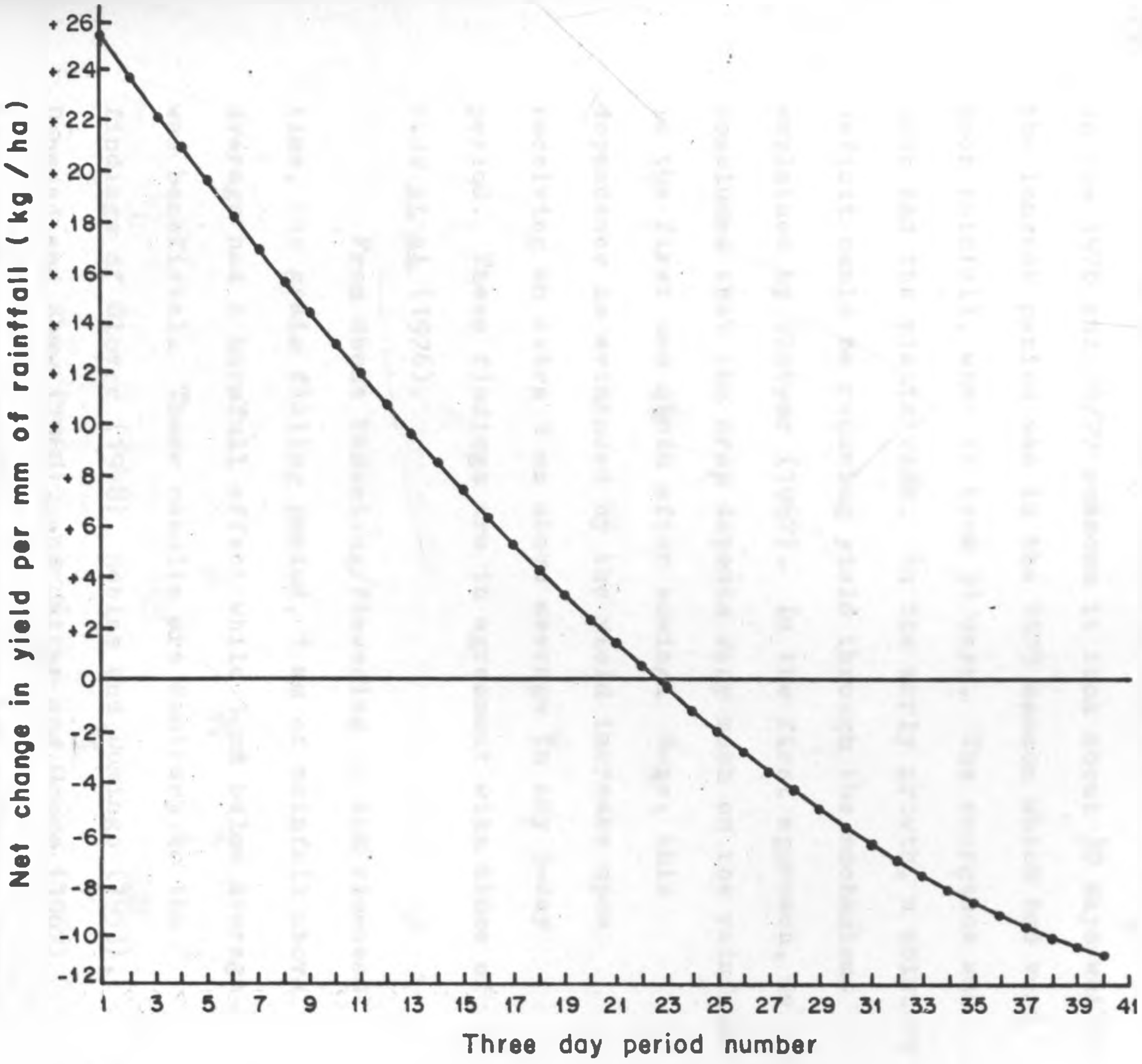

Fig. 4 : Effect of 1mm of rainfall above average 3-day total rainfall on maize yield for each 3-day period during the growing season at Katumani .

season had the interphase: sowing to emergence shortened. It took about one week in the 1974, 1975, 1977, 1978 and 78/79 seasons, while it took about three weeks in the 73/74 season which had a slightly below average rainfall. In the 1976 and 76/77 seasons it took about 30 days while the longest period was in the 1973 season which had very poor rainfall, when it took 51 days. The emergence was poor and the plants weak. In the early growth, a moisture deficit could be reducing yield through the mechanisms explained by Slatyer (1967). In the first approach, we concluded that the crop depends very much on the rainfall in the first one month after sowing. Here, this dependence is evidenced by the yield increase upon receiving an extra 1 mm above average in any 3-day period. These findings are in agreement with those of Huda _et al_ (1976).

From about tasseling/flowering to wax ripeness time, the grain filling period, 1 mm of rainfall above average had a harmfull effect while 1 mm below average was beneficial. These results are contrary to the findings of Glover (1948), Robins and Domingo (1953), Denmead and Shaw (1960), and Salter and Goode (1967) that about tasseling/flowering time the moisture demand is high. They also contradict the remarks made in the first approach of this study that during the grain filling period, higher amounts of moisture are conducive to high yield. During the whole period when 1 mm of rainfall above 3-day total led to low yield, normally low rainfall amounts were received. The highest average 3-day rainfall total received during the tasseling - flowering interphase was 6.4 mm, while that received from flowering to wax ripeness varied from 0.7 - 5.00 mm. During this period, high temperatures in the absence of adequate moisture have been found to have very unfavourable effects (Smith, 1914; Hendricks and Scholl, 1943; Stacy et al. 1957; Runge, 1968) by dehydrating the photosynthetic apparatus, reducing the rate of floral primordia initiation and by dehydrating and imparing the germination or growth of the pollen tube from the stigma to the ovules (Robins and Domingo, 1953). Since in this case the reduced yield is due to excess rainfall, it therefore appears that the average total rainfall received in any 3-day period is adequate for the plants needs. An excess moisture probably reduces yield, in the presence of low levels of available nitrogen, by creating anaerobic conditions (Shaw, 1976). It could also be reducing yield by washing away pollen grains at anthesis, hence reducing the yield potential.

From wax ripeness to full ripeness heavy rains are seen to have had a harmfull effect as found by Huda et al (1976). During this time the crop requires more hours of sunshine to promote quick ripening and drying. Excess rainfall may delay harvesting and cause loss due to rotting by fungus and/or germination of mature grains while on cob.

### 5.2.2.3 EFFECT OF 1°C TEMPERATURE RANGE ABOVE OR BELOW 3-DAY AVERAGE ON MAIZE YIELD.

Unlike the rainfall, the temperatures did not vary much in the same 3-day periods. The average 3-day maximum temperatures had coefficients of variation which ranged from 3.9% - 12.6% while the average 3-day minimum temperatures had coefficients of variation which ranged from 4.5% - 17.0% (table 47). Despite this small relative variation the crop was sensitive enough to respond to small changes in the temperatures as shown in figure 5.

The figure shows that from 10-days prior to sowing to about tasseling/flowering time, a 1°C of temperature range above average 3-day values increased yield albeit at a decreasing rate from 88 kg/ha. 1°C of temperature range below average during the same periods had the opposite effect.

When temperature range is considered as a variable affecting yield, it is worth noting the effect of maximum and minimum temperatures in influencing the Net Assimilation Rate (NAR) i.e. the dry matter produced by photosynthesis less what is broken down by respiration. Other factors not limiting, high temperatures, but not exceeding the maximum thresholds, increase both the rates of photosynthesis and respiration. Whereas photosynthesis is a daytime process, respiration is both a day and night process. Consequently, for a large NAR, there should be reasonably high temperatures during daylight hours to accelerate photosynthesis and reasonably low temperatures

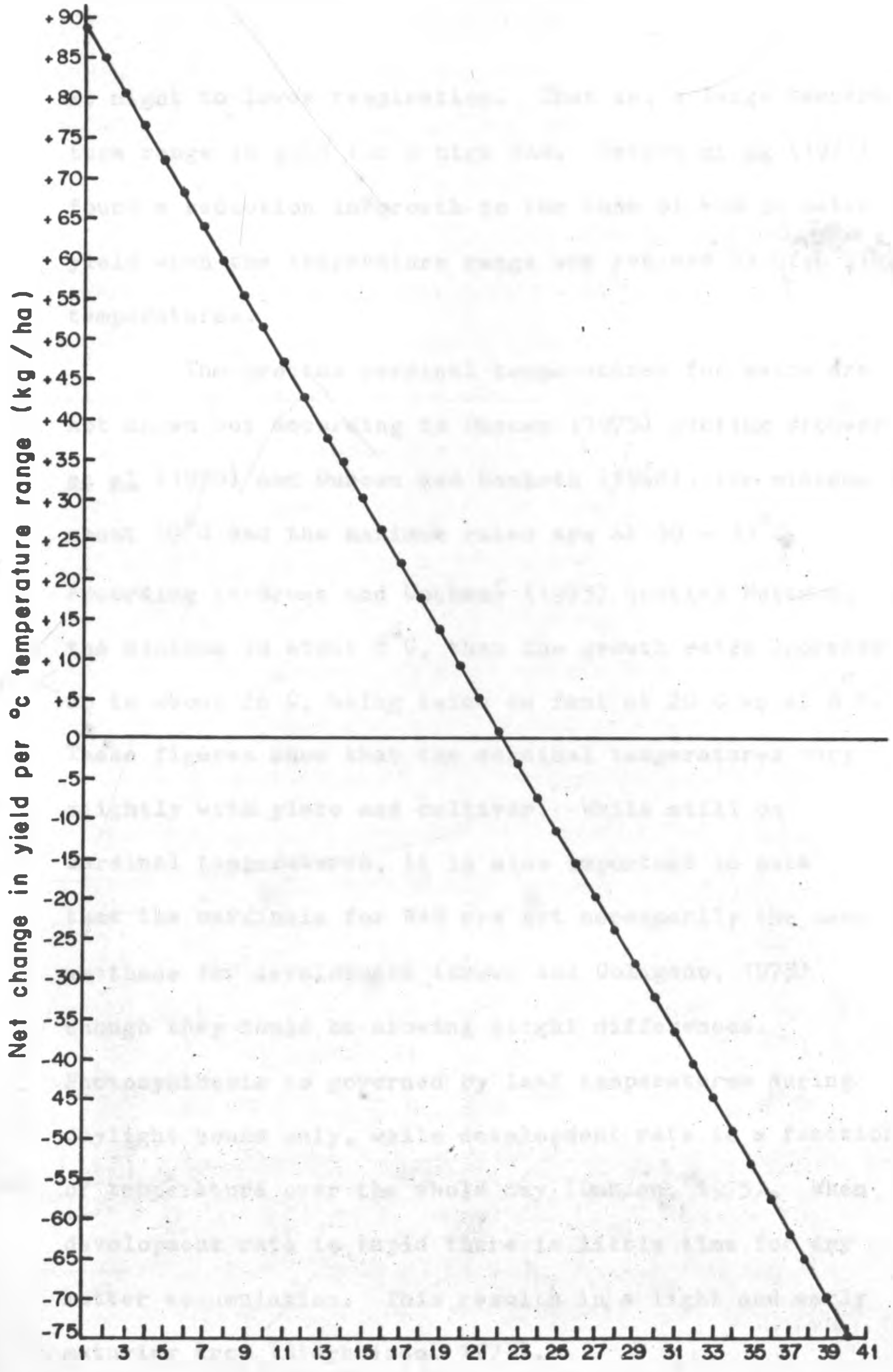

Fig. 5 : Effect of one degree of temperature (°C) above average temperature range on maize yield for each 3-day period at Katumani .

at night to lower respiration. That is, a large temperature range is good for a high NAR. Peters et al (1971) found a reduction in growth to the tune of 40% in maize yield when the temperature range was reduced by high night temperatures.

The precise cardinal temperatures for maize are not known but according to Duncan (1975) quoting Brouwer et al (1970) and Duncan and Hasketh (1968), the minimum is about 10°C and the maximum rates are at 30 - 33°C. According to Brown and Cochemé (1973) quoting Nuttson, the minimum is about 8°C, then the growth rates increase up to about 26°C, being twice as fast at 20°C as at 8°C. These figures show that the cardinal temperatures vary slightly with place and cultivar. While still on cardinal temperatures, it is also important to note that the cardinals for NAR are not necessarily the same as those for development (Brown and Coligado, 1975) though they could be showing slight differences. Photosynthesis is governed by leaf temperatures during daylight hours only, while development rate is a function of temperature over the whole day (Duncan, 1975). When development rate is rapid there is little time for dry matter accumulation. This results in a light and early maturing crop (Bierhuizen, 1973).

Turning to the temperatures experienced at Katumani, it can be seen that the temperature range varied from 8.6 to 13.2°C (table 47). This range is relatively small compared to one of 20°C that would be obtained under an ideal environment of mean minimum temperature of 10°C and mean maximum of 30°C. The small temperature range experienced is perhaps one of the factors accounting for the generally low yields experienced in the area. The decrease in yield when the temperature range was increased by 1°C seems to be due to limitations in photosynthesis when moisture is limiting, a common phenomenon in the area. This arguement is in support of the observation that during the grain filling period high temperatures have an unfavourable effect in the absence of adequate moisture (Smith, 1914; Stacy *et al*, 1957; Runge, 1968). Otherwise, minimum temperatures not below the minimum cardinal and maximum temperatures not beyond the maximum cardinal for maize, an increase in the temperature range by 1°C during this period should have led to a yield increase as found by Das (1974) because of a high Net Assimilation Rate.

## 5.3 SEASONAL YIELD VARIATION AND PREDICTION

From the above discussion we have noted that both temperatures and rainfall can limit yield, with the rainfall being more able to do so because of its large seasonal variations which had a coefficinet of variation of 53.7%.

The seasonal total which ranged from 85.2 mm in the 1973 season to 590.3 mm in the 78/79 season, shows the relatively wide range of seasonal rainfall included in the sample. Like the seasonal total rainfall, the maize yield varied considerably, ranging from 0 kg/ha in 1973 and 1973/74 seasons to 2805 kg/ha in the 1974 season (table 48). The zero yields were recorded in the years with low seasonal total rainfall of 85.2 mm in 1973 and 210.5 mm in 1973/74. The latter figure is however large enough by Katumani standards to give a yield other than zero. Then why zero yield in this season? See shortly. Though zero or low yields were observed in seasons with low rainfall, it did not follow that in the seasons with high rainfall the yields were proportionately high. For example, the 1974 season had the highest yield with 431.9 mm of seasonal total rainfall while the season with the highest total rainfall, 78/79, of 590.3 mm had a yield of 1288 kg/ha. Why not the highest yield in this season?

The answers to both questions can partly be obtained by looking at the rainfall distribution in each season. The distribution was not well such that there was no match between the moisture supply and crop demand. This was particularly true in the poor seasons when most of the rain was concentrated in about a quarter of the growing season, thereby subjecting the crop to severe stress in the rest. Depending on when the stress hit, the plants either failed to produce any ears or produced ears with few scattered and shrivelled grains.

Because of the poor rainfall distribution, total seasonal rainfall is a poor means of relating rainfall to yield. This is evidenced by the coefficient of

Table 48: Observed and predicted yields, Katumani.

| SEASON | OBSERVED YIELD (kg/ha) | PREDICTED YIELD (kg/ha) |
|---|---|---|
| 1973 | 0 | -49 |
| 7374 | 0 | 163 |
| 1974 | 2805 | 2935 |
| 7475 | 815 | 802 |
| 1975 | 96 | |
| 7576 | 750 | 722 |
| 1976 | 0 | |
| 7677 | 405 | 493 |
| 1977 | 955 | 1075 |
| 7778 | 2250 | 2034 |
| 1978 | 1139 | 1151 |
| 7879 | 1288 | 1294 |
| 1979 | 840 | 627 |

determination of 53.3% and a large coefficient of variation of 70.9% (table 8) obtained. The use of the second degree equation with rainfall and temperature range in 3-day periods gives a good prediction of most values with a low coefficient of variation of 19.6% (table 46). The agreement between the observed and predicted figures is seen in figure 6 and table 48. These results are encouraging considering that the equation can be used at any time of the season to give a prediction unlike by the first approach where prediction can only be given at the end of the season. The equation is however far from final. With accumulation of more data it will need revision and expansion to include the interaction terms as well.

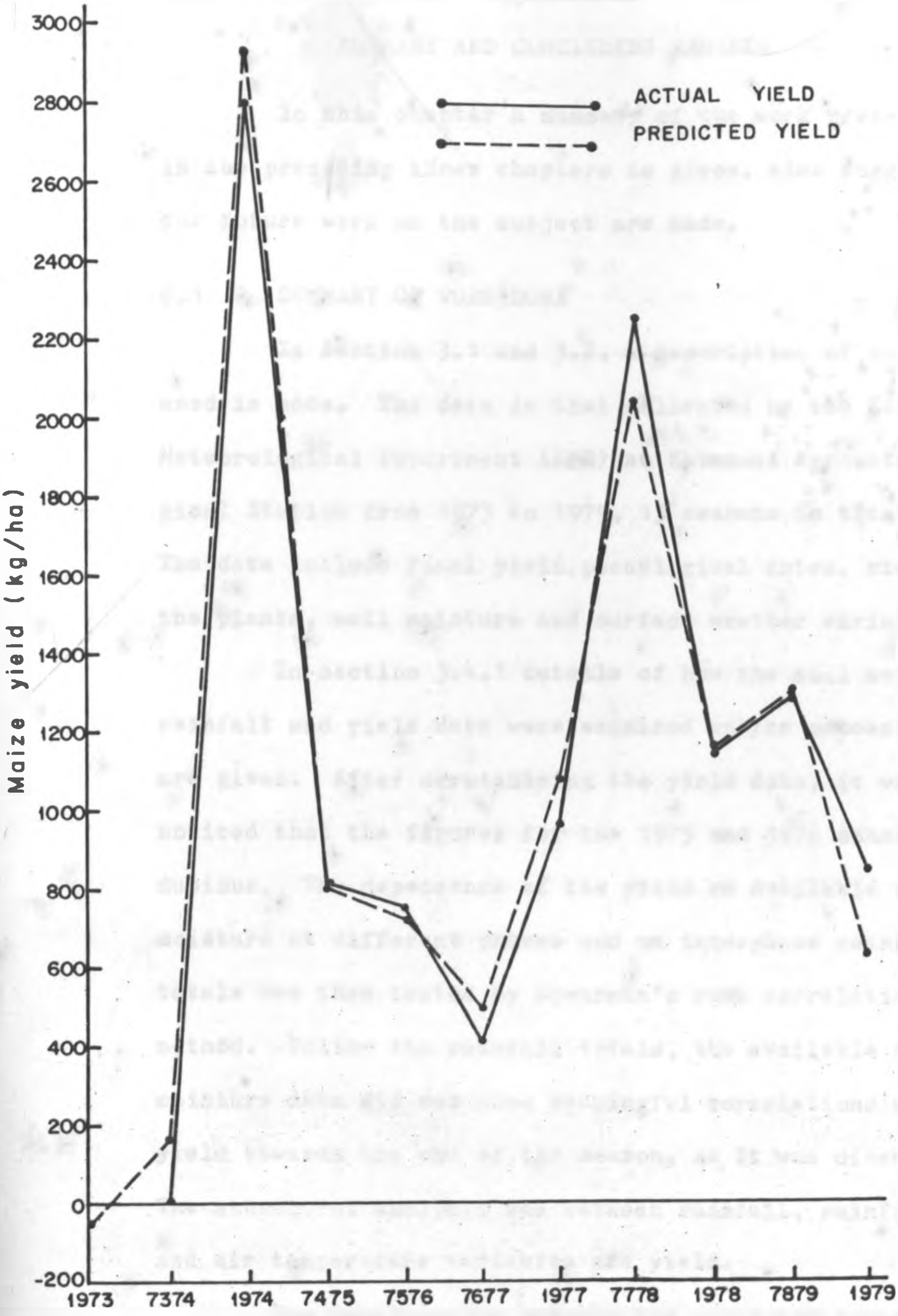

Fig. 6 : Actual and predicted yield for different seasons, using the regression equation for rainfall and temperature range effects on maize yield by 3-day periods at Katumani

# CHAPTER VI

# SUMMARY AND CONCLUDING REMARKS

In this chapter a summary of the work presented in the preceding three chapters is given, also suggestions for future work on the subject are made.

## 6.1 SUMMARY OF WORK DONE

In section 3.1 and 3.2, a description of the data used is made. The data is that collected by the Kenya Meteorological Department (KMD) at Katumani Agrometeorological Station from 1973 to 1979, 13 seasons in total. The data include final yield, phenological dates, state of the plants, soil moisture and surface weather variables.

In section 3.4.1 details of how the soil moisture, rainfall and yield data were examined and/or processed are given. After scrutinising the yield data, it was noticed that the figures for the 1975 and 1976 seasons are dubious. The dependence of the yield on available soil moisture at different phases and on interphase rainfall totals was then tested by Spearman's rank correlation method. Unlike the rainfall totals, the available soil moisture data did not show meaningful correlations with yield towards the end of the season, so it was discarded. The subsequent analysis was between rainfall, rainfall and air temperature variables and yield.

The relationship between the yield and interphase seasonal rainfall totals was investigated (section 3.4.2) after discarding or pooling some of the rainfall variables because of multicollinearity. The contribution of each variable as it was added was measured by the coefficient of determination, $R^2$, and tested by the t and F tests. Comparison was made for equations with the same variable combinations with and without a dummy variable, intended to distinguish the two seasons in a year. The results (section 4.1) show that equations with a dummy variable have an insignificant advantage over those without by having a slightly higher $R^2$ and lower error sum of squares. Nevertheless, the role of the dummy variable in distinguishing seasons should not be ignored at the moment because of the short run of data used. The overall results were improved with the exclusion of 1975 and 1976 seasons. The rainfall total from the 9th leaf phase to flowering (LFR) did not contribute significantly in explaining the yield variability. The combination of the variables SER, ELR and FWR was best. However, the equation with these variables cannot be used to predict yield at any time of the season as to get all these variables one has to wait for almost the end of the season. Therefore, such an equation is only important in explaining the history of the relationship between rainfall and yield.

In view of this, a second approach (section 3.4.3) had to be employed. In this approach the yield data was related to rainfall and air temperature (maximum, mean and range) variables in 3, 5, 7 and 10-day periods, by first and second degree equations using Fisher's (1924) technique as modified by Hendricks and Scholl (1943). The results (section 4.2.1) show no definite order in which the divisions of the growing season increase or decrease in superiority in their role of smoothing the explaining variables. However, the combination of rainfall and temperature range in 3-day periods in a 2nd-degree equation explains the yield variability better. Further analysis (chapter V) was based on this combination with 1975 and 1976 data and the quadratic term of the temperautre range omitted. The latter was omitted because its regression coefficient was low and insignificant.

The final equation was later differentiated with respect to rainfall and temperature range and the t values substituted for t = 1 to t = 40, to note respectively the effect of 1 mm and 1°C temperature range above or below average in 3-day periods. 1 mm of rainfall above 3-day average was beneficial from 10-days prior to sowing to about tasseling/flowering time, then had a negative effect up to maturity. 1°C temperature range above 3-day average had a similar trend. 1 mm or 1°C temperature range below average had opposing effect of the same magnitude.

It appears that the major limitation to yield is either poor distribution of rainfall or inadequate rainfall in the presence of high temperatures. Despite the large deviations in the yield, the equation gave a good prediction (figure 6 and table 48). The predicted yields have a coefficient of variation of 19.6%.

As the area is normally having poor rainfall which result in either low yields or crop failure, there is need to promote and encourage the cultivation of the short term maize variety under moisture conserving agronomic practices. It would of course be best to supplement soil moisture by irrigation particularly in the first one month after sowing, but water availability, capital and skill are major constraints.

## 6.2 RECOMMENDATIONS FOR FUTURE WORK

The results of the second approach are promising and encouraging for two main reasons. One, that the final equation gives a good prediction; two, that the equation can be used to assess the effect of rainfall and temperature on yield at any time of the season. However, considering the length of data used, no definite conclusions can be given at present.

It is therefore suggested that work on the subject be continued and based along similar lines after more data are gathered. Such work should start by testing the proposed model. Later on, improvements may be done. The improvements may start by introducing the interaction terms to the present model. Later equations of higher degrees together with their interaction terms can be tried as well. The exclusion of the interaction terms in this study was necessary because of the need to reduce the number of predictor variables, but this could have obscured some valuable information. For instance, when evaluating the effect of 1 mm of rainfall above or below average, the effect could not be seen at assumed temperature levels and vice versa.

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# REFERENCES

Acland, J.D. 1973. East African Crops. pp.124 - 133. Longman, London.

Akehurst, B.C. and Sreedharan, A. 1965. Time of Planting - A brief review of experimental work in Tanganyika, 1956-62. E. Afr. Agric. For. J., 30, 189 - 201.

Allan, A.Y. 1972. Factors affecting maize yields in Western Kenya, with special reference to time of planting. Ph.D Thesis, Makerere University, Kampala.

-------, 1973. Maize production trends in Kenya and the influence of seasonal rainfall variations on output. In 'Agroclimatology of the Highlands of Eastern Africa'. Proc. WMO No.389, pp.161 - 168.

Baier, W. 1973. Crop-weather analysis model: Review and model development. Jour. of Appl. Met., 12, 937 - 947.

------, 1977. Crop-weather models and their use in yield assessments. WMO Tech. Note No.151.

Barnes, D.L. and D.G. Woolley 1969. The effect of moisture stress at different stages of plant growth. I. Comparison of single-eared and a two-eared corn hybrid. Agron. J., 61, 788 - 790.

Benci, J.F. and Runge, E.C.A. 1976. Modelling corn production - yield sensitivity to temperature and precipitation. In 'Agrometeorology of the maize (corn) crop. Proc. WMO No.481, pp.282 - 287.

Bierhuizen, J.F. 1973. The effect of temperature on plant growth, development and yield. In Slatyer, R.O. (Ed.) 'Plant response to climatic factors.' Paris, UNESCO, pp.89 - 97.

Brouwer, R., Kleinendorst, A. and Locher, J. 1973. Growth responses of maize plants to temperature. In Slatyer, R.O. (Ed.) 'Plant response to climatic factors. Paris, UNESCO, pp.169 - 174.

Brown, L.H. and Cocheme, J. 1973. A study of the Agroclimatology of the Highlands of Eastern Africa. WMO Tech. Note No.125.

Brown, D.M. 1976. Response of maize to environmental temperature: A review: Agrometeorology of the maize (corn) crop. Proc. WMO No.481, pp.15 - 26.

Chao, L.L. 1969. Statistics: Methods and Analyses. McGraw-Hill, Inc., New York.

Claassen, M.M. and Shaw, R.H. 1970. Water deficit effects on corn. I. Vegetative Components. Agron. J., 62, 649 - 652.

-------, 1970. Water deficit effects on corn. II. Grain Components. Agron. J., 62, 652 - 655.

Coligado, M.C. and Brown, D.M. 1975a. Response of corn (Zea mays L.) in the pre-tassel initiation period to temperature and photoperiod. Agric. Met., 14, 357 - 367.

-------, 1975b. A bio-photo-thermal model to predict tassel - initiation time in corn (Zea mays L.) Agric. Met., 15, 11 - 31.

Cooper, P.J.M. 1975. Studies on the soil atmosphere composition under maize, grass and bare fallow in Western Kenya. E.A. Agric. For. J., 40, 313 - 331.

------- and Law, R. 1976. The effect and importance of soil temperature in determining the early growth vigour and final grain yields of hybrid maize in the highlands of Kenya. Agrometeorology of the maize (corn) crop. Proc. WMO No.481, pp.265 - 281.

Dagg, M. 1965. A rational approach to the selection of crops for areas of marginal rainfall in East Africa. E. Afr. Agric. For. J., 30, 296 - 300.

Das, J.C. 1974. Forecasting maize yield in Zambia using multiple regression with weather factors as predictors. International Tropical Meteorology meeting, Jan. 31 - Feb. 7, 1974, pp.243 - 247.

Davis, E. and Pallesen, J.E. 1940. Effect of the amount and distribution of rainfall and evaporation during the growing season on yields of corn and spring wheat. Jour. Agric. Res., 60, 1 - 23.

Denmead, O.T. and Shaw, R.H. 1959. Evapotranspiration in relation to the development of the corn crop. Agron. J., 51, 725 - 726.

-------, 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agron. J., 52, 272 - 274.

Dowker, B.D. 1963. Rainfall reliability and maize yields in Machakos District. E. Afr. Agric. For. J., 28, 134 - 138.

-------, 1964. A note on the reduction in yield of Taboran maize by late planting. E. Afri. Agric. For. J., 30, 33 - 34.

Duncan, W.G. 1975. Maize physiology. In Evans, L.T. (Ed.) 'Crop physiology. pp.23 - 50. Cambridge University Press.

East African Meteorological Department 1970. Temperature data for stations in East Africa. Part 1 Kenya.

-------, 1975. Climatological statistics for East Africa. Part 1 Kenya.

Fisher, R.A. 1924. The influence of rainfall on the yield of wheat at Rothamsted. Roy. Soc. (London). Phil. Tras., Ser. B., 213, 89 - 142.

-------, R.A. and F. Yates 1963. Statistical tables for Biological, Agricultural and Medical research. Oliver and Boyd, Edinburgh.

Gangopadhyaya, M. and Sarker, R.P. 1965. Influence of rainfall distribution on the yield of wheat crop. Agric. Met., 2, 331 - 350.

Glover, J. 1948. Water demands by maize and sorghum. E. Afr. Agric. For. J., 13, 171.

-------, 1957. The relationship between total seasonal rainfall and yield of maize in Kenya highlands. Jour. Agric. Sci., 49, 285 - 290.

------- and Wynne, M.D. 1962. Light rainfall and plant survival in East Africa. 1. Maize. Journal of Ecology, 50, 111 - 118.

Goldson, J.R. 1963. The effect of time of planting on maize yields. E. Afr. Agric. For. J., 29, 160 - 163.

Gray, R.W. 1970. The effect on yield of the time of planting of maize in South-west Kenya. E. Afr. Agric. For. J., 35, 291.

Haun, F.R. 1974. Prediction of spring wheat yields from temperature and precipitation data. Agron. J., 66, 405 - 409.

Hendricks, W.A. and Scholl, J.C. 1943. Techniques in measuring joint relationships: The joint effects of temperature and precipitation on corn yields. North Carolina Agr. Exp. Sta. Tech. Bul. 74.

Huda, A.K.S., Childyal, B.P., Tomar, V.S. 1975. Contribution of climatic variables in predicting rice yield. Agric. Met., 15, 71 - 86.

Huda, A.K.S., Ghildyal, B.P., Tomar, V.S. 1976. Contribution of climatic variables in predicting maize yield under monsoon conditions. Agric. Met., 17, 33 - 47.

Jolliffe, I.T. 1973. Discarding Variables in a Principal Component Analysis: Real Data. Appl. Statist., 22, 21 - 31.

Katz, R.W. 1977. Assessing the impact of climatic change on food production. Climatic Change, I, 85 - 86.

-------, 1979. Sensitivity analysis of statistical crop - weather models. Agric. Met., 20, 291 - 300.

Lomas, J. and Shashoua, Y. 1973. The effect of rainfall on wheat yields in an arid region. In Slatyer, R.O. (Ed.) 'Plant response to climatic factors'. Paris, UNESCO, pp.531 - 538.

Palmer, A.F. 1973. Photoperiod and temperature effects on a number of plant characters in several races of maize in the field. In Slatyer, R.O. (Ed.) 'Plant response to climatic factors'. Paris, UNESCO, pp.113 - 119.

Pengra, R.F. 1952. Estimating crop yields at seeding time in the Great Plains. Agron. J., 44, 271 - 274.

Peters, D.B., Pendleton, J.W., Hageman, R.H., and Brown, C.M. 1971. Effect of night air temperature on grain yield of corn, wheat and soybeans.

Agron. J., 63, 809.

Robins, J.S. and Domingo, C.E. 1953. Some effects of severe soil moisture deficits at specific growth stages of corn. Agron. J., 45, 618 - 621.

Runge, E.C.A. and Odell, R.T. 1958. The relation between precipitation, temperature and the yield of corn on the Agronomy South Farm, Urbana, Illinois. Agron. J., 50, 448 - 454.

-------, 1968. Effects of rainfall and temperature interactions during the growing season on corn yield. Agron. J., 60, 503 - 507.

Salter, P.J. and Goode, J.E. 1967. Crop responses to water at different stages of growth. Farnham Royal, U.K., Commonwealth Agricultural Bureaux.

Shaw, R.H. 1976. Water use and requirements of maize - A review. Agrometeorology of the maize (corn) crop. Proc. WMO No.481, pp.119 - 134.

Simango, V.A. 1976. Maize yield in relation to rainfall and solar energy in Kenya. M.Sc. Thesis, University of Nairobi.

Slatyer, R.O. 1967. Plant water relationships. Academic Press, London and New York.

-------, 1973. The effect of internal water status on plant growth, development and yield. In Slatyer, R.O. (Ed.) 'Plant response to climatic factors'. Paris, UNESCO, pp.177 - 191.

Smith, J.W. 1914. The effect of weather upon the yield of corn. Monthly Weather Review, 42, 78 - 93.

Sreenivasan, P.S. and Banerjee J.R. 1973. The influence of rainfall on the yield of rain-fed rice at Karjat (Colaba District). Agric. Met., 11, 285 - 292.

Stacy, S.V., Oscar Steanson, Jones, L.S., and Foreman, W.J. 1957. Joint effects of maximum temperatures and rainfall on corn yields, Experiment, Georgia. Agron. J., 49, 26 - 28.

Stanhill, G. 1973. Simplified Agroclimatic procedures for assessing the effect of water supply. In Slatyer, .R.O (Ed.) 'Plant response to climatic factors'. Paris, UNESCO, pp.461 - 476.

Survey of Kenya 1970. National Atlas of Kenya.

Swanson, E.R. and Nyankori, J.C. 1979. Influence of weather and Technology on corn and soybean yield trends. Agric. Met., 20, 327 - 342.

Thompson, L.M. 1969. Weather and Technology in the production of corn in the U.S. Corn Belt. Agron. J., 61, 453 - 456.

------, 1976. Weather and technology in corn production. Agrometeorology of the maize (corn) crop. Proc. WMO No.481, pp.309 - 313.

Todorov, A.V. 1977. Guide-book for agrometeorological observation. E.A.M.D.

Turner, D.J. 1966. An investigation in the causes of low yield in late-planted maize. E. Afr. Agric. For. J., 31, 249 - 260.

Veihmeyer, F.J. and Hendrickson, A.H. 1927. Soil moisture conditions in relation to plant growth. Plant Physiol., 2, 71- 82

---------, 1949. Methods of measuring field capacity and wilting percentages of soils. Soil Sci., 68, 75-94.

---------, 1950. Soil moisture relation to plant growth. Ann. Rev. Plant Physiol., 1, 285-304.

---------, 1955. Does transpiration decrease as the soil moisture decrease? Trans. Amer. Geophys. Union, 36, 425-448.

Zhang, P. and Gong, G. 1980. Ancient precipitation records in China. WMO Bulletin, XXIX, 7-10.