

NATURAL RESOURCES SYSTEMS PROGRAMME
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Report Title

A manual for virtual laboratory experiments in agriculture for agricultural colleges: The use of PARCHED-THIRST software in agricultural systems simulations.

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NRSP Production System

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1. The Effect of Rainfall Patterns on Crop Yield

Objectives of the module

After completing this module, students will be able to:

- Explain the effect of climate on crop yield
- Explain the effect of planting date on crop yield

Requirements for the module

- Knowledge of word and spreadsheet software such as Microsoft Word and Microsoft Excel
- Computer with Microsoft Windows 98/2000/XP
- PARCHED-THIRST software

1.1 Introduction

There is a close relationship between crop production and climate. Other factors that influence crop performance are soil type and land management practices. One major climatic factor influencing crop yield is rainfall. Its amount and distribution determines the amount of soil water to be stored for crop use during the growing season. Temperature and solar radiation also affect the performance of a crop and soil water availability. High temperatures and solar radiation encourage fast growing of the crop (early maturity) and high evaporation rates of soil water. Low solar radiation and temperature causes slow plant growth rate (late maturity) and low evaporation rates.

1.1.1 Water requirement for maize crop

Maize is an efficient user of water in terms of total dry matter production and among cereals it is potentially the highest yielding grain crop. For maximum production a medium maturity grain crop requires between 500 and 800 mm of water depending on climate. To this, water losses during conveyance and application must be added. The crop factor (kc) relating water requirements (ET_m) to reference evapotranspiration (ET_o) for different crop growth stages of grain maize is for the initial stage 0.3-0.5 (15 to 30 days), the development stage 0.7-0.85 (30 to 45 days) the mid-season stage 1.05-1.2 (30 to 45 days), during the late season stage 0.8-0.9 (10 to 30 days), and at harvest 0.55-0.6 (<http://www.fao.org/ag/agl/aglw/cropwater/maize.stm>).

1.1.2 Water supply and maize crop yield

The schematic graph in Figure 1.1 shows the growth periods of maize.

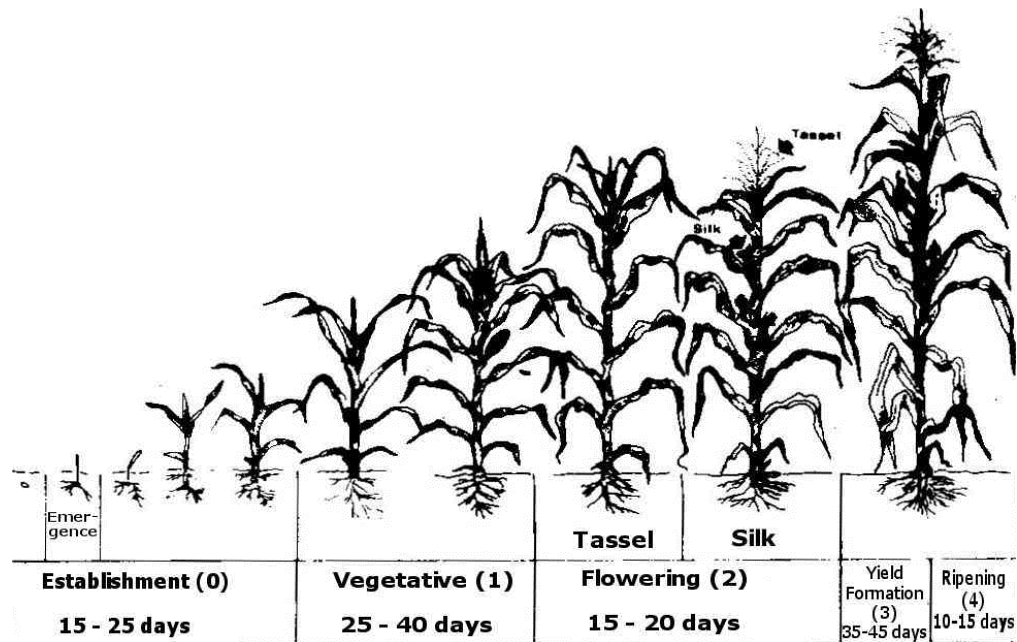


Figure 1.1: Maize crop development stages

Frequency and depth of irrigation and rain has a pronounced effect on grain yield. Maize appears relatively tolerant to water deficits during the vegetative (1) and ripening (4) periods. Greatest decrease in grain yields is caused by water deficits during the flowering period (2) including tassling and silking. Dry matter partitioning in different parts of maize from planting to pollination is seen on reduced in grain number per cob. This effect is less pronounced when in the preceding vegetative period (1) the plant has suffered water deficits. Severe water deficits during the flowering period (2), particularly at the time of silking and pollination, may result in little or no grain yield due to silk drying. Water deficits during the yield formation period (3) may lead to reduced yield due to a reduction in grain size. Water deficit during the ripening period (4) has little effect on grain yield.

On the other hand maize flourishes on well-drained soils and waterlogging should be avoided, particularly during the flowering (2) and yield formation (3) periods. Water logging during flowering (2) can reduce grain yields by 50 percent or more. Where water supply is limited it may therefore be advantageous to meet, as far as possible, full water requirements so as to achieve near maximum yield from a limited acreage rather than to spread the limited water over a larger acreage.

1.2 PARCHED - THIRST Model

PARCHED THIRST is an acronym for **P**redicting **A**rable **R**esource **C**apture in **H**ostile **E**nvironment **D**uring **T**he **H**arvesting of **I**ncident **R**ainfall in **S**emi **A**rid **T**ropics. The model was developed to simulate the rainwater harvesting systems in semi arid tropics. It simulates the runoff process, soil-water movement and the crop growth and yield in response to daily climatic data. It is a process-based model with a user-friendly interface. PARCHED-THIRST (PT) is a lumped parameter model where the landscape is divided into units of land assumed to be homogeneous landscape; this is referred to as profile in the model. The collection of these profiles forms a system, which can either, be rainfed or rainwater harvesting depending on the number of profiles. A rainwater harvesting system is represented by more than one profile where one or more profiles represent the runoff generation areas and the other represent the runoff receiving area and the only transferable mass between these profiles is the surface runoff.

The inputs to the model are

- Weather variables, which include rainfall, evaporation, maximum and minimum temperature, relative humidity, radiation and wind speed.
- Location and latitude, where the later is used in Penman equation to estimate evaporation.
- Criteria for sowing (timing), user defined or predicted by model. In case of user defined, the input is the date of sowing for a particular season. Predicted sowing date is estimated by the model based on the available soil water required for planting, number of rainy days before planting, the earliest date of which the season is expected to begin and maximum number of days that the model can wait before deciding it is time for sowing.
- The number of years of simulation together with start date of the season and number of seasons to be simulated.
- Crops parameters such as plant population density (number of crop stands per hectare), crop cultivar and water logging. Crops that can be simulated by the model are limited to cereal crops such as maize, millet, sorghum and rice cultivars. The parameters for crop cultivar are inbuilt in the model.
- Weed parameters including time of weeding operations which is number of days after crop emergence, maximum rate of water uptake by weeds, rate of root advancement and maximum root depth.

- Soil properties inputs to the model including soil layer depth and initial soil moisture content for each layer, soil type (texture), soil fertility equilibrium rate, soil strength which determines the resistance of soil to root growth, soil drainage parameter which determines rate at which water drains out of the soil profile and macro pores distribution and flow rate. Soil surface inputs parameters are bund height if storage is allowed, percentage of soil evaporation reduction if there is any surface treatment like crop cover, and mulching, area represented by the profile and slope of the profile.

Given all this information the PT Model is able to simulate maize crop yield, runoff generation, evapotranspiration, soil moisture, and crop growth development stages. The outputs from simulations are stored in a spreadsheet format file, which can be accessed using Microsoft Excel for analysis and interpretation. For example daily rainfall data charts can be used to explain the maize crop failure in a given season, and also compare the yields from different locations with different climates.

1.3 Exercises

1.3.1 Exercise 1 –Igurusi Case

Step One: Start PT V2.3 and open the Igurusi system

- Double-click on the PTv2.3 model icon or from the Start task bar go to *Programs* and from the program list click PTv2.3. The PTv2.3 main window and Welcome screen will appear as shown in Figure 1.2.

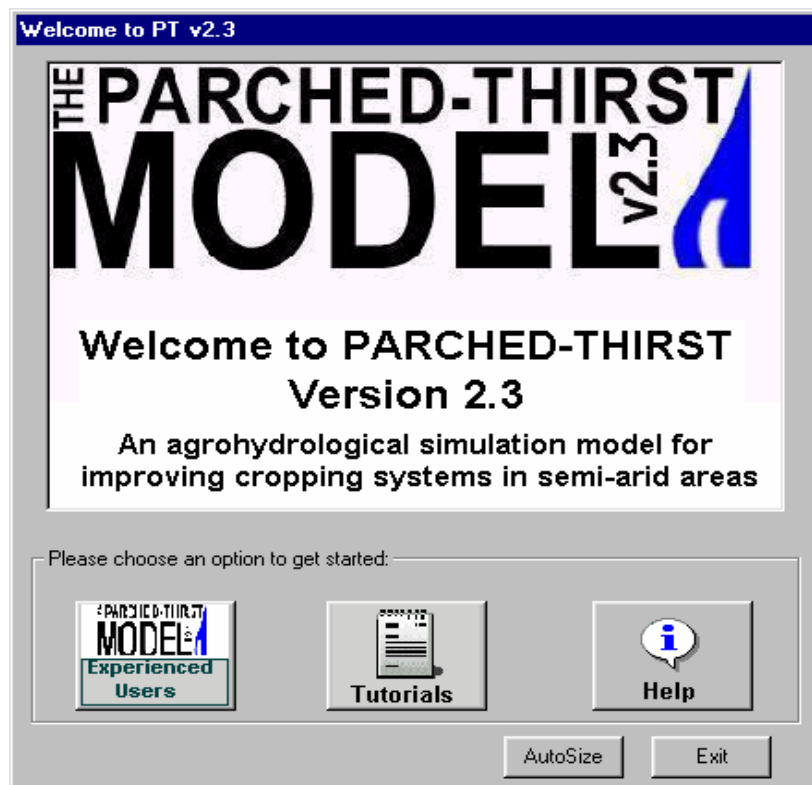


Figure 1.2: PT Model Welcome Screen

- On the Welcome screen click of Figure 1.2 Click on the icon *Experienced User* to be taken straight to the main system window of PTv2.3 shown in Figure 1.3.
- On the system menu (Inside circle 1 in Figure 1.3), click on *File*. From the drop down menu that will appear, click on *Open*. The *Open System* Window similar to that of Figure 1.4 will then appear. Choose the file *Mbeya Igurusi* and click on *Open*.

You will have opened the Mbeya Igurusi system. It is a rainfed system and its main window is similar to the PT Model main window.

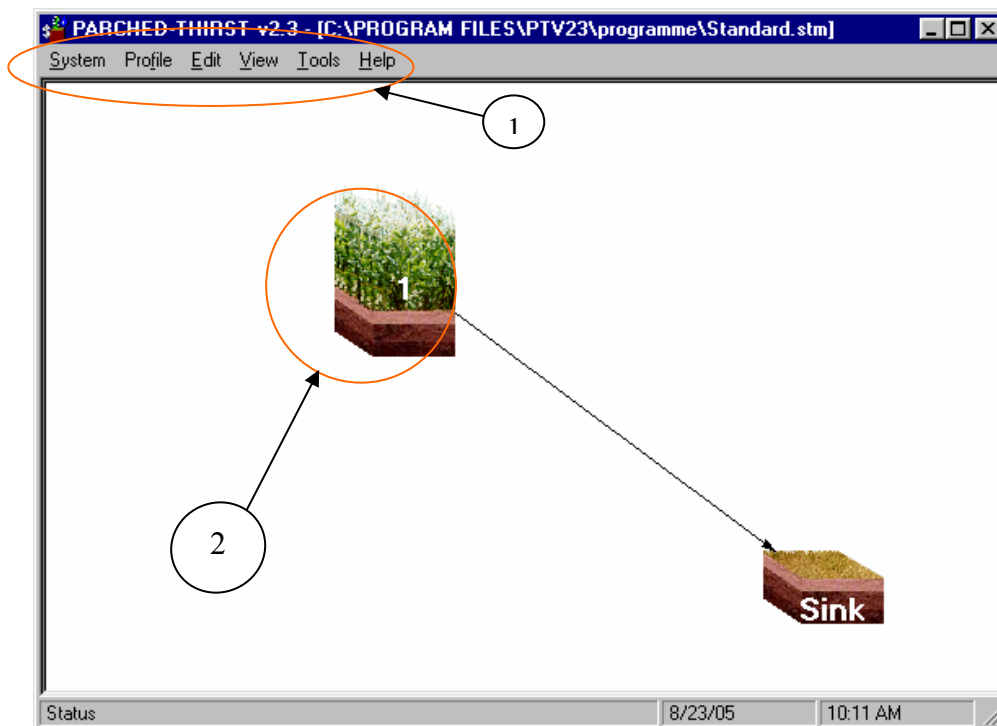


Figure 1.3: PT Model Main Window

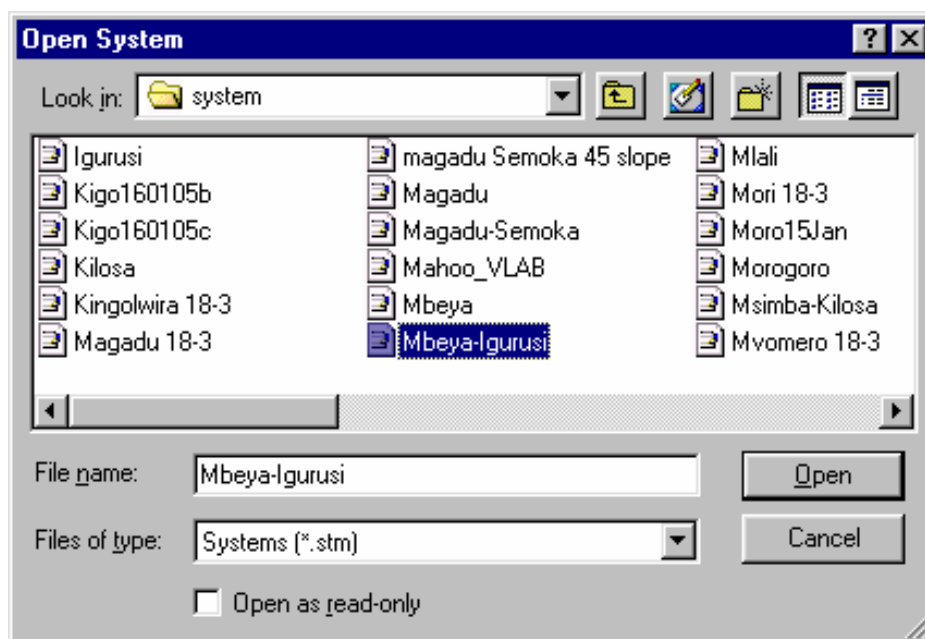


Figure 1.4: Open System Windows

Step Two: Specify System settings

- From the system menu, click on *File* and from the *File* drop down menu, click on *Properties* to open the *System Properties* window as shown in Figure 1.5.

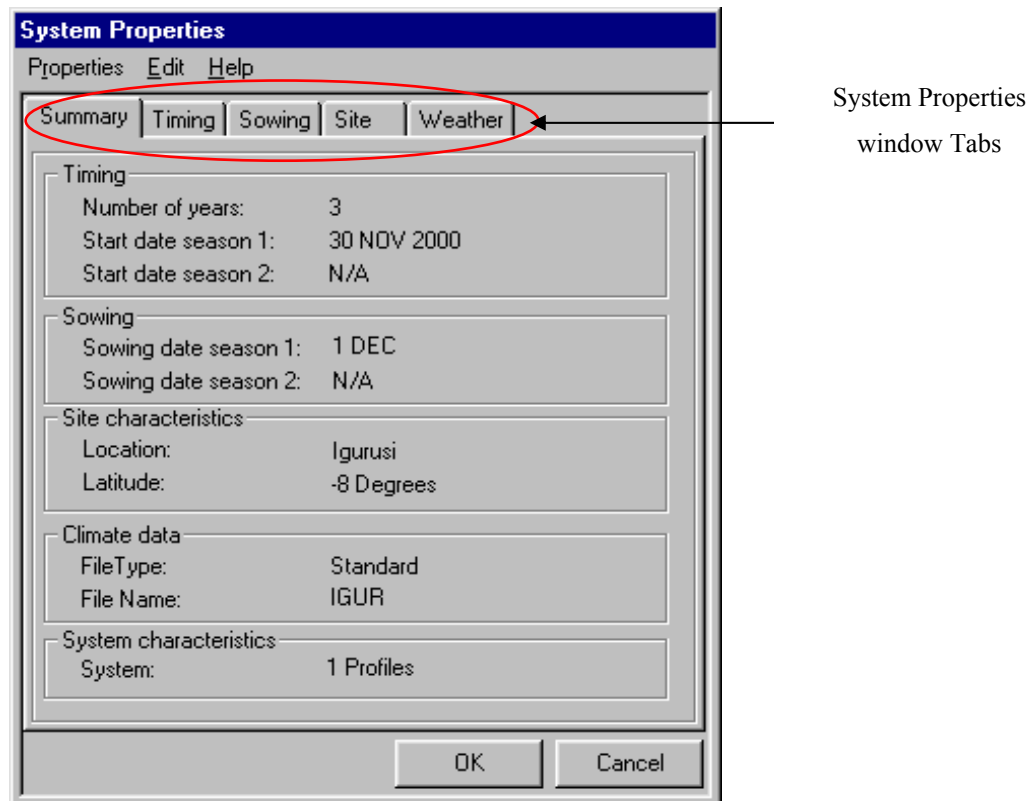


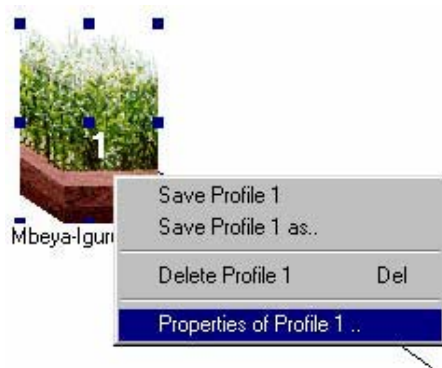
Figure 1.5: System Properties window

The window above displays a summary of system settings. In this exercise, you don't need to change these properties. However, you will need to modify them in the following scenarios. To achieve this, just Click on any one of the window's Tabs (inside the red circle in Figure 1.5, i.e. *Timing, Sowing, Site, Weather*) and a form will be displayed that will allow you to edit the properties. You will have to click on *OK* after updating the system properties

- Click OK to return to the Igurusi system main Window.

Step Three: Specify profile settings

- From the Igurusi system main window, right click on the *Profile Icon* (inside circle 2 on Figure 1.3). From the drop down menu that will appear (Figure 1.6), select and click on *Properties of profile 1*.



Note: You may also open the profile properties window by just *double clicking* on the Profile icon.

Figure 1.6: Opening the Soil Profile Properties

The profile properties window will then appear as shown in Figure 1.7 below

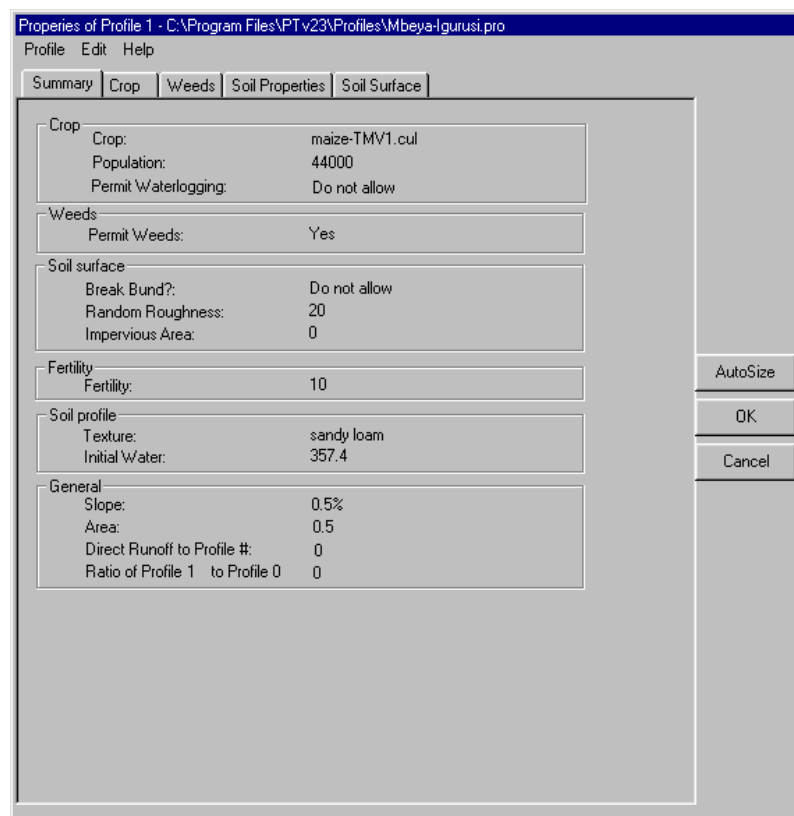


Figure 1.7: Igurusi Soil Profile *Properties Window*

Similarly, to view or to modify details of the soil profile, Click on any one of the tabs *Crop, Weeds, Soil Properties or Soil Surface*.

For the sake of this whole exercise, **do not change** any profile setting

- Click the *OK* button to return to the system main window, ready for running simulation.

Step Four: Run Simulation

- From the *System* menu go to *File* from the *File* drop down menu click on **Run**.

The first window that appears, will prompt you to specify the location and the name of the summary output file as shown in Figure 1.8 below.

- Leave the location unchanged and in the file name box, type in a name you will be able to remember (e.g. *IgurSum_1Dec* may mean that the file is a summary output for Igurusi simulation for maize planted on 1st December).
- Click on *Save* button to continue. A second window, similar to the previous will appear. In the same way, type in the name of the *Daily Output* file (e.g. *IgurDaily_1Dec*).
- click the *Save* button again to continue.

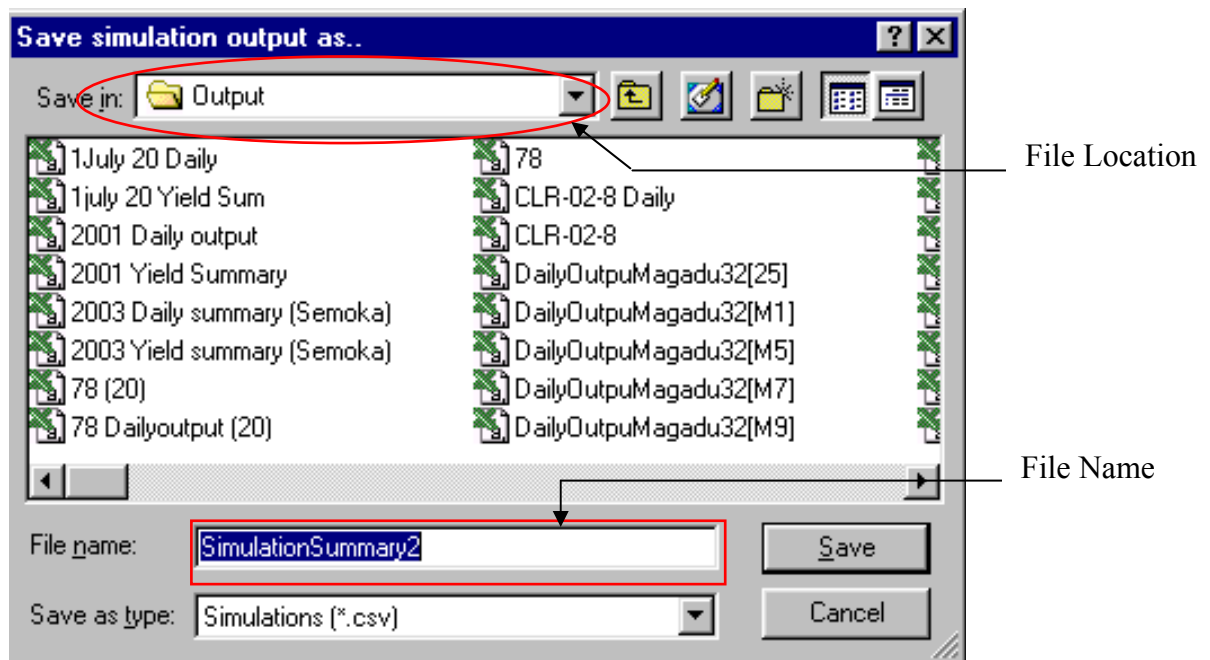


Figure 1.8: Saving summary output file

Note: If the filename you specified already exists, you will see a *Warning Message* as shown in Figure 1.9. By clicking *Yes* the already existing file will be replaced by the actual results from simulation. Otherwise, you will be brought back to the previous window to specify a different file name.

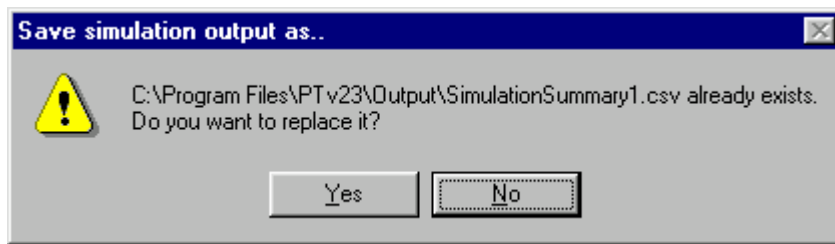


Figure 1.9: Warning message when you specify an already existing output file

- On the *See simulation Graphics?* (Figure 1.10) message box, click on *Yes* be able to see simulation graphics

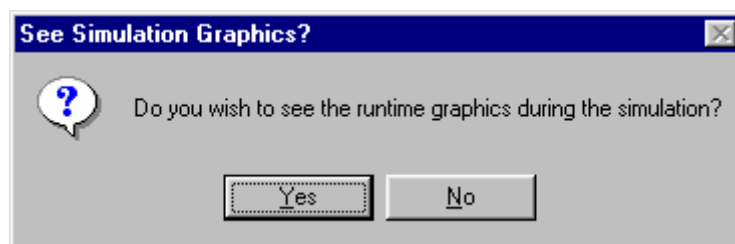


Figure 1.10: See Simulation message box

- Under *Speed of Simulation* (Figure 1.11), select *Medium* or *Fast* and click *OK*.

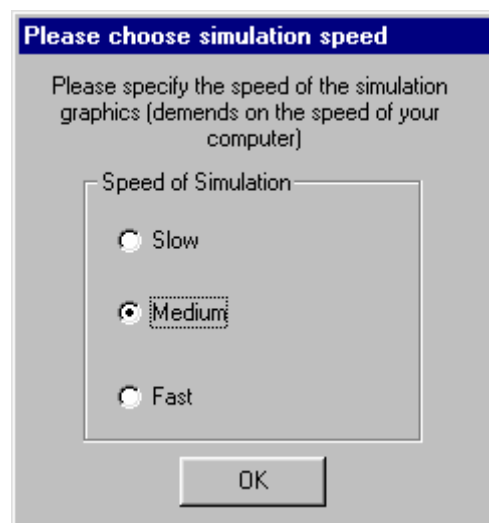


Figure 1.11: Speed of Simulation message box

You are going to see run time simulation graphics, as shown in Figure 1.12. Wait until simulation graphics finish.

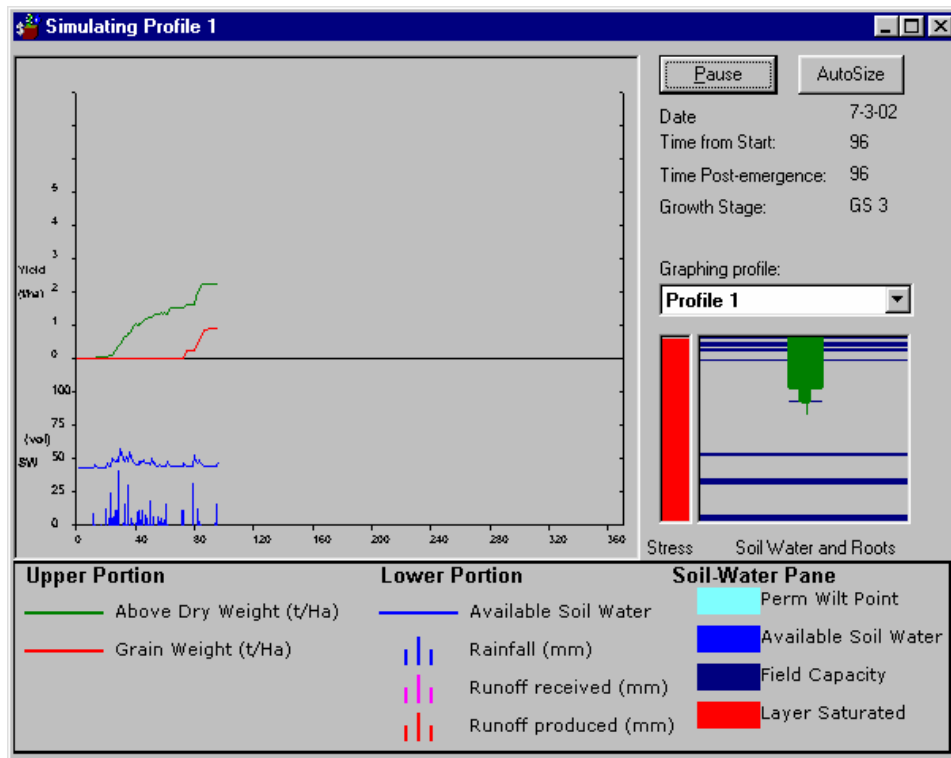


Figure 1.12: Run time Simulation graphics

- For the following message boxes (Figure 1.13 and Figure 1.14), answer *OK*



Figure 1.13: Warning message

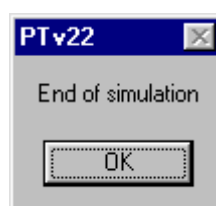


Figure 1.14: End of simulation message

- You will see the Simulation Output Summary window, as shown in Figure 1.15.

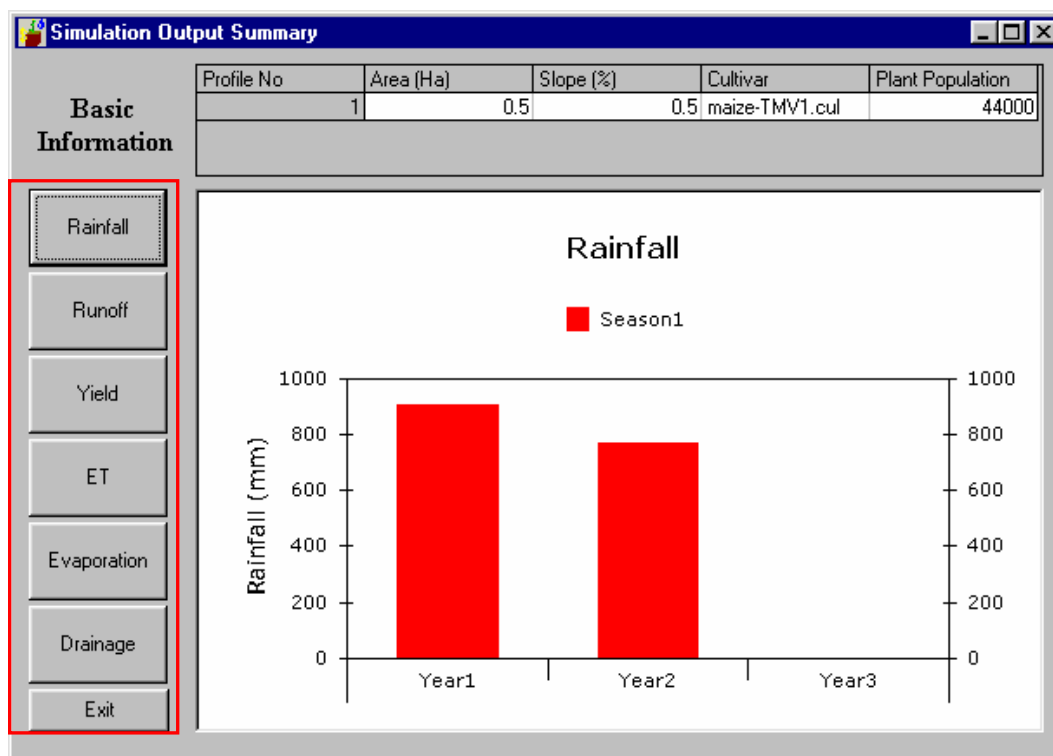


Figure 1.15 Simulation Output Summary Window

The first window shows output total seasonal rainfall. In order to view output results for other parameters, click on the command buttons on the LEFT of the output summary window (see red rectangle in Figure 1.15). These are *Runoff*, *Yield*, *ET*, *Evaporation* and *Drainage*.

- Record your results in Table 1.1 and click on *Exit*
- Open again the System Properties window (Refer **Step Two**) and change the Planting date to 5th December
- Re run simulation (Refer **Step Four**) and records your results in Table 1.1.

Assignment 1

- Repeat the exercise for dates indicated in Table 1.1 and record your results.
- Analyze your yield and rainfall results.

Table 1.1: Table of Results - Igurusi

| Site | Planting date | Yield (t/ha) | | |
|---------|---------------------------|--------------|--------|---------|
| | | Year 1 | Year 2 | Average |
| Igurusi | 1 st December | 1.35 | 1.05 | |
| | 5 th December | | | |
| | 10 th December | | | |
| | 15 th December | | | |
| | 20 th December | | | |
| | 25 th December | | | |
| | 30 th December | | | |
| | 5 th January | | | |
| | 10 th January | | | |
| | 15 th January | | | |

1.3.2 Exercise Two – Uyole site case

All procedures are similar to those in **Exercise 1** but you will open the *Uyole* system instead of the *Mbeya-Igurusi* system. You can view the system and the profile settings in the same way as in Exercise 1.

Assignment 2

Run simulations and record your results for different planting dates in Table 1.2.

Table 1.2: Uyole table of results

| Site | Planting date | Yields (t/ha) | | | |
|---------|---------------------------|---------------|--------|--------|---------|
| | | Year 1 | Year 2 | Year 3 | Average |
| Igurusi | 1 st December | | | | |
| | 5 th December | | | | |
| | 10 th December | | | | |
| | 15 th December | | | | |
| | 20 th December | | | | |
| | 25 th December | | | | |
| | 30 th December | | | | |
| | 5 th January | | | | |
| | 10 th January | | | | |
| | 15 th January | | | | |

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2. Performance of maize under different soil types

Objectives of the module

After completing this module, students will be able to:

- Determine soil textural classes using PT Model
- Run rains fed simulations using PT Model and record the results
- Understand the influence of different soil types on maize yield

Requirements for the module

- Knowledge of word and spreadsheet software such as Microsoft Word and Microsoft Excel
- Computer with Microsoft Windows 98/2000/XP
- PARCHED-THIRST software

2.1 Introduction

Maize is a major staple food for many Tanzanians. It is grown in many regions by most farmers particularly small- scale farmers who are mostly resource poor. The crop is mostly grown under rain fed conditions prevailing in different agro-ecological zones. The performance of maize is usually influenced by environmental conditions that include weather conditions, soil characteristics, and management operations.

Weather conditions that influence maize production include rainfall amount and distribution, temperature, relative humidity, wind, solar radiation etc. Soil characteristic is another important aspect that affects maize production. This includes physical properties such as texture, structure and water holding capacity.

2.2 Soil texture

Soil texture refers to the relative proportion of particles of various sizes in a given soil. The texture of the soil cannot be altered and thus is considered a basic property of that soil. The determination of soil particle distribution is referred to as mechanical analysis and the various groups into which the mineral particles are separated and referred to as separates.

Table 2.1: Particle-size classification based on the International and USDA systems

| International system | | USDA system | |
|----------------------|---------------------|------------------|---------------------|
| Soil separate | Diameter range (mm) | Soil separate | Diameter range (mm) |
| Coarse Sand | 2-0.2 | Very Coarse Sand | 2-1 |
| Fine Sand | 0.2-0.02 | Coarse Sand | 1-0.5 |
| Silt | 0.02-0.002 | Medium Sand | 0.5-0.25 |
| Clay | < 0.002 | Fine Sand | 0.25-0.1 |
| | | Very Fine Sand | 0.1-0.05 |
| | | Silt | 0.05-0.002 |
| | | Clay | <0.002 |

In general, the process of particle-size analysis involves the following steps

- (i). Screening a soil sample through a 2.0mm sieve to remove soil fractions not belonging to the particle size distribution (composition)

- (ii). Destroying organic matters by treating with hydrogen peroxide
- (iii). Removing other cementing materials such as calcium carbonate and oxides of iron and aluminium by acid treatment
- (iv). Dispersing completely the remaining matter into primary particles by churning or shaking after adding some dispersing agent like sodium oxalate or sodium exametaphosphate, and
- (v). Determining the proportion of various separates in the dispersed material by a specified method. The International Pipette method and the Bouyoucos Hydrometer method are the most widely used.

The International Pipette Method involves the removal of a known amount of suspension from a definite depth after specific time interval. The fractions removed at appropriate times give the percentages of sand, silt and clay in the sample.

In the Bouyoucos Hydrometer Method, the amount of a particular soil separate present in suspension at some specified time is read directly on a specifically made hydrometer. Data so obtained are used for the determination of soil textural classes.

2.2.1 Soil textural classes

The overall textural designation or class is determined on the basis of mass ratios of the three fractions (sand, silt, clay). Soils with different proportions of sand, silt and clay are given different designations as shown in textural triangle (Figure 2.1). These soil textural classes are determined by using soil textural Triangle method or PT Model.

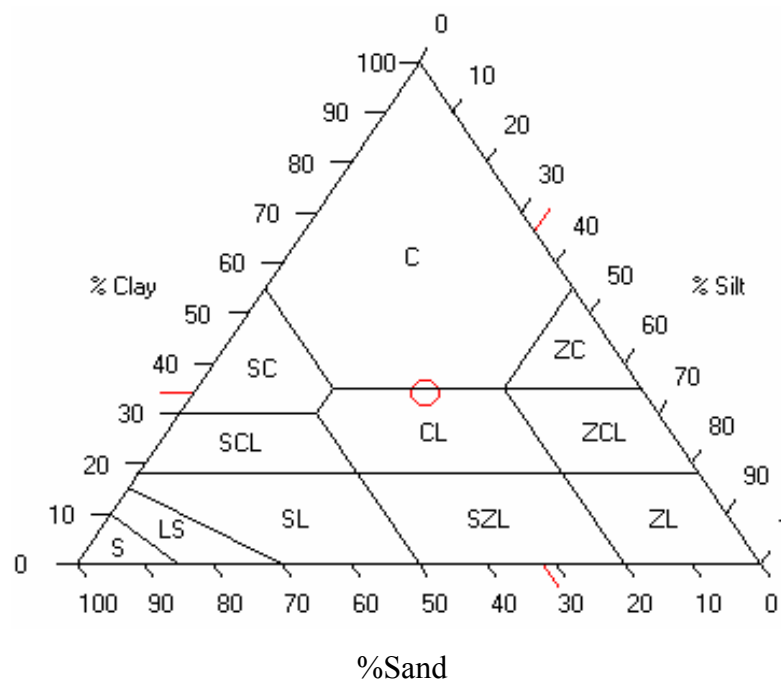


Figure 2.1: Soil textural triangle

There are three major textural soil classes i.e. sands, clays and loams.

Sand: The sand group includes all soils of which the sand separates make up 70% or more of the material by weight. For example sand and loam sand.

Clay: A soil to be designated a clay must carry at least 35% of the clay separate and in most cases not less than 40%, for example, sandy clay, silty clay and clay.

Loam: The loam, group that contains many sub divisions, is more difficult to explain. An ideal loam is composed of approximately 40% sand, 40% silt and 20% clay, and may be defined as a mixture of sand, silt and clay particles that exhibit light and heavy properties in about equal proportions. For example sandy loam, silty loam, silty clay loam, clay loam, sand clay loam and loam.

These soil textural classes have different impact on anchorage, root penetration, drainage, aeration, movement and retention of moisture, availability of plant nutrients and chemical and biological characteristics of the soils. According to literature, loams are the best soils for agricultural production.

2.3 Crop simulation models

Scientists have developed different computer models to help study various agricultural processes. Examples of crop simulation models are

- PARCHED-THIRST

- DSSAT
- APSIM

In this module the PARCHED-THIRST (PT) software is used to study the performance of maize crop under different soil types. The PT Model is described in the section below.

2.4 The PARCHED THIRST Model

The PT Model is an agro hydrological simulation model for improving cropping systems in semi arid areas and is a useful tool for studying the effects of soil types on crop yields in a given locality. The PT Model must have a profile as well as a system under which it works. A profile has properties, which define a soil characteristic, the soil surface, the crop to be grown and any weeds. The profile must be linked with the sink that represents an undefined destination for runoff lost from the cropped area. A system, which can be thought of as a landscape, is a profile linked to the sink; the profile has its own properties with information on the geographical location (including weather data to be used), simulation start dates and crop planting dates. The PT Model can as well reveal the relationships between different soil types and their characteristics such as drainage, available water, evapotranspiration, runoff etc. and their influence on maize yield. Figure 2.2 shows the components of the PT Model.

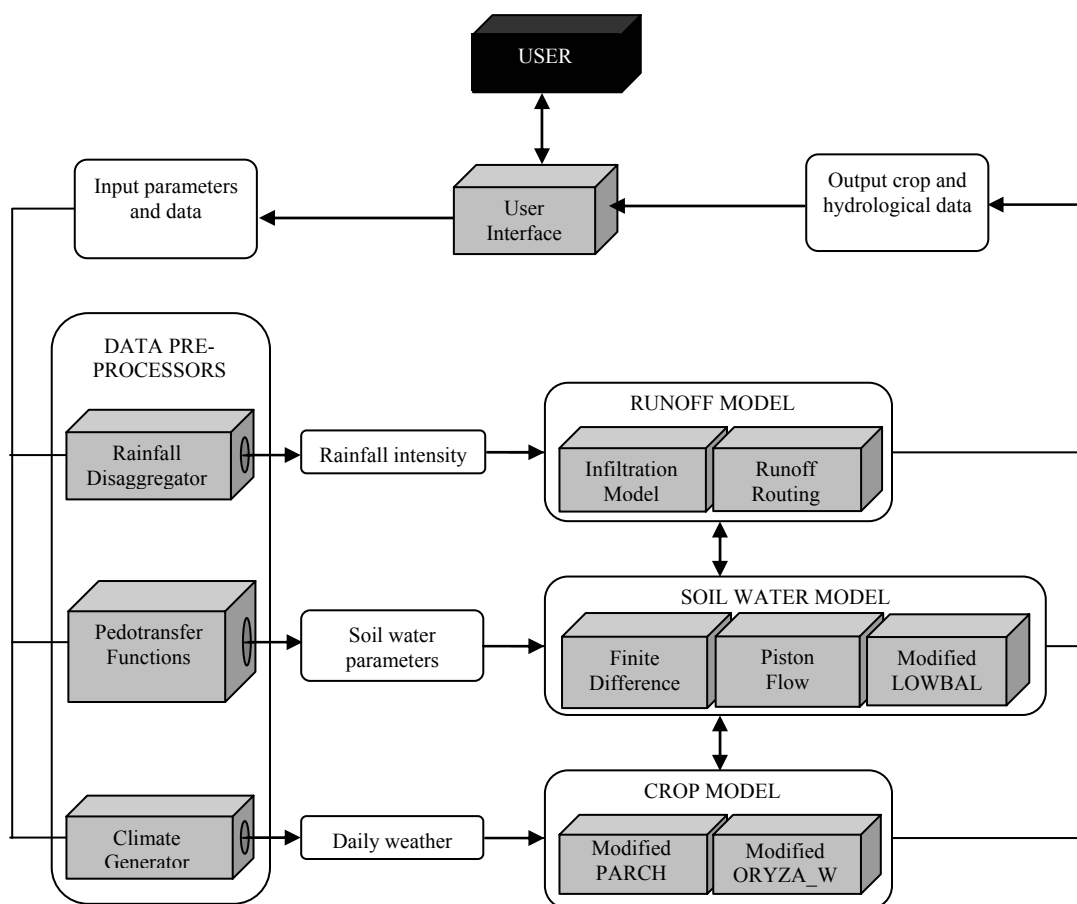


Figure 2.2: Components of the PARCHED THIRST Model

2.5 Exercises

Exercise: 1

1. Open PTv2.3 by double clicking on PTv2.3 icon on the computer.
2. Click on Experienced user as shown in figure 2.3.



Figure 2.3: PT Model welcome screen

A standard profile connected to the sink with an arrow will appear as shown in Figure 2.4.

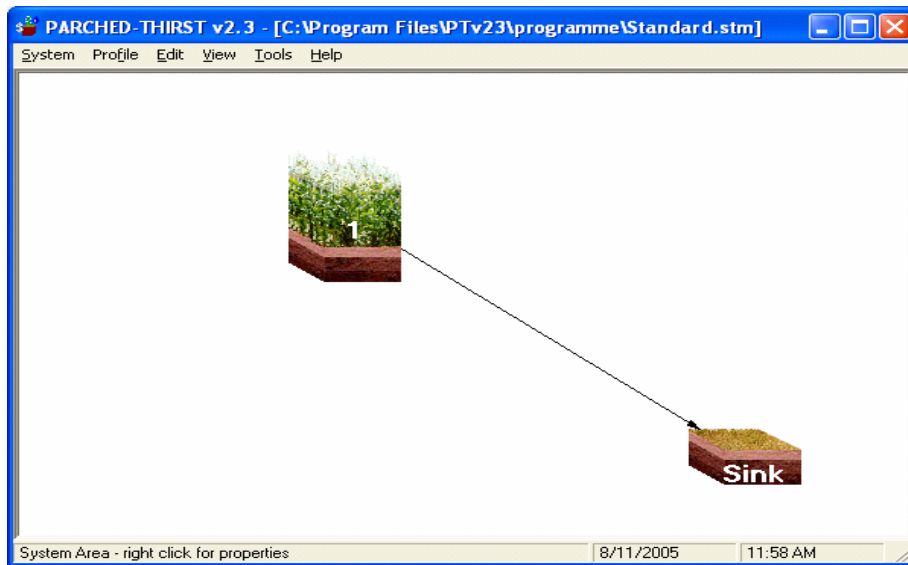


Figure 2.4: PT Model main window

3. Click on system and select open as shown in Figure 2.5.

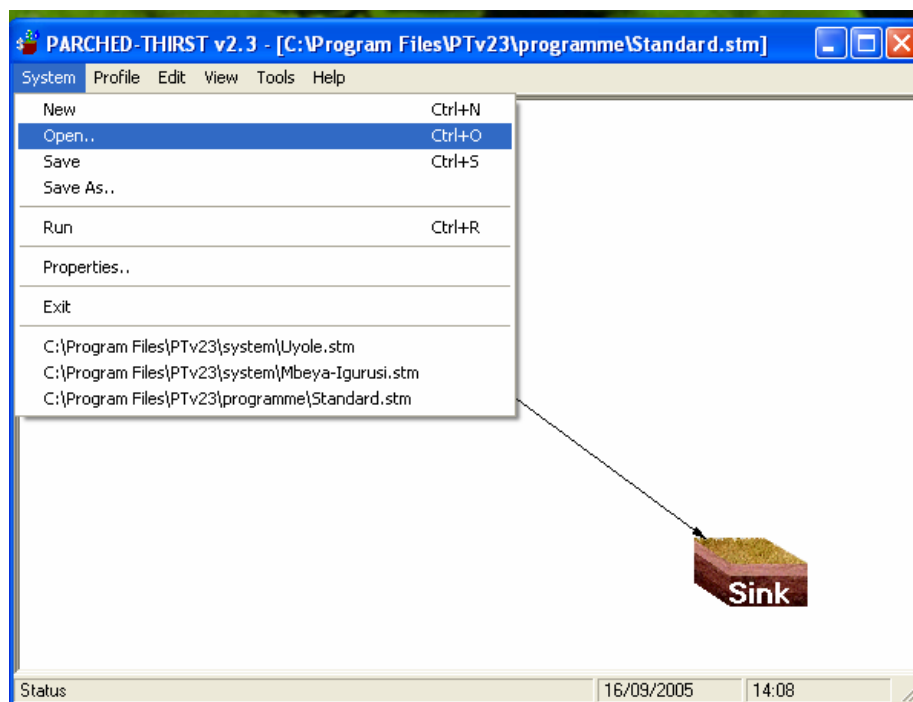


Figure 2.5: Opening an existing system

4. In the systems folder select Kilosa and click open as shown in figure 2.6.

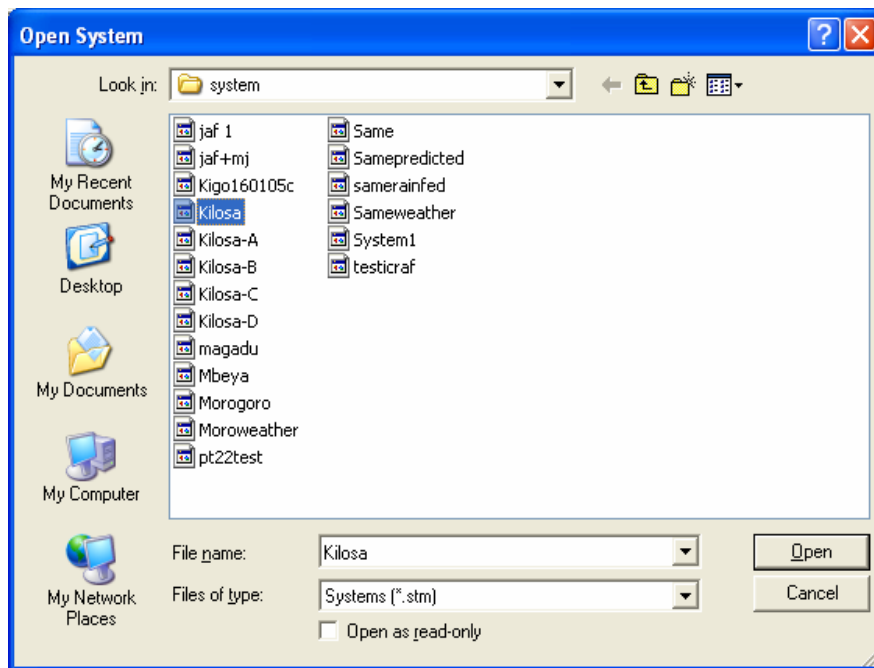


Figure 2.6: Selecting an existing system

5. Right click on the Kilosa profile and select properties of profile 1 as shown in Figure 2.7.

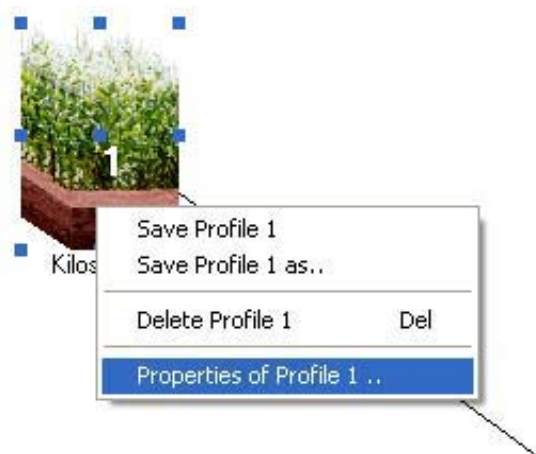


Figure 2.7: Opening the profile properties

Click on the properties of profile 1. The following table will appear as shown in Figure 2.8.

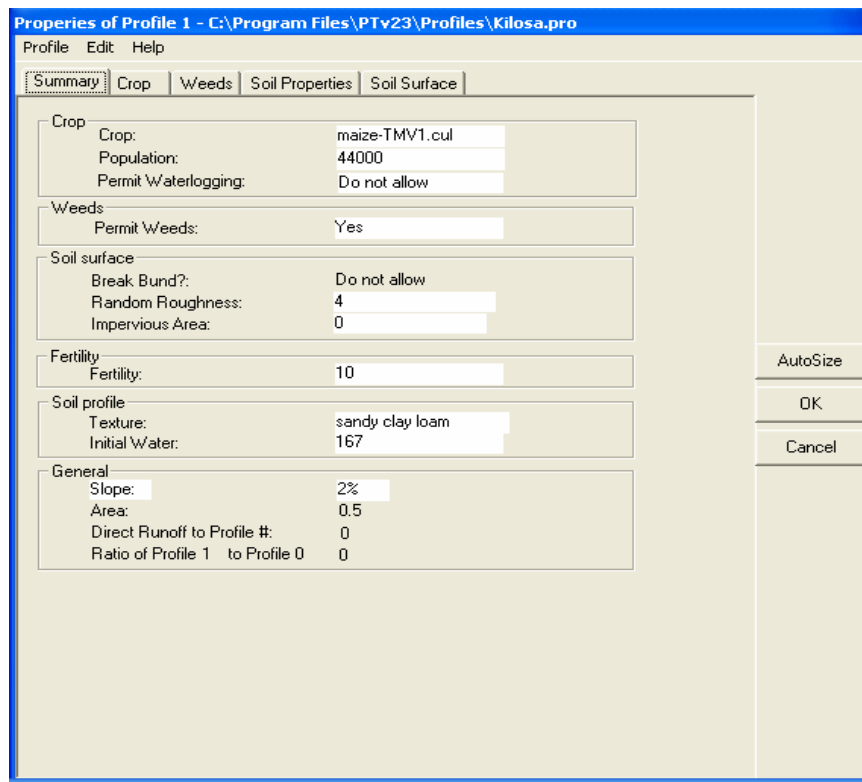


Figure 2.8: Profile properties window

Check entries in different profile properties one by one i.e Crop, Weed, Soil properties and Soil surface. On soil properties look at different textural class of soil layers and their corresponding sand, clay, silt organic matter, bulk density and cation exchange factor proportions. Then do the following assignment and click OK.

Assignment 1.

Fill in the following Table 2.2:

Table 2.2: Soil texture

| Soil layer | Sand | Silt | Clay | Organic matter | Bulk density | Cation Ex. Factor | Textural Class. |
|------------|------|------|------|----------------|--------------|-------------------|-----------------|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |

6. Click on the system and select properties as shown below in Figure 2.9.

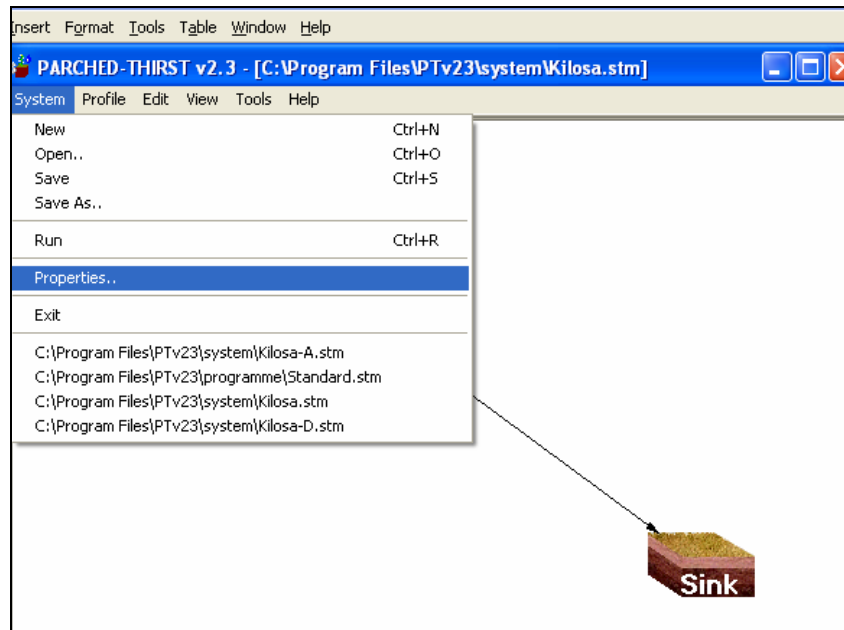


Figure 2.9: accessing the system properties

Click on properties and check entries in each system properties i.e. Summary, Timing, Sowing, Site, and Weather as shown in Figure 2.10 Then click OK.

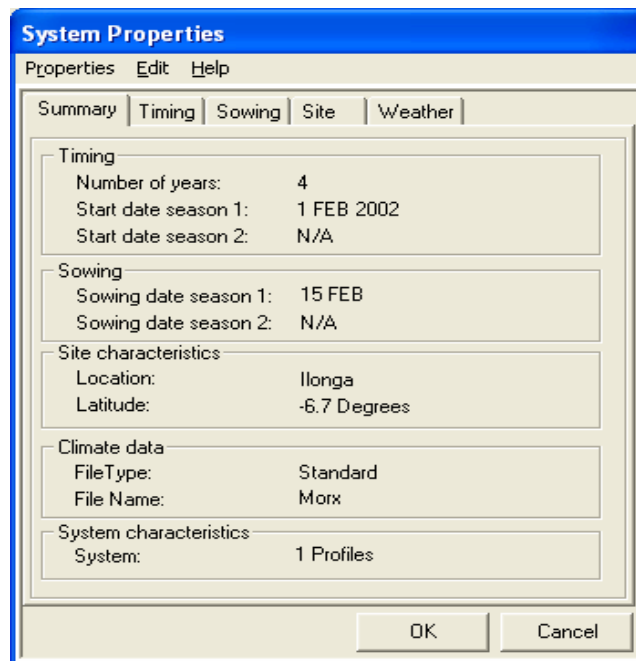


Figure 2.10: System properties window

7. Click on system and then select Run as shown below in Figure 2.11.

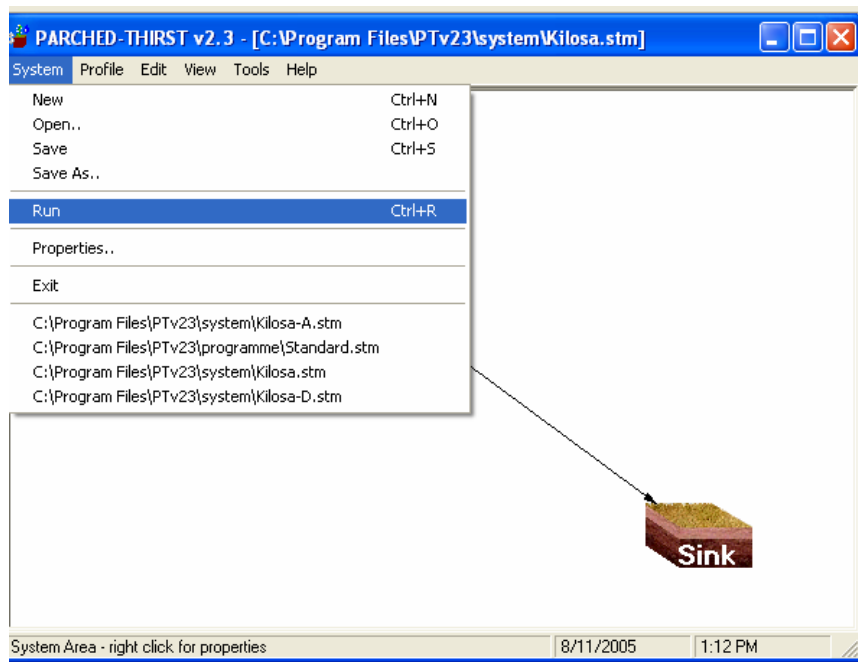


Figure 2.11: Running simulation

8. Specify file name (e.g. Exercise 1 Summary) as shown in Figure 2.12 and then save.

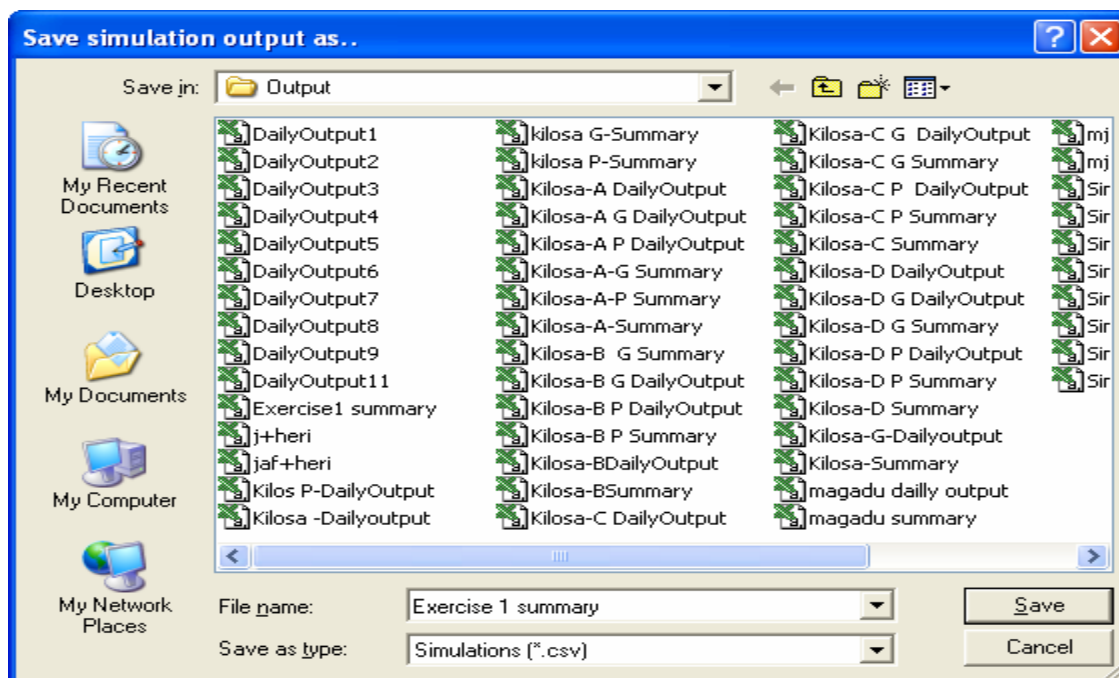


Figure 2.12: Saving the summary output file

9. Specify file name (e.g. Exercise 1 Daily output) as in Figure 28 and then save.

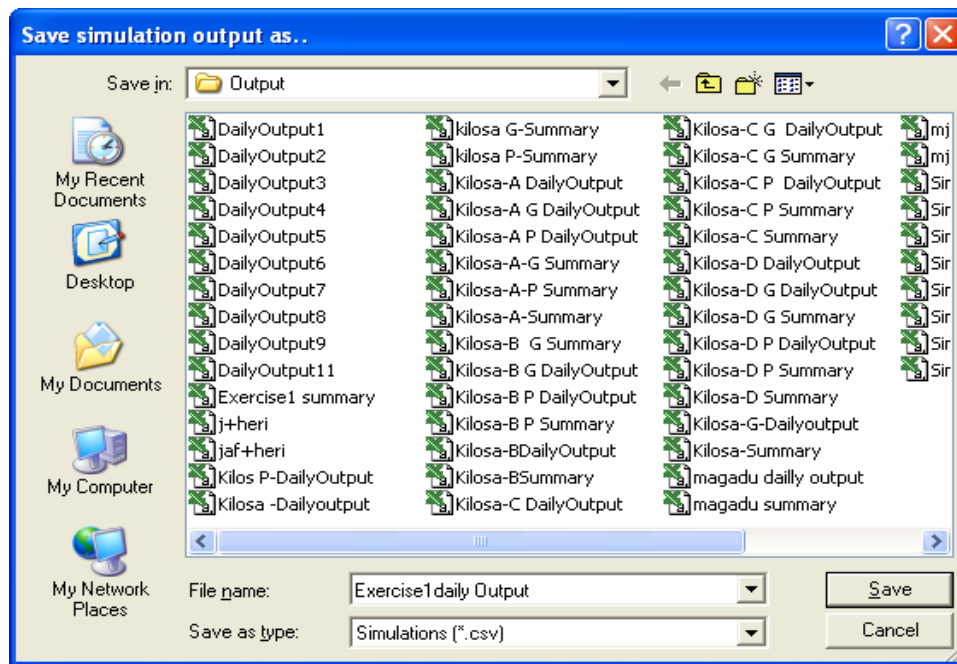


Figure 2.13: Saving the daily output file

10. Click on Yes on the message box that appears (Figure 2.14).

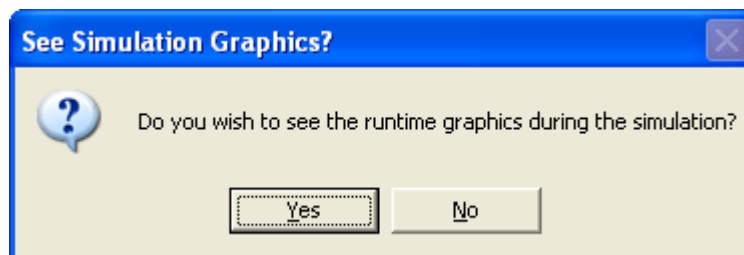


Figure 2.14 Simulation message box

11. Select medium speed on the window in figure 2.15 and click OK. Then click OK to end the simulation as in Figure 2.14. On the *End of simulation* message that follows (Figure 2.16) click OK.

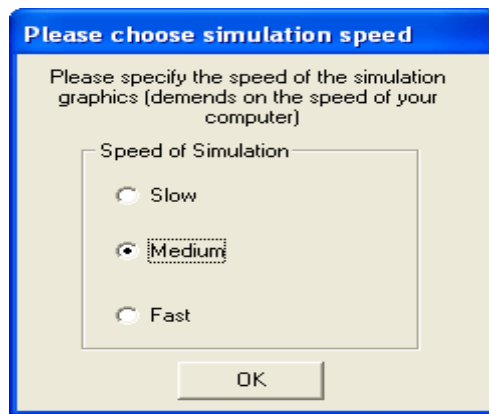


Figure 2.15: Specifying the speed of simulation

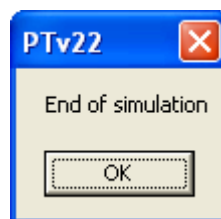


Figure 2.16 End of simulation

The output summary window of Figure 2.17 will appear

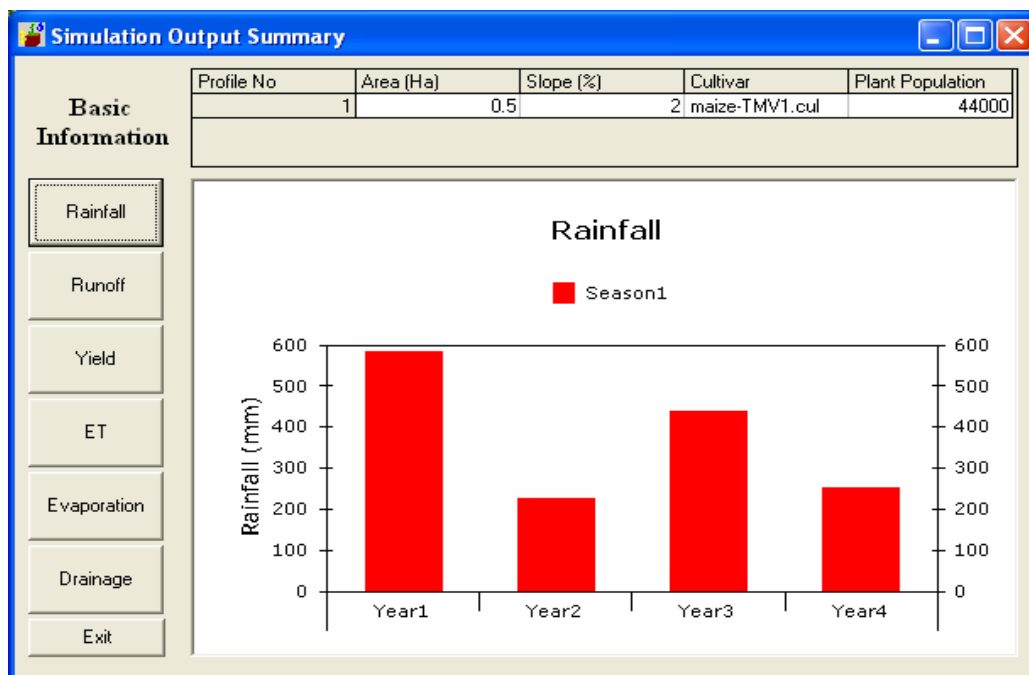


Figure 2.17: Output summary window

12. click on **Yield** button to view yield results

Assignment 2

- Repeat the procedure from step 7 – 12 for each soil type and complete Table 3.

- Comment on your results.

Table 2.3: Maize yield for different soil types

| Soil type | Yield t/ha. | | | | |
|----------------|-------------|------|------|------|---------|
| | 2002 | 2003 | 2004 | 2005 | Average |
| Sand clay loam | | | | | |
| Sand clay | | | | | |
| Sand loam | | | | | |
| Clay | | | | | |
| Clay | | | | | |

2.6 Appendices

Assignment 1

| Soil layers | Sand | Silt | Clay | Organic matter. | Bulk density | Textural Class. |
|-------------|------|------|------|-----------------|--------------|-----------------|
| 1 | 0.54 | 0.19 | 0.26 | 0.0391 | 1.4 | Sandy clay loam |
| 2 | 0.45 | 0.16 | 0.38 | 0.0221 | 1.6 | Clay |
| 3 | 0.37 | 0.14 | 0.48 | 0.0153 | 1.3 | Clay |
| 4 | 0.47 | 0.06 | 0.46 | 0.0119 | 1.5 | Sandy Clay |
| 5 | 0.46 | 0.16 | 0.38 | 0.01105 | 1.505 | Sandy Clay |

Assignment 2

| Soil type. | Yield t/ha. | | | |
|-----------------|-------------|------|------|------|
| | 2002 | 2003 | 2004 | 2005 |
| Sandy Clay Loam | 1.20 | 0.60 | 0.70 | 0.42 |
| Sandy Clay | 0.65 | 0.19 | 0.39 | 0.25 |
| Sandy Loam | 1.00 | 0.20 | 0.60 | 0.35 |
| Clay | 1.00 | 0.20 | 0.40 | 0.30 |
| Clay | 1.18 | 0.25 | 0.42 | 0.40 |

2.7 References

Mzirai, O.B., T. Bwana, S.D. Tumbo, F.B. Rwehumbiza and H.F. Mahoo (2004),

PARCHED THIRST HANDBOOK, SWMRG – PT Help Office

<http://www.fao.org/ag/agl/aglw/cropwater/maize.stm>