Maize yield simulation under rain-fed and rainwater harvesting systems Using Parched-Thirst model

Siza. D. Tumbo, Thadeo. Mpulila, Omari. B. Mzirai, Henry. F. Mahoo,
Filbert. B. Rwehumbiza, Johnson. R. M Semoka, Nuhu Hatibu
Soil Water management Research Group, Sokoine University of Agriculture, Morogoro,
Tanzania: E-mail: swmrg@suanet.ac.tz or swmrg@yahoo.co.uk

Abstract

Simulation models can be used to analyze site-specific effects of rainfall and rainfall patterns and the analysis thereafter used to advise farmers on the best farming systems and appropriate planting dates. At district and national level, simulation models can be the best estimators of crop yields compared to traditional survey methods. PARCHED-THIRST model, which is an agro-hydrological simulation model for maize, rice, sorghum and millet, was used to predict maize yield under both RWH and rainfed farming systems. Data set on soils and crop yields in the RWH system, in Mwanga district, was obtained through physical survey and interviews with farmers. The second set of data on soils and crop yields for rainfed system was provided by the Phosphate Rock Utilization project at Sokoine University of Agriculture in Morogoro, Tanzania. Weather data were obtained from Tanzania Meteorological Agency and by an NGO in Mwanga District. Results of simulation showed good agreement between simulated yields to measured yields under both RWH and rainfed conditions. For example, for 2001 cropping season, maize yields were 0.4 t/ha and 0.41 t/ha for measured and simulated yields, respectively. For RWH system yields were 0.93 t/ha and 0.95 t/ha for reported yields and simulated yields, respectively, under micro-catchment RWH system in 2003. Simulation for different planting dates showed that planting dates in rainfed systems in Morogoro district are quite unreliable, however; there is a good chance of obtaining good yields with early to mid February planting.

Key Words: Agro- hydrology simulation models, modeling, crop models, rain-fed systems Rainwater harvesting system, maize yield simulation, Parched-Thirst model,

Introduction

PARCHED-THIRST model, which stands for Predicting Arable Resource Capture in Hostile Environments During The Harvesting of Incident Rainfall in Semi-arid Tropics, is a process-based model, which combines the simulation of hydrology with growth and yield of a crop. PARCHED-THIRST model is an integration of PARCH model (a crop growth simulation model) and THIRST (a rainwater harvesting simulation component). The THIRST component was added to PARCH model with the aim of including the effect of rainwater harvesting on crop yield (Young and Gowing 1996). The anticipation during development phase of the THIRST component were to assist to design the most appropriate system given site characteristics that might be useful in optimizing predicted crop yields; and act as a tool for technology transfer both from researchers to the farmers and from location to location (Matthews and Stephens 2002). In general crop models also can be applicable in assessing the influence of crop managements on crop yields; such influences are on planting dates, weeding, and plant population. An extension of capability of PT model is its usefulness in investigating the influence of weather variability, effect of land water management, and soil variability on cereal crops yield, which most of other crop models are lacking.
Some reviewers suggest that crop models are not valid for use beyond the specific set of conditions for which they were designed (Stephens and Middleton, 2002). At their best, their outputs are only relevant to the conditions that were used to calibrate them. Others say that; most crop models are developed for strictly defined hypothetical production situations with uniform fields. When they are then used in real field conditions where several limiting factors

may occur simultaneously, they fall outside of their domain of validity. Therefore, evaluation of models under various conditions is very important. The original PARCH model was validated using data obtained from various parts of the world by the developers of PARCH (Bradley and Crout 1994). This was in addition to an independent evaluation, which was carried out in Kenya (Stephens and Hess, 1999). However, an independent validation of PARCH-THIRST model has never been done.

Proper crop yield estimation is critical for any country especially where it has to estimate food deficit/surplus and therefore plan for import/export strategies. Within a country, import/export strategies means one region with food surplus can export its surplus food to another district, which is facing food shortage. With advances in weather forecasting, soon crop simulation models will start to be used in yield forecasting in Tanzania. This will have a significant impact to meteorological departments/agencies that instead of providing only weather forecasting, the departments/agencies will be able to provide yield forecasts in collaboration with Ministries of Agriculture.

Therefore, the main objective of this study was to validate the PT model using maize yields. Specific objectives of the study were (i) to compare measured maize yields to simulated yields under rain-fed conditions and (ii) to compare measured maize yields to simulate yields under rainwater harvesting conditions.

Materials and Methods

Location of study area

Two case study sites in Tanzania were selected and used for this study. The sites are Kigonigoni in Mwanga District where RWH is being practiced and Magadu in Morogoro where mainly rainfed agriculture is being practiced.

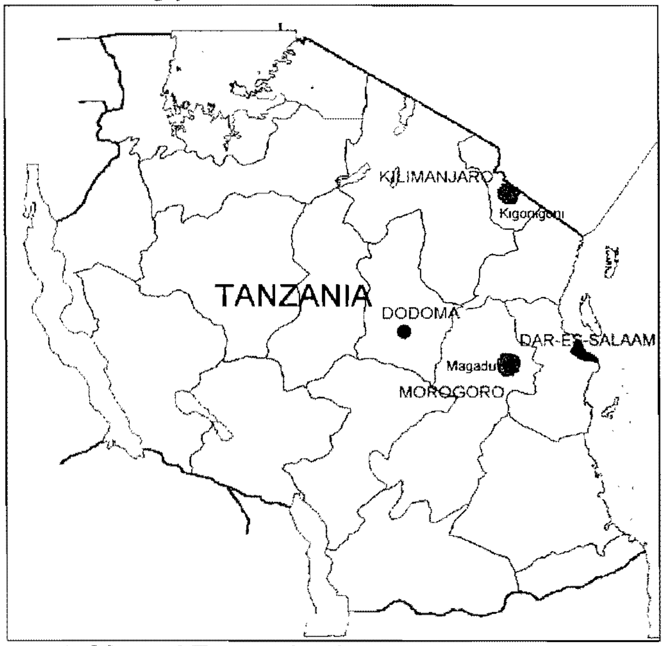


Figure 1: Map of Tanzania showing the case study sites

Kigonigoni Site

This study area is located in the semiarid plains of the Eastern Pare Lowlands (EPLL) in North-Eastern Tanzania. The area lies between latitudes 3° 21'and 4° 42' South, and longitudes 37° 10' and 38° 32' East. The altitude ranges between 600 – 700 m above mean sea level (Figure 1). Rainfall distribution is bimodal, with the first season, starting in late October to January (locally known as *vuli*). This season has a mean rainfall of 360 mm. Long rains, locally known as *Masika*, occurs between February and May with mean rainfall of 460 mm.

The area is characterized by rolling plains with Silty Clay soils of relatively low fertility formed on the basement complex rocks of the Pare Mountains (Hatibu *et al* 2002).

Magadu Site

The study area is located between latitude 6°.85' South and longitude 37° 64' East and at an elevation of 568 m above sea level. The field site is located at the foot slopes of the Uluguru Mountain (Figure 1).

Rainfall distribution is bimodal with the first season (normally with short rains) starting from November to January and the second season (long rains) starting from February to May. The annual rainfall ranges between 800 and 950 mm. The area is characterized by Kaolinitic clay soils, which are well drained.

<u>**Data collection**</u>

Soil data

Soils at Kigonigoni were silty clay (Hatibu *et al.*, 2002) while those at Magadu were mostly clay type (Semoka, 2003). The model estimated saturated hydraulic conductivity from the soil texture and dry bulk densities of both soils using the Campbell (1985) method.

Weather Data

Daily rainfall, pan evaporation, maximum and minimum temperatures, relative humidity, wind run and solar radiation data were obtained from Tanzania Meteorological Agency (TMA) for Same and Morogoro weather stations. Since the Magadu site is very close to the Morogoro weather station, Morogoro weather data was used directly in simulating Magadu maize yields. However, Same station and the Kigonigoni site are about 50 km apart with Kigonigoni having rainfall data only. Therefore, this study used rainfall data obtained at Kigonigoni and pan evaporation, maximum and minimum temperatures, relative humidity, wind run and solar radiation from Same station.

Yield and other Field Data

At Kigonigoni the maize yields for the 2003 *Masika* season were obtained through interviews with farmers of the specific fields indicated in Table 1. The other parameters collected together included cropping areas, catchment areas, slopes in the catchment and cropping areas. The cropping and their respective catchment areas are also shown in Table 1. Slopes in the field and catchment areas were estimated at 2% and 40%, respectively. To reduce bias in the reported data, average values were used to simulate maize yield as shown in the last row in Table 1.

Table 1. Estimated catchment areas, cropping areas and their corresponding reported maize yields for the 2003 season at various fields in Kigonigoni.

Field area name	Catchment area (ha)	Cropped area (ha)	Yield (t/ha)
Kitunga	20	10.0	1.00
Kitunga	5	5.0	0.60
Koana	5	4.0	0.90
Ngolala	30	15.0	1.20
Average	**15**	**8.5**	**0.93**

Yield and field characteristics at Magadu were obtained from Semoka (2003). Maize grain yields were colleted for 4 consecutive years i.e. 1999, 2000, 2001 and 2002 from the absolute control plots of the Rock Phosphate Utilization Project. Yield and planting dates are shown in Table 2.

Table 2. Planting dates and average maize yield at Magadu site from 1999 to 2002 cropping seasons.

Year	Planting date	Yield (t/ha)
1999	9/March/1999	0.6
2000	5/March/2000	0.3
2001	7/March/2001	0.4
2002	1/March/2002	0.1

Source: Semoka, (2003)

Rainwater Harvesting and Rainfed Systems Simulation Scenarios

Using soil and weather data for the year 2003, the following simulation scenarios were investigated: (i) micro- catchment RWH (ii) micro-catchment +in-situ and (iii) rain-fed conditions. For the rainfed scenario soil and weather data for the years 1999, 2000, 2001 and 2002 were used. Rainfed simulations included auto-simulation and semi-auto simulation (where the model was allowed to predict the optimum planting dates), and manual simulation where planting dates were fixed as they were planted during the actual experimentation. Then simulated maize yields were compared to measured for both rain-fed and RWH cases. These simulations were also useful in explaining different soil-water-plant relationships.

Results and Discussions

Rainfed Simulation Scenario

Simulated maize grain yields and planting dates

Planting dates for long rains in Morogoro is between mid-February and the first week of March. Simulated maize yields for different dates from 1999 to 2002 are shown in Figures 2a to 2d. Figures 2a and 2c shows much better yields compared to Figures 2b and 2d regardless of the planting dates. For the years with good yields, such as 1999 and 2001, the earlier the planting dates the better. For 1999, the yields obtained when the planting dates were between 1st February and 5th March averaged at around 0.6 t/ha and after 5th March the yields dropped drastically. For 2001, yields dropped drastically and almost linearly from 0.9 t/ha to 0.6 t/ha for planting dates between 1st February and 20th February. The yields even dropped further from 0.6 t/ha to 0.2 t/ha for planting dates between 20th February and 1st March.

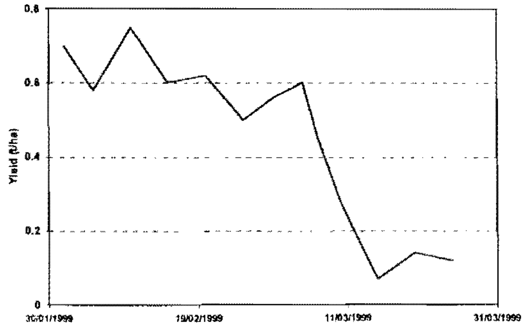


Figure 2a. Simulated yields at different planting dates in 1999

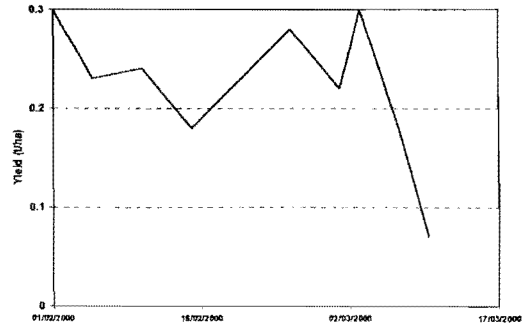


Figure 2b. Simulated yields at different planting dates in 2000

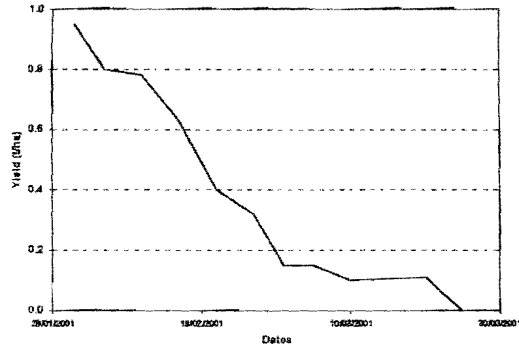


Figure 2c. Simulated yields at different planting dates in 2001

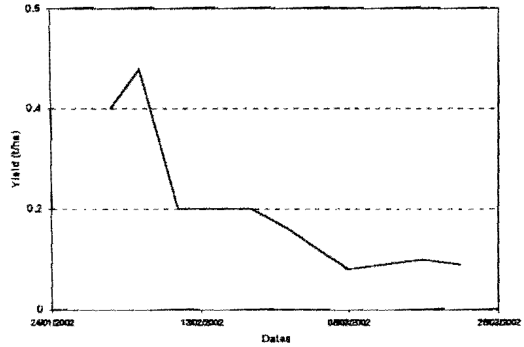
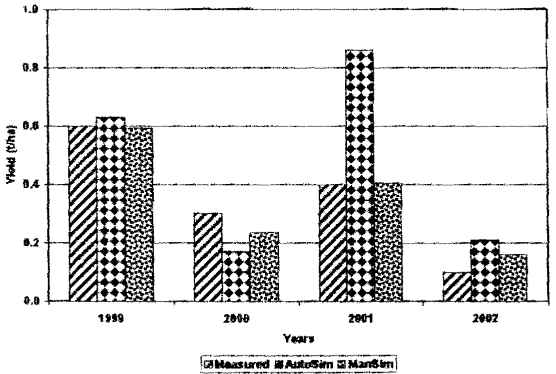


Figure 2d. Simulated yields at different planting dates in 2002

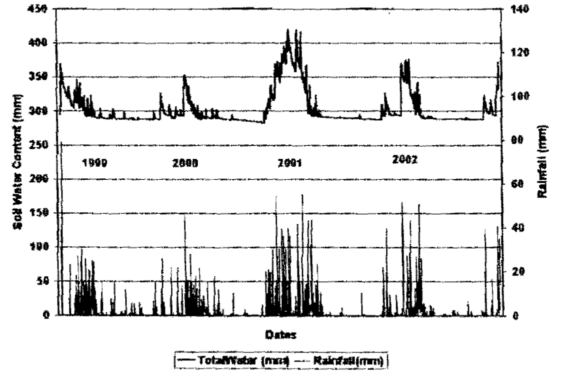
The analysis above suggests that for better maize yields the best planting dates for Magadu area and possibly Morogoro District is third week of February instead of first week of March. The information effect of yield on planting date obtained above is an indicative that the model can be useful in predicting the proper planting dates of a particular location.

Comparison between measured and simulated yields

Figure 3 shows measured and simulated maize yields for Magadu site. Maize yields under *AutoSim* simulation means the PT model is allowed to pick the best planting date based on the amount of moisture in the soil. Conversely, *ManSim* simulation yields are average yields obtained from yields simulated using six different planting dates between 10th February and 5th March, which is the window within which maize planting is done. Temporal yield averaging allows smoothening of individual effects such that the average yields obtained are more representative of actual yields. The temporal smoothening can be related to spatial smoothening done on measured yields in the sense that several replications are used to obtain representative yields for measured yields.



3. Measured, auto simulated and averaged simulated yields from 1999 to 2002



4. Actual daily rainfalls and PT-based soil-water balance from 1999 to 2002

In each case, the simulated conditions were closely marched to the experimental conditions. In *ManSim* simulation where the actual planting dates were fixed, the simulated yield results agreed well with the experimental results as observed in Figure 3. For example, in 1999 average simulated maize yield is 0.59 t/ha while the measured is 0.6 t/ha. Similarly, the same can be observed for the years 2000, 2001 and 2002 where simulated yields are 0.23 t/ha, 0.41 t/ha and 0.16 t/ha and the measured yields are 0.3 t/ha, 0.4 t/ha and 0.1 t/ha, respectively. Almost the same can be observed between *Measured* and *AutoSim* with the exception of yield in 2001. The higher yields obtained in the *AutoSim* can be explained using Figures 2c and 4. In figure 2c,there was a possibility of obtaining yields of up to 1.0 t/ha if maize seeds were planted in early February. Figure 4 shows that the higher yields obtained in 2001 were due to good rains obtained during the short and long rainy seasons and the shorter dry spell between the two rainy seasons.

Furthermore, Figure 4 shows that good short rainy seasons are frequently followed by good long rainy seasons. However the short rains for 2000 and 2002 were very poor compared to the short rainy seasons in 1999 and 2001. This means observation of short rain is a good indicator of the long rains in Morogoro. However, the amount of data used to reach this conclusion is very limited to make any significant conclusion.

Rainwater Harvesting Simulation Scenario

Measured and Simulated yields in RWH systems

Table 3 shows results between yields (as reported by farmers) and the simulated yields using the PT model. The two simulated scenarios used to capture two farmers' RWH practices included micro-catchment RWH (with crop cover such as lablab) and the second practice is micro-catchment RWH (without crop cover). Simulated conditions (weather, soil and crop data) were set to match closely to those under farmers' conditions that were practicing RWH. Results in Table 3 shows good agreement between simulated (0.83 t/ha) and the reported yields by farmers (0.93 t/ha) in micro-catchment RWH practice with no cover crop. In the case of micro-catchment RWH with cover crop, the simulated yield was 0.93 t/ha while that reported by farmers was 0.95 t/ha. The results support the argument that PT model can be used to predict maize yields under rainfed as well as micro-catchment RWH systems

Table 3. Average and simulated yields.

Description	Catchment Area (ha)	Cropped Area (ha)	Yield (t/ha)
Reported yields by farmers	15	8.5	0.93
Micro-catchment (with no cover crop)	15.	8.5	0.83
Micro-catchment (with crop cover)	15	8.5	0.95

Figure 5 shows the effects of type of RWH system and planting date on yield. The results show that, micro-catchment rainwater harvesting with crop cover gave higher yield compared to other RWH systems. Micro-catchment system only came second followed by crop cover only for yields before 8th February 2003 but micro-catchment and crop cover only had similar yield outputs after 8th February 2003. A comparison between RWH (micro-catchment with crop cover) system and conventional farming; indicated that there is yield increase of 120 % and 71% for maize planted on 1st February and 25th February 2003, respectively. This shows the advantage of RWH over conventional tillage. Another observation is that the peak yield for maize planted before 8th February are lower compared to those planted after 8th February. It can therefore be assumed that the best planting dates for 2003 season were between 20th and 25th February 2003. Therefore, the PT model can be used as a tool to analyse previous season yields as well as estimate yields under various RWH systems

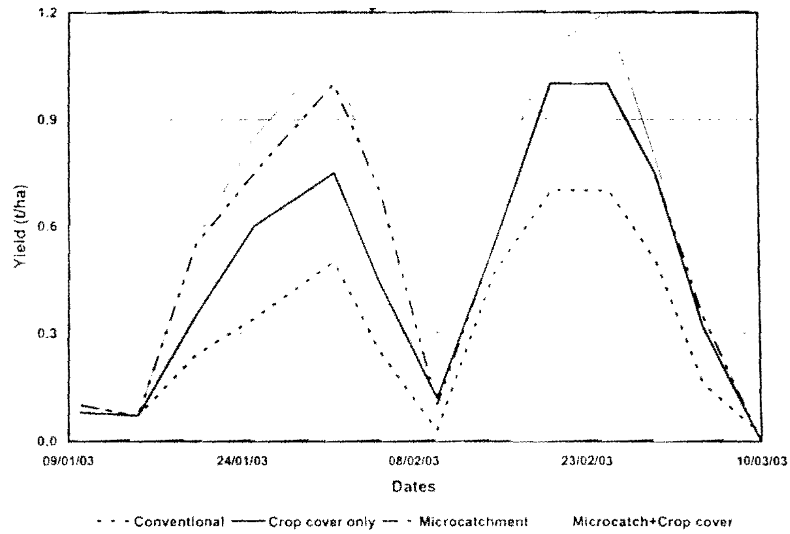
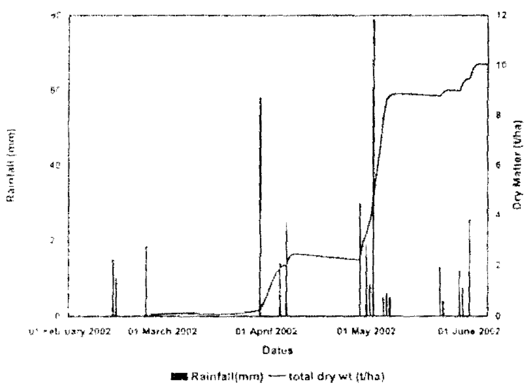


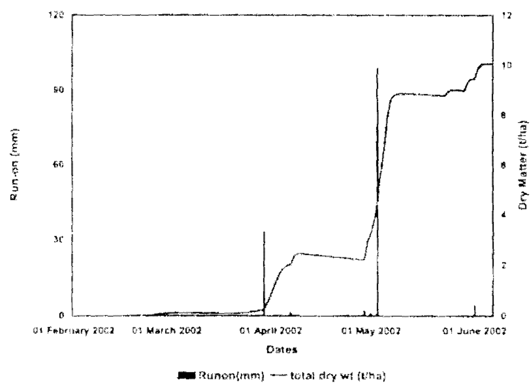
Figure 5. Effect of RWH systems and planting dates on maize grain yield.

Figures 6a shows rainfall events during the growing season and corresponding total dry matter accumulation. It can been seen that all drastic yield increase are associated with rainfall events, which means water is the more limiting factor in crop growth in most sub-Saharan Africa. Figure 6a further shows three different periods of dry spells. The first and third dry spells showed no decrease in dry matter (i. e dry matter content remained constant). However, the second dry spell, somewhere between April and May, showed decrease in dry matter.

The PT model also has the potential to show how run-on contributes on dry matter accumulation in maize, this is shown in Figure 6b where the run-on infiltrates into the cropped basin, thus increasing the amount of water available to the plants, which contributes to dry matter formation and accumulation in the plants. The dry matter accumulated is directly related to the amount of run-on into the cropped area.



a. Rainfall events and accumulated dry matter accumulation.



b. Runoff events and accumulated dry matter accumulation.

Conclusions

The model has predicted/ forecasted yield well on both conditions (Rain-fed and Rainwater Harvesting Conditions. It has also managed to explain the effects of crop management especially planting dates on yields. In addition, the model has been able to deliver different Plant-Soil-water relationships, such as run-on and accumulated dry matter, Rainfall and dry matter accumulation on both conditions, and rainfall and soil water content. The challenges we are facing are on easy access of the quality (weather, yield and soil) data, availability of trained personnel, hardware, software and technical support. A positive opportunity is that there is an enthusiastic community in modelling and use the model. Therefore the model is highly recommendable to potential users i. e. MAFS, TMA, District councils and NGOs.

Reference

Bradley,R.G., and Crout, N. M. J. 1994.PARCH-User Guide. Sutton Bonnington, U.K. University of Nottingham

Campbell, G. S. 1985. *Soil Physics with BASIC. Development in Soil Science,14.* Amsterdam:Elsevier.150pp.

Hatibu, N., Young, M. D. B., Gowing, J. W., Mahoo, H. F. and Mzirai, O. B. 2002. Developing improved dry land cropping systems in semi-arid Tanzania. Part One: experimental evidence of the benefits of rainwater harvesting for maize. *Experimental Agriculture* 39: 297 – 292

Matthews, R. B., and Stephens, W. 2000. Crop – Soil Simulation Models, Application in Developing Countries, CABI Publishing

Semoka, J. R. M. 2003. Research Report for 2003 (Progress report No. 10), Rock Phosphate Project, Department of Soil Science, Sokoine University of Agriculture, Morogoro, Tanzania

Stephens, W. & Hess, T. M. 1998. Modelling the benefit of soil water conservation using the Parch model-a case study from arid regions of Kenya *Journal of Arid Environments* (1999) 41: 335 – 344

Young, M. D. B and Gowing, J. W. 1996 *The PARCHED-THIRST Model User Guide* (v1.0) Department of Agricultural and Environmental Sciences, University of Newcastle-upon- Tyne, Newcastle-upon-Tyne