

SOKOINE UNIVERSITY OF AGRICULTURE
R 8088A

Parched-Thirst v2.1 Help Office and Upgrading to v2.2¹

Annex A.1

SOIL-WATER MANAGEMENT RESEARCH GROUP

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Abbreviations and Symbols

AE	Agricultural Engineering
AICAD	African Institute for Capacity Development
APSIM	Agricultural Production Systems Simulator
ASARECA	Association of Strengthening Agricultural Research in Eastern and Central Africa
BACAS	Bureau for Agricultural Consultancy and Advisory Service
BASIC	Beginners All-Purpose Symbolic Instruction Code
CLUWRR	Center for Land Use and Water Resources Research
csv	comma separate values
DADP	District Agricultural Development Plan
DAELP	Department of Agricultural Engineering and Land Planning
DFID	Department for International Development
DMC	Drought Monitoring Center
DSSAT	Decision Support System for Agricultural Technologies Transfer
ECA	East and Central Africa
GIS	Geographic Information System
GMWD	Generators of Missing Weather Data
GO	Governmental Organization
GUI	Graphical User Interface
HTML	The Hypertext Markup Language
IMTR	Institute of Meteorology Training and Research
KUL	Katholieke Universiteit Leuven
MAFS	Ministry of Agriculture and Food Security
MIFIPRO	Mixed Farming Improvement Project
NGO	Non-Governmental Organization
NRSP	Natural Resources Systems Programme
ODBC	Open Data Base Connectivity
PT	PARCHED –THIRST
RELMA	Regional Land Management
RPA	Runoff Producing Area
RRA	Runoff Receiving Area
RWH	Rainwater Harvesting
SAIPRO	Same Agricultural Improvement Project
SCS	Soil Conservation Service
SEARNET	Southern and Eastern Africa Rainwater Harvesting Network
SIAC	Statistics in Agricultural Climatology
SS	Soil Science
SUA	Sokoine University of Agriculture
SWMnet	Soil-Water management Research network
SWMRG	Soil-Water Management Research Group
TMA	Tanzania Meteorological Agency
USDA	United State Department of Agriculture
WARFSA	Water Research Fund for Southern Africa
WMO	World Meteorological Organization
WPLL	Western Pare Lowlands

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1 INTRODUCTION

1.1 Background

Over a period of 8 years, the Natural Resources Systems Programme (NRSP) funded the development of the PARCHED-THIRST (PT) software. The software was planned to be a support tool for planning and managing rainwater harvesting (RWH) systems as means to improve the integrated management of rainwater resources. PARCHED-THIRST, 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 (Young *et al.*, 2002). By 2001, the PT software had a first generation user-friendly version. However, there was limited use of PT as a decision support aide even though the level of awareness of the efficacy of RWH for crop production had established a modest potential demand for this software in Eastern Africa. Therefore, there was a need to facilitate both the availability and use of PT, targeting researchers and planners in government organizations (GO), non-government organizations (NGO) and private sectors who are working, or demanding information on RWH.

PARCHED-THIRST software is an integration of PARCH software (a crop growth simulation software) and THIRST (a RWH simulation component). The THIRST component was added to PARCH software with the aim of including the effect of RWH on crop yield (Young and Gowing, 1996). The anticipation during development phase of the THIRST component was to assist design of 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 farmers and from location to location (Matthews and Stephens, 2002). In general, crop models can be applicable in assessing the influence of crop management on crop yields as affected by planting dates, weeding and plant population. An extension of capability of PT 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. Furthermore, 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 district/region with food surplus can export its surplus food to another district/region, which is facing food shortage. With advances in weather forecasting, crop simulation models have started to be used in yield forecasting. This has a significant impact to meteorological departments/agencies such as the Tanzania Meteorological Agency (TMA) and the Department of Food Security and Early Warning in the Ministry of Agriculture and Food Security (MAFS) that instead of providing only weather forecasting, the departments/agencies would be able to provide yield forecasts.

Therefore, the project was aimed at facilitating the availability and use of the PARCHED THIRST software v2.1 by potential users. It was anticipated to improve awareness on the potential of the software as well as providing advice and help to target users. The project was supposed to collect feedback from a wide cross-section of users and on the basis of these improve and upgrade the software to meet the needs of a wide cross-section of users. In addition, the project was supposed to promote and build capacity of target clients especially TMA and District Agricultural and Extension officers. Furthermore, the project was required to facilitate establishment of a sustainable HELP office at SUA to support use of the software in the long-term.

1.2 Rationale

Water has long been considered to be the main limiting resource for crop growth in semi-arid sub-Saharan Africa (SSA). Although water is limiting, it is often the distribution rather than lack of total seasonal amounts of rainwater that is affecting crop growth and final yields (Baron *et al.*, 2003). Therefore, the main constraint is poor management of rainwater. One solution of augmenting soil-water for plant growth is through RWH. RWH for crop production is therefore practiced by resource poor farmers in the semi-arid areas of Tanzania in order to alleviate shortage of soil-water. However, there are inadequate means and tools for optimizing planning and benefits from this technology. The purpose of the project was to contribute in filling this gap by facilitating a wide use of the PT software as a planning and decision support tool for water use allocation by planners and policy makers.

For effective use and application of the software, the target users require some technical support (Mathews *et al.*, 2000). This project was therefore designed to provide such support to target users in Tanzania and the Eastern and Southern Africa sub-region. The need for this kind of support was identified by a number of studies (e.g. Fry, 1996, Stephens and Hess, 1996 and Kebreb *et al.*, 1998) who showed that adoption of previous models has been very limited. However, only limited attempt has been made in the past to pro-actively support the users, obtain feedback on problems faced by them, and then up-grade the model to remove these constraints.

1.3 Objectives

The main objective of the project was to promote the use of the PT software in planning wider development of RWH systems at District and National levels. The specific objectives of the project were:

- To promote PT use and identify clients needs for further improvement of PT software.
- To improve the PT software to become more user-friendly.
- To validate the PT software.
- To determine and implement strategies that will make the use of PT software more sustainable.
- To promote PT through collaborative development of case studies and virtual experiments with relevant stakeholders.

2 THE PARCHED-THIRST SOFTWARE

PARCHED-THIRST software 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 1) as described in the following sub-sections.

2.1 Data Preprocessors

Climate generator: PT software 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 software 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 software 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 software uses soil texture and bulk density information to generate these hydraulic parameters in case they are not available.

2.2 Soil moisture modeling

Accurate soil moisture accounting is vital for both runoff and crop growth simulation. PT software provides a choice of three simulation components, which are:

One-dimensional finite-difference: Based upon the PARCH model (Bradley and Crout, 1994) the soil-water balance module in PT software uses a finite-difference solution to Richards equation as described by Hillel (1977). It also includes a simple, two-parameter macropore flow model based on Jarvis *et al.* (1991) which allows for bypass flow of infiltrated water from the top layer of the soil under saturated conditions.

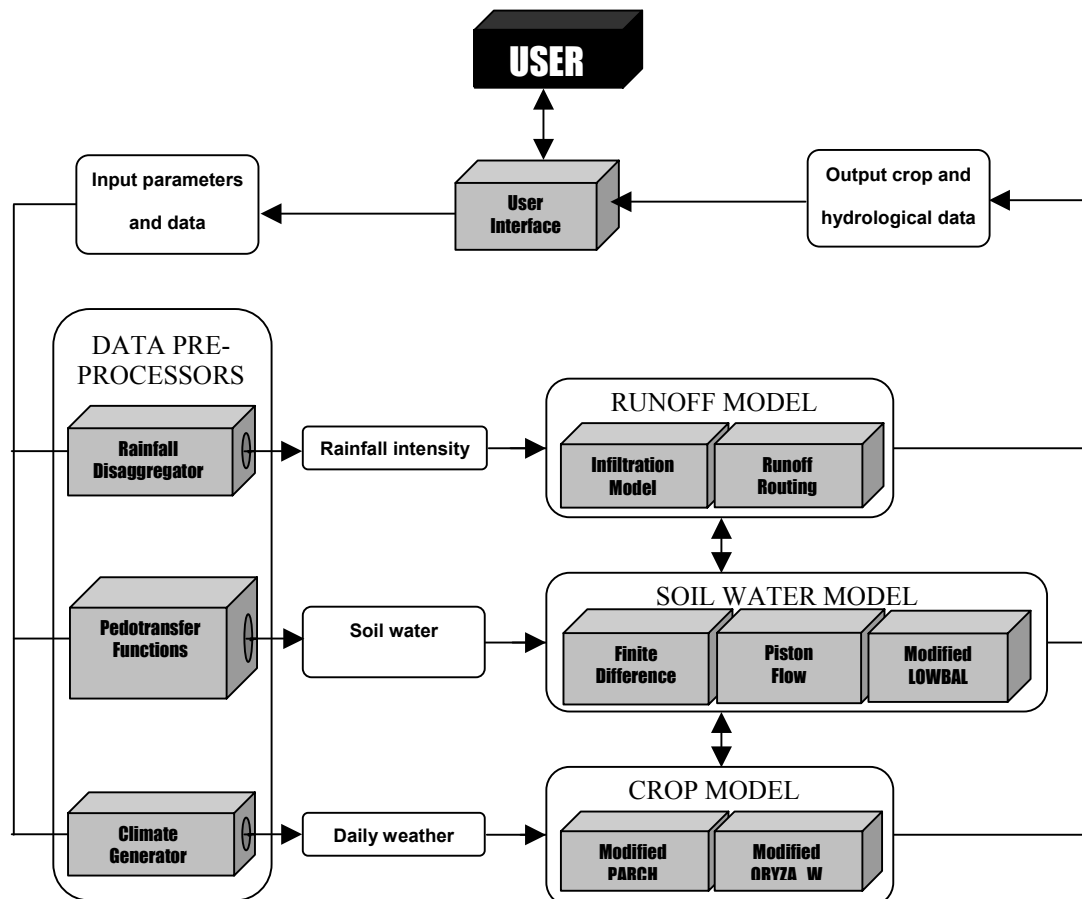


Figure 1 : Components making up the PARCHED-THIRST software

Piston Flow: In wet coarse textured soils, the finite-difference method can underestimate the observed speed of water through the soil profile (van der Meer, 2000). PT software includes a modified version of the finite-difference approach, which includes piston flow (van der Meer, 2000), to allow water to move from one layer, through any intervening layers whose water content is greater than or equal to field capacity, into the next closest layer with a water content lower than field capacity layer. This enables a better match to the speed of movement of water in wet, coarse textured soils.

Lowbal: PT software has been designed to model a number of RWH systems including those growing under rainfed, lowland rice as found in the Lake Zone of Tanzania. For these systems, where rice is grown in puddled soils above an impenetrable layer and groundwater is deep, the LOWBAL model included with ORYZA_W (Wopereis *et al.*, 1996) is suitable. The LOWBAL is a simple one-layer soil-water model, which simulates the shrinkage and cracking of the puddled layer.

2.3 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).

Depression storage: Depression storage can be either permanent for structures such as bunds around rice fields or temporary for tillage-induced relief. Temporary depression storage is calculated from random roughness using an approach described by Mwendera and Feyen (1992). Random roughness tends to decrease after tillage due to the effects of rainfall and wind. In PT, the reduction with time is modeled as a function of cumulative rainfall (Zobeck and Onstad, 1987).

Surface Sealing: The development of a soil crust or surface seal can dramatically reduce infiltration (and thus increase infiltration excess). Rawls and Brakensiek (1989) present a relatively simple crust factor, which is used to modify the hydraulic conductivity of the surface of the soil. As crusts reach a stable state very quickly (usually after approximately 0.5cm of rain), the development of a crust with time is ignored.

Runoff routing: Estimation of runoff rates is important for erosion risk assessment. On larger catchments, runoff lag times can be significant. Runoff routing is accomplished using the USDA-SCS synthetic unit hydrograph with the time of concentration of the drainage basin calculated according to Kirpich (1940). One unit hydrograph is calculated for each interval determined by the input intensity data (normally 5 minutes) and these are added together to calculate actual runoff rate at any given time.

2.4 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.

PARCH Model: 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.

ORYZA_W Model: 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.

2.5 Modeling approach

PT software 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 software, both the usability and functionality of the software have been iteratively tailored to user needs through seminars and workshops in the UK and Tanzania (Young *et al.*, 2001). In modularization, PT 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 software 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 software 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 behavior 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 software and eases debugging, maintenance and further development.

3 METHODS

The methodologies used in this project aimed at achieving further improvement of PT software and identify strategies for sustainable use of PT software through assessment of clients’ needs. Therefore, three main types of activities were carried out; these are (1) promotion of the software and solicitation of clients’ needs for improvement of PT software, (2) improvement of the software and (3) implementation of strategies for sustainable use of PT and (4) uptake promotion of the PT software

3.1 Promotion and Evaluation of the Software

The process of getting feedback from clients involved promotion and distribution of the package using various means including mailing of PT CDs to clients, making the software downloadable through the internet and conducting various trainings, workshops and conferences. The following sub-sections detail the promotion and evaluation of the software.

Distribution of CDs to clients

In March 2002, 138 CDs containing PT version 2.1 were mailed and some given physically to clients together with questionnaires (Annex B1). Table 1 shows the typology of the clients and number of CDs distributed.

Table 1: Distribution of CDs to clients

Typology of the Clients	No.
District Agricultural and Extension Officers to targets areas	9
Irrigation engineers	8
Personnel working with NGOS in the targets areas	8
Government department working on agriculture and water resources	9
Agricultural research institutions	14
Rainwater harvesting (RWH) projects and organizations	14
Lecturers at Sokoine University of Agriculture (SUA) and University of Dar Es Salaam	13
Scientist/researchers working on different SWMnet/ASARECA network and countries	28
Scientists and researchers in international organization and networks	5
Participants who attended SIAC courses	10
Participants who attended PT launching workshop	22
Postgraduate students at Universities	4
Total	138

More details on people who received PT CDs such as their professions locations and addresses are shown in Annex B1. Approximately 10% of those who received the PT software CD by mail provided feedback (Annex B2).

Availability through the Internet

The software was made available initially at the SUA main website and later moved to Soil-Water Management Research Group (SWMRG) server. The Department of Agricultural Engineering and Land Planning (DAELP) server was later created and this forced the merging of the SWMRG server into DAELP server and therefore the software moved into DAELP server. Now the PT website has moved again to SUA server after the SUA administration agreed to host the software through the Computer Center. The new site is <http://www.suanet.ac.tz/cc/PTModel.html>. The software website contains contact mail and email addresses so that support can be provided. Mirror website has been established at the Katholieke University of Leuven (KUL) in Belgium, and the software can now also be downloaded from the following website:

http://www.agr.kuleuven.ac.be/vakken/IC03_IC04/runoffirri/PTmodel_download.aspx

Launching and distribution of the software at National level

The software was officially launched in Tanzania on 15th January 2002 by the Minister for Science, Technology and Higher Education Hon. Dr. Pius Ngwandu (MP) at the Institute of Continuing Education (ICE) SUA (Annex B15). A total of 60 participants and 15 journalists from various news media attended the event. In this event, the Minister issued CDs to the following:

- Director for Commission of Science and Technology,

- Director for Department of Research and Development, Ministry of Agriculture and Food Security,
- Director for Department of Crops Development, Ministry of Agriculture and Food Security,
- Director for Institute of Resources Assessment, University of Dar es Salaam,
- Director for Tanzania Meteorological Agency,
- Representative, United Kingdom Department for International Development (DFID) UK, and
- District Agricultural and Livestock Development Officers from Same, Mwanza, Njombe and Maswa Districts.

Launching and distribution of the software at sub-Regional level

At sub-regional level, the PT software was launched in Zambia on 2nd December 2001, during the Southern and Eastern Africa Rainwater Harvesting Network (SEARNET) conference. The conference was attended by 38 people from 10 different Southern and Eastern Africa countries, which included Kenya, Tanzania, Zambia, Botswana, Mozambique, Eritrea, Uganda, Ethiopia, South Africa and Zimbabwe. The Global Water Partnership, RELMA and the Government of Netherlands were also represented at the conference. Fifteen copies of CDs were distributed to representatives of the ten different countries, Netherlands representative and RELMA. Nearly all participants requested for copies and promised to send feedback on the software. The Southern Africa representatives requested to produce more copies of PT software and distribute to different organizations in South Africa and send the list of recipients to PT Help Office (Annex B3).

Promotion of the software through SWMnet

Major effort of promoting the software was through the SWMnet workshop, which was held from 28th – 30th October 2002 in Nairobi, Kenya. The background behind the workshop was that, models such as APSIM, DSSAT and PARCHED-THIRST have been developed or introduced, however, they are not widely applied (SWMnet, 2002). Therefore, one of the aims of the workshop was to initiate a process of articulating users' constraints. In the workshop, a paper on PT software was presented and CDs were distributed to participants. The participants came from 10 different countries in the East and Central Africa (ECA) sub-region.

Distribution of the software during SIAC training sessions

PT software CDs were also distributed during the training course on Statistics In Agricultural Climatology (SIAC) undertaken in 2001, 2002 and 2003 in Nairobi, Kenya. The participants were given brief training on how to use the PT software before being provided with manuals and CDs. The participants were from Kenya, Uganda, Madagascar, Rwanda, Egypt, Sudan, Niger, Mozambique and Ghana. Feedback from the course participants were collected from participants who attended the SIAC course.

Use of the software through courses taught at SUA

PT was used to develop virtual laboratory experiments for courses taught at Sokoine University of Agriculture (to both undergraduate and postgraduate students) as well as Ilonga and Uyole Agricultural Training Institutes. For SUA, courses included were CIT 200 Computing Applications; AE 116: Computer Applications for Agricultural Engineers; CS 201: Crop Physiology; CS 205- Annual Crops, SS 302: Land husbandry and Conservation Agriculture; SS 301: Soil Water Management and Conservation; AE 312-Principles of Hydrology; and Irrigation Scheduling. More courses could be included in the future.

PT software training

Five training were conducted in which CDs were distributed and participants asked to provide comments on the performance of the software. The first training and evaluation was conducted immediately after the national launching of PT software. The second training was conducted during a course on irrigation and water management, which was sponsored by the African Institute for Capacity Development (AICAD). All participants who attended the AICAD course were presented with PT software CDs. The third training involved six Rwandese scientists who were from the Ministry of Agriculture in Rwanda. The fourth training was given to District Agricultural Extension staff from Same and Mwangi Districts including staff from Traditional Irrigation Project (TIP) and Mixed Farming Integrated Project (MIFIPRO), which are working as NGOs in the two districts, respectively. The fifth training, which was also used to obtain feedback, involved staff from Tanzania Meteorological Agency and SUA.

Evaluation by external reviewers

Two reviewers with expertise in computer science evaluated the software at two different stages. The first reviewer evaluated version 2.1 of the PT software. The second reviewer evaluated PT version 2.3, which formed one of the inputs to the improvement of PT software to version 2.4.

Compilation of feedback

The feedbacks from the users were compiled depending on the issues raised. The issues were as presented in the questionnaire provided with the software CD and those distributed during the workshops. Another list of feedback was compiled from the reviewers' comments. The feedbacks were grouped into the following categories: user-friendly interface, programming, input and output data format, areas requiring further improvement, help, tutorials and general comments.

3.2 Improvement of PT software

Improvement of the software required understanding on the software in details taking into consideration feedbacks from the users and reviewers. This was achieved by using the following software: Visual Basic, Project Analyzer, Visustin, HTML Help Workshop and Wise for Window Installer. These are briefly described in the following sub-sections.

Visual Basic development environment

Visual Basic 6 development environment was used to modify and upgrade the codes of the PT software. Visual Basic has set of tools to simplify rapid application development for Microsoft Windows (Microsoft, 1999a). The "Visual" part refers to the method used to create the graphical user interface (GUI). The "Basic" part refers to the BASIC (Beginners All-Purpose Symbolic Instruction Code) language. Visual Basic has data access features, which allow creation of databases, front-end applications, and scalable server-side components for most popular database formats, including Microsoft SQL Server and other enterprise-level databases.

Project Analyzer for Visual Basic

Project Analyzer is a complete code review and quality control tool for Visual Basic (Avoisto, 2003a). Project Analyzer for Visual Basic is used to identify and remove problems, redundancy and dead codes. It provides recommendations for better coding style, and check for error prone places in the project, which means smaller and faster code with less errors. This tool was used to identify and remove the dead codes, identify areas which required error handling routine, documenting the codes and also understanding of the codes.

Visustin

Visustin is the software designed for Visual basic and other development environments for visualization of flow charts (Avoisto, 2003b). Visustin analyzes and visualizes single procedures

written in several languages and dialects, including VB.NET, C/C++, C#, Java and JavaScript. Therefore, Visustin was also used in understanding the codes, its basic function was to visualize the codes in the flow charts. It was used to check if the procedures were syntactically correct.

Microsoft HTML Help Workshop

The Hypertext Markup Language (HTML) Help Workshop is a help authoring tool with a graphical interface for creating project files, HTML topic files, contents files, index files, and everything else you need to put together in online help system or Web site (Microsoft, 1999b). Microsoft HTML Help workshop is designed to create help systems using source files based on HTML. With HTML Help Workshop, help systems can be created for distribution with a software program or as stand-alone systems on a Web site. HTML Help Workshop allows organization of different files that make up the content of the help system into a single project (.hhp) file, and to author HTML files with a text editor. Therefore, the HTML workshop was used to organize different help files and produce PT Help.

Wise for Windows Installer

Wise for Windows Installer is an installation development system for creating and editing Microsoft Windows Installer (MSI) installation packages (Wise Solutions, 2004). It is a complete and user-friendly front end for generating Windows Installer database files, which are executed by the Windows Installer engine. It is used to create installations that are compliant with Microsoft's Windows 2000 logo program. This is a Microsoft technology that provides a standard installation engine that can be used for the installation of any 32-bit or 64-bit Windows software product. Wise for Window installer was therefore used to create the "msi" installation file.

3.3 Validation of PT software

Two case studies at two different sites in Tanzania were used as the basis of validating the PT software. The sites are Kigonigoni in Mwanza District, where RWH is being practiced and Magadu in Morogoro, where mainly rainfed agriculture is being practiced. Figure 2 shows the Kigonigoni and Magadu sites. Detailed report on the methodologies used is given in Annex B4.

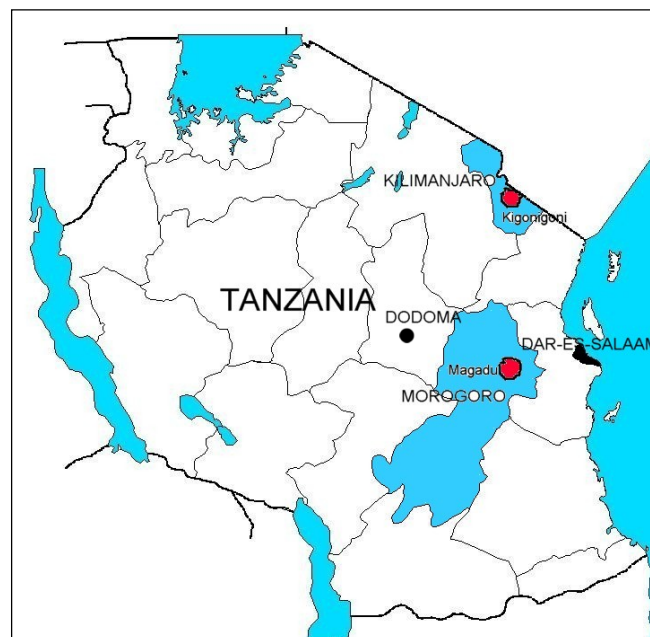


Figure 2: Map of Tanzania showing the case study sites.

3.4 Strategies for ensuring sustainability of PT software

The initial strategies for sustainability of PT were identified during proposal development, which included the establishment of PT Help office, establishment of short courses and linking PT software with the Bureau for Agricultural Consultancy and Advisory Service (BACAS) at SUA. The methodologies presented here refer to the establishment of the Help Office, establishment of short courses and linking PT software with BACAS at SUA.

Establishment of PT Help Office

The process of establishing PT Help office involved identification of a proper location for the office, staff, hardware and software. This was followed by furnishing of the office, recruitment of support staff, purchase of hardware and necessary software. It also involved determination of functions of the PT Help office, which are mainly help, support and advisory services.

Development of short courses on PT software

The process of establishing short courses and seminars involved of identification of training materials and its development, investigation of the areas of interest for different types of clients and methods of delivery.

Development of mechanism for linking the PT Help office to BACAS

Linking PT Help office to an existing University organ was important for its sustainability. The initial organ that was identified was BACAS. The linking process involved identification of the appropriate University organ for the linkage, awareness rising, training, involvement in the development of the software and negotiation with the identified organ.

3.5 *Development of Case Studies and Virtual Laboratory Experiments*

The uptake promotion of the PT software was done through development of case studies and virtual laboratory experiments.

3.5.1 *Development of case studies*

Case studies development involved two staffs from each of the following: Kilosa and Morogoro Districts in Morogoro Region, and Same District in Kilimanjaro Region; Ministry of Agriculture and Food Security (MAFS) Headquarters and Tanzania Meteorological Agency (TMA). The three districts were used to promote PT use at District level since the staffs at that level are the frontline extension staff, dealing with farmers and therefore they are more aware of farmers' production constraints. Specifically, Kilosa District was involved because the Ilonga Agricultural Research Institute is located nearby. This is the institute that developed TMV1, which is the only maize variety beside the local one in the PT software. Morogoro District was involved because that is where most of the validation data for the software was obtained, the Sokoine University of Agriculture is located and farmers are growing TMV1. The involvement of Same District was due to the fact that the district is very popular in rainwater harvesting, some staffs were involved during testing and preliminary use of the software and the climate is semi-arid. The involvement of MAFS and TMA was aimed at promoting the use of the software at National level.

In the process of developing case studies, those from the Districts were handled separately to those from TMA and MAFS. The reason being that the level of awareness on simulation models and exposure to PT software was different. Those staff from TMA and MAFS had more experience in the use of models compared to those from the Districts. In general most of the District-level staff had little experience in computers. Therefore, two training workshops on computer use and PT software were organized. The second training workshop was also used to introduce the issue of developing case studies. Participants were asked to identify a problem that they thought could make use of the PT software as a case study.

The training workshops were then followed with two write workshops (writeshops). A writeshop is a form of workshop designed and implemented in a way that fast-track the development of materials, revise and put them into final form as quickly as possible, taking full advantage of the expertise of carefully selected workshop participants. A typical writeshop brings together experts from diverse groups to develop a publication or materials on a given theme. The first writeshop was for drafting the case studies and identification of information gaps. The second writeshop was for finalizing the case studies. The period between the first and the second writeshop was used to collect additional information and evidence from the case study sites. The exercise involved field observations and discussion with farmers.

Development of case studies by TMA and MAFS also involved the use of writeshops. Two writeshops were organized with similar reasons as indicated for district-level staffs. The involved staffs were from the Department of Agro-meteorology and the Unit for Crop Monitoring of Early Warning Systems from TMA and MAFS, respectively.

In addition to case studies, communication products were also designed drawing information from the case studies. These communication products were in the form of posters. Posters were chosen over other types of communication media because they can be read easily and comfortably by many people.

3.5.2 Development of virtual laboratory experiments

Virtual laboratory experiments are experiments conducted using simulation models. The aim of developing these experiments were to strengthen student's understanding in simulating various agricultural systems with the expectation that after graduation they will be good advocates and users of simulation softwares and specifically the PT software.

The development of virtual experiments involved the Sokoine University of Agriculture (SUA) and two (colleges of agriculture (Ilonga and Uyole Agriculture Training Institutes (ATI)). Given the different levels of understanding and somehow application of simulation models, the two groups were handled separately in the process of developing these experiments. Since college tutors had limited knowledge on PT software and little experience in computers, two training workshops were organized for them in addition to two writeshops. The exercise also involved staffs from Ilonga and Uyole Agricultural Research Institutes (ARI). Therefore, the training and virtual experiments development for each college involved one tutor and one research from the respective areas.

In the case of SUA, development of virtual experiments involved staff from the Directorate of Computer Centre, the Departments of Agricultural Engineering and Land Planning, Crop Science and Soil Science. The target was to develop five virtual laboratory experiments. The design of the experiments also used a writeshop approach. This approach allowed the PT Help Office staff to interact with appropriate instructors and help them develop the virtual experiments in a short period.

4 RESULTS AND DISCUSSIONS

4.1 Feedback on Evaluation of PT software

Feedback on PT version 2.1 from Clients

This section presents a summary of the feedback obtained from clients on PT version 2.1. The feedback has been divided into four categories as follows. (i) Feedback obtained from the target users who received CDs and questionnaires; (ii) Feedback from PT workshops, (iii) Feedback from internet users and (iv) Feedback from the SIAC participants.

Feedback from users who received CDs and questionnaires

Responses from clients were based on the key issues raised in the questionnaire (Annex B1), which were:

- Experience of using simulation models
- PT software application
- Usefulness of the software to their work
- Problems experienced during running the software
- Suggested improvements

Most of those who provided feedback were lecturers, researchers and postgraduate students from different universities and research institutions with some knowledge and/or experience on different simulation models. Their initial response was that PT v2.1 is easy to install and run as compared to PT v2.0, and its welcoming screen is more user-friendly. On the issue of usefulness of the software, most of them commented that the software can also be used in environmental science and management in addition to RWH systems. Several problems were identified, which relate to smooth running of the software. Some of the problems identified included:

- Dialogue windows were wider than the size of their computer screen, which led to dialogue windows overflow to invisible areas.
- Crashing of the software during manipulation of data input without informing the user on the type of the problem encountered.
- The interface for new users always stopped and provided a message stating, “The model has performed illegal operation”. The statement was not providing any clue on the type of operation performed.
- Though there was an online help, there was still a need of linking the help in each dialogue boxes, so that users can quickly access the appropriate help.

Feedback from clients who attended workshops

Due to the problems of getting feedback from the mailed questionnaires, one PT training workshop and a special evaluation session were designed to review and get feedback on the performance of PTv2.1. The workshop was carried out immediately after the national-level PT launching and it included new users, who had not used the earlier version.

The workshop was attended by 11 participants with different professional background (Figure 3). Participants had computer knowledge but little experience in computer programming while the other six (6) had knowledge on some standard computer packages such as Microsoft word and Microsoft Excel. Only one participant had little computer knowledge.

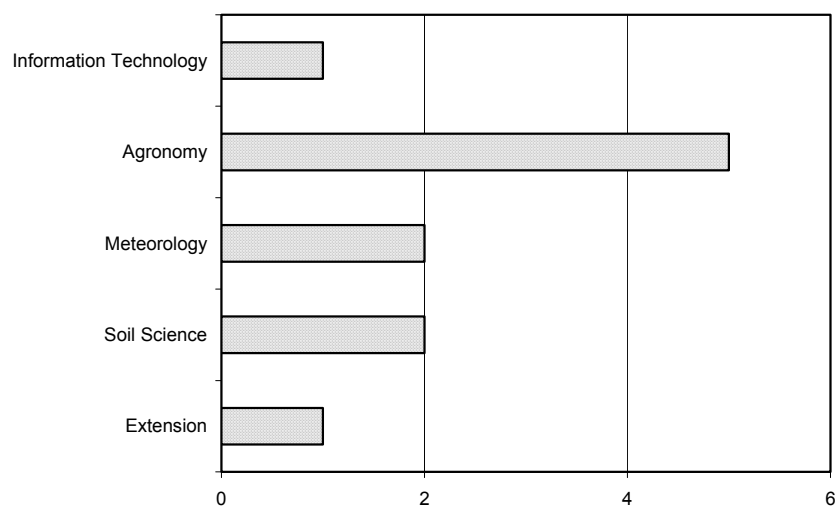


Figure 3: Field of specialization of the workshop participants

In the workshop, participants were required to install PTv2.1 in the computers, to go through the tutorial and the PT Wizard, which is for new users. At the end, participants were asked to provide feedback. The issues and responses raised by participants are shown in Table 2.

Table 2: Issues and Responses as feedback from workshop participants:

Issue	Response
Installation procedure	All participants responded that the installation procedure was easier compared to earlier versions.
HELP facility	10 participants out of 11 found it very useful.
User interface	10 participants, who had used the earlier version, commended on the new user interface as welcoming and guiding.
The Wizard	10 participants found it very useful. Only one participant commented that it is not very user friendly.
Output format	Participants suggested that the summary output should remain with two parameters i.e. grain and biomass yield.
Aspects for improvement	<ul style="list-style-type: none"> • Climatic generator needs to include some physical variables in addition to statistical behaviour of climatic variables. • More crops should be incorporated in the software to give users wide selection of crops.
General comments	<ul style="list-style-type: none"> • It is a good tool for planning and decision making especially in areas where RWH is practiced. • PT Training including knowledge in computers is highly required at various District levels.

- More professionals should be exposed to the software, as it is useful in many aspects.
- To come up with concrete suggestions for improvements in the software more than three days is required

Feedback from MAFS and TMA

The evaluation of the software involved two people for two days, one with background in agrometeorology who was from MAFS and another in meteorology who was from TMA. The objectives of the evaluation were:

- To identify problems in running the software,
- To exploit different uses of the software, for example adding value to meteorological data.
- To develop strategies for promoting the uses of the software, and
- To provide suggestions on required improvement and possible application of the software in the real world.

The team evaluated the software using developed PT software tutorials. Some of the identified problems are shown in Boxes 1 and 2. As shown in Box 1, more growth stages need to be defined in the software, error messages are too short and the software should enable input of observed data.

First Reviewer

Another issue of concern from the reviewer was that different runs with similar inputs resulted into different outputs. Quoting the reviewer's statement:

“The user is not expecting any difference between the 1st and 2nd run. What is happening on re-running the same data?”

The response of the software to weeds was another issue that was raised. The reviewer expected yield to remain constant or increase with the frequency of weeding. The reviewer state: “Assuming either the 1st or the 2nd run is correct, if it is be compared with the 3rd run, the user expects to get the weed removal effect. Given the fact that the weeding were done at 20, 60 and 100 days after emergence no one expects such a huge reduction of yield because a 3 times weeded field is almost weed-free. There is a need to investigate the reasons for that unusual behavior.” The above stated problems showed that PT software needed more improvements that are scientific.

Box 1: Identified problems by the agrometeorologist (MAFS)

- 1) There is a need to define more the growth stages 1, 2 and 3. i.e. growth stage 1 covers from emergency to tasseling.
- 2) Error messages are too short. Make them more elaborative and give suggestions.
- 3) The software should enable input of observed data and the graphical output show results of observed data versus simulated, and with and without RWH.
- 4) On Weather Generator. This capability is excellent in gap filling the missing weather data therefore should be used to supplement the measured data rather than replacing it.
- 5) There should be User's manual showing how to run the software, principles used to calculate certain values and functions, just to mention a few.
- 6) The output summary should contain summaries of input data and the outputs of the same. Repeated running should be consistent.

On model application, the first reviewer showed that these agro-hydrological models are actually needed urgently for advising policy makers and farmers. Researchers and extension staff can use them in advising policy makers and farmers on issues such as increase land pressure due to population growth and land degradation, which forces people from high potential highland to move to the marginal areas, including semi arid lowlands area. Furthermore, the software can be useful in the semi-arid areas where moisture availability through RWH is important and its management is critical.

Second Reviewer

Box 2 shows feedback from the second reviewer. The comments are focused more on improving the tutorials and adding post-processing subroutines. On possible uses of the software, the reviewer mentioned the generation of climatological, agro-meteorological, hydro-meteorological quantities required by various users and interfacing with atmospheric dynamical models to provide vegetation canopy properties and sub-surface hydrological processes.

The project team should therefore promote the software and create awareness of the capability of the software for various uses to targeted potential users.

Feedback from Internet Downloads

Initial mails were received from the University of Midlands, Zimbabwe and KUL, Belgium on how difficult it is to download the software. This was one of the reasons why the software was shifted to different servers from time to time. People who managed to download the software could not be tracked properly as the website did not force people to register before they download. However, few provided feedback in terms of email correspondence with the PT Help office especially on the problems encountered while using the software. Most of these included students from Makerere University in Uganda and Stockholm University in Sweden. Due to frequent SUA server downtime and power breakdowns, the project team decided to create a mirror site at a location where the server is more reliable. The link to the site is:

http://www.agr.kuleuven.ac.be/vakken/IC03_IC04/runoffirri/PTmodel_download.aspx

Feedback from SIAC participants

The participants found the software to be useful in agricultural planning in semi arid areas. Almost all participants saw the software to be applicable in their home country as they also have the same condition of inadequate and erratic rainfall (Annex B10). It was also found that the software is useful in the field of agro-meteorology as it can be used to fill gaps of missing data, which is a common problem in many local stations. The software ability to use the rainfall overlay in generating climatic data was also found to be useful.

Participants complained that the time allocated for the software in the course was short for them to provide critical feedback. However, their contribution in the discussion and questions raised during demonstration and practices showed how the software was well conceived. The participants also suggested that the software should be quickly exposed to users and improvement should continue. Initiatives should be made to include the software in Institutions

Box 2: Feedback from the Meteorologist (TMA)

- 1) The tutorial instructions in the booklet are not easy to follow and therefore need to streamline the steps.
- 2) Simple method should be availed for flexible extraction of products from the software simulation for post processing using different platforms, i.e., creation of a user friendly data base for both inputs and outputs.
- 3) There is a need to introduce a flexible procedure to capture snapshots of simulation run-time graphics
- 4) There is a need to avail detailed literature and references for the various components used in the software for users to assess formulation of the various modules in the software

such as Institute of Meteorological Training and Research (IMTR) and Universities. Matters that raised serious concern included the following:

- The error messages do not specify what kind of error the user has committed. It could be useful to indicate this for the user to avoid it if possible.
- When an error is committed, the software has no option of going one-step back. Instead, it closes down for the user to start afresh everything. This reduces the user-friendliness of the software hence discourages a new user.
- The meanings of the initials used in the simulation output are not explained anywhere. This brings confusion to a new user as the abbreviation may have different meaning from what the user thinks.
- It is difficult to compare simulation output because there is no option for viewing the different simulation output on the same screen.
- Since weather data for each year has to appear as different file, data formatting becomes too laborious for users who have many years of data to be changed to formats compatible to the software.
- Some participants raised concern on the threshold values for rainfall and initial soil water. The rainfall threshold (1000 mm) seems to be too low and the initial soil water (440 mm) seems to be too high.
- Some simulations could not be executed in old version computers, e.g. the rainfall overlay simulation, could not be executed in old version computers.
- The tutorial and help give details of v2.1 while the demonstration was on v2.2. This should be rectified.

Participants suggested that the rainfall intensity graphs should be included in the output as it is also very useful information during planning process. They also requested for copies of the software, which was distributed to them at the end of the course.

Feedback on PT v2.1 from external reviewer

This section provides summary of the evaluation of PT version 2.1 by an external reviewer. Full report is given in Annex B5. The review identified three main problems, which are described in the following paragraphs.

Software crashing without giving reasons: This often occurs when trying your own data. The reason for this problem is due to lack of error handlers, which can trap runtime errors. Normally, a good program will be having one error handler for every fifty lines of codes. Suggested solutions included editing the runtime software functions and subroutines (referred to later as methods) to allow error trapping, including adding helpful messages designed to diagnose and correct the errors.

Customization of the software outputs: The software outputs cannot be customized without interfering with the operation of the software. Suggested solution is to separate the code that runs the software to generate outputs from the code that formats the outputs. Therefore, the output methods need to be separated from the main part of the software that generates the daily output so that these two can run independently. The second task is to document each output variable generated, so that users can select those that they require to format and write out in their preferred style.

Options for incorporating new scientific findings: Observation was that the current software is rigid such that it does not allow advanced users who might want to refine the software to incorporate new scientific findings.

The problems identified by the external reviewer are pertinent for smooth running of the software and adoption by clients. The last problem mentioned above, however, is to a larger

extent handled by the software such as addition of new crop varieties. It is possible that the reviewer was not aware that the software has that capability.

Feedback on PT versions 2.2 and 2.3 from clients

This sub-section provides evaluation results from the two training sessions on the use of PT versions 2.2 and 2.3, which were given to district and national level staff. Six staff, three from each of the two districts of Western Pare Lowlands (Same and Mwanga), who are practicing RWH, were involved in the training. Detailed report for the training is given in Annex B6. This group was trained on PT version 2.2. The second training involved researchers from SUA and Tanzania Meteorological Agency (TMA) and included experts in soil and water management, agronomy, soil science, computer science, meteorology and statistics. This group was trained on PT version 2.3.

District agricultural and extension officers filled a questionnaire to evaluate several aspects including the usefulness of PT. About 33% indicated that the software is useful for crop production in areas practicing RWH and 50% indicated that is useful for advising farmers. Furthermore, 33% said they would use it for both training and planning. But again when asked the same question using a different approach, 66% indicated that they would use the acquired knowledge to train other staff. On the duration of the training, 83% said one week is short for training and proposed the duration to be two weeks. They also asked researchers to visit and provide backstopping until they become conversant in running PT software

The second training was conducted after a request from SUA, TMA and MAFS staff. At the end of training, the participants were also given a questionnaire to fill. Their expertise on models/modeling is shown in Figure 4. Most of the participants had some experiences in the use of models and standard computer packages, thus they had high level of computer literacy compared to the district agricultural and extension officers.

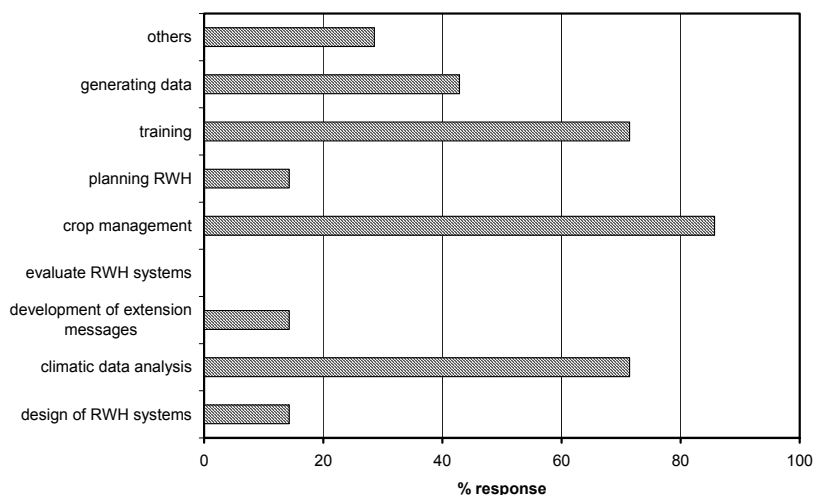


Figure 4: Areas participants feel the software can be applied

Participants identified some areas that the software can be useful (Figure 5) and areas that need improvement. Areas that the software is useful include:

- i In the design of experiments on regulated deficit irrigation to determine the most critical stages to apply water for enhanced crop productivity,
- ii In advising farmers on the proper ways of crop management,

- iii In evaluating certain agronomic aspects such as planting date and water balance on crops such as maize,
- iv In estimating yields under rainfed conditions and identifying needs for supplementary irrigation, and
- v In weather data records and climatic data analysis.

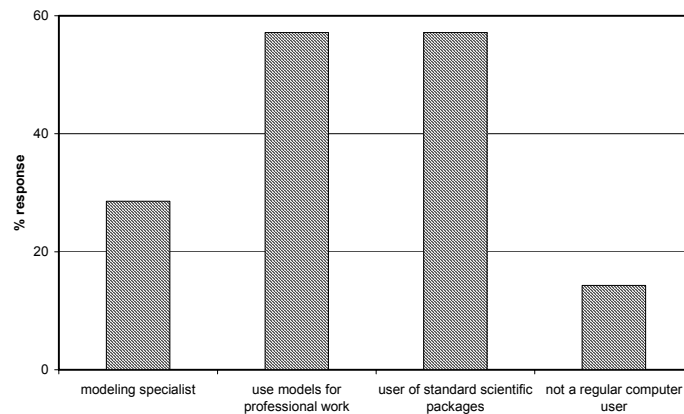


Figure 5: Participants expertise with regard to models/modeling.

Areas that have problems and need improvement include:

- i File handling is still not user-friendly to some participants and therefore, further improvement is required especially for meteorological data input.
- ii Nutrients subroutines should be added so that assessment of the effects of fertilizer inputs (N and P) on yield can be done.
- iii Subroutines for supplementary irrigation should be included so that the software can be used for supplementary irrigation applications.
- iv More crops and varieties such as beans should be added so that the software can have much wider application.
- v Provide economic evaluation to help farmers decide on optimal inputs use.

Feedback from external reviewer on PT v2.3

This section provides a summary evaluation of PT version 2.3 by another external reviewer. A full report is given in Annex B7. In the review, twelve different technical issues were evaluated as briefly described:

- i. *PT capabilities:* Reviewer's views was positive in that PTv2.3 can certainly do the jobs it claims to do, with some limitations, mainly to do with ease-of-use and ease-of-adaptation to users' own needs.
- ii. *Clients and meeting their needs:* The reviewer observed that there is a lack of clarity in the documents about the identification of exactly who would use PT, and under what circumstances. The users are rather vaguely grouped, so specific examples of PT users (in e.g. Tanzania) would make things clearer. Agricultural planners and researchers could use the software in its current form; however, for extension workers and students, they will need several training sessions to be comfortable.
- iii. *Dissemination:* The reviewer concluded that at the time of evaluation most materials were either not available or not accessible in the Internet both at the University of Newcastle upon Tyne and at SUA. Materials on PT software that were available at the

Center for Land Use and Water Resources Research (CLUWRR) Newcastle upon Tyne website were outdated.

- iv. *Downloading:* The reviewers' observations showed that the downloadable version was PTv2.1 from the CLUWRR website but the Tanzanian site at SUA was not responding. However, he was able to get a copy by email from SUA, which gave an impression that the help-desk is functioning. Reviewers' advice was to establish a mirror site at a more reliable location.
- v. *Installation:* Package should be used to follow Microsoft guidelines for installation, which is the current standard that avoids the use of executable setup files, which are susceptible to viruses.
- vi. *Help sub-system:* The Help sub-system is impressive, and seems complete. There is a need to add a context-sensitive "help" button to every dialogue box and form because it enhance the ease-of-learning of the package considerably.
- vii. *Tutorials:* The tutorial has been revised and extended from v2.1, and now includes more details about using the climate generator. The major component missing from the tutorials is a clear exposition of how a real user such as an agricultural extension officer can use the software. Some worked examples – taken from real-life use of PT – are necessary in the tutorials.
- viii. *Background information:* Readme and PDF files were not available from the installed system. Publication lists were included in the Help and Tutorials, but none of the listed documents were provided as PDF or screen-readable and printable versions. This is easily corrected, and should be, if PT is to be a more accessible and self-contained package.
- ix. *Using the system:* PT v2.3 uses a simplified Windows multiple-document interface and it has a Menu Bar similar in style to that in popular Windows programs such as Word or Excel. The main advantage is that users can shorten time they need to become familiar with a new program. Issues that need attention is disabling multiple loading of package simultaneously, greying buttons when their use is not valid and adding resize and minimize options to "modal" forms and removing unnecessary buttons such as "autosize" buttons.
- x. *File locations and structure:* Current structure allow user to write to "Program Files" directory. Since Windows 2000/XP may not allow unprivileged users to access "Program Files" it is appropriate to create user's own writeable folders, which can be identified and created at installation. There is also a need to change the format and structure of the weather data files since are still cumbersome and awkward or using ODBC connections to read external databases directly.
- xi. *Own crop/climate data:* On the whole, the facilities in PT for modifying "system" and "profile" information are flexible and clearly explained. However, more documentation is required for a researcher who might adapt PT to use a crop other than those predefined (rice, maize).
- xii. *Case study:* There is a need to write-up some case studies and worked examples on the use of PT to assist real-life RWH planning and implementation. Case studies will remove doubt on the practical benefits of the software. For planning, the point is to compare different RWH scenarios (across a number of years), not to look in detail at the growth of a crop through a season.

In summary, section 4.1 has shown a wide range of feedback from clients and external evaluators, which could be categorized into two broad categories: software-type and scientific-type feedback or evaluation. Most of the feedbacks provided were either problems in the use of

the software or suggestions to improve the software. Most of the scientific-type problems were not dealt because the project focus was on software-type problems. The scientific-type problems required more time to be addressed and solved within the project period. The following sections describe the improvement of the software and strategies for software sustainability.

4.2 Improvement of PT software

The PT software went through a three-stage improvement that is from v2.1 to 2.2, 2.3 and 2.4 (Annex B14). The first two versions (2.2 and 2.3) had minor differences because they were produced at an interval of about 6 months. The presentation that follows is divided into two parts, improvement from v2.1 to 2.2 and 2.3 and from v2.3 to v2.4.

Improvement of PTv2.1 to v2.2 and v2.3

Key issues, which were identified by clients and reviewers after evaluation of PTv2.1 and required improvement, are shown in Box 3 of which some were handled in PT versions 2.2 and 2.3.

Adjusting resolution of dialogue forms: The problem of compatibility of resolution was handled by including resizing option on every dialogue of the PT software. This problem however was realized to be pertinent only if the screen of the target computer has 800 by 600 pixels resolution or less. Specification of the computer resolution of which software can run has been included in the read-me file. The user is requested to change the computer resolution to the minimum settings required by the PT software, which is any resolution above 800 x 600 pixels.

Frequent crushing of the software: Frequent crushing of the software was handled by including error-handling statements in runtime subroutines and functions. These subroutines and functions were identified using the Project Analyzer software. Explanatory messages were added in every error handling routine, and provision was provided to correct the problems in order to avoid crushing of the software. Crushing of the software was also associated with redundant codes. These redundant codes were cleaned and variables were assigned proper types and some maintained as of variant types. These reduced substantially software crushing and increased the running speed of the software.

Software output interface: The codes that run the software to generate outputs were separated from the codes that format the outputs. However, it was found out that the inputs, outputs and core codes were highly intertwined for modules such as soil-water, crop and runoff generation, which means, a total separation was not achieved within the project period. The simulation output summary has been modified and contains all the basic information that the user can access (Figure 6). The daily output are stored in the file predefined by the user and that can be retrieved if the user need to do further specific analysis from the daily outputs.

Box 3: Some of the identified improvements for PT v2.1

- i. Adjust the dialogue forms resolutions to fit the screen resolution.
- ii. Removing frequent crushing of the model.
- iii. Notify users when a problem is encountered.
- iv. Conversion of files to PT file format.
- v. Improve the output interface to be more user-friendly.
- vi. Increase flexibility to allow advanced users to incorporate new scientific findings.

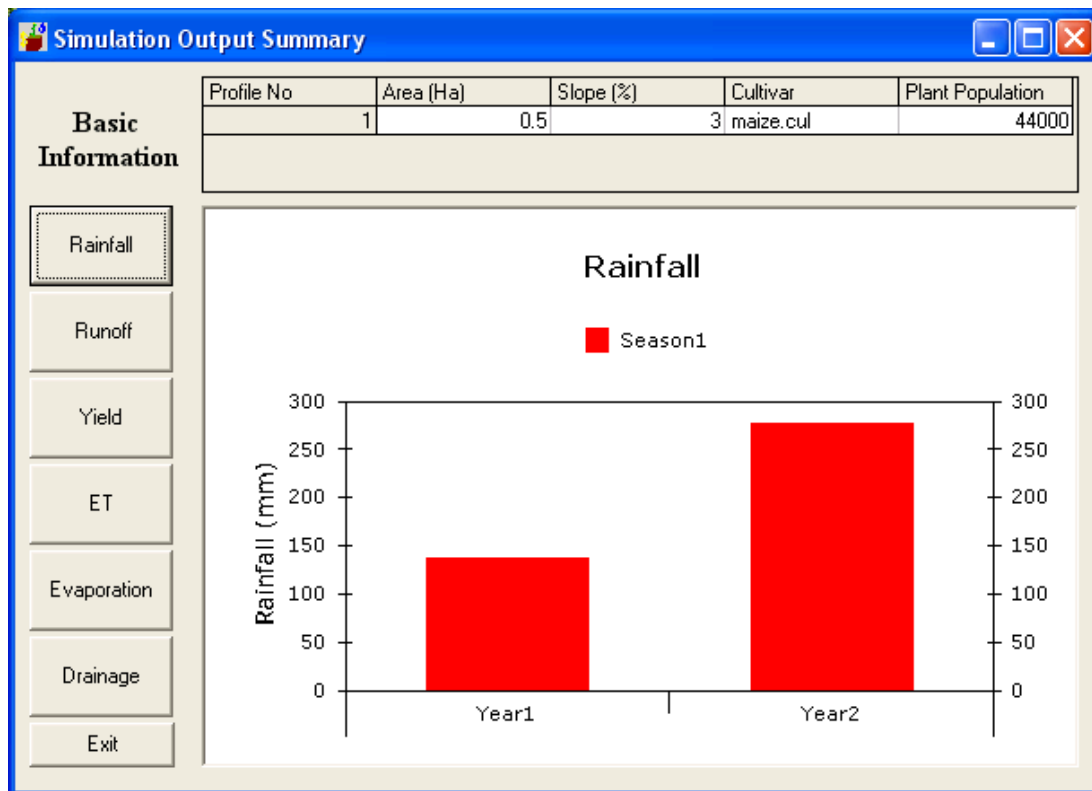


Figure 6: Simulation summary output interface

Conversion from to PT file format: The problem of data conversion was solved by including subroutine for converting data from the format, which is a standard World Meteorological Organization (WMO) format of weather data to PT format. This will reduce the time spent by the users on formatting their data into the format used in PT. Current; there has been some initiatives to change from CLICOM to Climsoft format, which will likely need another sub-routine.

As described before, the difference between v2.2 and v2.3 are minor. Changes made in version 2.1 to produce v2.2 included removal of Excel interface because it was the main cause of frequent crashing and failure of the software to run in some computers especially clone computers. In addition, resolution problems of the dialogue forms were solved and some of the redundant codes were removed. Version 2.3 added a sub-routine for converting files to PT files and an improved software output interface and output file format, which now included two types of files, daily output and seasonal summaries, which are both saved as .csv files.

Improvement from PTv2.3 to PTv2.4

Most of the improvements made in v2.3 to produce v2.4 were based on the second external reviewer, whose suggestions were presented in section 4.1.4. Some of the issues for improvement made on PT v2.3 were:

- File handling for some users was still not user friendly especially for meteorological data input. Need to change format and structure of weather data file (read external databases directly).
- PT needs to follow Microsoft guidelines for installation, disabling multiple loading of package simultaneously; greying buttons when their use is not valid and adding resize and minimize options to “modal” forms and removing unnecessary buttons.
- PT lacks background information such as Read-me files and hence it is not self-contained package. Need to add a context-sensitive ‘help’ buttons to every dialogue box and form.

- Case studies need to be included to remove doubt on the practical benefits of the project. Some of the issues mentioned above were tackled in PTV2.4. Other problems were not tackled because extensive work is required. For example, adding more crops or crop varieties in PT software would require determination of specific crop parameters such as length of growth stages, specific leaf area, growth rate at each growth stage and other parameters as shown in Figures 7 and 8. In order to add supplementary irrigation component, additional funding is required.

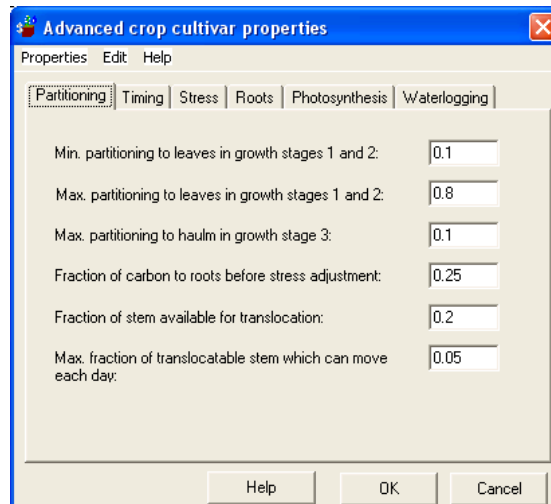


Figure 7: Dialogue window showing partitioning parameters required for adding new crop

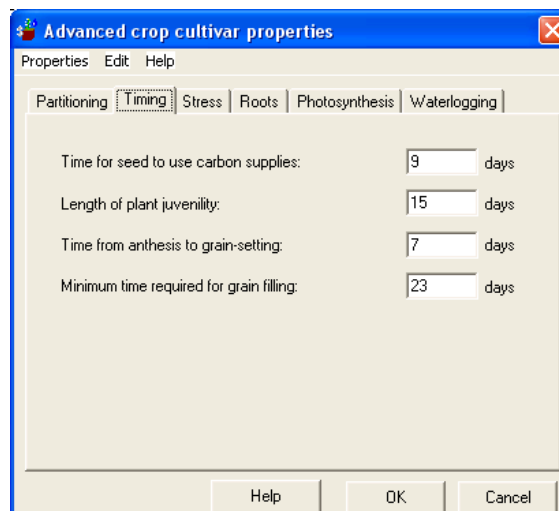


Figure 8: Dialogue window showing timing parameters required for adding crop

Formatting of the data to read open data sources was not done. However, improvement was carried out to read WMO standard data format. To be able to read data from open database there is a need for restructuring the codes, this could not be attained within the project lifetime. However, the documentation of the codes would enable this to be carried out in future.

Background information has been included, these include Readme file (Figure 9). Context-sensitive buttons have been added into every dialogue and forms (Figure 10). The help files have been edited for the text to match the figure and missing picture has been inserted.

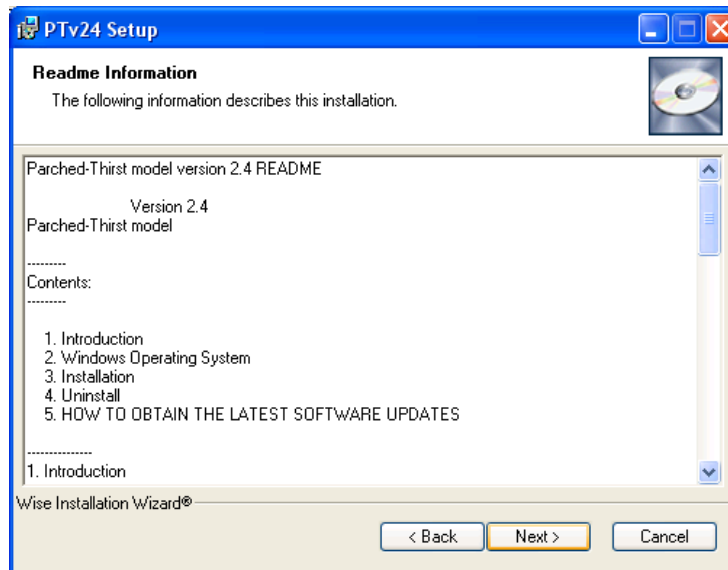


Figure 9: Read-me screen as appearing during installation.

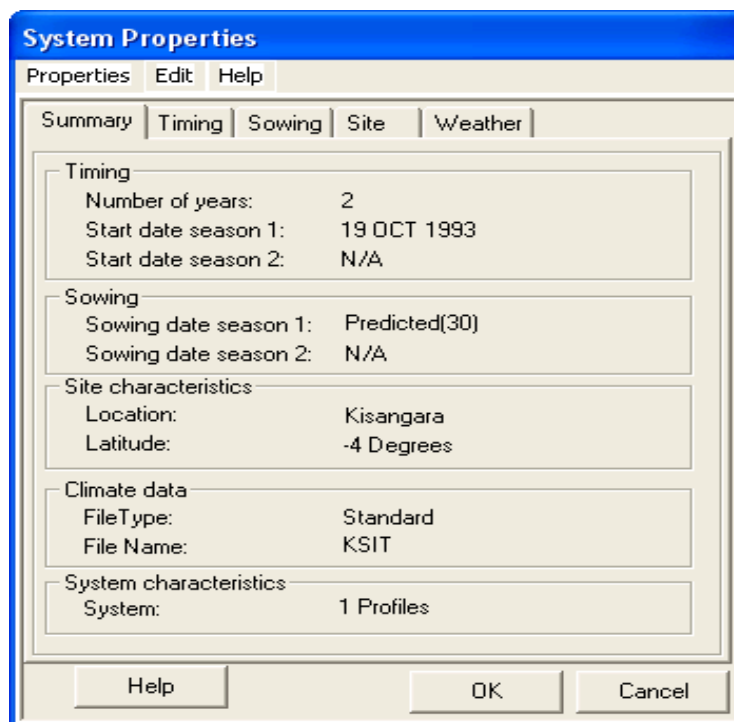


Figure 10: System properties dialogue showing context –sensitive Help button.

Microsoft guidelines for installation, which are to use “msi” package rather than an executable setup program have been used. The user is now prompted to select the destination folder (Figure 11).

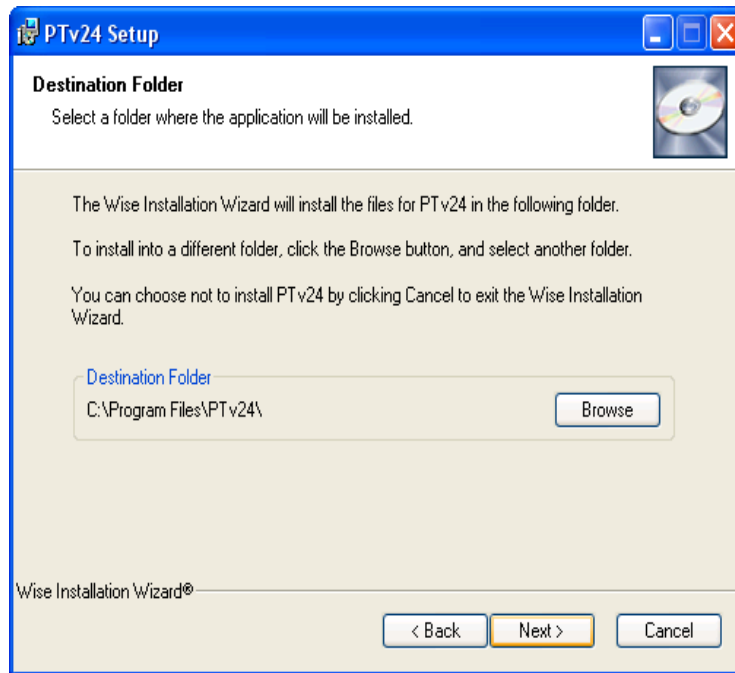


Figure 11: Dialogue during installation with the destination folder.

4.3 Validation of PT software

Comparison between measured and simulated yields

Figure 12 shows measured and simulated maize yields for Magadu site. Maize yields under *AutoSim* simulation means PT 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.

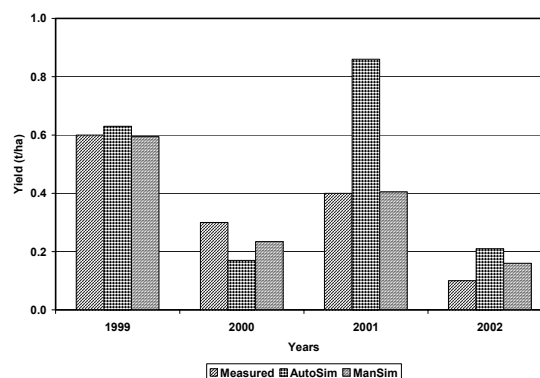


Figure 12: Measured, auto simulated and averaged simulated yields from 1999 to 2002

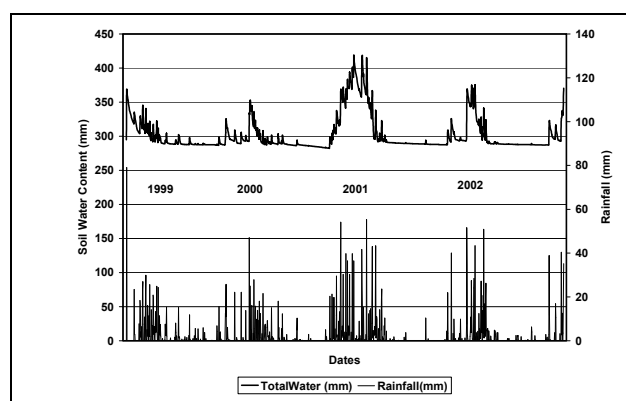


Figure 13: Actual daily rainfalls and PT-based soil-water balance from 1999 to 2002.

In each case, the simulated conditions were closely matched 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 12. 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 13, which 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.

Measured and Simulated yields in RWH systems

Table 3 compares results between yields (as reported by farmers) and the simulated yields using the PT software. 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 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 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 14 shows the effects of type of RWH system and planting date on yield. The results show that, micro-catchment RWH with crop cover gave higher yields compared to other RWH systems. Micro-catchment system (without crop cover) only came second followed by crop cover only for yields of maize planted before 8th February 2003 but micro-catchment and crop cover only had similar yields of maize planted after 8th February 2003.

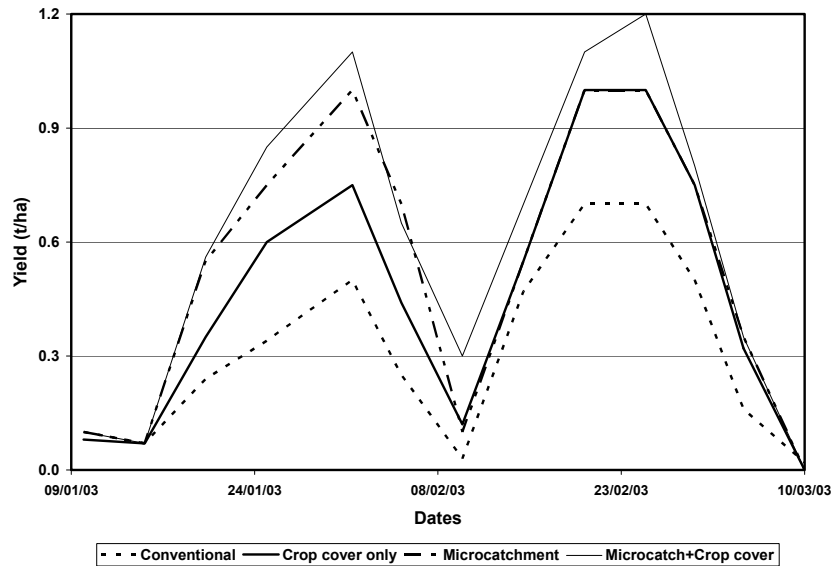


Figure 14: Effect of RWH systems and planting dates on maize grain yield

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 software can be used as a tool to analyse previous season yields as well as estimate yields under various RWH systems. Full validation work is given in Annex B4.

4.4 Implementation of sustainability strategies

Main areas for sustainability of PT software, which were determined during project write-up included establishment of PT Help Office, running of short courses and linking of the PT Help office with BACAS. Results are presented and discussed in the following sub-sections.

PT Help Office

Establishment of PT Help office

The PT Help Office was established in June 2002 within the SWMRG, which is housed at the Department of Agricultural Engineering and Land Planning at SUA. The Help office had two permanent staff, who are academic staff at SUA, and recruited other two staff. The main tasks of the PT office were to solicit feedback from users, upgrading the software to be more user-friendly, provide training, promote the use of the software and investigate ways for sustainable use of PT beyond project period. During the project period, the team upgraded PT from version 2.1 to version 2.3 and in collaboration with staff in the Computer Center upgraded it to version 2.4. The team promoted the software in Tanzania and neighbouring countries through networks in ECA countries such as SEARNET, SWMnet and SIAC organizing teams.

The Computer Center has the capabilities and will be hosting PT software. Staff at the Computer Center who will be involved with PT are the ones currently maintaining the SUA network, web and email servers. The Computer Centre has staff with background in computer science, which is prerequisite for provision of technical assistance that clients would likely request. Two SWMRG team members will continue to provide support to clients through SWMRG and the Computer Center. In addition, some academic members of staff in the Departments of Soil Science, Crop

Science and Agricultural Engineering and Land Planning, have shown strong interest in providing backstopping on PT.

Services

The services to be offered by the PT Help office were identified through interaction with clients included promotion, upgrading, training, data access and formatting, tracking of users, website establishment and maintenance. The following subsections describe some of the aspects in details.

Training

Interaction with users and potential users of PT software showed that the PT Help Office has to continue conducting trainings on the use of the software and the training should not be less than two weeks. This was realized during training of District Agricultural and Extension officers in January 2004 (Table 4). Therefore, duration and frequency of training in PT software to potential users is critical. The project team proposes that the PT Help office should provide training of about two weeks possibly two times a year to the same participants who participated in the first training.

Table 4: Response of participants on duration of the training

Comments on the duration of training	Frequency	Percent
Adequate	0	0
Not adequate	6	100
Total	6	100
Reason for the length of training		
Time was so short to do enough practice it should be 2 weeks	5	83
Time was so short to do enough practice it should be 3 weeks	1	17
Total	6	100

The probable reason for a two weeks training period is that target users, who are mostly District Agricultural and Extension Officers, have little computer knowledge. Figures 15a and 15b show that very few staff are familiar with computers and most of them have limited access to computers in their working places. Figures 15c and 15d show different areas of specialization and potential areas for PT software application, respectively. The figures suggest that most staff identified as having limited computer knowledge have necessary professional background in agriculture to be able to use PT. Therefore, the software training should include some components of basic computer knowledge. The detailed report is given in Annex B6.

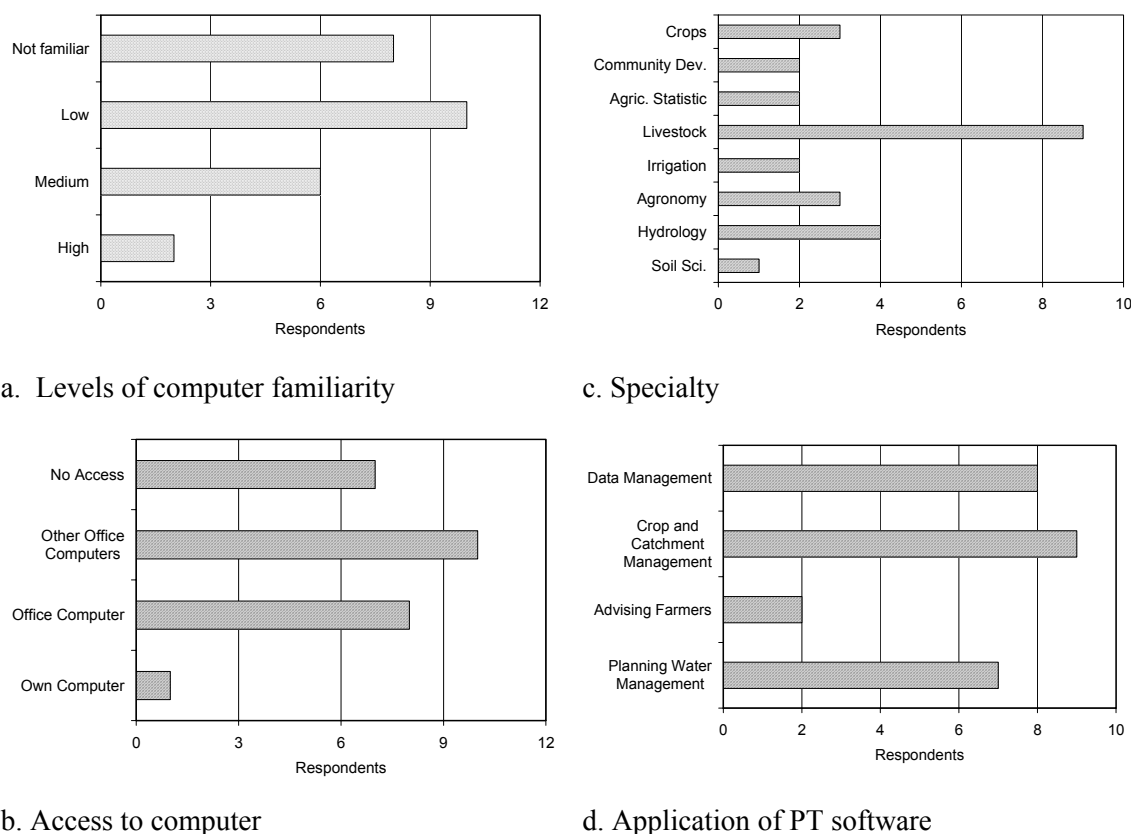


Figure 15: Need of extended training and supports

Tracking of users

District Agricultural and Extension officers from Same and Mwanga districts showed the need for continued tracking and support by the project team to monitor PT use in their districts (Table 5). The next paragraphs show experience of the project team through its Help office in tracking the use of PT in the target districts.

Table 5: Users preference on services to be provided by PT Help office

Issues	Frequency	Percent
The PT Help office should provide training to other officers in the Districts	1	17
I am satisfied with the PT training received	2	33
The Help office should perform frequent visits to the Districts	3	50
Total	6	100

The first tracking was done in April 2004, after the training of agricultural and extension officers from the target districts of Same and Mwanga on the use of PT software. It was found that with the exception of the trainee from MIFIPRO, trainees from the district offices had limited access to computers and therefore they had limited practice on PT software (Annex B9). The main reason for limited access is that the few available computers are used for administrative work. The MIFIPRO trainee had already loaded the software and started to run it.

Due to the problem of limited access to computers, the project facilitated the purchase of computers for the two districts in June 2004. The follow-up visit made at the end of June and early July 2004 found that Same and MIFIPRO Trust Fund had started to do more practice on PT

software while Mwanza District had not done anything yet (Annex B9). The next follow-up visit was done in February 2005, whereby some representative from Same and Mwanza Districts were invited to present their progress in a PT Workshop, which was attended by staff from TMA, MAFS and SUA. In their presentations, Same District had used the software to assist in locating underground water storage systems while MIFIPRO had provided data to the project team so that they can be simulated on their behalf and had distributed rain gauges in villages so that they can collect reliable rainfall data for simulation of RWH scenarios using PT software (Annex B8).

Therefore, tracking on the use of PT software by target users is critical for its sustainability. Mathews and Stephens (2002) stated that tracking of users is the main reason of uptake or failure of most of software packages. That statement is supported by Semoka (2005) on DSSAT that most of the academic staff at SUA who attended DSSAT courses agreed that the software is useful, but they admit to have not used it because of lack of follow-up activities. In developed countries, tracking can be achieved easily by the use of telephones, emails and website but in the target districts, this was done physically because of lack or unreliable modern communication systems. In summary, the tracking efforts revealed that users faces different type of problems that needed to be tackled before they can be in a position to use the software.

Data access and formatting

Another area that needs support of PT Help Office is to facilitate acquisition of data. The main data input required by the software include climatic, crop and soil data. For example, Same and Mwanza Districts lack basic data on soils and crops that is required to run the software. Some of the soil data required include soil depth, soil texture for different layers, bulk density, CEC and organic matter content. Current soil data available for the whole district is the FAO world soil map at a scale of 1:5,000,000 (FAO, 1995). The map provides information such as soil type, texture and slope. However, the FAO soil map at that scale is too coarse to use in the PT software.

On the crop side, the main crop being grown in the two districts is TMV1 maize variety already in the software. The software can be used in high rainfall areas by just including appropriate crops or crop varieties. Adding maize varieties such as *Staha* and *Hybrid*, which are grown in moderate and high rainfall areas in the Southern Highlands of Tanzania, will increase wide use and sustainability of the software in Tanzania. Therefore, the PT Help Office should also be involved with developing a database of different crops or crop varieties.

Weather data is another dataset that users need and has to be built in the software. Due to privatization, the Tanzania Meteorological Agency the sole custodian of climatic data in the country charges for climatic data. Given the small amount of funds allocated by the Government to the Districts, data acquisition by the Districts will be very difficult if not impossible. Therefore, there is a need for the PT Help Office to facilitate weather data acquisition from the Tanzania Meteorological Agency or by generating synthetic data using softwares such as MarkSim or the weather generator in PT.

However, for planning purposes, users can rely on Generators of Missing Weather Data (GMWD). Several GMWD are available, however their use depend on their capability to generate spatial and temporal data series. PT software has one of these GMWD, which can generate temporal data series provided short-term data exist at the point of interest. Another example of GMWD is MarkSim model (Jones *et al.*, 2002). MarkSim is a GIS based model for generating weather data for crop modeling and risk assessment. MarkSim model is capable of simulating four weather variables, which are rainfall, maximum and minimum temperatures and solar radiation. MarkSim is designed to produce simulated daily weather data for any point in the tropics as long as the location (latitude, longitude and altitude) is known. The MarkSim output file is in the format of DSSAT, which is similar to the PT file format.

Data format used in PT is identical to DSSAT format, which is not very convenient to users. Given the fact that weather data formats are not yet standardized even within the Tanzania Meteorological Agency, there are some efforts of changing climatic data formats from to a different format such as Climsoft format. Therefore any effort to change the current format will likely be short lived. However, the current format is not difficult to use as long as users are familiar with computer data formats especially comma separate values (csv). Since most potential users of PT software are computer illiterate the need to provide assistance in weather data formatting is inevitable. Assistance has been given to several users. Therefore, the PT Help Office can use these facilities to support users of the software by formatting and supplying weather data.

Short Courses

Several short courses were conducted and the following paragraphs give the details of the short courses that were provided including course materials that were developed. This section also looks at the experience on income generation through short courses.

Course materials and courses offered

In order to provide training and to make the software more user-friendly and have a wider audience, development of appropriate course materials is important. The first and the second sets of course materials were prepared for the SIAC courses, which comprised mostly agrometeorologists (Annex B16). The course materials for the year 2002 were:

- Getting started with PT version 2.1
- Simulation of RWH system performance
- Investigation of the influence of weather variability

The second SIAC training conducted in 2003 added course material on other aspects of PT, which were:

- Generating climatic data with and without rainfall overlay
- Managing raw weather data from other countries/sources

The aspects mentioned above were later incorporated into the PT Handbook (Annex B11), which was designed to incorporate different types of tutorials to cover different types of clients. The handbook contains information on:

- Using climate generator
- PT application in investigating crop management:
 - Assessment of the effect of planting date
 - Assessment of the effect of weeding in crop yield
 - Effect of plant population on crop yield
 - Investigating the influence of weather variability
 - Investigating the effect of water management
 - Investigating the influence of soil variability

The PT Handbook was used both during the AICAD training on irrigation and water management and PT training of District Agricultural and Extension officers in March 2004. The PT session provided in the AICAD training was too short for participants to provide comments on the handbook. During the second training, which was solely dedicated to PT, participants had the opportunity to comment on the handbook (Annex B6). All participants found the handbook useful but two participants indicated that the handbook needs some elaborations for beginners. On issues that need to be added, 50% of participants thought it was too early for them to comment. In general, few users have so far commented on the handbook and therefore comments

from more people are required. There is some indication that the handbook needs some improvements because of the comments from the two participants who said that it is difficult for beginners.

Therefore, the types of the courses offered varied depending on the clients' professional background or interests. For example, the meteorologists were mainly interested on climate data generation and general simulation of the software whereas agronomists were interested on the effect of soil and crop parameters on yield. Some of the courses offered PT training only while in other courses PT was one of the course components. Other types of courses that included PT components were those offered to SUA students, which are within SUA curriculum, course AE 317- Rainwater harvesting and SS302 – Land husbandry and Conservation. In these courses, elements of PT are included and offered to the undergraduate students opting for these courses. PT course is also offered on request from the individual or group of people who need to use PT software.

The first series of courses that offered PT components are those on Statistics in Applied Climatology (SIAC), which were offered in 2001 to 2003. The other courses that included PT component were the AICAD course in irrigation water management in 2004 and the study tour by a group of scientists from the Ministry of Agriculture, Rwanda, in 2004. Two short courses, which comprised PT software only, were also conducted by the project. The first course comprised of District Agricultural and Extension Officers from Same and Mwanza districts and the second course was offered to selected staff from SUA and Tanzania Meteorological Agency in February 2005.

Income generation through courses

Income generation through short courses on PT software was originally thought to be the main strategy to the sustainability of PT. This was because the income generated from such courses was thought that it would be able to cover the running costs of the PT Help office. Simple considerations on income and expenditure showed that this was not a viable option. Assuming two staff are recruited and their salaries is tagged at around \$500 per month, a total of \$12,000 will be required per year. Short courses are likely to generate a profit of not more than \$200 per course per person. Considering one short course per year and 20 participants per course, total income will amount to only \$4,000. This does not mean that PT courses should not be conducted, but rather the intention of conducting short courses should aim at its wider adoption and not self-support. Second, to organize a short course that will only comprise PT software is appropriate in certain circumstances but the option is more attractive if the PT components are combined with other training components such as RWH, land husbandry, forecasting and irrigation water management. Therefore, the project team decided to lobby so that PT is integrated into other courses. In addition, the team organized and conducted two short courses on PT, which comprised PT alone mainly to target stakeholders.

Institutionalization

Institutionalization in this case is defined as the process of integrating PT software into SUA main activities, which are teaching, research and extension. In research, the software can be integrated into various research undertakings in areas such as crop science, soil science and land and water management. In teaching, PT software can be integrated into relevant courses being offered at SUA. The extension component deals with real-life application of the software, therefore, the software can be integrated into courses being offered to extension officers. Therefore, this was thought by the project team, as good strategy for software sustainability.

Linking PT software to University Unit

Linking PT and its Help office to an existing organ within SUA is important for sustainable use of the software. The initial organ that was identified was the Bureau for Agricultural Consultancy

and Advisory Service (BACAS). BACAS was established by the Faculty of Agriculture in 1991 to handle consultancy and advisory services as well as short courses and contract research (BACAS, 1991). Some of the services that BACAS provides include feasibility studies, project analysis and technical evaluation, project planning and operation, training and institutional building, policy and strategy assessment and development and contract research. The advantage of linking BACAS with PT was that the Faculty of Agriculture is the main stakeholder as it houses among others the three key Departments of Agricultural Engineering and Land Planning, Crop Science and Soil Science. However, the only way that BACAS could have interest in PT software is when some clients forward their requests for specialized training requiring the PT. It was with this background that SWMRG considered that the best alternative was the Computer Center.

The Computer Center was established in 1993 as an arm of the University responsible for teaching, research and consultancy in areas related to application of computer technology (Computer Center, 2002). In particular, the Computer Center has among others the following tasks:

- To develop and review computer curricula for undergraduate and postgraduate students as well as for staff from within and outside the University.
- To provide information and communication technology knowledge to students and all University staff and other members of the society.
- To develop software with special application to Agriculture, Science, Forestry and Veterinary challenges.
- To conduct research in computerization of Agricultural, Forestry, Veterinary Medicine, Allied Science and other land use undertaking for purpose of increasing the speed of information processing, and dissemination and therefore, to enhance speed and accuracy in decision making.

Furthermore and with regard to the task of developing specialized software to Agriculture, Science, Forestry and Veterinary challenges, the Computer Center will harness the capabilities of its staff and students to formulate specialized software to efficiently solve genuine problems specific to the University areas of expertise. The strategies to achieve the stated tasks are:

- To put in place conducive and motivating environment for software development.
- To encourage researchers to seek computer-based technical solution to research problems.
- To promote software development capability to industries applying expertise related to SUA programmes.

It can therefore be deduced that, the Computer Center is more appropriate to link with PT software compared to BACAS.

The Linking Process

The linking process was challenging than it was initially imagined. The process started in December 2003. Two approaches were initially thought in establishing the link. The first approach was to use normal University bureaucracy, which means ideas are presented to research and postgraduate committees at Departmental, Faculty and then University level until it reaches the University senate. The second approach was to write a letter to ask the Computer Center to host the software since our assessment revealed that between BACAS and the Computer Center, the Center is the most appropriate unit of the University to host the software. The second option was seen to be the easiest and would allow faster and easy collaboration including handing over of the software to the Computer Center.

The process of convincing SUA senior authorities took longer than expected by both the project team and the SUA community. During promotion, the team realized that the software had more problems

that required to be addressed than originally thought. Therefore, the project had to concentrate on the pre-requisites for software acceptability, which were improving the software to be more user-friendly, find means to validate the software and find areas, which the software could be used to solve real-life problems.

On the SUA administration side, the team identified two problems that could have hampered PT hosting, which were higher staff turnover and accepting new responsibilities. As is the case in other developing countries, professionals in computer science are few in comparison to the demands. Since the SUA salary scheme could not compete with those of private organizations, the Directorate of Computer Center has faced very high staff turnovers. It was until recently when demand and supply started to stabilize and SUA increased the salaries that the high turnover has stopped. Accepting new responsibilities sometimes has negative effects otherwise thorough analysis and evaluation is done. Due to lack of experts, the Directorate of Computer Center was in a difficult position to decide the hosting of the software.

Strategically, the project team decided to involve the top administration at the Computer Center indirectly by jointly organizing and conducting PT training to District Agricultural and Extension staffs from Same and Mwangi in February 2004. The Computer Center responded positively by sending its Associate Director to open the course and award of certificates to the participants.

In next move, the project team decided to involve the junior staff at the Computer Center directly by training them in running the software, explaining the input and output files, exposing them to computer codes and finally the process of producing the software. The higher number of staff involvement was necessitated by the high turnover rate. It was assumed that if some decided to leave, then at least some would remain behind and continue to work with the software. These interactions ended up building a strong link between the project and the Computer Center staff to the extent that these staff agreed to work together with the team in documenting the codes and upgrading PT v2.3 to PT v2.4. This effort was positively acknowledged by the Computer Center and asked the project to organize stakeholders' workshop on PT software so that the Computer Center could know them and vice versa.

The workshop brought in representatives from TMA, MAFS, Same and Mwangi Districts, MIFIPRO and academic staff members from SUA (Department of Agricultural Engineering and Land Planning, Soil Science and Crop Science). The workshop aimed at understanding the interests of each organization on PT software. Interests of different organization were determine by asking participants to comment in three broad areas, which were (1) opportunities in having PT software in their organization, (2) requirements to make users continue using the software and (3) joint activities that can be done immediately. Detailed comments are given in Annex B8, but some of the factors, that could ensure continued use of the software, are listed below based on the type of user. Factors put forward from the Districts representatives were also included:

- Clients should continuously be informed on the PT software changes.
- PT Help Office should provide follow up and backstopping to Districts.
- The Help Office should provide follow up training for more capacity development.
- Training on ArcView GIS should be conducted for building up maps and databases.

TMA and MAFS representatives mentioned the following factors/activities:

- SUA should continue building capacity of clients in the use of the software.
- The PT Help office should provide non-meteorological data, such as soil and crop data.
- Stakeholders should seek for funds internally and externally to assist in data collection.

The academic staff members at SUA mentioned the following with regard to sustainability of the software:

- PT team should sensitize researchers and instructors at SUA.

- SUA administration through the Computer Center should develop teaching modules so that they can be used as a teaching software to students and in the process encourage them to use it for research.
- The PT help office should continue improving the software so that it includes fertility components and more crop varieties.
- Comments from SUA Computer Center on sustainability of the software were:
- Train the computer Centre staff in specific areas of computer programming so that they become competent developers of PT software.
- Staff to be involved with PT should be facilitated so that they will be able to provide improvement on the software

The above comments showed some commitment from stakeholders and that more work needs to be done so that potential clients can be able to use and continue improving the software.

During the workshop, the Computer Center agreed to host the software because it realized that there are serious stakeholders who would like to be helped, supported and advised on PT. The software is now housed within the Computer Center, which has been providing some short courses in other computer related applications such as Microsoft Office and various statistical packages. The Computer Center has also created a website on PT software (<http://www.suanet.ac.tz/cc/PTmodel.html>). PT software will now be offered as one of the short courses that are being conducted by the Computer Center. The Center now needs very little assistance as it has qualified staff to host and provide help, support and advice to clients.

4.5 Case Studies and Virtual Laboratory Experiments

The case studies developed show how the PT software can be used and in general the need to promote the use of the agro-hydrological or crop-soil simulation models at district and national level to assist in advising farmers. The virtual experiments show how simulation models can be used to strengthen student's understanding in simulating various agricultural systems.

4.5.1 Case Studies

A total of five case studies were developed. Three of them were developed by district agricultural officers from Kilosa, Morogoro and Same (Annex B19) and the other two case studies were developed by participants from the Tanzania Meteorological Agency (TMA) and the Ministry of Agriculture and Food Security (MAFS) (Annex B21). The PT Help Office provided support in all the stages of development of the case studies. The titles for the case studies are:

- i. *PT Software as a Tool for Studying Farming and Conservation Measures in High Slope Areas: Case-Study of Vidunda Village in Kilosa District* (Kilosa District)
- ii. *The Use of PT Software in Determining Appropriate Management Practices for Maize production in Fulwe Village in Morogoro District* (Morogoro District)
- iii. *Matching the Catchment Area to the Cropping Area in a Rainwater Harvesting System – The case study of a field in Makanya village, Same District* (Same District)-(Same District)
- iv. *Crop Forecasting using the PT software – case of maize* (MAFS) and
- v. *Use of PT software to study drought recurrence in Tanzania* (TMA).

For each case study, a communication product, in form of a poster, was developed (Annex B20 and Annex B22).

A brief summary on these case studies is given in the following sections.

Case study 1: Studying appropriate farming and conservation measures in high slope areas- Vidunda Village, Kilosa District

This case study demonstrated how the software can be used to advise farmers on proper land management so as to reduce runoff and soil erosion. The study was necessitated by the fact that the main reason for low yields by farmers in Vidunda village in Kilosa District was not well known to district officials especially extension officers and farmers themselves. It was thought that the solution is for farmers to shift to another area especially in the lowlands rather than staying in the mountainous areas. The reason for the advice was based on the fact that due to the steep slopes, automatically yields will be low because a big proportion of the rainwater normally ends up as runoff with little infiltrating into the soil. On the other hand, the agricultural extension officers thought that if farmers decide to stay then they should adopt terraces in the area because the yield will be expected to increase (the details about this case study are in Annex B19).

The case study shows that, maize yields are low; but Vidunda village receives enough seasonal rainfall for maize production. Runoff generation simulations showed that, conventional farming in steep slopes produce more runoff compared to terraced and contoured farms. Other conservation measures resulted in zero runoff because the bunds that allow runoff water to pond and therefore infiltrate slowly into the soil.

Comparison of maize yields (from 2002 to 2005) on deep and shallow soil depths shows that yields under deep soils are significantly higher compared to the shallow depth with the exception of year 2002 as shown in Table 6. Comparison of yields between conventional tillage with 90 cm soil depth and the three soil conservation measures (contour bunds, terraces and terraces with bunds) shows no difference. This shows that with deep soil depths, conservation measures have no significant impact on yield. It is obvious that the continuous farming on steep slopes without any conservation measures must have contributed in reducing the soil depth due to runoff/erosion thus leaving unfertile bare soil with stones behind.

It was therefore deduced that the low yields, which Vidunda farmers get, is mainly caused by the effect of shallow soil depth (sometimes less than 30 cm) rather than other factors as it was thought by district agricultural extension officers.

Table 6 Simulated maize yields for different conservation measures and soil depths.

Conservation Measures	Maize Yield (t/ha)			
	Year 2002	Year 2003	Year 2004	Year 2005
Deep Soil (90 cm soil depth)	0.8	0.5	0.5	0.4
Shallow Soil (30 cm soil depth)	0.7	0.2	0.2	0.2
Contour Bunds	0.8	0.5	0.5	0.5
Terraces	0.8	0.5	0.6	0.3
Terraces with Bunds	0.8	0.5	0.5	0.4

Case study 2: Determination of appropriate management practices for maize production, Fulwe Village; Morogoro District.

This case study shows that the software can be used to understand a problem that might not be possible to identify without tools such as crop-soil simulation models. Villagers in Fulwe village were facing problems of low and unreliable maize yields. The extension workers attributed this

to improper choice of planting dates but they were unable to successfully advise farmers on proper planting dates. In some cases they advised farmers to plant once the rains started, but still farmers ended up with lower yields compared to those who planted a bit late. It was therefore necessary to use the PT Software as a tool that could assist in the identification of the proper planting window by simulating maize yields for different planting dates in Fulwe village (The details about this case study are in Annex B19).

Existing information shows that the important growing window for maize in Fulwe village is between January and May. Daily rainfall trend over the long rainy season for different years showed a consistent pattern of dynamic two dry-spells between January and the first week of March. Dynamic here means that the actual dates of occurrence of the dry spells are not known. Farmers in Fulwe village normally plant their maize between mid-January and mid- February. Given the dynamic nature of the dry-spells, it also means that the start of the season is highly variable. It is therefore possible that some of the maize crop face moisture stress which affect the final yield. Furthermore, the area gets good rains between mid-March and April. There is poor rainfall in May in the sense that it is both low and there are more frequent dry spells. These characteristics have a significant effect on the final yield because most of the grain weight accumulation occurs in May.

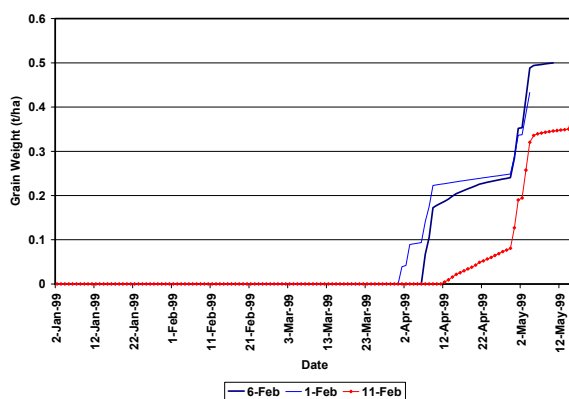
Maize yield was simulated for different planting dates from 1999 to 2004. The results show that on average, the best planting dates that resulted with highest yields were between 20 January and 12 February. The average yields were between 0.45 and 0.49 t/ha and maximum yields ranged between 0.61 and 0.78 t/ha. However, the maximum yields were not occurring only on dates with maximum yield (around February 5) instead they occurred anywhere between 20 January and 12 February (a three-week window). The simulated maize yields compared well with those reported by farmers, which averaged between 0.5 and 0.7 t/ha. Therefore it was observed that planting dates might not be the primary or the only reason for the low yields. It was therefore necessary to carry out an analysis of dry matter accumulation.

Results of dry matter accumulation indicated that dry matter accumulations at different planting dates were almost the same. Therefore, the effect of different planting dates on dry matter accumulation was not apparent. This led to the conclusion that dry matter accumulation could not justify the significant difference observed in the maize yield. Therefore, further analysis of grain weight accumulation was necessary. For maize, and many other crops, the grain filling stage is one of the critical periods for water requirements. Therefore availability of water at this period would increase partitioning of dry matter to grain leading to good crop yield.

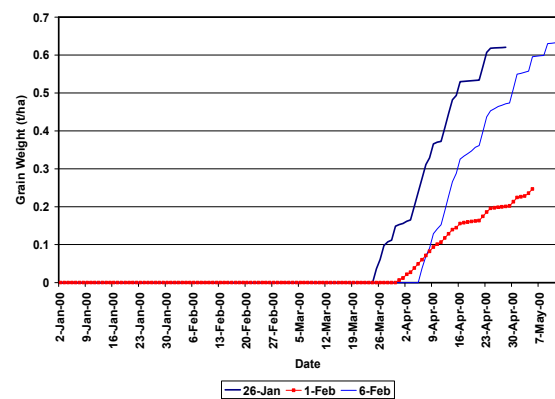
Results show that each planting date responded differently to grain weight accumulation. The earlier the start of grain filling the earlier was the planting/sowing date. Therefore, the start of grain filling is fixed for a particular variety of maize. However, the start of the grain filling stage and subsequent days are very important to the final yield. For example, the comparison of grain filling rate for maize planted on 1st February and those planted on 6th February show that at the first few days of grain accumulation the maize planted on 1st February was being affected by very short dry spells compared to maize planted on 6th February. The grain filling was severely affected from 10th February because of a much longer dry-spell. The same dry-spell period showed that the rate of filling affected the older plants most compared to the younger ones since the growth rate of the maize planted on the 11th February was higher than that planted either on 1st or 6th February.

The second chart (year 2000) in Figure 16 shows a steady increase in grain weight compared to the 1999 chart, where the increase is step-wise. The steeper slopes for maize planted on 26th January and 6th February indicates a good supply of water during the start of grain filling. There was a dry-spell during the start of the grain filling stage for maize planted on the 1st February.

Figure 17 (a) shows that all the lines are steadily increasing without any cross-over and the first line (21-January) having a steeper slope and therefore higher yield than the other two lines. Under normal circumstances, when the rainfall distribution is good even during grain filling stage, this is supposed to happen. The reason for the lower yields for the maize crop planted on 28th January and 1st February is the decrease in the rainfall amount toward the end of the rainfall season. This is contrary to the 2003 chart in Figure 17 (b) because there is a cross-over between 1st February and 11th February lines. The maize planted on 1st February suffered severe water stress at the start of grain filling stage. Maize planted on the 11th February did not suffer water stress because the rainfall came on time such that the rate of grain filling was very high. The intersection of the grain filling lines was caused by the fact that the younger plants tend to have the highest growth rate compared to the older ones under the same good environmental conditions (no water stress in this case). Therefore, when the water stress came, already the maize planted on 11-February had achieved good yield and the maize planted 1-February grain accumulation had already been limited because of the previous dry-spells.

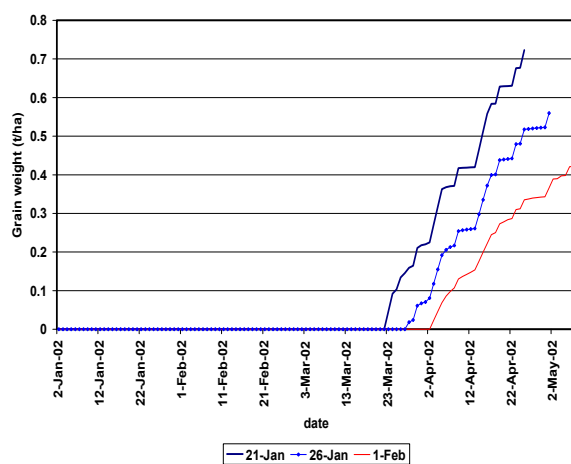


(a) Year 1999

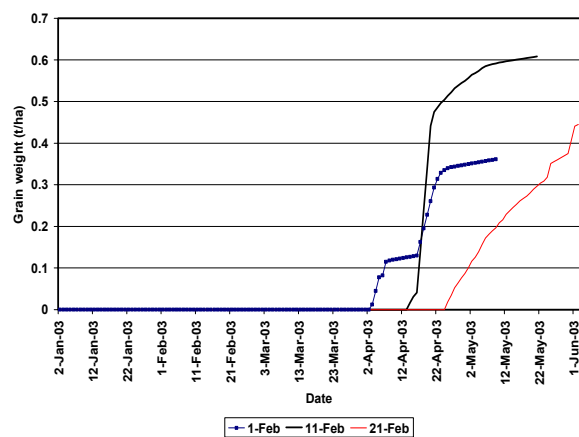


(b) Year 2000

Figure 16: Maize grain filling for 1999 and 2000 season



(a) Year 2002



(b) Year 2003

Figure 17: Maize grain filling for 2002 and 2003 seasons

Therefore, the low and variable maize yields that farmers were experiencing in the village were essentially due to water stress during grain filling stage and not due to the planting dates. Nevertheless, late planting also can result into lower yields if a normal rainfall pattern occur,

which means decrease in the amount of rainfall towards the end of the season. These results require that farmers should harvest rainwater, store it and use it to mitigate dry-spells during the grain filling stage.

Case study 3: Matching the Catchment Area to the Cropping Area in a Rainwater Harvesting System – Makanya village, Same District.

This case study demonstrated the way the PT software can be used to advise farmers on the appropriate catchment areas in micro-catchment rainwater harvesting systems. Most farmers in Same district harvest rain-water from catchment areas and direct it to a cropping area. However, they don't know how to correlate the catchment area to the cropping areas. The main practice of most farmers is to expand both the cropping areas and the catchment areas. The case study shows how the software can be used to determine the optimum size of the catchment area and how one can limit the expansion of the cropping area ((The details about this case study are in Annex B19).

Maize yield simulation in rainwater harvesting system showed that for a cropping area of 1.3 ha, (with the exception of *vuli* of 2000 and to some extent *masika* of 2001), maize yields did not respond to the increase in the catchment area beyond 13ha. This may be due to the fact the catchment area is too large for the cropping area; and therefore, the cropping area needs to be increased to match the catchment area.

When the cropping area was increased to 3ha, maize yields response with increase in the catchment area showed that *Masika* of 1998 and 1999 and *vuli* of 1998 and 2000 responded to the changes in the catchment area. The four seasons showed increase in yield with increase in the catchment area. Through simulations using the PT software, the optimum catchment area was achieved between 40 and 45 ha. Therefore, the ratio of catchment area to cropping area is 40:3 or 45:3, meaning a ratio of 13:1 or 15:1 will be optimum for the farmers in the area with similar catchment characteristics.

The simulation results for the rainfed scenario (Table 7) 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 in Same District.

Table 7 Maize yield (t/ha) in rainfed system in the 1.3 ha cropping field.

Year	<i>masika</i>	<i>vuli</i>
1998	0.41	0.06
1999	0.20	0.22
2000	0.11	0.09
2001	0.13	-

Case Study 4. Using PT Software to Forecast Maize Yield - MAFS

Early warning of a pending poor crop harvest in highly variable environments like the ones in Tanzania provides policy makers time to take appropriate actions to ensure food security in vulnerable areas. This case study which was developed by participants from the Ministry of Agriculture and Food Security (MAFS) used the PT software to forecast maize yields for year 2004 at Wami and Morogoro stations, based on daily rainfalls of its analogue years (1980 and

1988) prepared by the Tanzania Meteorological Agency (TMA) (The details about this case study are in Annex B21).

Results showed that analogue years showed good correlation with the actual year for the Wami 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 April) were very similar.

For Morogoro station, there is significant deviation between the actual year (2004) and analogue years. Although the annual cumulative rainfall in the actual and analogue years are more or less the same (about 900 mm); the rainfall pattern in the actual year during the season is far different from the patterns in analogue years.

As seen in Figure 18, yield simulations show that, for the Wami case, there is good correlation between yield in analogue and actual years as in the case for rainfall. Yields in the actual year – 2004 (0.65 t/ha) deviated slightly from those in analogue years; the average deviation for the two analogue years from the actual yield is 0.2 t/ha. However, for Morogoro site (Magadu), deviation in yield between actual and analogue years is more pronounced (-0.64 t/ha from 1980 and +0.43 t/ha from 1988). This is justified by the difference in the rainfall patterns observed between actual and analogue years.

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

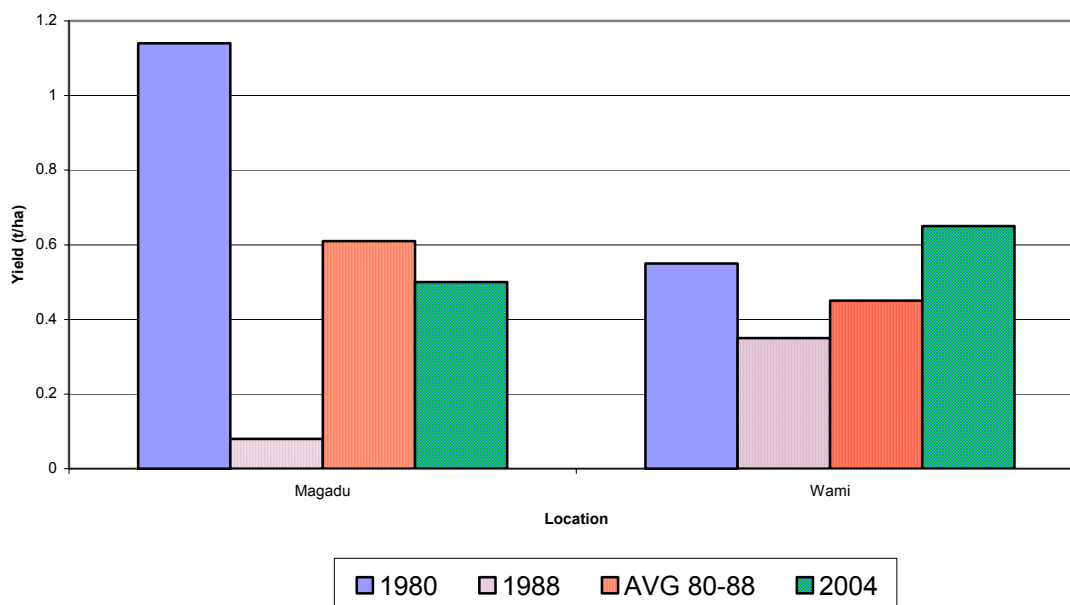


Figure 18: Simulated yields at Morogoro and at Wami weather stations for 1980 and 1988, which are analogue years for 2004 and the actual simulated yield for 2004.

Case Study 5. Understanding Drought Recurrence in Tanzania: The Case of Morogoro

In this case study, the PT and INSTAT + softwares were used to study the sequence and the frequency of occurrence of agricultural and meteorological droughts using 35 years (1971-2004) weather data for Morogoro Station (The details about this case study are in Annex B21).

Agricultural drought were reflected by poor maize yield (below 0.5 t/ha) while meteorological droughts were reflected by below normal seasonal rainfall (350mm).

Analysis with INSTAT+ software showed that the possible average rainy season start date for Morogoro was 28 February. The years that had the chances of starting the season on or around 28 February were 22 years out of 30 (73%). The start date was based on the condition that the rainy season starts when there is a cumulative rainfall of about 20 mm over the two days and that there is no dry spell of 10 days in the next 30 days after the rainy season start. When considering unconditional cases (i.e. when the dry spells condition is ignored), the long-term average date of start of rainy season was 11 March.

Analysis of crop yield simulations using PT for the last 35 years (1971 to 2005) revealed that a total of 13 droughts occurred, of which 10 were agricultural and 8 were meteorological (Figure 19). It was realized that agricultural droughts are not necessarily associated with meteorological droughts and vice versa.

For the ten (10) years where agricultural droughts occurred, five years (1976, 1982, 1988, 2003, 2005) were coupled with meteorological droughts and the other five were not. Agricultural droughts not coupled with meteorological drought mainly resulted from poor distribution of rainfall. In three (3) out of eight (8) years where meteorological droughts occurred, maize yield was beyond the cut-off level (1977, 1987 and 1994) of 0.5 t/ha owing to the presence of enough rains during the critical moisture requirement phase.

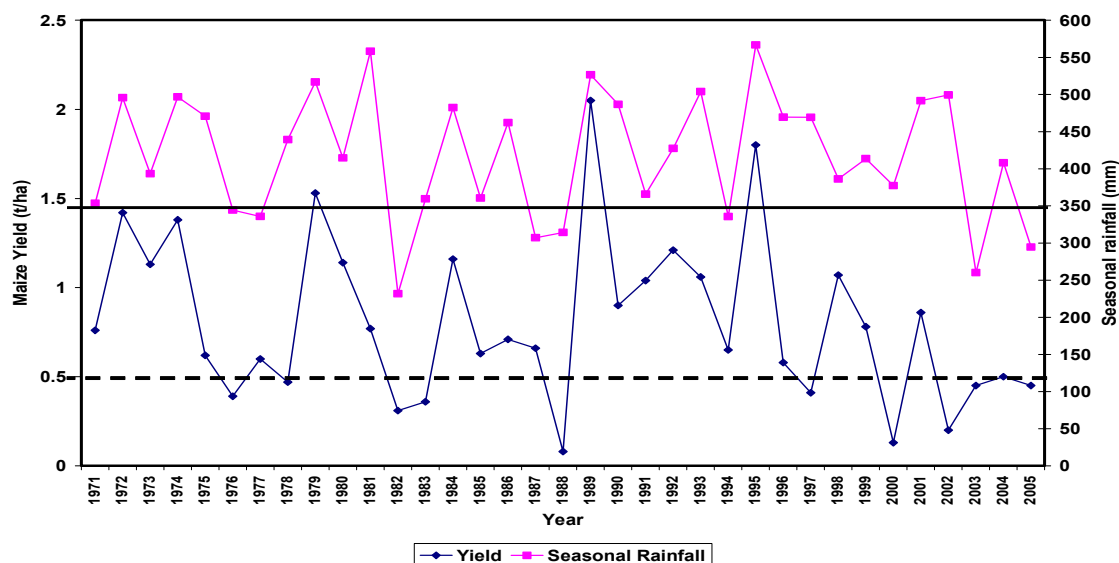


Figure 19: Meteorological and agricultural droughts for 35 years

Figure 20 shows the sequence of drought occurrence over the last 35 years and Table 8 shows the summary statistics for Figure 20.

It was realised that on average, meteorological droughts reoccur every six (6) years (1976, 1982, 1988, and 1994). However, since 1995, the trend/pattern was altered, as the agricultural drought didn't recur until 2003. Agricultural 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 and 2003).

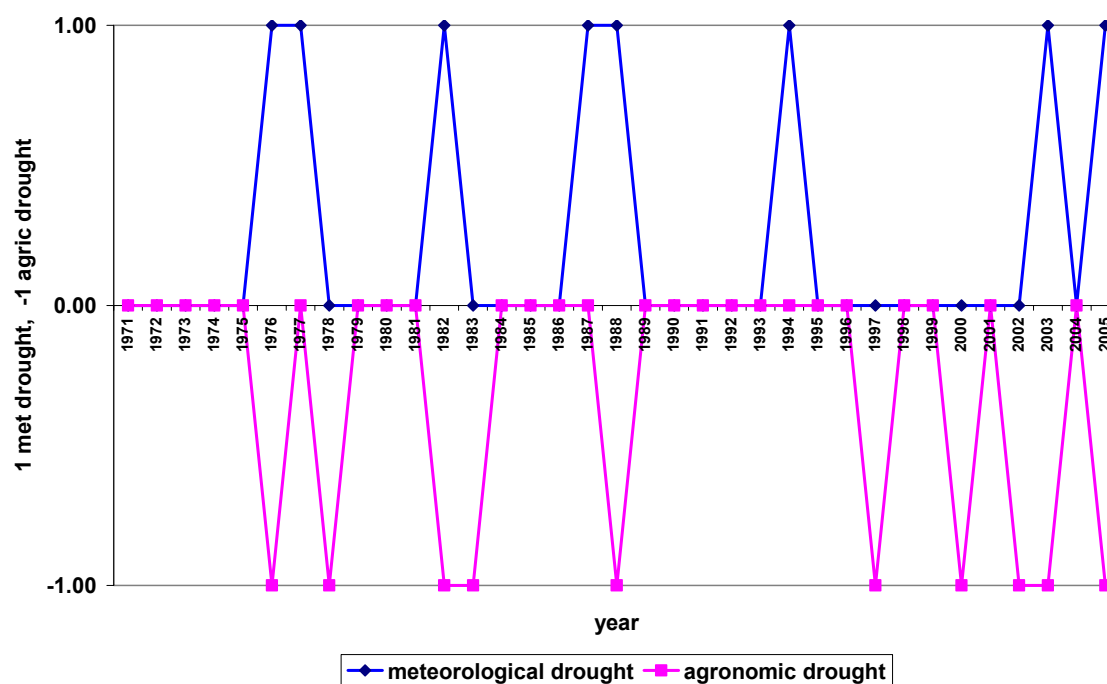


Figure 20: Meteorological drought and agricultural drought recurrence

Table 8 Summary statistics for drought recurrence

Statistics	Agricultural 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

Based on the analysis above, an advisory strategy for farmers could be developed given the characteristics of drought in their areas. One way could be to adopt the proper planting date. For instance, based on PARCHED-THIRST software, the best planting dates for Morogoro is 1st March. Other measures to improve productivity include rainwater harvesting (RWH) with storage during the period of heavy rains and supplementary irrigation during the critical moisture period.

4.5.2 Virtual Laboratory Experiments

This section consists of two compendia. The first compendium contains six modules on agricultural systems simulation, written for use by both undergraduate and postgraduate students at Sokoine University of Agriculture (Annex B23). The second compendium includes two experiments, developed for use by students at Ilonga and Uyole Agricultural Training Institutes (Annex B24). In all experiments, preset data sets are provided to allow students to easily follow up the exercises.

Module 1: Agricultural Systems Simulation I

This module was designed for the course CIT 200 (Computing Applications) taught to all second year undergraduate students at Sokoine University. This module introduces students to models, their importance and applications in agricultural systems simulation. The PARCHED-THIRST

software package is taken as a prototype of many agricultural systems software, and is dealt with in details.

The module gives an overview of the components that build up the PT software and describe the structure/format of the data input and output to the software. Thereafter, students are introduced to running simple simulations with PT as well as accessing and working with output files from simulations.

Module 2: Agricultural Systems Simulation II

This module was developed for course AE 116: Computer Applications for Agricultural Engineers, offered to all first year BSc Agricultural Engineering students. This is an advanced version to Module I i.e. *Agricultural Systems Simulation I*. This module provides an in-depth description of the PT software, different areas in which the PT software can be used including the planning and design of rainwater harvesting systems. The Exercises take students in the simulation of rainwater harvesting systems, exploring the output data files, manipulation and plotting of data (the details about this module are in Annex B23).

Module 3: Maize Growth and Development under Different Ecological Scenarios

This module was designed for courses CS 201: Crop Physiology and CS 205- Annual Crops, taught to all undergraduate students pursuing BSc Agriculture General, BSc Agronomy and BSc Horticulture. This module assist students in understanding maize growth and developmental stages and their importance in relation to yield, how different crop management practices such as planting date and method; spacing (population/densities); fertilizer application (amount/time/type and method); irrigation schedules and pest and diseases control do affect maize growth, development and yield. Also students are made to understand easily how crop growth characteristics such as leaf area index (LAI), biomass partitioning affect growth, development and yield of maize crop.

The module contains three exercises, through which students are guided in the simulations of different situations. Students are finally required to access and analyse output data and therefore to draw up conclusions (the details about this module are in Annex B23).

Module 4: Soil and Water Conservation

This module was designed for the courses SS 302: Land husbandry and Conservation Agriculture and SS 301: Soil Water Management and Conservation taught to all undergraduate students in BSc Agronomy and BSc Agricultural General respectively. The module is designed to assist students to understand the effect of ridging (soil & water conservation) on depression storage and generation of surface runoff, the effect of bund height (e.g. size of ridges) on profile moisture and consequently maize crop yield, the effect of ground cover (including mulching) on soil evaporation/evapotranspiration, the effect of soil bulk density (proxy for extent of soil compaction) on surface runoff, as well as understand the effect of texture of surface soil layer(s)/horizon(s) (e.g. sand vs. clay) on surface runoff and infiltration.

Two exercises are given in this module, whereby students will be running simulations for different soil conservation measures and recording the outputs (the details about this module are in Annex B23).

Module 5: Agro-meteorology and Hydrology

This module was developed for the course AE 312-Principles of Hydrology offered to third year BSc Agricultural Engineering students. The module deals with using the PT climate generator to generate missing climatic data using historical data of the same station.

In addition, the PT software is used to establish rainfall-runoff correlation for selected sites.

The first exercise is designed to guide students through the process of generating missing data as well as accessing and analysing the generated data. In the second exercise, students are expected to record rainfall and runoff from simulations, and to determine the correlation between the two parameters (the details about this module are in Annex B23).

Module 6: Water Productivity and Irrigation Scheduling

This module was developed for postgraduate students taking MSc Irrigation Engineering. The experiment seeks to assist students in understanding how to determine proper timing and amount of irrigation water to apply to realise maximum crop yields, and to determine the water productivity.

Simulations will be run for a set of prepared data sets, each representing a given irrigation schedule. Necessary parameters will then be recorded and analysis done to compare the various scenarios simulated (the details about this module are in Annex B23).

Module 7: Performance of maize under different soil types

This module is intended for teaching Soil Science subjects at Ilonga and Uyole Agricultural Training Institutes. The experiments are designed to assist students to determine soil textural classes using the PT software, and to understand the influence of different soil types on maize yield. Simulations will therefore run for different soil profiles and maize yield response analysed (the details about this module are in Annex B24).

Module 8: The Effect of Rainfall Patterns on Crop Yield

This module is intended to assist Agricultural Science and Agro-meteorology Tutors at Uyole and Ilonga Agricultural Training Institutes. The experiment allows easy demonstration of the effect of rainfall amount and patterns to crop yield. It also addresses the effect of planting dates. The experiments simulate agro-hydrological simulation of three different areas: Mbeya in the Southern Highland with high rainfall (up to 1000 mm per season), Morogoro – medium rainfall (between 400 and 600 mm per season) and Western Pare Lowlands – very low rainfall (between 200 and 400 mm per season). Therefore, the module allows students to understand the importance of site-specific management of soil and water (the details about this module are in Annex B24).

5 SUMMARY AND CONCLUSIONS

5.1 Summary

The project facilitated the availability and use of the PARCHED-THIRST software to potential users. The aim was achieved through (1) distributing the software to potential clients through internet, mails, workshops, and trainings and thereafter soliciting feedback, (2) upgrading the software to become more user-friendly, (3) developing strategies to sustain provision of service to support use of PT software by a range of clients and (4) Uptake promotion of the use of the PT software.

Distribution of the software involved official launching at national and regional levels, mailing CDs to more than 138 clients, distribution during national events (such as National Water Week and Engineers' Day) and distributing to target clients (in Same and Mwanga Districts, TMA and MAFS and academic staff at SUA, during SIAC courses participants, SEARNET annual conferences and SWMnet workshops and meetings). Clients and external reviewers were able to provide useful feedback through identification of the trouble shooting areas. The feedback was categorized as software-type and scientific-based, meaning some issues needed software reprogramming while the other required scientific research in agro-hydrology, respectively. The feedback and suggestions provided were used to build a strong foundation towards improving the

software not only for the project lifetime but also in the years to come. Furthermore, through distribution, training and promotion, several clients showed strong interest in using the software. Among these, include extension staff in the Districts of Same and Mwanza, SIAC participants, Department of Agro-meteorology of Tanzania Meteorological Agency, Ministry of Agriculture and Food Security and staff at Sokoine University of Agriculture especially Departments of Crop Science, Soil Science and Agricultural Engineering and Land Planning.

Using the feedback from clients and review reports from external reviewers, The PT software was upgraded to versions 2.2, 2.3 and 2.4. Tools that were employed to upgrade the software included Visual Basic 6, Visustin –flow chart visualization tool, Project Analyzer, Microsoft HTML workshop and Windows Installer. The latest software (version 2.4) contains better and more user-friendly output interface graphics, context sensitive buttons, comprehensive background information, tutorials, rarely crash, and subroutine for data conversion to PT format has been included. To improve clients' confidence on the software, validation of the software was also done for rainfed and rainwater harvesting systems. The results showed good agreement between actual and simulated yields.

Strategies to sustain the use of the software were required so that clients who have started to use and showed interest in the software could be helped, supported and advised. Therefore, the project team established the initial Help office, which was later transferred permanently to the Computer Center of Sokoine University of Agriculture. In order to generate income to support the office, short courses were developed including course materials to fit various clients, ranging from meteorologists and hydrologists to soil and crop scientists. The PT Help office offered courses on PT software to various types of participants such as SIAC participants, District Agricultural and Extension Officers and participants to a course on Irrigation and Water Management sponsored by AICAD. The involvement of stakeholders over a period of three years and their strong interest in the software including academic staff at SUA and the potential shown by the PT software in predicting yield and other parameters were enough to convince SUA administration through its Computer Center to agree to host the model.

The uptake component of the project allowed the development of two key PT products that can be used over a long period of time by students, academicians and practitioners. The first product is the five case studies that were developed in collaboration with stakeholders. The uptake component was also able to involve staff from the Ministry of Agriculture and Food Security, Tanzania Meteorological Agency and three Districts. The kind of involvement was quite unique in the sense that stakeholders representing these Institutions were involved in an interactive manner (writeshops) in the development of the case studies. The problems of the case studies were identified by the stakeholders themselves and the PT Help Office assisted in modelling the problems using the PT software. In the second set of products, virtual laboratory experiments, staffs from Sokoine University of Agriculture, Uyole and Ilonga Agricultural Training and Research Institutes were involved in an interactive development through writeshops. The exercise resulted into eight virtual laboratory experiments in different areas in agricultural sciences: soil science, crop science, environmental science and agricultural engineering.

5.2 Conclusions

Soliciting feedback from clients is very challenging and an expensive exercise especially in developing countries because very few clients responded to questionnaires that were mailed to them and most of the responses received were through face-to-face communication especially during trainings and workshops. In general, in order to get reliable and significant responses, face-to-face communication is the most reliable means. In addition, upgrading of agro-hydrological models in developing countries is still a problem because emphasis on computer

applications and programming is almost lacking. There is a need to emphasise training in these areas so that more programmers will emerge especially during this information age. Furthermore, a lot of scientific information generated ends up in scientific papers within individual countries. Researchers need to be enlightened to deposit their knowledge if possible in models because the generated knowledge will be put into use. Lastly, models still have limited market demand, therefore there is a need to improve promotion of models in developing countries to increase the market demand of these scientific models.

In general, the project is considered a success since the software was upgraded, the Help office established and some clients either have started to use the software (Same District, MIFIPRO and SUA) or are planning to use it in the near future (Tanzania Meteorological Agency and Ministry of Agriculture and Food Security). Effort is now towards strengthening its use to those who have started and further uptake promotion to other potential clients. Networking with other organizations with similar interest both inside and outside the country is another effort that is being pursued. Currently, the PT Help office has started to work with Katholieke Universiteit Leuven and Makerere University to promote the use of PT around Lake Victoria area and the first training was implemented in April 2005.

These case studies have proved the importance of agro-hydrological simulation models in assisting investigation and solution building of very complex agricultural systems that can not be easily understood. Furthermore, the case studies have shown how the PT software can be used in its current form (i.e. without fertility component) by frontline extension staff. Its strength in comparison to other models is its capability of being able to handle the surface characteristics and the various water components from rainfall, runoff, infiltration and evaporation. With regard to virtual experiments, students graduating from Sokoine University of Agriculture, Ilonga and Uyoile Training Institutes will have the know-how and principle knowledge on agro-hydrological simulation models and specifically PARCHED-THIRST software.

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