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Designing a rainwater harvesting system for crop production using the PT Model: A case study of a field in Makanya village, Same District for Same district.

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Designing a Rainwater Harvesting System for Crop Production Using the PT Model: A Case Study of a Field in Makanya, Same District

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Introduction

Background

Rainwater harvesting (RWH) refers to the concentration, collection, storage of rainwater runoff for both domestic and agricultural use. This definition implies that the catchment area from which the water is drawn in most cases is larger than the cropped area. RWH systems for crop production can be categorised into three groups: in-situ, micro-catchment and macro-catchment. The in-situ RWH involve capturing water where it falls. In the micro-catchment RWH, the main source of water is an external catchment and the distance from the catchment area to the cropping area is negligible. The catchment area is relatively small and the climate of the two areas is considered the same. Macro-catchment RWH is very similar to micro-catchment but the transfer distance is relatively large (sometimes more than 10km) and therefore, the climate of the catchment area and receiving area are in most cases different.

The amount of runoff water, from the catchment area, in RWH system is a function of rainfall amount and intensity, the size of the catchment area, slope of the land and soil and surface characteristics. The ratio of catchment to command area is inversely related to the amount and intensity of rainfall, the impermeability of soil, and the slope of the land on which it falls. Rainfall intensity is particularly important, since intense storms generate high amounts of runoff. The above parameters are site-specific in the sense that the topographic characteristics are different from one location to another and so is the rainfall amount and intensity. Since these parameters are site-specific then the ratio between the catchment area and cropping area is not a fixed number.

Farmers in Makanya village in the Western Pare Lowlands (WPLL) are practicing all the three types of rainwater harvesting. For those practicing micro- and macro- catchment RWH to a larger extent they know the importance of having a large catchment area compared to the cropping area but they don't have a tool to allow them to decide on the sizes of the catchment areas that will be optimum for their cropping areas.

Therefore, the main objective of this case study was to determine the optimum catchment area for a farmer's field in Makanya, who is practicing macro-catchment RWH using the PARCHED-THIRST model.

Description of the PT Model

PARCHED-THIRST stands for Predicting Arable Resource Capture in Hostile Environments During the Harvesting of Incident Rainfall in the Semi-arid Tropics. 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) or catchment area and runoff receiving areas (RRAs) or cropping area. 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 model is comprised of a number of components as shown in Figure 1.

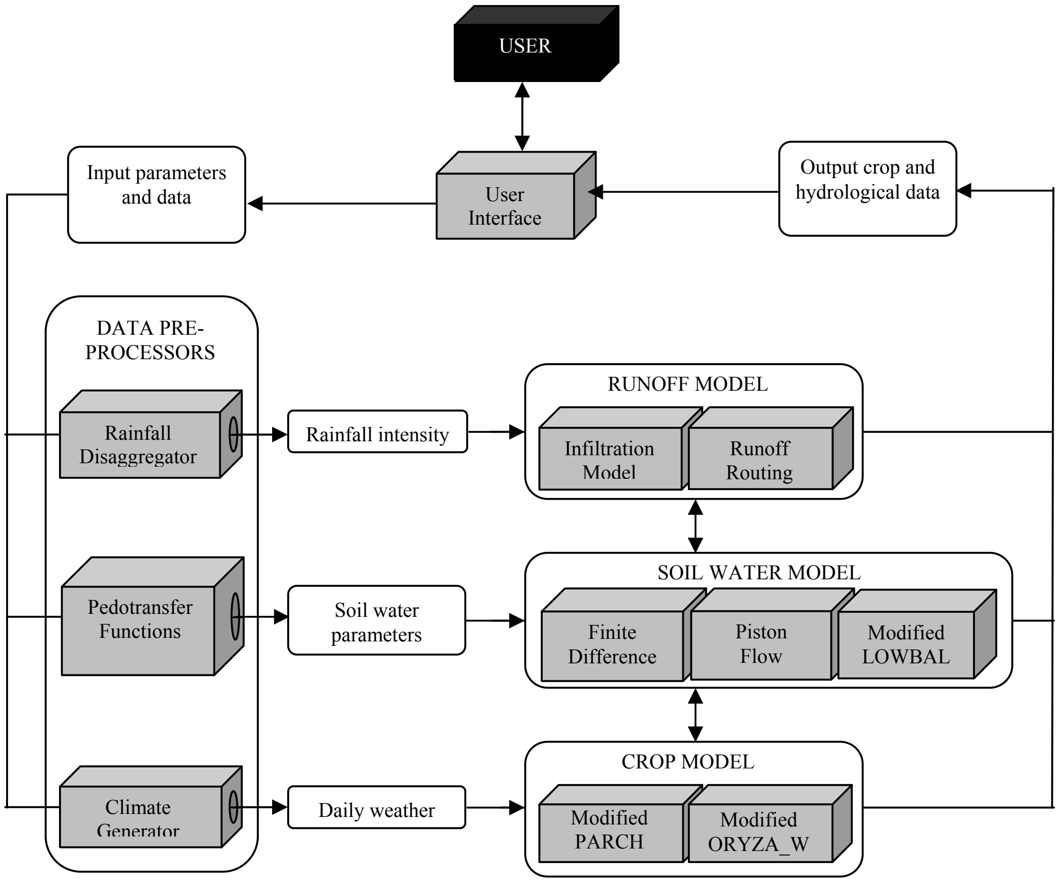

Figure 1: Interaction between the components making up the PARCHED-THIRST model.

Methodology

Location of the Study Area

The study was carried out in Makanya village, in the Western Pare lowlands, Same District, Kilimanjaro region. The village is located within the Makanya river sub catchment at latitudes $4^0 8'$ and $4^0 25'$ South and longitudes $37^0 45'$ and $37^0 54'$ East. The area is generally regarded as Semi-arid (Figure 2)

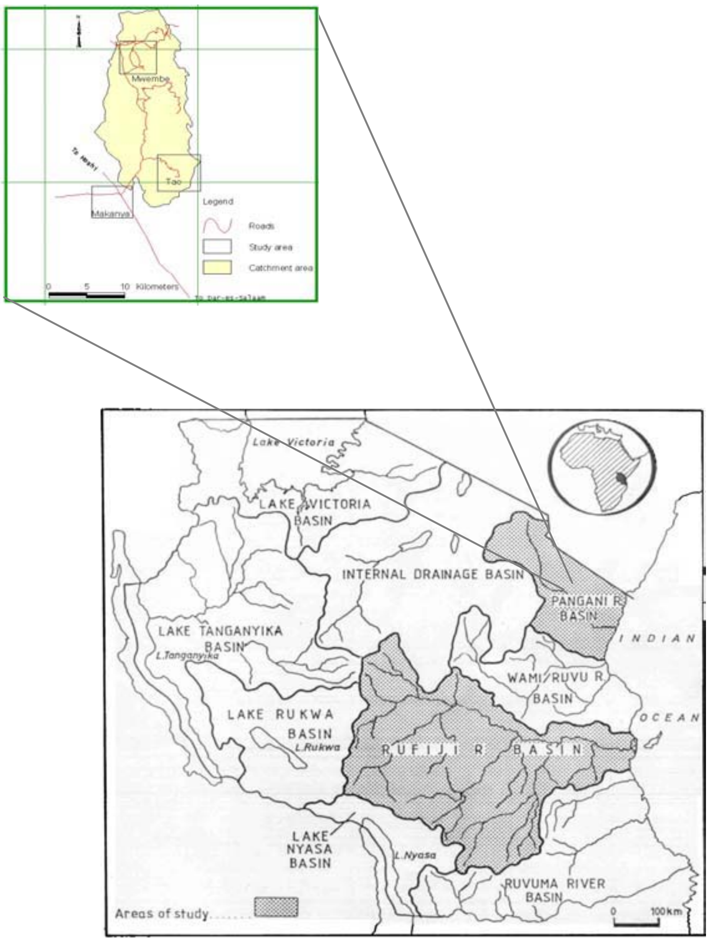

Figure 2: Map of Tanzania showing location of Chome-Makanya catchments
(Source: SWMRG, 2003)

The village lies along the Moshi – Dar es Salaam highway, about 140 km from Moshi town.

Climate

This area has two rainy seasons. The first season - *Masika* - starts from mid March to the end of May. The second season - *Vuli* - starts in early October and ends in February. The long-term average annual rainfall is 400mm. This rainfall is unevenly distributed and in most cases erratic. Due to the nature of the rainfall the area experience long dry spells during the growing season. The dry spells cause reduction in crop yield or total crop failures. On average the rainfall received is not enough to meet water requirements for maize crop. The temperature varies from 15 ^{0}C during cold seasons to 32^{0}C during hot seasons. Wind speed is very high (up to 200 km/day) from September to February before the start of *Masika* season; which increases evapotranspiration.

The role of RWH

The soil types found in Makanya village and suitable for crop production are mainly sandy loam, and clay. The crops grown are mainly maize, and lablab beans, whereas cotton, sweet potatoes, cowpeas, and pigeon peas are grown in small scale. Most of these crops are produced using RWH techniques. Runoff generated in the highlands, is diverted by the farmers (in the lowlands) into their crop fields. More runoff diversion is made from side road dams and culverts, footpaths and livestock routes.

Therefore different forms of water harvesting are common in this village, but the highest potential lies on external catchment RWH systems. At Makanya village the potential area currently receiving runoff from external catchment is more than 550 ha. This area is divided into three classes of suitability for RWH, depending on the easy availability of runoff (Mbilinyi *et al*, 2003). The green part is receiving significant amount of runoff water from upstream compared to the light yellow part. In general, some fields in the light yellow part are only cultivated if significant amount of runoff is received from upstream. When enough runoff is received, which happens rarely, runoff is diverted into storage structures such as “charco-dams” for livestock uses, underground water tank for domestic use and irrigation of horticultural crops.

There is room for improving the RWH practices by farmers in Makanya village. Currently, the diversions are ad hoc and sometimes resulting into conflicts. It was for this reason that it was felt that the PT model can be used to assist in the design of the rainwater harvesting systems.

Figure 3 and 4 show the field that the model was used to determine its required catchment area. The field consists of underground water storage tank and above ground water tank. The above ground tank is supposed to receive water from the rooftop while the underground tank is supposed to receive water from the same catchment area required to feed the field/cropping area.

Figure 3: Photograph showing a portion of the case study field and water harvesting structures and PT Help office investigators.

Figure 4: Photograph showing a wider view of the case study field and PT Help office investigators.

Data collection

The data required for the purpose of this study included soil profile, size of the study areas, climate and types of crops grown. Soil samples were analyzed to give the full picture of soil type in the study area. Climate data for this area was collected from the Same meteorological office. The crop variety used was maize TMV1. In order to determine the sizes of the cropped and the catchment areas, a topographic survey using GPS was conducted. Soil survey was also done by analyzing and determining the soil texture and organic matter content. The plan view of the surveyed area is shown in Figure 5. The map is showing six distinct areas: (1) farm under development (1.3 Ha), (2) underdeveloped farm (1.7 Ha), (3) current catchment area (13 Ha), (4) 1st future catchment area (41 Ha), (5) 2nd future catchment area (13 Ha), and (6) track reserve.

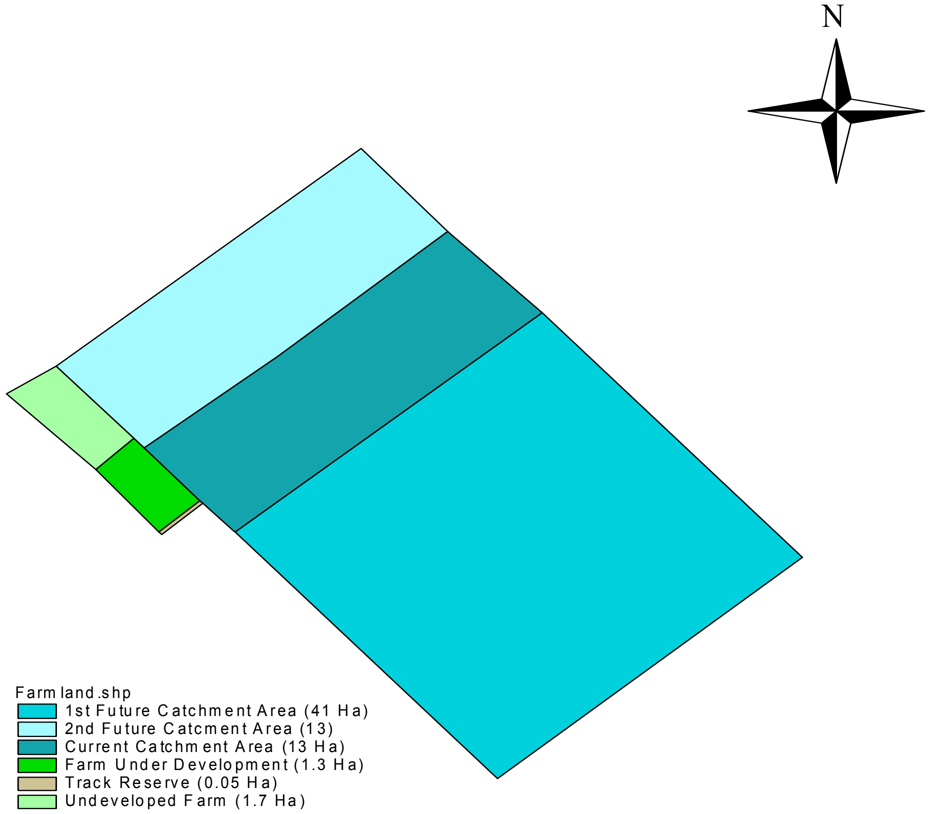

Figure 5. Plan layouts of a case study farm and catchments.

Simulation of different RWH scenarios

The field under consideration belonged to a farmer, who is also the village agricultural extension officer. His initial development includes a cropped area of 1.3 ha receiving runoff from a catchment area of 13 ha. His future expansion is to have 3 ha of cropped area with an external catchment of 67ha (Figure 5). Therefore, the challenge in this case was to advise the farmer on the appropriate size of the catchment area and cropping area. This led to the following questions being asked: should the farmer maintain the current catchment area and cropping area? Or should the catchment area be increased to satisfy the cropping area? Or should the cropping area be increased to match the catchment area? Therefore, these questions set the scene for the simulation scenarios (different sizes of catchment area) for 1.3 and 3.0 ha cropping areas. The scenarios are summarized in the Table 1.

Table 1: Simulation scenarios for the current cropping area of 1.3 ha and 3.0 ha.

Scenario	Catchment area (ha)	Description
1.	13	Current catchment and cropping area.
2.	26	Addition of a smaller catchment area (17 ha).
3	45	Consideration of an ideal area 45 ha.
4.	55	Combination of the current catchment area and 1st future catchment area
5.	67	Consideration of all the catchment areas (67 ha)

Rainfed system simulation was also performed in addition to macro-catchment RWH. Normally, farmers believe that there is insignificant yield of maize production is under rainfed only. Since most farmers apply crop cover, the simulation also considered this by reducing soil evaporation by 20%. Figure 6 and 7 show representation of rainfed and RWH harvesting simulation in the PT model, respectively.

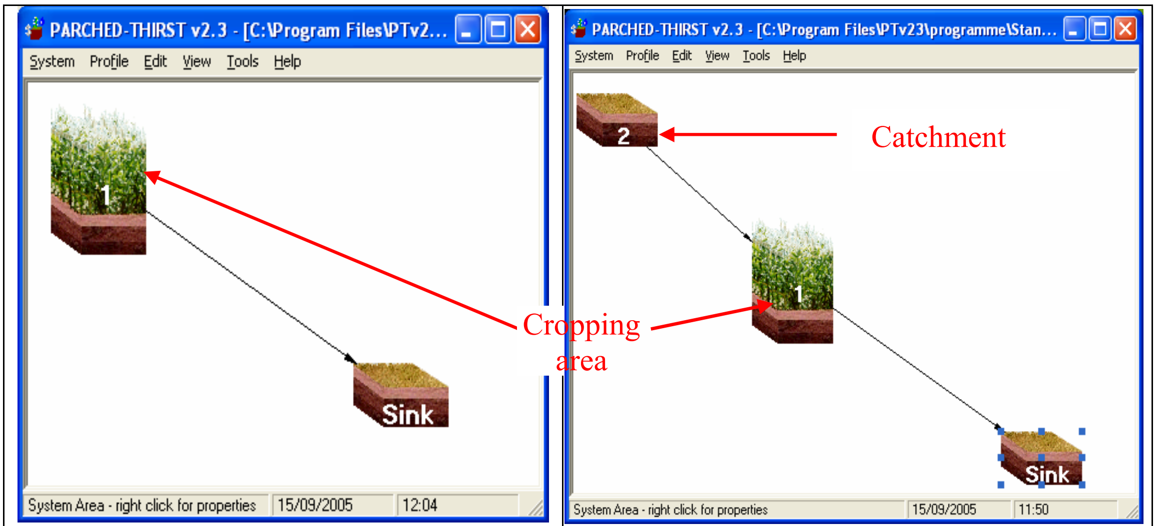

Figure 6. Representation of a rainfed system

Figure 7. Representation of RWH system

Weather Data

The weather data of four years, 1998 to 2001, was used for simulation. The data was obtained from the Same meteorological station, which has similar rainfall pattern as that at Makanya village. The required weather data for crop simulation in the PT model include daily rainfall, evaporation, minimum and maximum temperatures. Since rainfall is an important parameter fro crop production is discussed further here. Figure 8 shows cumulative *masika* seasonal rainfall for the four years of simulation. The window, March – April – May also known as MAM, is one of the two rainfall seasons. The other season is the *vuli* season, which covers September to December window. With respect to *masika* season, years 1998 and 1999 received rainfall above 250 mm and therefore relatively higher yield is expected compared to years 2000 and 2001.

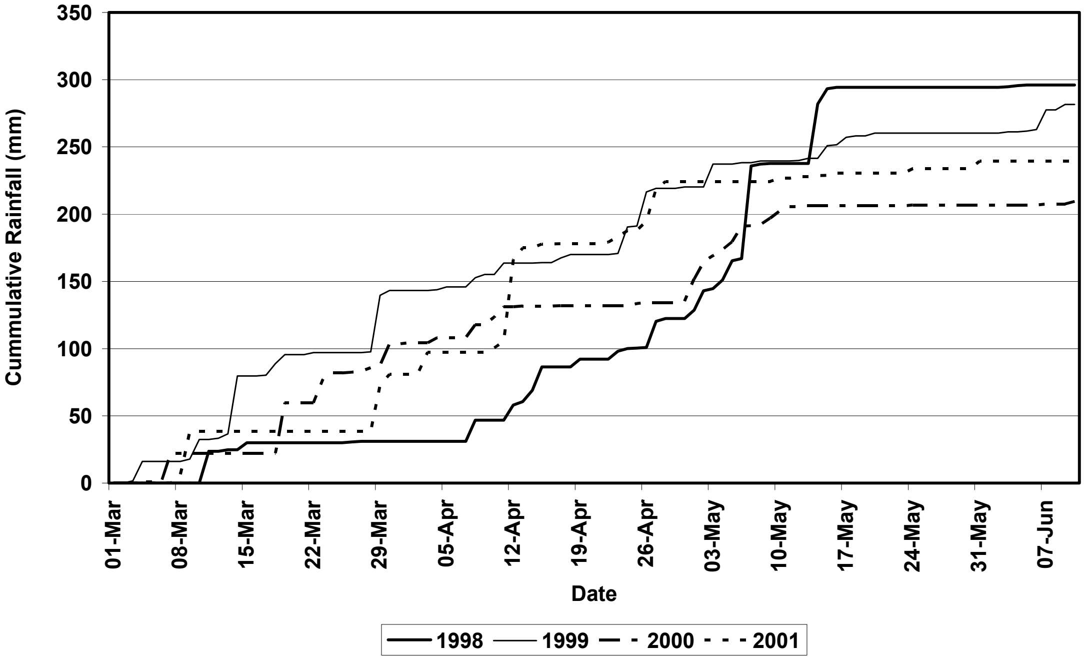

Figure 8: Cumulative rainfalls for four years of simulation computed using daily rainfall data from Same weather station.

Results and Discussion

Maize Yield under Rainwater Harvesting

Cropping area of 1.3 ha

Figure 8 and 9 show yield response, in rainwater harvesting system, to the changes in the catchment area for the *masika* and *vuli* seasons for a 1.3 ha cropping area. *Masika* of 1998 and 1999 and *vuli* of 2000 had higher maize yields compared to *masika* of 2000 and 2001 and *vuli* of 1998 and 1999, which resulted into insignificant yields. With the exception of *vuli* of 2000 and to some extend *masika* of 2001, other seasons did not respond to the changes in the catchment area. This might imply the catchment area as being too large for the cropping area; therefore, the cropping area needs to be increased to match the catchment area. Conversely, *vuli* of 2000 responded to the change in the catchment area as maize yield showed to increase with increase in the catchment area up to 45 ha. Therefore, the optimum catchment area suggested in this case is 45 ha.

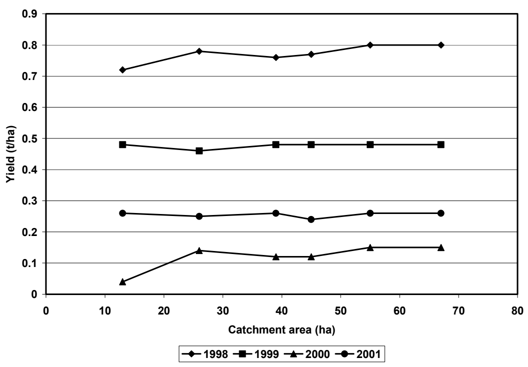

Figure 9: *Masika* simulated maize yield under different catchment areas for a 1.3 ha cropping area.

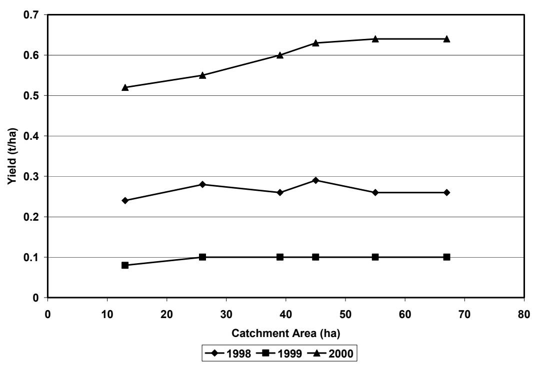

Figure 10: *Vuli* simulated maize yield under different catchment areas for a 1.3 ha cropping area.

Cropping Area of 3 ha

Figure 11 and Figure 12 show yield response with increase in the catchment area when the cropping area is increased to 3 ha. *Masika* of 1998 and 1999 and *vuli* of 1998 and 2000 responded to the changes in the catchment area. The four seasons show increase in yield with increase in the catchment area. The optimum catchment area is achieved between 40 and 45 ha. Therefore, the ratio of catchment area to cropping area is 40:3 or 45:3, meaning ratio of 13:1 or 15:1 will be optimum for the farmers in the area with similar catchment characteristics.

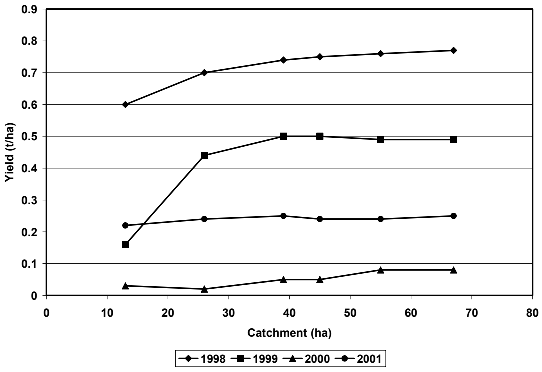

Figure 11: *Masika* simulated maize yield under different catchment areas for a 1.3 Ha cropping area.

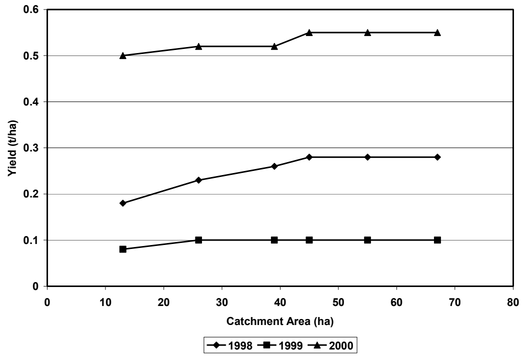

Figure 12: *Vuli* simulated maize yield under different catchment areas for a 1.3 Ha cropping area.

Simulation of the rainfed system

The simulation results for the rain fed scenario (Table 1) shows very low maize yields. The results indicate that the yields in *vuli* season are far lower than in the *masika* season. This proves farmers' statement that crop production without water harvesting leads to zero yield or very little yield. *Masika* maize yield in 1998 and 2000 were highest and lowest, compared to the rest of the years, respectively. The yields agreed very well with the received rainfalls as shown in Figure 8

Table 2. Maize yield (t/ha) in rainfed in the 1.3 ha cropping field.

Year	***masika***	***vuli***
1998	0.41	0.06
1999	0.20	0.22
2000	0.11	0.09
2001	0.13	-

SUMMARY AND CONCLUSION

This study explored the use of PT model in determining appropriate sizes of the catchment area and cropping area for farmer's field in Makanya village. The assessment involved simulation of the several options that had been explored by the farmer, which included increasing the current cropping area and catchment area. The study found that:

- The current cropping area of 1.3 ha is not enough for the current options of the potential catchment areas.
- The idea of increasing the cropping area to 3 ha seems to be the best option since the required catchment area is between 40 and 45 ha. The available catchment area is about 67 ha.

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