NATURAL RESOURCES SYSTEMS PROGRAMME
***PROJECT REPORT*[1]**

DFID Project Number

R8088A

Report Title

Use of PT software to study drought recurrence and planting dates in Tanzania.
Annex B21[TMA case study] of the Final Technical Report of project R8088A.

Report Authors

Hyera, T.M., Mboya, M., Tumbo, S.D., Mahoo, H.F., Mzirai, O.B., and Mbanguka, R.P.

Organisation

SWMRG, Sokoine University of Agriculture, Tanzania

Date

2005

NRSP Production System

Semi Arid

[1] This document is an output from projects funded by the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

Use of PT Model to Study Drought Recurrence in Tanzania

T. M. Hyera[1], M. Mboya[1], S. D. Tumbo[2], H. F. Mahoo[2], O. B. Mzirai[2], R.P. Mbanguka[2]

[1]Tanzania Meteorological Agency
[2]Soil-Water Management Research Group, Sokoine University of Agricuclture

Introduction

Accounts of historical droughts in Tanzania are often subjective and conflicting. This is mainly due to the fact that the term drought is not easy to define due to the various concepts and meanings to different interests. The difficulty in defining droughts can be attributed to the fact that a drought is a relative rather than an absolute condition. A particular set of weather events could cause wet conditions in a semiarid region while the same set of events could cause dry conditions (drought) in a humid region. Agriculturalists conceive drought as a shortage of moisture within the root zone for plant growth and development. However, what may be regarded, as drought to farmers growing annual field crops may not necessarily be drought to pastoralists practicing grazing. However, meteorologists regard droughts simply as prolonged periods of rainfall deficiency that cause serious hydrological imbalance.

Furthermore, farmers sometimes attribute crop failures to drought while it is nothing but failure to utilize the rainy season properly. This could be due to timing of the growing cycle of crops being out of phase with the rainfall pattern during given years. In that case the total rainfall during the season might not reflect any deficit, but a close study could reveal a shift in its usual distribution, being less during the critical stages of crop growth and development.

In recent years parts of Tanzania have experienced recurring droughts. The most devastating were those of 1983 - 1984 and 1993 – 1994 (Kavishe, 1993.). These droughts necessitated the rationing of hydroelectric power.

Rainfall in Tanzania is a very crucial factor in the ability of farmers and pastoralists to produce the foodstuffs needed for consumption by the people. Rainfed agriculture is the main stay of the economy; consequently severe droughts have disastrous impacts on the socio-economic development of the country. Studies of drought patterns in East Africa (i.e. Tanzania, Kenya, Uganda) and their potential impacts on the economy have been carried out by among others, Nieuwolt (1978), Ogallo (1984), Mhita (1990), Nicholson and Nyenzi

(1989), Ininda (1984) and Ogallo and Ambenje (1996). Ogallo (1984) found out that the whole of East Africa is drought - free in 21 out of 100 years. Recent studies, Kavishe and Matitu (1993) and Ogallo and Ambanje (1996) indicate that extreme rainfall anomalies are common over parts of Kenya and Tanzania. Some of the extreme anomalies are localised in nature, while others spread to cover wide areas and persist for several seasons or years. Nyenzi (1988) demonstrated that low rainfall in the country can be attributed to a diffused Inter Tropical Convergence Zone (ITCZ). Spectral analysis revealed that cycles of 2.3 years and 5 years were dominant and possibly related to the Quasi - Biennial Oscillation and fluctuations of the Southern Oscillation respectively. Jury and Mc Queen (1993) confirmed the presence of these oscillations using data from Tanzania.

This lack of common ground on drought has resulted in the memory of historical countrywide droughts being fuzzy. In studying historical droughts, it is therefore important to define the location and the economic activity that was affected. This case study attempts to reconstruct past droughts in Morogoro District, as reflected by yields of maize obtained using the PARCHED-THIRST (**P**redicting **A**rable **R**esource **C**apture in **H**ostile **E**nvironments **D**uring **T**he **H**arvesting of **I**ncident **R**ainfall in **S**emi-arid **T**ropics) model. Drought events are associated with below normal yields.

The Climate of Tanzania

The country's climate has been described in detail by many authors such as Thompson (1965), Griffiths (1972) and Nieuwolt (1979). It will suffice to give only a brief summary. The climate of Tanzania depends on the movement of the Intertropical Convergence Zone as the overhead sun migrates from north to south and vise versa. From December to March, high land surface temperature give rise to a large low pressure area centred between 10^{o}S and 15^{o}S with high pressure developed over North Africa and the Arabian Peninsula.

This situation gives rise to north - easterly dry airstream over the northern parts of the country bringing little rainfall in those areas. However, when the airstream reaches Southern Tanzania it acquires a more westerly direction that converges with moist south - easterly trades from the Indian Ocean giving rise to upward motion resulting in seasonal rainfall. This convergence zone is what is called the ITCZ. Intrusion of moist westerly airstream over western Tanzania from the Congo basin during southern summer, brings seasonal rainfall over south - western and western parts of the country. Local circulations like the Lake Victoria circulation and land - sea breeze are superimposed on the large synoptic features of the East African region.

Two rainfall regimes exist over Tanzania. One is unimodal regime (December - April) and the other is a bimodal regime (October - December and March - May). The former regime is experienced in southern, south - western and western parts of the country while the latter is found to the north and northern coast. A transition zone exists between these rainfall regimes (see Figure 2). In the bimodal regime, the March - May rains are referred to as the long rains (usually called Masika) whereas the October - December rains are generally known as the short rains (Vuli). The short rains are highly variable in space and time. Orography plays an important role in the rainfall distribution over Tanzania. Annual rainfall varies from 200 mm to 1000 mm over most parts of the country. Higher rainfalls are recorded over the highlands to the north - eastern and south - western parts. Central Tanzania is semi - arid with some parts receiving annual rainfall of less than 400 mm.

Causes of Droughts

Weather systems that cause droughts in Tanzania are to a large extent complicated. The weather systems that cause variations in the country's weather and climate are the monsoons, the Inter Tropical Convergence Zone, the subtropical anticyclones, African jet streams, and easterly/westerly wave perturbations.

Investigations of the various causes of droughts have been conducted by several authors in East Africa. These include those by Ogallo (1989), Nyenzi (1992) and Kabanda (1995) which have established that EL-Nino/Southern Oscillation has an influence on the occurrence of droughts in Tanzania. Nieuwolt (1978) and Minja (1982) found droughts to be associated with weak monsoons. The position of the ITCZ over Tanzania as dictated by mid-latitude and tropical disturbances is found to have an influence on the occurrence of droughts (Ogallo, 1984). Hyden (1996) found dry/wet southern summers to be associated with a northward/southward shift of the ITCZ from its normal position. This is consistent with increased/decreased weather activity over Southern Tanzania during such periods. The two major anticyclones which significantly influence the weather and climate of Tanzania are the Arabian and Mascarine high pressure cells (Ogallo, 1989, 1994)

It is evident from the above studies that global scale as well as regional forces is instrumental to the occurrence of droughts in this country. However, accounts of historical droughts in the country are often subjective and conflicting. This is mainly due to the fact that the term drought is not easy to define due to the various concepts and meanings of droughts to different people. For example, Palmer (1965) attributes the difficulty in defining droughts to the fact that a drought is a relative rather than an absolute condition. A particular set of weather events could cause wet conditions in a semiarid region while the same set of events could cause dry conditions (drought) in a humid region. Yevjevich (1967) suggested that run-sums represented the best basic concept for an objective definition of a drought. The sums of deviations are the run sum of negative deviations for a given run length in case of droughts and give an indicator of the deficiency of water supply or the severity of a drought.

Agriculturalists conceive drought as a shortage of moisture within the root zone for plant growth and development. However, what may be regarded as drought to farmers growing annual field crops may not necessarily be drought to pastoralists practicing grazing. Hydrologists take a drought to mean a severe reduction in stream, lake and reservoir levels. This may result in power and water rationing in urban centers. Economists view droughts as a serious water shortage that adversely affects the economy. However, meteorologists regard droughts as simply a prolonged period of rainfall deficiency that cause serious hydrological imbalance.

In Tanzania droughts are generally localized and never cover the whole country at any particular time. This lack of common ground has resulted in the memory of historical countrywide droughts being fuzzy. In studying historical droughts, it is therefore important to define the location and the economic activity that was affected. This case study attempts to reconstruct past droughts in Morogoro District, as reflected by yields of maize obtained from results of the PARCHED THIRST model. Drought events are associated with below normal yields while percentage mean yield is used to indicate severity of droughts.

It should be appreciated that what is sometimes regarded as drought is nothing but failure by farmers to utilize the rainy season properly. This could be due to timing of the growing cycle of crops being out of phase with the rainfall pattern during given years. In that case the total rainfall during the season might not reflect any deficit, but a close study could reveal a shift in its usual distribution, being less during the critical stages of crop growth and development.

Objective of Study

In this case study the PT model was used in order to:

1 Identify seasons over the last 30 years (1971-2005) that had poor maize yields, attributed to drought. When many years of rainfall data are available, the PT

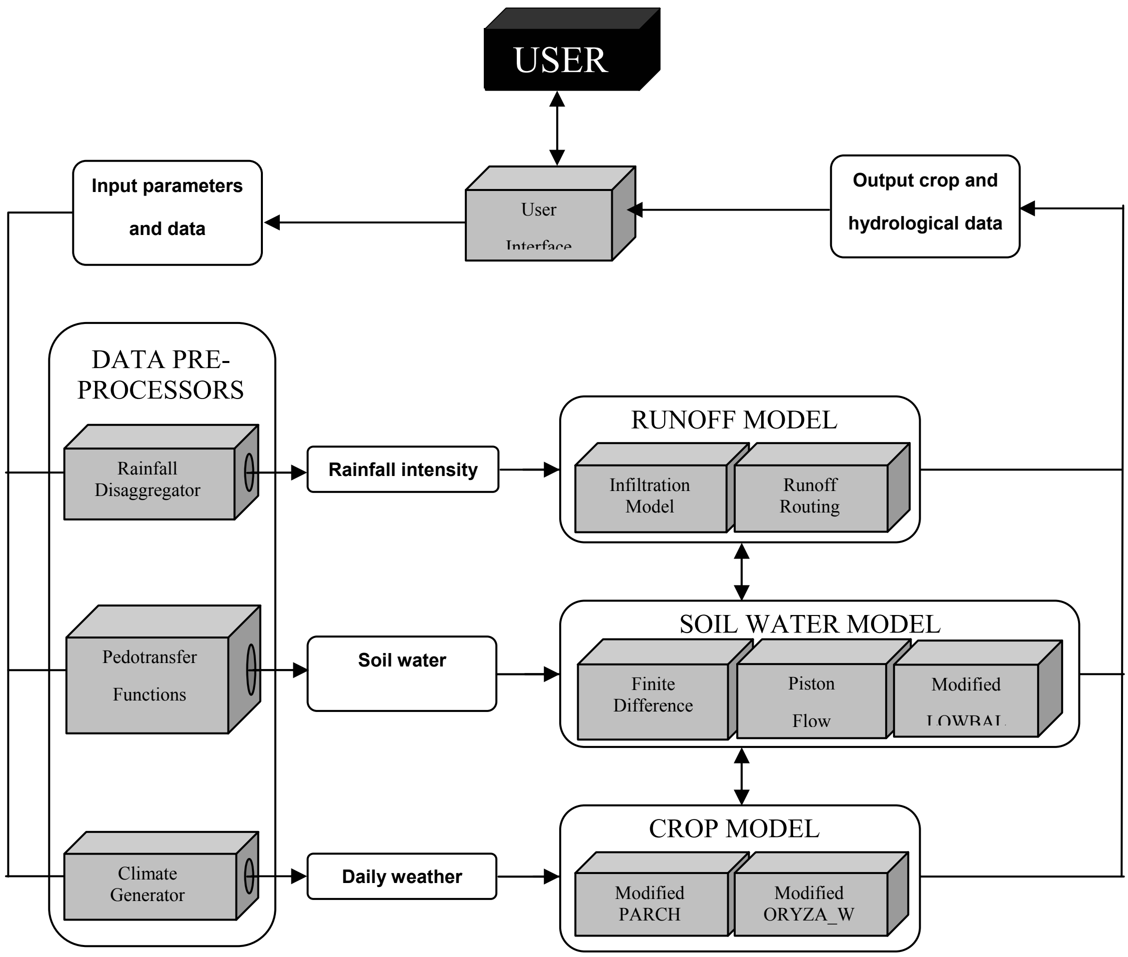
dialogue can quantify the season-to-season variation of the yields. We used daily data for 30 years from Magadu in Morogoro District.

2 Use the series of drought seasons identified in (1) above to characterize droughts in a district, i.e. to get various statistics of droughts such as frequencies and return periods and coefficient of variation.

3 To develop an advisory strategy for farmers given the characteristics of drought in their area, e.g. time of planting, best agronomic and cultural practices and alternative agricultural systems.

Methodology

The start of the rains was defined using INSTAT + software and maize (TMV1) yields were



obtained using PARCHED-THIRST model.

A brief description of PT

Figure 1. Components making up the PARCHED-THIRST model

PARCHED-THIRST model is a user-friendly, process-based model, which combines the simulation of hydrology with growth and yield of a crop on any number of distinct or indistinct RPAs and RRAs. It is a distributed model, which simulates the rainfall-runoff process, soil moisture movement and the growth of sorghum, rice, maize and millet in response to daily climate data. The landscape is divided into units, which are assumed to represent homogeneous portions of the landscape. The only transfer of mass between profiles is surface runoff.

A Brief description of Instat

Instat is a statistical package for analysis of data. It has its own language for data input and output that is similar to BASIC. Using the package, one can do the following:

1. Data entry and manipulation.
2. Graphics. Plots and histograms are high resolution
3. Statistics. Data summary and modelling, including ANOVA, regression, probability distributions and random sample generation
4. Climatic analysis. Summary and modelling of climatic data

A simple crop climate model calculates the crop-monitoring index from Frere and Popov (1979), based on previous work by Penman (1963). This model requires only decade rainfall and evaporation figures plus crop coefficients and a measure of soil capacity. It can easily be used on many years of rainfall data to derive the values for the crop index in each year, perhaps to consider the effect of different planting dates. The values of the index for different crops or different soil depths can also be studied.

A further module allows the simulation of a very simple irrigation scheme to be studied. The values of the crop index are used to measure the success of the scheme. The area to be cropped or the volume of the reservoir can be varied in successive years. The minimum information you need is rainfall data for one or more years, evaporation data and a set of crop coefficients.

The default is for the season to start on the first period with more than 30mm, but many options are possible. The options when there is surplus water can be varied. In this study, the start of the rains was defined as when there is a cumulative rainfall of about 20mm over the first two days and there is no dry spell of 10 days in the next 30 days after the rainy season starts. Two types of droughts were defined: Agronomic droughts and meteorological droughts. It was assumed that an agronomic drought occurs when maize yield level is less than 0.5 t/ha and the meteorological drought was defined by the situation where the cumulative amount of rainfall during the long rainy season (From 1st March to 14th June) is less than 350mm.

To analyse the recurrence of droughts, the years where agronomic droughts occurred were assigned a "1", those where meteorological drought occurred were assigned a "-1" and where there was no drought a "0". These numbers were then plotted in a single chart and summary statistics evaluated.

Results and discussion

Start date of rainy season Magadu (Conditional)

The Figure 2 shows the start date based on the rainfall and considering the dry spells under the condition that the rainy season starts when there is a cumulative rainfall of about 20mm over the two days and that there is no dry spell of 10 days in the next 30 days after the rainy season start.

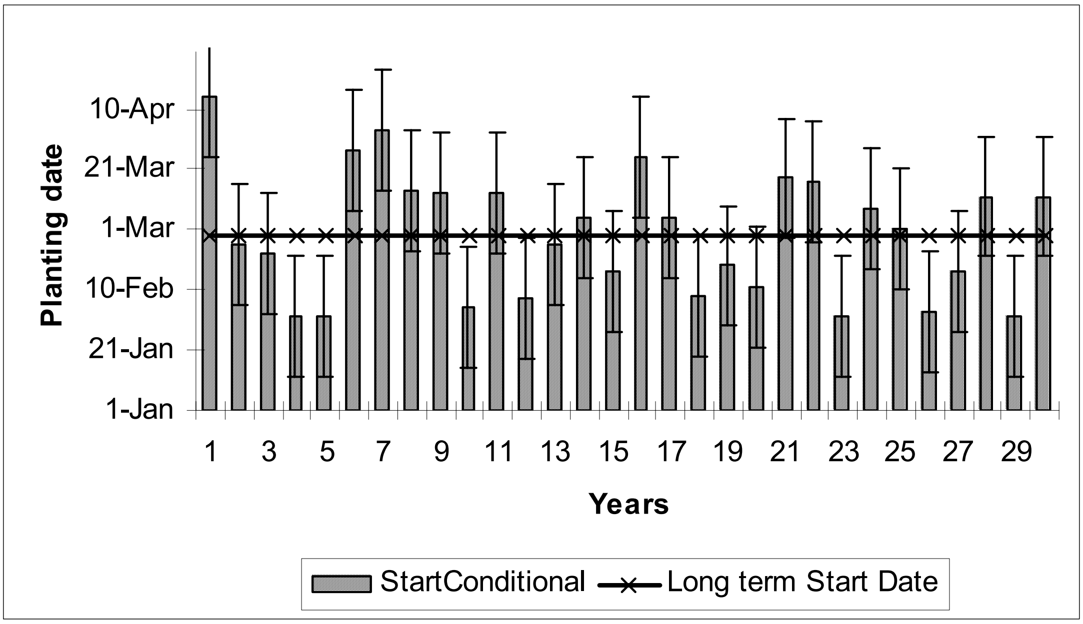


Figure 2. Conditional starts of the rainy days

The start of season is a critical event in relation to crop production. In the semi arid tropics the length of the growing seasons are shorter, and failure to timely start the season can lead to serious risk of crop production. Figure 2 shows the start date of about thirty years. The possible average start date was found to be 28 February. The years that had the chances of starting the season on or around 28 February was 22 years out of 30 (73%). However, this considered a dry spell of 10 days after the possible planting date. The risk on the start date can be checked if only the amount of water i.e. 200 mm over the 2 days is the only considered factor ignoring the dry spells.

Figure 3 shows the risk of ignoring the dry spells. Two conditions are considered. Starting unconditionally where a dry spell is not considered and start with condition where the dry spell of 10 days in the next 30 days is considered. It is observed that if conditions are imposed it is only 5 out of 30 years where the season could not start which is about 17%. When considering unconditional cases the long-term average of start date is 11 March.

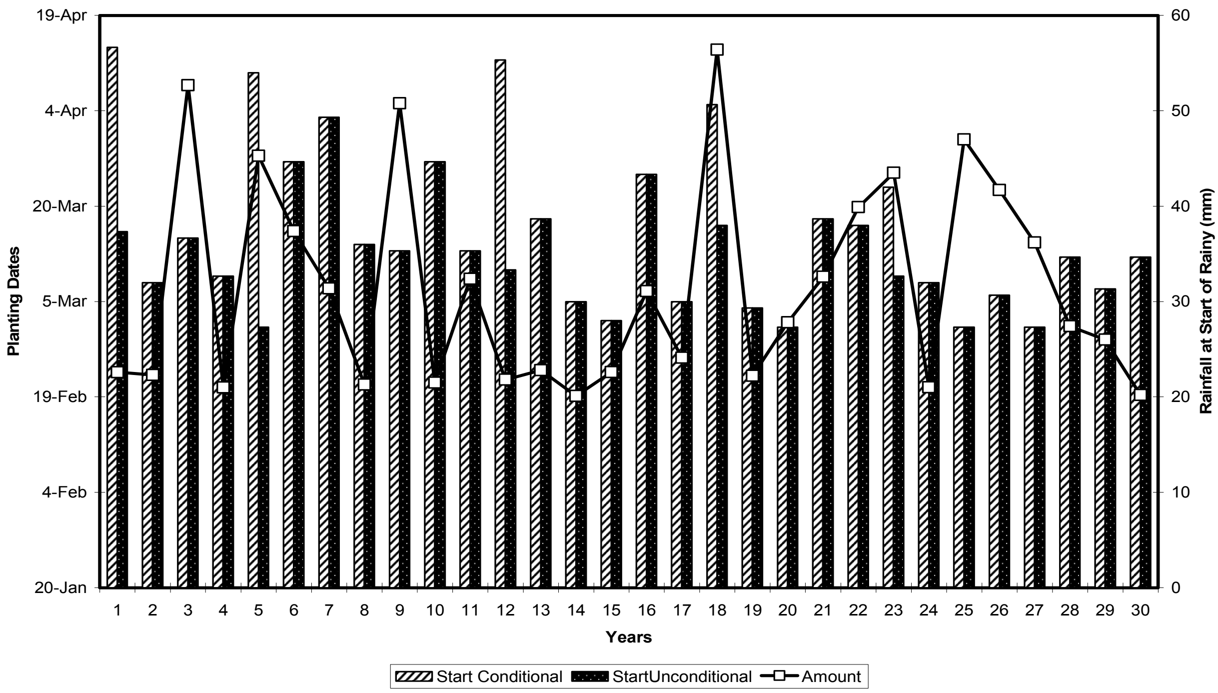


Figure 3 Risk of changing the planting date for Morogoro station (Magadu) from Instat

Droughts over the last 35 years

A summary of the rainfall and crop yields analysis for the last 35 (1971 to 2005), for Morogoro is shown in Figure 4 and Table 1 and 2 in appendix.

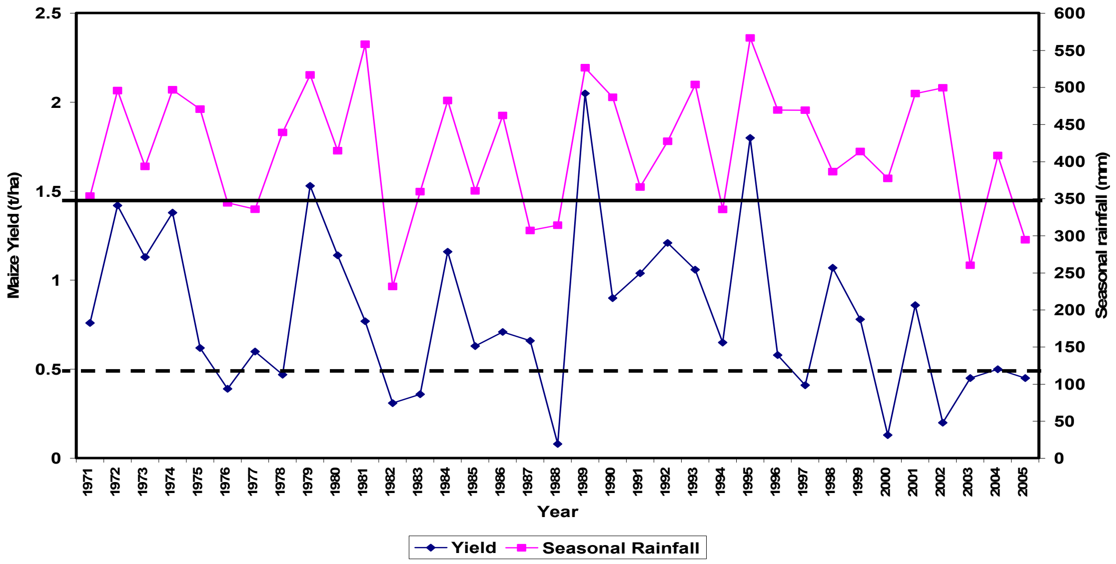


Figure 4 Meteorological and agronomic droughts for 35 years

Over this period a total of 13 droughts occurred, of which 10 were agronomic and 8 were meteorological. It was realized that agronomic droughts are not necessarily associated with meteorological droughts and vice versa.

Table 3 shows that for the (10) years where agronomic droughts occurred, five years (1976, 1982,1988, 2003, 2005) were coupled with meteorological droughts and the other five were not. Agronomic droughts not coupled with meteorological drought mainly resulted from poor distribution of rainfall.

Table 3. Droughts based on yield (Cut-off < 0.5 t/ha)

Year	Yield	SRain
2002	0.2	499.4
1997	0.41	469.3
1978	0.47	439.3
2000	0.13	377.4
1983	0.36	359.5
1976	0.39	344.4
1988	0.08	314.2
2005	0.45	294.6
2003	0.45	260.2
1982	0.31	231.7

Table 4.Droughts based on seasonal rainfall (Cut-off = 350 mm)

Year	Yield	SRain
1982	0.31	231.7
2003	0.45	260.2
2005	0.45	294.6
1987	0.66	307.2
1988	0.08	314.2
1994	0.65	335.6
1977	0.6	335.8
1976	0.39	344.4

For example in year 1997 (Figure 5), the seasonal rainfall amounted to about 469mm but the yield was only 0.41 t/ha because the rains were intensive at the start of the season (March & April) but there was very little rain during the period of critical moisture requirement (tasselling and grain filling). Consequently, the dry matter accumulation stagnated and the grain weight gain did not build up satisfactorily.

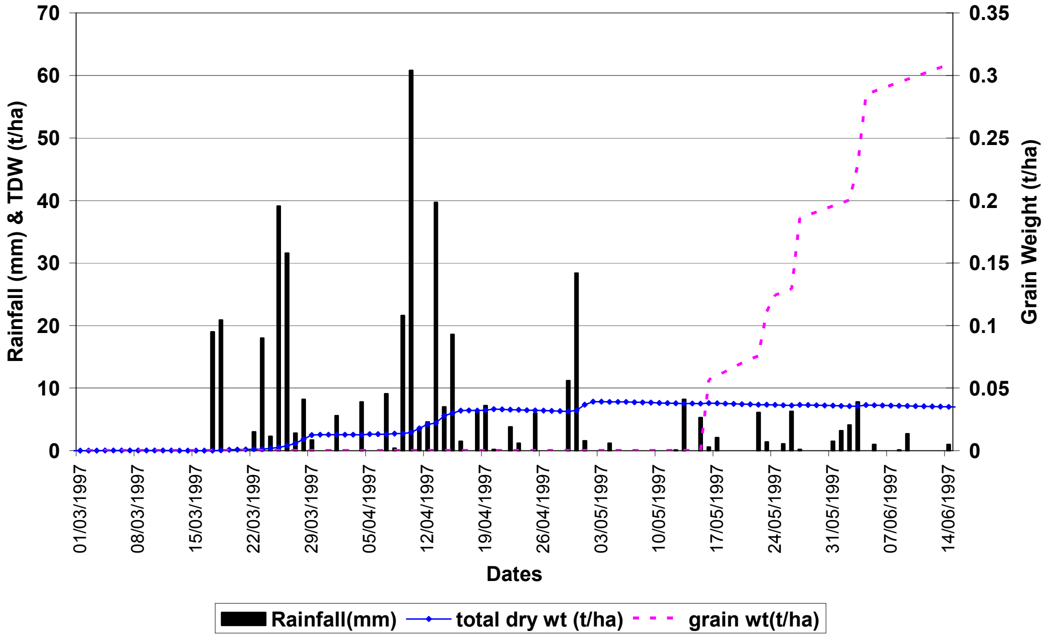


Figure 5 agronomic droughts in year 1997

In three (3) of the eight (8) years where meteorological droughts occurred, maize yield was beyond the cut-off level (Table 4), i.e. there were no agronomic droughts (1977, 1987 and 1994). For example, the total seasonal rainfall in 1994 (Figure 6) was below the cut-off level (only 335 mm) and the maximum daily rainfall did not exceed 34 mm throughout the season but fortunately; there were no prolonged dry spells. Grain weight grain was favoured by the presence of enough rains during the critical moisture requirement phase.

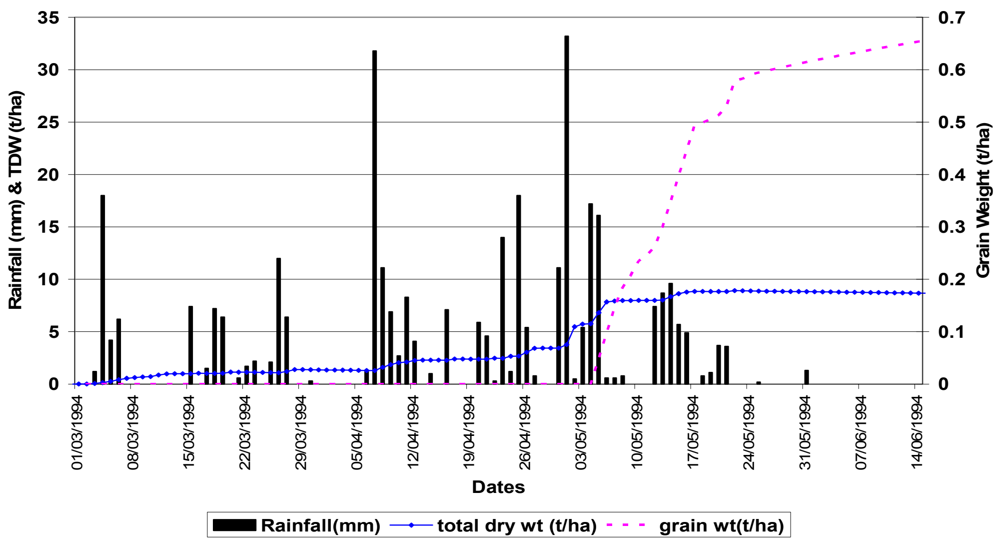


Figure 6 meteorological droughts in year 1994

Where there was sufficient and evenly distributed rains, yield levels were also high as shown in Figure 7 (year 1995).

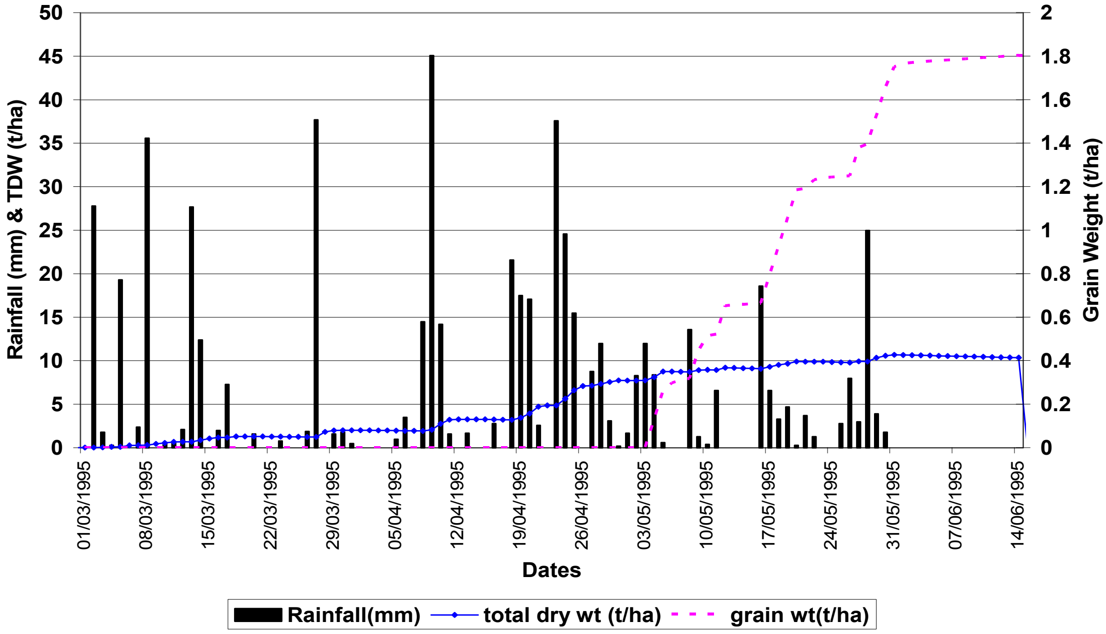


Figure 7 Good rains good yield for the year 1995

Drought recurrence

Figure 8 shows the sequence of drought occurrence over the last 35 years and Table 5 shows summary statistics for the figure.

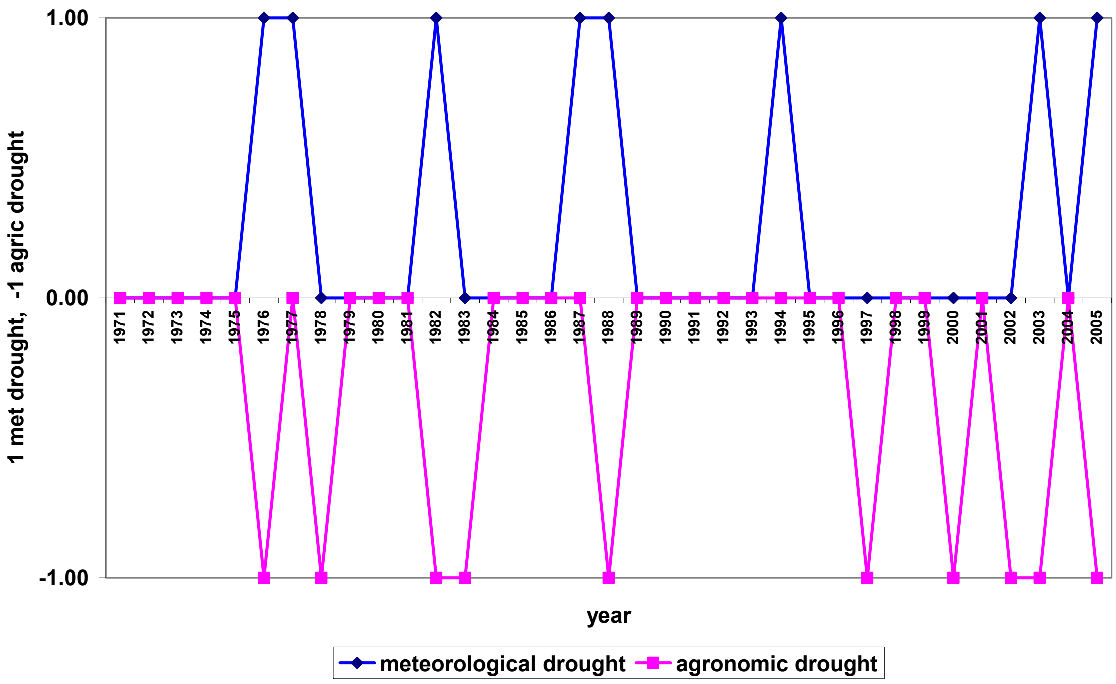


Figure 8 meteorological drought and agronomic drought recurrence

Table 5 Summary statistics for drought recurrence

Statistics	Agronomic drought (Yield < 0.5 t/ha)	Meteorological drought (Seasonal rainfall < 350 mm)
Mean recurrence (years)	4.2	6.0
Standard deviation (years)	2.2	1.8
Coefficient of variation (%)	51.9	30.0

Past years experience showed that in average, meteorological droughts reoccur every six (6) years (1976, 1982, 1988, and 1994). However, since 1995, the trend/pattern was altered, as the agronomic drought didn't reoccur until 2003. Agronomic drought recurrence did not show a clear pattern for the 35 years (52% coefficient of variation). However, it is apparent that the frequency of recurrence since 1997 is increasing (1997, 2000, 2002, 2003).

Based on the analysis of drought done above, an advisory strategy for farmers could be developed given the characteristics of drought in their area. One way could be to adopt the proper planting date. For instance Figure 9, based on PARCHED-THIRST model shows that the best planting dates for Morogoro is 1st march.

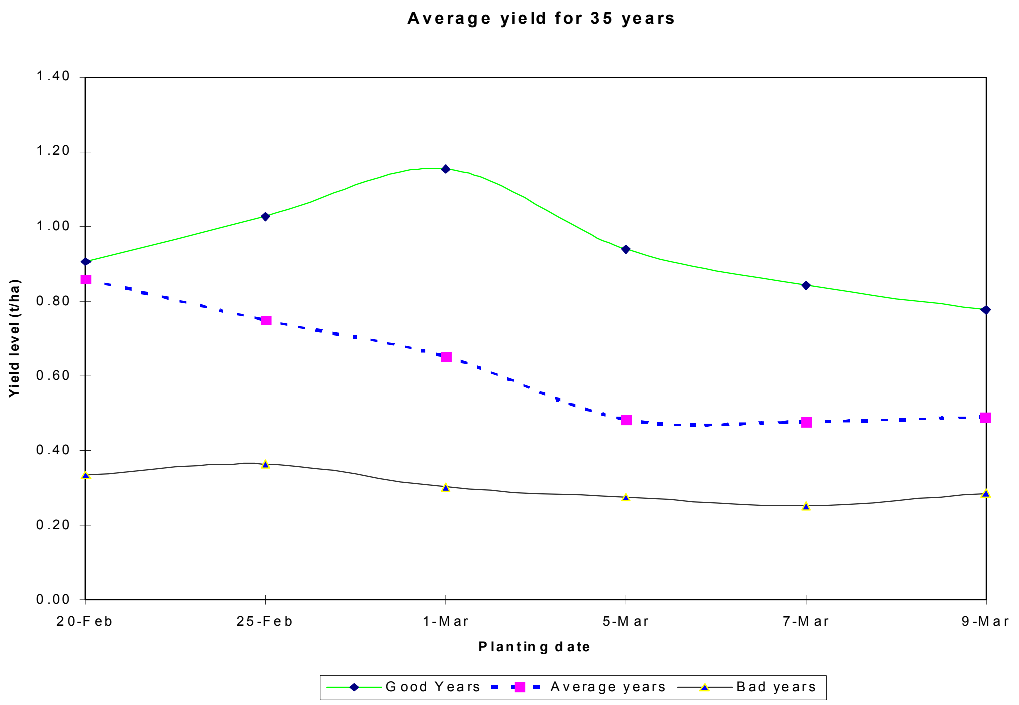


Figure 9. Best planting dates for Morogoro

Other measures to improve productivity include rainwater harvesting (RWH) during the period of heavy rains and supplementary irrigation during the critical moisture period. Other measures could be emphasizing proper population and variety agronomic and cultural practices and alternative agricultural systems. For instance for Morogoro, the recommended population is 44000 plants/ha for TMV1.

Conclusion

Over the 35 years period studied (1971 to 2005) for Morogoro, a total of thirteen droughts occurred, of which ten agronomic and eight meteorological. It was assumed that agronomic drought occurs when maize yield level is less than 0.5 t/ha and meteorological drought was defined by the situation where the cumulative amount of rainfall during the long rainy season (From 1st March to 14th June) is less than 350mm and

It was realized that agronomic droughts are not necessarily associated with meteorological droughts and vice versa. For the ten years where agronomic droughts occurred, five years were coupled with meteorological droughts and the other five were not. Agronomic droughts not coupled with meteorological drought mainly resulted from poor distribution of rainfall. In three of the eight years where meteorological droughts occurred, there were no agronomic droughts. Grain weight was favoured by the presence of enough rains during the critical moisture requirement phase. Past years experience showed that on average meteorological droughts reoccur every six years, though the trend pattern was altered during the later years. Agronomic drought recurrence did not show a clear pattern over the 35 years but it is apparent that the frequency is increasing. Based on the analysis of drought an advisory strategy could be developed such as best planting dates, seed varieties, irrigation, rain water harvesting and plant population.

References

Frere and Popov, 1979. *Agro meteorological Crop Monitoring and Forecasting,* FAO Plant prod. & Prot. Paper no. 7, 64 pp. http://www.reading.ac.uk/ssc

Ininda, J., 1984: *Spatial and temporal characteristics of drought in Eastern and Southern Africa*. M.Sc Thesis. University of Nairobi

Instat+, Statistical Services Centre, The University of Reading

Kabanda, T.A., 1995: *Seasonal and Intra-Seasonal Dynamics and Precursors of Rainfall over Northern Tanzania,* M.Sc. Thesis, University of Cape Town.

Kavishe, M.M. and Matitu, M.R., 1993, *Drought frequencies over South-East Lake Victoria Basin of Tanzania*. Paper presented at the First African Meteorological

Society Meeting, January 8 - 12, Nairobi, Kenya.

Kavishe, M.M., 1996, *Bimodal Rainfall Variability over Tanzania*. Paper presented at the Third Kenya Meteorological Society Workshop, October 7-11, Mombasa. Mhita,

M.S., 1990. *The analysis of rainfall Data for agriculture in Tanzania*. TMRP Research Report No. 2/90; Directorate of Meteorology Tanzania.

Mhita, M.S., and Venalainen, A., 1992. *The Variability of Rainfall in Tanzania.* FINNIDA/SATCC/WMO Meteorology project doc., Helsinki, Finnish Mt. Institute.

Minja, W.S.M., 1982. *The weather anomalies during Northern Summers of 1972 and 1978 over Africa*. Tech. Conf. on Climate of Africa, Arusha Tanzania, pp 195 - 208.

Nieuwolt, S., 1978. *Rainfall and drought frequencies in East Africa*, Erkunde_32: 81 - 88.

Nieuwolt, S., 1979. *The East African Monsoons and their effects on Agriculture.* GEOJOURNAL, 3, 2: 193 - 200

Nyenzi, B.S. 1984. *Equatorial Zonally moving disturbances which contributed to the East African Long rains of March to May 1979*. M.Sc Thesis, FSU, 73pp.

Nyenzi, B.S. 1990. *Analysis of the Interannual variability of rainfall in East Africa.* Second Tech. Conf. on Weather forecasting in Eastern and Southern Africa, Nairobi, Kenya.

Nyenzi, B.S., 1988. *Mechanisms of East African Rainfall variability*. Ph.D Dissertation, FSU, Tellahasse, USA.

Nyenzi, B.S., 1992. *El Nino/Southern Oscillation (ENSO) Fluctuations and its influence to Southern Africa Climate*. Proceedings of the First SADC Conference on Climate

Change, Windhoek, Namibia, March 2 - 6, 1992, SADC - ELMS Coordination Unit, Maseru 1995.

Ogallo, L.J., and Nassib, I.R., 1984, *Drought patterns and Famines in East Africa during 1982 - 83*. TMP No. 15

Ogallo, L.J., 1980. *Time Series Analysis of rainfall in East Africa*, PhD. Thesis, University of Nairobi, Kenya.

Ogallo, L.J., 1989. *The Spatial and temporal patterns of East African seasonal rainfall derived from principal component analysis*. Royal Meteorological Society, 145- 167.

Ogallo, L.J., 1994. *Interannual Variability of East African Monsoons Wind Systems and their impact on East African Climate*. WMO/TD-No. 619, 99-104.

Ogallo, L.J., and Ambanje, P.G., 1996: *Monitoring Drought in Eastern Africa*.

WMO/TD NO. 753.

Palmer, W.C., 1965:*Meteorological Drought*. U.S.A. Weather Bureau Research paper No.45

Penman, H.L. 1963. *Vegetation and hydrology*. Tech. Comm. No. 53, Commonwealth Bureau of Soils, Harpenden, England. 125 p.

Robin M., S. William (2002), Crop-*Soil Simulation Models Applications in Developing Countries,* CABI Publishing, UK

Thompson, B.W., 1965: *Climate of Africa.* Oxford University Press.

Yevjevich, V., 1967: An objective Approach to Definition and Investigations of Continental Hydrological Droughts. Hydrology Papers, Colorado StateUniversity No. 23, August.