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Using PARCHED-THIRST software and seasonal rainfall forecasts to forecast maize yield.

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Report Authors

Ntikha, O. Tibanyenda, C., Tumbo, S.D., Mahoo, H.F. and Mbanguka, R.P.

Organisation

SWMRG, Sokoine University of Agriculture, Tanzania

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Using PARCHED-THIRST Model and Seasonal Rainfall Forecasts to Forecast Maize Yield

O. Ntikha[1], C. Tibanyenda[1], S. D. Tumbo[2], H. F. Mahoo[2] and R.P. Mbanguka[2]

[1]Crop monitoring of Early warning Systems, Ministry of Agriculture and Food Security
[2]Soil-Water Management Research Programme, Sokoine University of Agriculture

Introduction

Maize stands out as number one staple food crop in Tanzania and a good indicator for food security. The importance of crop forecasting in Tanzania began to rank high on the agenda following the Sahelian drought in the early nineteen seventies, which resulted in loss of life to humans and animals alike in most countries in sub-Saharan Africa. Recent observed changing weather patterns and frequent droughts have increased uncertainties in the farming community regarding production of sufficient maize to meet demands. Farming practices mainly based on rainfed agriculture make it necessary for crop simulation modelling using weather parameters as inputs, in order to be able to forecast crop yields.

Early warning of a poor crop harvest in highly variable environments like the ones in Tanzania allows policy makers the time they need to take appropriate actions to ensure food security in vulnerable areas. For instance after testing the model and it is found out that yield results simulated halfway through the growing season are within a 90% of the final District level yield values, such a model would be very useful. Like wise the model could be adopted for use with non-real time climate products such as seasonal forecasts to give an indication of crop production. Relevant advisories on the farming practices to be adopted, types of crops to be grown, etc would accompany this.

Following Sahelian drought and other frequent droughts and floods, efforts to establish crop monitoring and early warning system whose task among others is to forecast yields prior to harvest then began in different countries, including Tanzania. The unit for crop monitoring and early warning system in Tanzania is in the Ministry of Agriculture and Food Security (MAFS) and is known as the Crop Monitoring of Early Warning System. The unit has been using the Plant Water Satisfaction Index model that was developed by FAO to determine yield as well as harvestable production for different crops. Following the floods of caused by the *el nino* of 1997/78, the model failed to predict given the flood environment. Another tool the unit has started to explore for forecasting purpose is the INSTAT+ software application, which is a statistical package for analyzing climatological and crop data.

Forecasting challenges are many, as a number of scenarios exist in real farming practices in the country. For example, maize can be grown as maize crop, maize intercropped with nitrogen fixing crops and/or intercropping with non-nitrogen fixing crops. Modeling offers an opportunity to try different scenarios at low costs since the simulations can be carried out once the required data is assembled. The PARCHED-THIRST (PT) model offers such an opportunity. PT model is also within this limit of grain crops viz. maize, rice, sorghum and millets. As far as possible interest would be to upgrade the model to include major food crops in Tanzania viz. maize, rice, sorghum, millets, wheat, pulses, bananas, as well as roots and tubers. With PT model doing this it would entail taking the challenge to address user desire by extending its capability towards the desired milestone.

Furthermore, for complete integration in the forecasting routine, the model should be able to address issues related to length of growing periods taking into account available resources of the most important limiting factors such as soil moisture and impact of their extremes at different growth stages. This case study involves maize yield forecasting for year 2004 in two different sites, Magadu and Wami Prison, located in the same agro-climatic zone in the North East of Tanzania, using analogue years.

Objectives of the case study

1. To determine analogue years for the year 2004 using past 35 years data for Morogoro
2. To forecast yield for two areas in Zone 1 (Wami and Morogoro), using analogue years for MAM 2004 seasonal rainfall forecast.
3. To compare yield forecasts and the actual yield for the two areas studied.

Forecasting maize production using analogue years

Forecasting crop yields can be made possible by the use of analogue seasons or years with a computer based crop simulation model. Climate forecast systems that are able to provide analogue seasons or years and thus some forecast distribution have become increasingly utilized in agricultural systems (Everingham et al., 2001a, b; Meinke and Hammer, 1997; Singels and Bezuidenhout, 1999; Hansen et al., 2001). Everingham et al., (2002) states that an example of two forecast systems commonly used to produce analogue years are the 3-phase sea surface temperature (SST) system and the 5-phase Southern Oscillation Index (SOI) system. The 3-phase SST approach derives analogue years by partitioning years that correspond to El Nino, La Nina and neutral conditions. The 5-phase SOI phase climate forecast system utilizes pre-determined clusters of the SOI representing patterns of variability in month-to-month values of the SOI. Five clusters or phases of the SOI were identified as: ‘consistently negative’, ‘consistently zero’, rapidly falling’, ‘rapidly rising’ and ‘consistently near zero’. The 5-phase SOI system typically derives analogue years by partitioning years with the same SOI phase for those key months preceding the period of interest and then comparing how the distribution of the response (e.g. rainfall) changes among each of the phases. For some locations, forecast accuracy can be increased by combining other oceanic and atmospheric parameters with ENSO (El Nino-Southern Oscillation) parameters in the forecasting method.

Every year, the Tanzania Meteorological Agency (TMA) is involved with seasonal forecasting for short and long rains in collaboration with drought monitoring centres in Nairobi and Harare. Crop simulation models such as PARCHED-THIRST (PT) can be used together with analogue years to predict the crop yield. The accuracy of the prediction will depend on the accuracy of weather information as well as weather forecasts.

Description of the PARCHED-THIRST Software

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 runoff producing areas (RPAs) and runoff receiving areas (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. The first version of PT (PT v1.0) simulated only maize under micro-catchment RWH. Version 2 (PT v2.0) includes the simulation of rice and macro-catchment systems up to the hillside or small catchment scale. It comprises a number of components (Figure 2) as described in the following sub-sections.

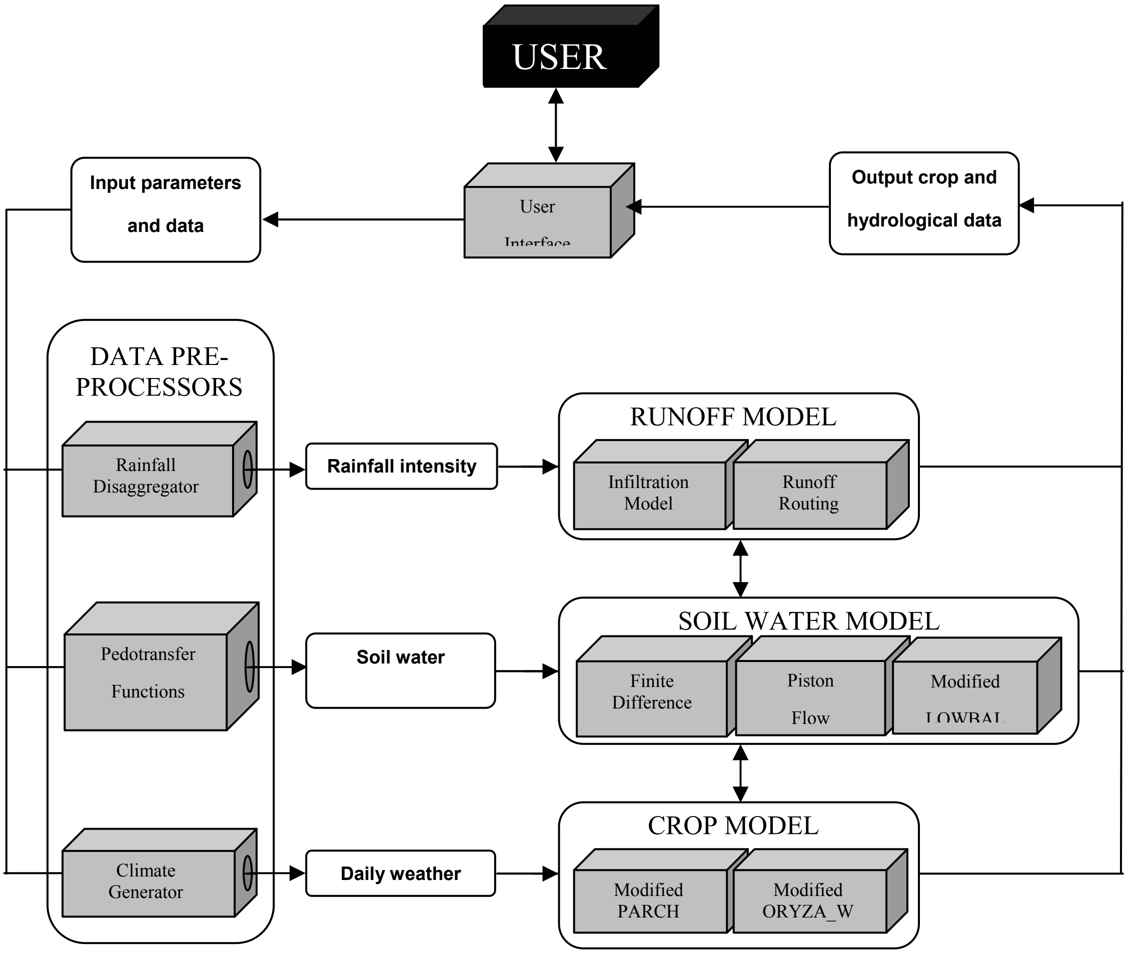

Figure 2. Components making up the PARCHED-THIRST model

Data Preprocessors

Climate generator: PT model requires daily climate data to run. In many areas, climatic data have only been collected for few years and/or contain large numbers of missing data. PT model therefore includes a climate generator, which can be used to generate longer series of data with the same statistical properties and 'fill in' missing data using the statistical properties of available actual data at the same site or from other climatically similar sites.

Rainfall Disaggregator: The runoff component requires rainfall intensity data at intervals of less than 1 day – typically 5 minutes. PT model provides a rainfall disaggregator, which generates 5 minutes rainfall intensity data from an assumed rainfall intensity distribution similar to that proposed by Oron et al. (1989).

Pedotransfer functions: The process-based soil moisture and runoff components in most crop models require a number of time-consuming and difficult-to-measure soil hydraulic parameters including the hydraulic conductivity and water retention relationships. PT model uses soil texture and bulk density information to generate these hydraulic parameters in case they are not available.

Soil moisture modelling

Accurate soil moisture accounting is vital for both runoff and crop growth simulation. PT model provides a choice of three simulation components, which are *0ne-dimensional finite-difference, Piston Flow and Lowball*

Runoff model

Runoff and infiltration on both the RPA and RRA are calculated using the Green and Ampt (1911) infiltration equation. Runoff amount is infiltration excess, which is modified by depression storage and surface sealing. Runoff routing is simple, based upon the Soil Conservation Services (SCS) unit hydrograph (USDA, 1972). The model takes into account *Depression storage, Surface Sealing* and *Runoff routing.*

Crop models

PT incorporates two crop models – PARCH (Bradley and Crout, 1994) for the simulation of sorghum, millet, maize and ORYZA_W (Wopereis *et al*., 1996) for the simulation of rainfed, lowland rice. The PARCH model simulates the growth of sorghum, millet and maize in response to the capture of light, water and nutrients on a daily basis. Partitioning of resources between crop organs depends upon empirical equations, which account for growth stages and stress. Resources allocated to leaves and roots increase leaf area and root length, which feed back into increased light interception and water and nutrient uptake.

The ORYZA_W is a model developed to simulate water-limited growth and development of rice. It is based upon the ORYZA 1 model (Kropff *et al*., 1994) but modified to enable linkage to LOWBAL and to include the effects of drought on plant growth and development such as leaf rolling and senescence and plant death. Like PARCH, ORYZA_W uses a daily time step and partitions dry matter according to development stage and stress. Nutrient supply is considered non-limiting and weeds are not simulated.

Modelling approach

PT model has been developed in Microsoft Visual Basic using an approach, which has been user oriented and iterative, and modular- or component-based. In the case of user-oriented development of the model, both the usability and functionality of the model have been iteratively tailored to user needs through seminars and workshops in the UK and Tanzania (Young *et al.,* 2001). In modularization, PT model comprises of a number of components, which combine and produce the required functionality. This modular approach has a number of advantages: (1) individual components can be easily updated with only minimal alterations to the code increasing usefulness (2) new components (e.g. other crop models) can be slotted in according to need.

Furthermore, the model is object oriented. Although the modular design means that crop and soil-water balance components are largely unchanged from PARCH and ORYZA_W, the user interface and linkages between the models are all object-oriented. This forms the basis for the rationale behind the model front-end. Each simulation scenario is known as a *system*. A system has a number of properties, which include for example, start date and sowing dates. It is also made up of a number of profiles. These are one-dimensional 'blocks' of soil/plant/atmosphere, which are assumed to represent an area with homogeneous soils, topography and vegetation. Each profile is composed of crop, soil and weed objects, which define the behaviour of the profile. A soil object is itself composed of a number of soil layer objects each with defined physical properties. As well as being conceptually easy for users to understand, object-orientation increases the robustness of the model and eases debugging, maintenance and further development.

Methodology

The PT software is used to demonstrate the use of crop simulation model to forecast crop yield for March-April-May (MAM 2004) based on the seasonal rainfall forecast, which is prepared by the Tanzania Meteorological Agency (TMA). Daily rainfalls of analogue years (1980 and 1988) are used as input into the model. The weather data to be used are those for Wami Vijana Prison and Morogoro weather stations. The two stations are all located in the south of the North-East agro-climatic zone (zone 1) and are about 50 km apart.

Determination of Analogue Years

Forecast for seasonal rainfall forecast for March-April-May (MAM) 2004 is shown in Figure 1. The forecasting methods are mainly based on SST and SOI systems in which the analogue years are derived. Appendix 1 shows a table, which include analogue years for different zones. For example, 1970, 1980 and 1988 were analogue years for the seasonal rainfall forecasting for MAM 2004 in Zone 1.

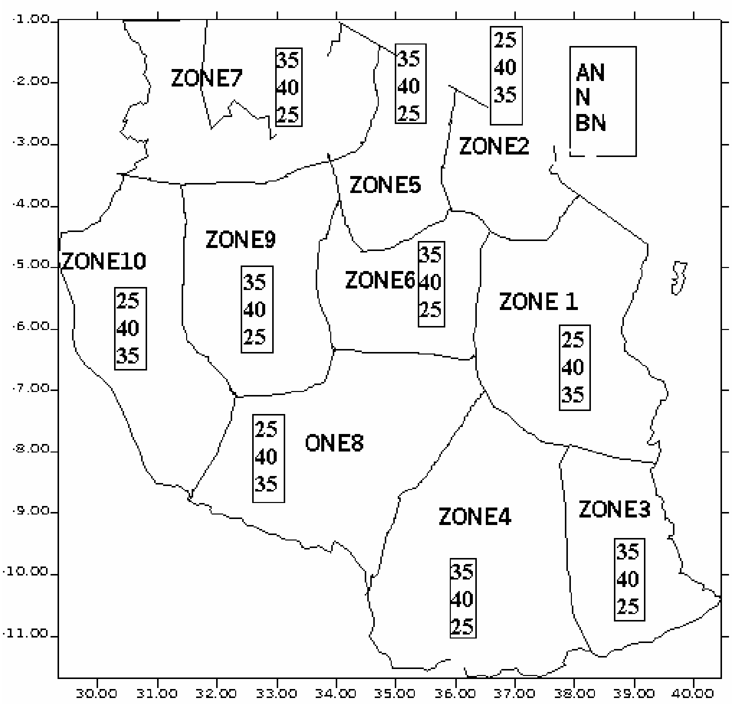

Figure 1. Seasonal rainfall forecast for March-April-May (MAM) 2004.

Results and Discussion

Weather

Figure 2 shows the cumulative rainfalls for the analogue years, 1980 and 1988, and the year being forecasted, 2004. The analogue years show good correlation with the actual year for the Wami Vijana Prison weather station from start of the year to mid April. The total rainfall in the actual year was 1200mm, which is slightly above that in the analogue year 1980 (1050mm). Also, the rainfall patterns during the long rainy season (1st January to 30th of April0 are very similar as shown in Figure 3.

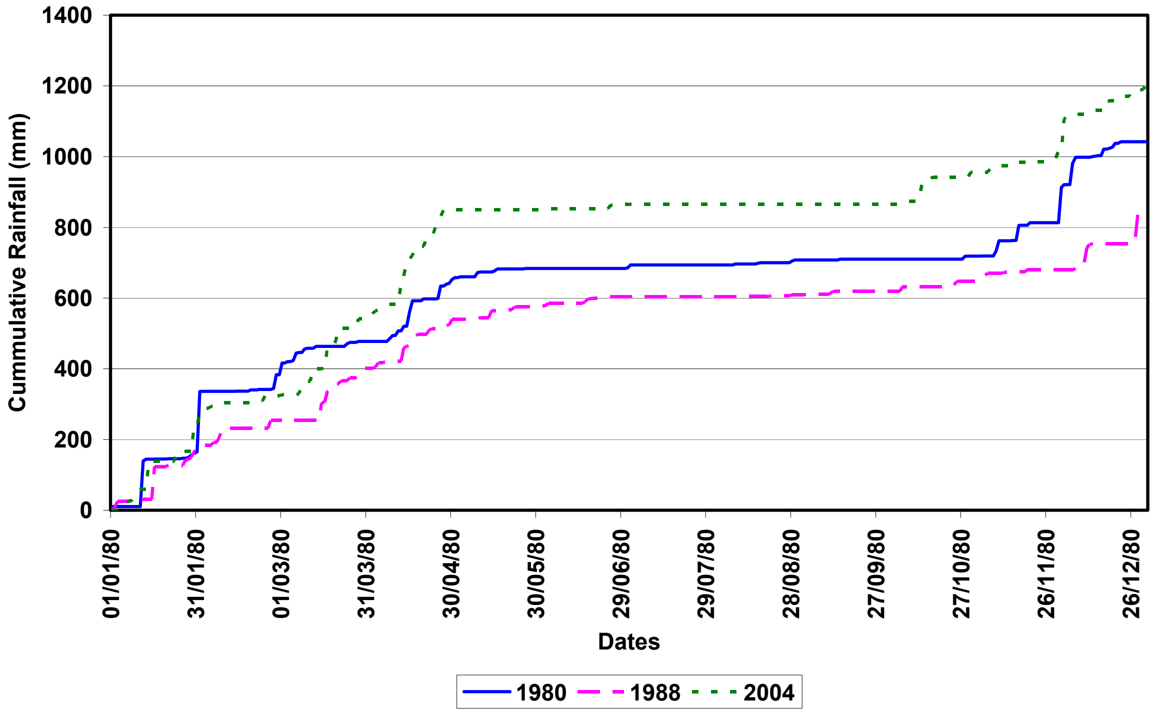

Figure 3. Cumulative rainfall at Wami Prison weather station for 1980 and 1988 analogue years for year 2004 and the actual cumulative rainfall at Wami Prison for year 2004.

For the Morogoro weather station, there is significant deviation between the actual year (2004) and analogue years. The deviation was caused by the analogue years to under-predict the daily rainfall. The pattern is likely to over-predict maize yield. The annual cumulative rainfall in the actual and analogue years are more or less the same (about 900 mm); however, the rainfall pattern in the actual year during the season is far different from the patterns in analogue years as it can be seen in Figure 4.

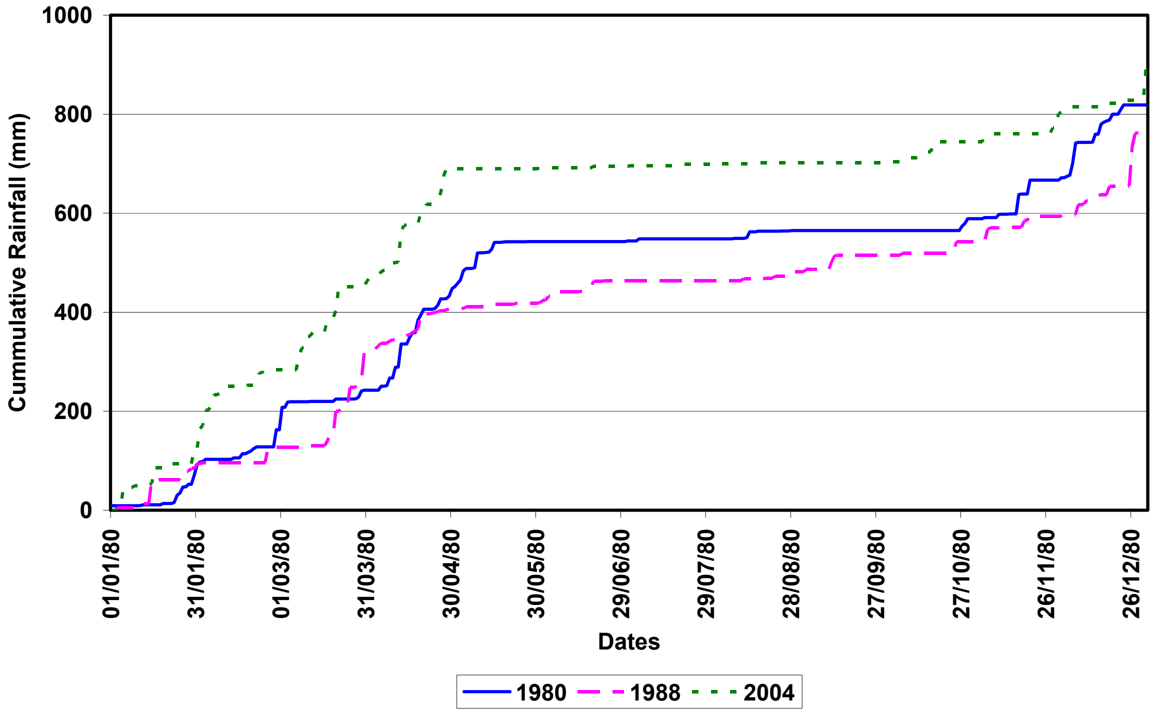

Figure 4. Cumulative rainfall at Morogoro weather station for 1980 and 1988 analogue years for year 2004 and the actual cumulative rainfall for year 2004.

Yield

Figure 5 shows simulated yields for Magadu and Wami stations for 1980 and 1988, which are analogue years for 2004 and the actual simulated yield for 2004. For the Wami case, yield in the actual year – 2004 (0.65 t/ha) deviate slightly from those in analogue years (0.1 t/ha from 1980 and 0.3 t/ha from year 1988), the average deviation (for the two analogue years) from the actual yield is then 0.2 t/ha; i.e. there is good correlation between yield in analogue and actual years as it is the case for rainfall. However, for Magadu site (Morogoro), deviation in yield between actual and analogue years is more pronounced (-0.64 t/ha from 1980 and +0.43 from 1988). This is justified by the difference in the rainfall patterns observed between actual and analogue years.

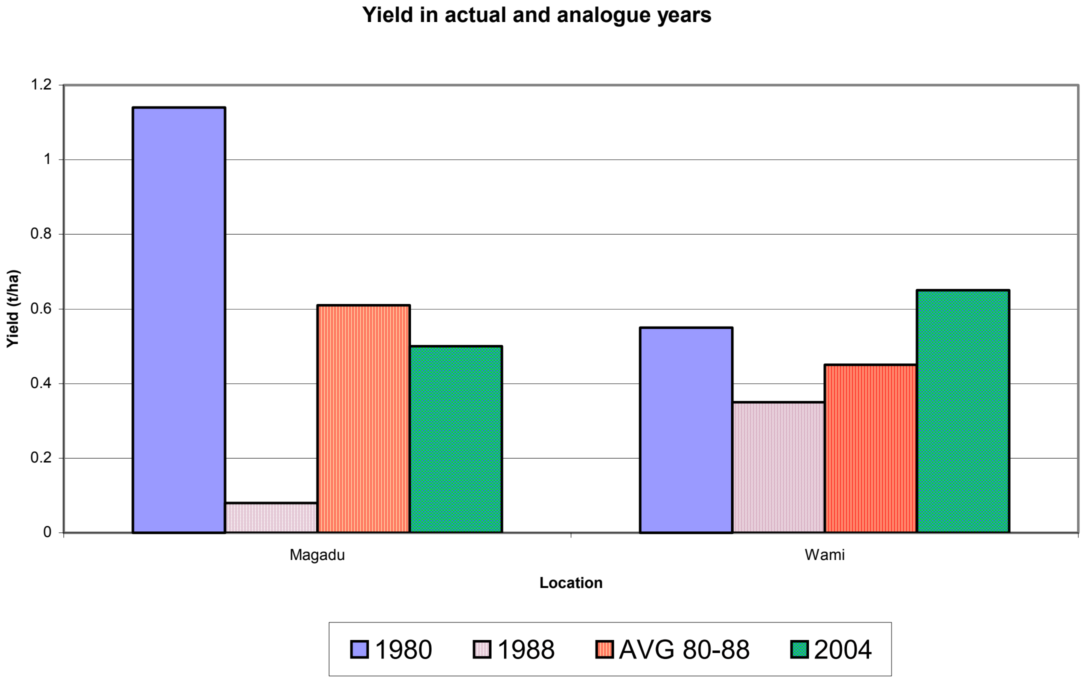

Figure 5. Simulated yields at Magadu (close to SUA-Morogoro weather station) and at Wami weather station for 1980 and 1988, which are analogue years for 2004 and the actual simulated yield for 2004.

Conclusions

From the above cases it is clear that the PT model has the potential of forecasting yields and thereby forecast production early enough to p[provide decision makers with anticipated food situation at the beginning of the cropping season as soon as seasonal weather forecast is released.

Since one of the methods used in seasonal forecasts focuses on analogue years to the year under forecast, the accuracy in yield forecasting depends on the degree to which rainfall patterns in analogue years resemble rainfall patterns in actual forecast years.

For different locations within the same agro-climatic zone, there exist variations in weather, especially rainfall as it can be observed for Magadu and Wami sites, which are 50 km apart, in Zone 1 (North-East agro-climatic zone). Thus seasonal rainfall forecast from analogue years for a given zone does not represent every location within the zone. Likewise, yield forecast based on analogue years do not apply to all localities within the zone.

Way forward

Further exploration is required by using as many analogue years as possible to test the potentiality of the PT model in yield forecasting as accurate as possible. From the findings above, the averaged yields from the two stations showed a better correlation than that from individual years and individual stations. It is accordingly recommended that this exercise should be extended to more analogue years to ascertain the promising results from the PT model. The extension could preferably base on a sample representing all existing agro-ecological zones in Morogoro region and the results averaged at district level.

It is envisaged that the forecasting process will go through crop production followed by food security situation. Yield figures arrived at as demonstrated above will be multiplied by crop area obtained through a different component and production forecasts. To forecast Food Security Situation one will need to accommodate food requirement parameters available from different components and food security status will be obtained as *P/R=SSR* expressed in percentage terms; where P= Production, R= Demand (All users), and SSR= Self-Sufficiency ratio.

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Appendix 1: Statistical data used for forecasting seasonal rainfall for March-April-May (MAM) 2004 in Tanzania, by Tanzania Meteorological Agency (Source: Mr. Mlaki of TMA).

year	zone1	zone2	zone3	zone4	zone5	zone6	zone7	zone8	zone9	zone10
1994	1422.4	399.4	240.3	404.1	387.8	53.5	427.9	494.6	169.3	316.5
1995	949.7	538.1	351	301.6	432.1	135.9	417.9	283.9	286.5	290.7
1986	902.7	584.8	585.9	333.7	384.9	119.7	381.4	291.3	317.6	190.1
1968	841.2	766.3	472	420.5	412.7	365.4	606.8	308.3	318.9	443.6
2002	794.6	415.2	452.5	415.7	601.8	77.6	562.7	211.9	444.1	417.9
1972	764.8	485.9	544.8	385.5	278.6	138.8	231.7	356.7	253.2	345.1
1984	753.8	278.7	541.8	270.4	191.3	181.4	193.4	279.7	209.8	225.2
1967	735.7	459.8	516.7	387.6	541.5	165.7	488.2	353.8	413.5	289.5
1963	719.6	552.7	354.3	341.0	673.6	65.2	430.4	318.7	301.5	331.4
1996	710.5	407.9	342.1	368.0	352.9	291.1	273	313.6	353.3	303.6
1983	707.6	286.5	494.4	346.2	634.7	135.5	285.3	228.4	270.5	267.8
1969	707.3	172.2	525.7	271.8	191.8	61.2	336.3	222.2	283.2	279.9
1976	695.4	249.6	519.4	325.7	223.5	205	333.3	335.1	378.2	421.2
1966	684.7	486.6	214	241.1	472.2	146.7	283.3	239.3	313.1	293
1978	672.1	917.1	817.9	463.9	348.1	184.9	273	272.9	351.3	522.3
1992	664.8	457.8	814.2	298.2	298.1	172.6	260.6	267.2	358.6	274.6
1979	658.3	941	379.5	504.1	611.8	116.1	253.3	466.8	211.4	428.9
1993	640.2	329.5	532.4	442.1	123.8	108.4	418.2	326.2	188.2	252.7
1998	633	590.1	361	275.0	421.9	128.6	496.6	293.8	269.0	368.7
1975	631.5	336.3	535.6	494.4	500.4	146.5	512.7	307	334.9	292.9
1999	624.4	342.3	461	485.7	448.2	292.8	425.5	562.5	346.2	353.6
2001	614	273.6	383.9	324.9	417.0	220.7	249.3	220.7	133.0	310.6
1997	567.9	581.1	542.3	117.8	550.9	107.3	606.1	233.1	386.7	306.3
1989	561.1	543.4	587	556.3	475.0	272.7	388	455.2	296.2	296.2
1964	553.7	688.7	380.9	250.3	537.7	166.5	484.5	223.1	391.7	397.6
1981	550.3	559.3	253	247.6	533.6	192.1	621	127.2	336.0	452
1977	525.4	343.7	282.3	362.4	400.0	85.7	488	230.3	395.6	412.1
1962	521.2	393.8	436.4	455.9	542.5	143.6	624.9	260.3	340.4	450.8
1973	500.1	163.2	298.2	576.1	222.5	136.4	175	236.3	309.2	299
1982	493.8	391.5	479.3	359.4	440.7	137.3	400.7	279.8	255.5	338.1
1987	485.3	327.6	228	315.6	351.7	235.1	380.5	170.3	308.3	311.7
1990	465.3	594.3	389.9	257.1	301.9	309.4	558.7	180.9	733.8	506.9
1974	459	332.2	553.7	390.7	455.2	281.5	380	307.9	599.2	558.5
1971	447	533.9	424.5	369.8	358.4	112.8	315	334	214.4	408.7
1991	445.6	280.8	787.8	501.1	320.0	147.3	401.2	268.3	128.8	269.2
1965	440.1	239	598.9	499.3	381.2	134.6	284.8	264.5	295.6	420.5
2000	439.3	221.5	489.7	321.3	329.2	204.4	133.1	247.9	240.8	244
1985	433.8	409	284	197.2	503.4	114.8	471.9	289	342.6	246.7
1970	387.4	377.7	224.8	310.5	477.8	190.8	536.7	282.1	345.4	416.1
1988	366.2	305.5	362.3	172.6	407.1	201.7	567	384.4	352.3	342
1980	334.6	348.1	559.1	570.9	407.4	355.7	428.5	332.4	358.6	270.1
1961	267.9	246.1	612.1	431.3	360.4	137	386.6	308.9	202.4	244.6
2003	266.1	276.7	149.1	331.2	139.6	76.9	418.6	203.5	275.5	373.9

AN	25	25	35	35	25	35	35	25	35	25
N	40	40	40	40	40	40	40	40	40	40
BN	35	35	25	25	35	25	25	35	25	35