NATURAL RESOURCES SYSTEMS PROGRAMME

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Maize growth and development under different ecological scenarios.
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Objective

The main objective of this module is to understand the overall growth, development and yield of a maize crop is a function of the genetic potential to react to the environmental conditions under which the crop is grown.

Specific objectives include the following

- Identify maize growth/developmental stages and their importance in relation to yield
- Understand 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
- Understand how crop growth characteristics such as Leaf Area Index (LAI), biomass portioning affect growth, development and yield of maize crop

Requirements for the Module

- Weather data files
- Soil characteristics (physical and chemical)
- Start dates for different growing seasons
- Planting dates for different seasons
- Location of the areas (latitude), size of the area under cultivation, slope, surface characteristics (level of soil cover in percentage)
- Spacing (plant population)
- PARCHED-THIRST Model
- Spreadsheet and Word processing packages such as Microsoft Excel and Word

3.1 Introduction

3.1.1 Crop Growth and Development

Growth refers to increase in size, volume, density. For example, cell enlargement or growth of a crystal. On the other hand, development refers to growth with differentiation. For example, panicle bud (primordial) does not only grows in size but also shows up different parts on it such as branches, spikelets, glumes, anthers, etc. Therefore, growth in the grain in dry matter that includes differentiation.

Since virtually every gene of a plant affects plant growth, there are thousands of physiologic genetic steps that are component processes of a "system" giving rise to yield. A number of steps are integrated via a complex network of interacting pathways, manifested as photosynthesis, respiration, translocation, water and mineral uptake and distribution, leaf production and leaf area increase, photoperiod and temperature response, flowering, fertilization, grain filling, senescence and death. At the "output" end of "box of metabolic wants" (listed above; inputs are solar energy, water, Carbon dioxide, minerals, etc., to the seed) there are two ultimate processes;

(i) Net accumulation of photosynthate (dry matter); and,
(ii) Partitioning of dry matter into economically important organ(s), e.g. grain in cereals.

Crop physiologists measure photosynthetic accumulation by determining the total plant dry weight, which is mostly made up of carbon compounds synthesized during photosynthesis. Great deal of genotypic differences exists in this character, and also there exist many cultivars by stage of plant development and cultivars by environment interactions.

In order to analyze the growth of the crop, the two best parameters are leaf area (indicating the capacity for photosynthesis) and dry weight (measure of total production) determined at regular intervals during crop growth. Since the yield at harvest is determined by a series of events taking place throughout the growth period of the crop, simplified growth analysis conducted as an adjunct to standard yield trial procedure is very useful in:

(i) Understanding how high yield is achieved and how a particular genotype does very well in a particular environment and why others are not, i.e., adaptability of a cultivar; and,
(ii) Understanding how best we can breed for a better plant, which yields high as well as being stable in productivity.

Growth and development is a coordinated system of sub-processes. It involves cell division: cell enlargement; and, cell differentiation. The process of growth and differentiation of individual cells into tissue, organs and organisms is called development. Growth initiated in the apices of stem and root meristems is called first-degree growth, and accounts for the increase in length of axes and is responsible for formation of lateral appendages, e.g. branches, leaves and floral parts.

3.1.2 Measurement of growth at different periods

Increases in volume (size) are measured by quantifying expansion in one or two directions, e.g. length, width, diameter or area. Weight increases are measured by use of fresh or dry weights. Dry weight is more reliable than fresh weight, and is obtained by drying freshly harvested material for 24 to 48h at 70-80^{o}C.

3.1.3 Growth curves (kinetics)

Growth curves are idealized as being S-shaped with three distinct phases; logarithmic, linear and senescence phases. This is especially true for annual plants (Fig. 3.1). In the logarithmic phase, size increases exponentially with time i.e. growth rate is slow at first but continuously increases at an increasing rate. In the linear phase, increase in size continues at a constant rate, usually maximum rate for some time. In the senescence phase, the growth rate decreases. It is difficult to determine growth curves of perennial plants, i.e. idealized growth and growth rate curves. Growth curves of fruit crops such as grape, blueberry, currant, olive and stone fruits (peach, apricot, cherry and plum) show interesting double sigmoid growth curves where the first "senescence" phase is followed by another lag-phase, and then a second sigmoid phase follows.

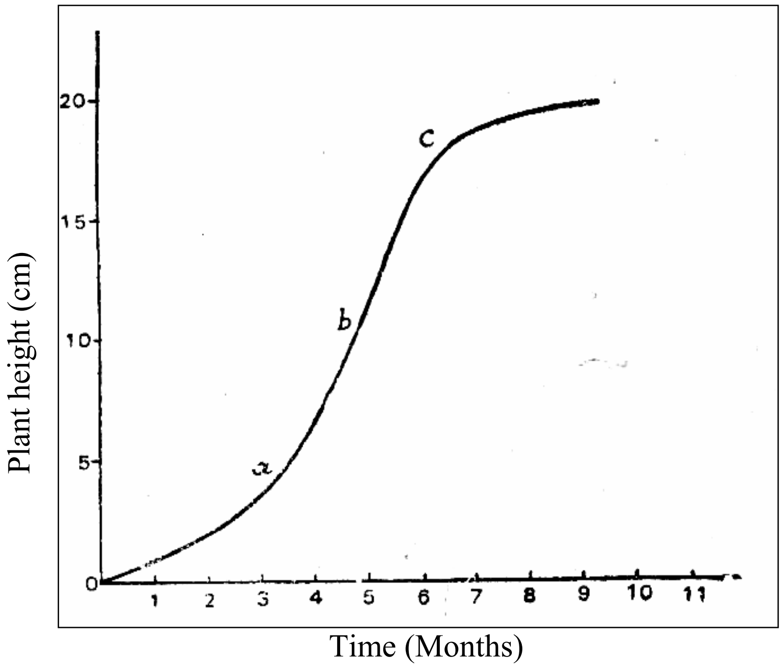

Figure 3.1. Idealized growth curve – a typical S-shape for annual crop.

3.2 Reproductive growth

After establishment of roots, stems and leaves, the plant flowers and then forms fruits and seeds. The time from seed germination to flower development in annual crops represents the vegetative phase of growth. Most angiosperm species produce bisexual (perfect) flowers. Monoecious species, e.g. maize, pumpkin and many hardwood trees form staminate and pistillate flowers at different positions along a single stem. Dioecious plants have both male and female flowers, e.g. papaya.

When ovules become fertilized, seed and fruits develop. Developing seeds are usually essential for normal fruit growth. If seeds are present only in one side of a young apple fruit, only that side of the fruit will develop, and seeds are essential for normal strawberries. Young seeds are rich in auxin, which is important for fruit development. There are fruits that develop without seed in them either because no fertilization occurred or it occurred followed by an abortion soon after. Such fruits are pathenocarpic fruits and include banana, melon, pineapple, some citrus, grapes, peaches, etc. Seedless fruits are sometimes very desirable, e.g. for processing.

Soon after fertilization, when seed begin to develop, there is an accumulation of sucrose, glucose and fructose in the ovules. These sugars are later on used in cell wall formation and starch or fat synthesis. A similar accumulation of proteins, amino acids and amides (glutamine and asparagines) also takes place, which end up in storage as protein bodies. The stored starch, proteins, and other compounds make the bulk of food we obtain in cereal grains and other plants. Fruits contain various substances such as starch and sugars (fructose and sucrose, glucose and sugar alcohol, and other compounds, depending on the type of fruit).

3.3 Growth stages in maize

Table 3:1. Maize growth stages (Adapted from IITA/CIMMYT Research Guide)

Stage	DAS*	Features
V_E: Emergence	5	The coleoptile emerges from the soil surface
V_1: First leaf	9	The collar of the first leaf is visible
V_2: 2^{nd} leaf	12	The collar of the second leaf is visible
Vn^{th} : Leaf		The collar of leaf number 'n' is visible. The maximum value of 'n' represents the final number of leaves, which is usually 16-23, but by flowering, the lower 4-7 leaves have disappeared
V_T: Tasseling	55	The last branch of the tassel is completely visible
R0: Anthesis	57	Anthesis or male flowering. Pollen shed begins
R1: Silking	59	Silks are visible
R2: Blister	71	Blister stage. Kernels are filled with clear fluid and the embryo can be seen
R3: Milk	80	Milk stage. kernels are filled with a white, milky fluid
R4: Dough	90	Dough stage. Kernels are filled with a white paste. The embryo is about half as wide as the kernel. The top part of the kernels are filled with solid starch
R5: Dent	102	Dent stage. If the genotype is a dent type, the grains are dented. The 'milk line' is close to the base when the kernel is viewed from the side in both flint and dent types
R6: Physiological maturity	112	Physiological maturity. The black layer is visible at the base of the grain. Grain moisture is usually about 35%

*DAS: approximate number of days after sowing in lowland tropics where maximum and minimum temperatures may be 33 °C and 22 °C respectively. In cooler environments, these times are extended

Note: Each growth stage (vegetative or reproductive) is defined only when 50% or more of the plants in the field are in that stage

Summary of how maize grows

i) Maize plants germinate grow and increase in weight slowly early in the cropping season.
ii) As more leaves are formed, become exposed to sun light, the amount of dry matter also increases.
iii) Leaves on the plants are first produced, and then followed by leaf sheaths, stalk, husks, ears, silks, cob and finally grains.
iv) At growth stage V_{10} there are enough leaves to intercept sun light, so the rate of dry matter accumulation increases rapidly.
v) Under favourable ecological conditions, this rapid rate of dry matter accumulation in above ground plant parts continue at nearly constant rate until near maturity (R_6)

Note:

- If maize crop is from under low plant density, prolificness may result. Increasing the number of plants (population) in a given area reduces the number of ears per plant and the number of kernels per ear.
- Maize yield per hectare will increase per increase in number of plants per hectare until the advantage of higher plant population per hectare is offset by reduction in number of kernels per plant (due to natural resource competition).
- The optimum plant population varies for different varieties of maize crop used with different locations/environments.
- Highest maize yield are usually obtained only where environmental conditions are favourable at all growth stages.
- Unfavourable conditions in early stages may limit the size of the leaves (photosynthetically active areas). In later stages, such conditions may reduce the number of silks produced. Such conditions result in poor pollination of the ovules and restrict the production and development of the ovules. Sometimes growth may stop pre maturely and restrict the size of kernel produced

In general, the amount of maize grain produced by the plant depends on the rate and length of time of dry matter accumulation. Therefore for best yields the farmer should consider the following:

- Select the appropriate site and apply fertilizers according to the soil test result
- Select the maize variety best suited for the location
- Plant early at the recommended plant population and spacing (density)
- Control weeds, insects and diseases appropriately
- Carry out all other actual practices to maximize the rate and length of time of dry matter accumulation in the grain

3.4 Effect of light on maize growth and development

Light quality: Only visible radiation is useful in photosynthesis. Longer wavelength heats up the atmosphere and the plant.

Light quantity: The intensity and duration throughout the crop growth period is one of the major determinants of total photosynthate produced. Hence you find more crop growth in tropical regions than in temperate regions.
Day-Length: while some plants flower in any time of the year 9day-neutral or photo-insensitive), others are photosensitive, i.e. they require either short day (or long night) or long days (short nights). For example sorghum, pearl millet and pigeonpea are short day plants. That means they will flower when the day lengthy is shorter than certain critical photoperiod period (CPP). Cultivars, which are day-neutral, could be bred to adapt to more locations and seasons.

Temperature, also, influences flowering (at cooler temperature it is delayed) and further interacts with photoperiod. Temperature also influences germination, leaf expansion and maturity.

With regard to the growth stages, genotypes perform better at a given location and season. Breeders can pick out the genotype, which flowers and matures at the right period or agronomist can decide on the date of sowing so as to get maximum yield.

3.5 Plant growth analysis

If we conduct a more detailed growth analysis, especially at the onset or end of different growth stages, and see the change in leaf area as well as dry weight and dry weight distribution within the plant, we have more information to compare the different cultivars. Some of the following parameters are found to be very useful:

RGR	: Relative growth rate	NAR	: Net assimilation rate
LAR	: Leaf area ratio	LAI	: Leaf area index
SLA	: Specific leaf area	CGR	: Crop growth rate
SLW	: Specific leaf weight	LAD	: Leaf area duration

3.5.1 Development of Leaf Area

Since the leaf area represents the capacity of the plant to produce dry weight, one can measure the leaf area per unit land or leaf area index (LAI).

LAI = area of leaves above unit land area/Land area

As the seedling grows, the leaf area increases and soon covers the ground completely, thus capturing maximum sunlight and preventing soil moisture loss. More than one “sheet of leaves” can use the intense sunlight. Hence if the leaf area is 2-3 times the land area (LAI = 2-3), maximum sunlight could be captured. We want cultivars, which produce higher leaf area in the earlier part of the season, and agronomists would like to promote leaf area increase by adding fertilizer. However, excessive leaf area is not desirable since, the leaves may shade each other or excessive moisture could be lost which are not desirable.

3.5.2 Dry matter accumulation and distribution

As the leaf area increases and more food is produced it is to be distributed properly to different organs at each stage so that maximum plant growth occurs. It should not be in excess in any part (e.g., having too much dry matter locked in stem, while the developing panicle and root needs it very badly is an undesirable situation). If you plot the dry weight at different stages of growth in different plant parts you would find that there exist cultivar differences. One can notice that high yielding plants do not lock up unnecessarily extra dry matter (e.g., hybrids have lesser stem and leaf than local land races).Also, stored carbohydrates move to developing grain, which is very much desirable under stress conditions.

3.6 Ecology

Maize, with large number of cultivars of different maturity periods, can be grown over a wide range of environmental conditions. In Tanzania the crop is grown from sea level i.e. 50 masl all the way to 2000 masl. Maize is a crop which requires a lot of light. Lack of light in low altitude and wet tropics may result into poor yields.

3.6.1 Water requirements

Maize is a plant which requires a lot of water, unlike other cereals such as sorghum or millets which are preferred to maize if annual rainfall is below 700 or 800 mm. Deficiency of water during any growth stage of maize does reduce grain yield. The magnitude of the reduction depends on the growth stage of the crop at the time of stress, the severity, duration of the stress, and susceptibility of the cultivar (used) to stress.

The young maize plant is moderately drought resistance, but is usually susceptible to unfavourable soil. At this time the crop relies primarily on its seminal roots, and the crop requires a very well aerated soil. i. e. too much moisture prevents optimum growth.

Water stress during vegetative development reduces expansion of leaves, stems, and roots and ultimately affects the development of reproductive organs and potential grain yield.

Maize is most sensitive to drought stress during pollination, when delayed emergence of silks may reduce fertilization and subsequent grain yields as a result of fewer seed numbers.

In general terms, maize grain yield is particularly sensitive to water deficits that coincide with tasselling-silking period and about two weeks after silking. Dry spells during tasselling-silking period does affect the mean kernel weight by reducing assimilate production or duration of grain fill or both. This stage of plant growth is also referred to as the “critical period”
Dry conditions are needed towards harvesting in order to reduce the moisture content of the grain, prevent incidence of ear roots and seed germination.

3.6.2 Time of planting/sowing

Time of planting/sowing is the critical factor affecting maize yields in Tanzania. Time of planting depends very much on location (geographical) and the cultivar being grown and soil moisture availability.As a general rule maize crop should be sown as near the beginning of the rains as possible.
Example: First week of March – Morogoro

First week of December - Mbeya
First week of December - Iringa
End of March - Kilimanjaro and Arusha
Early January - Mwanza

Planting should be done in a way that flowering coincides with the wettest lest months of the season. The main advantage for early sowing is that the soil/moisture relationship is the most important factor. Time of sowing may affect the crop early stages of growth and later in the cropping season. (Refer to water requirements section).

3.7 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 we will use PARCHED-THIRST (PT) software as a tool for learning crop growth. The following section gives brief details of the PT software.

3.8 The PARCHED-THIRST Model

The PT software is a computer-based simulation model that is user-friendly and process-based. It 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.

3.8.1 Components of the PARCHED-THIRST Software

The PT software is made up of various components as shown in Figure 3.2. The first component is the data preprocessors. These are used to prepare or convert input data into a form that it can be used by the various components of the model. The climate generator is used to generate missing weather data. Rainfall disaggregator is used to generate 5 minutes rainfall intensity data from an assumed rainfall intensity distribution. Pedotransfer function is used to generate difficult-to-measure soil hydraulic parameters.

Soil moisture model is used to model the movement of water in the soil whereas the runoff model is based on runoff amount that is infiltration excess, which is modified by depression storage and surface sealing. Runoff routing is only considered in the case of larger catchments because in those cases runoff lag times can be significant.

The PT model incorporates two crop models which are PARCH and ORYZA_W models. 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. ORYZA_W Model is a model developed to simulate water-limited growth and development of rice.

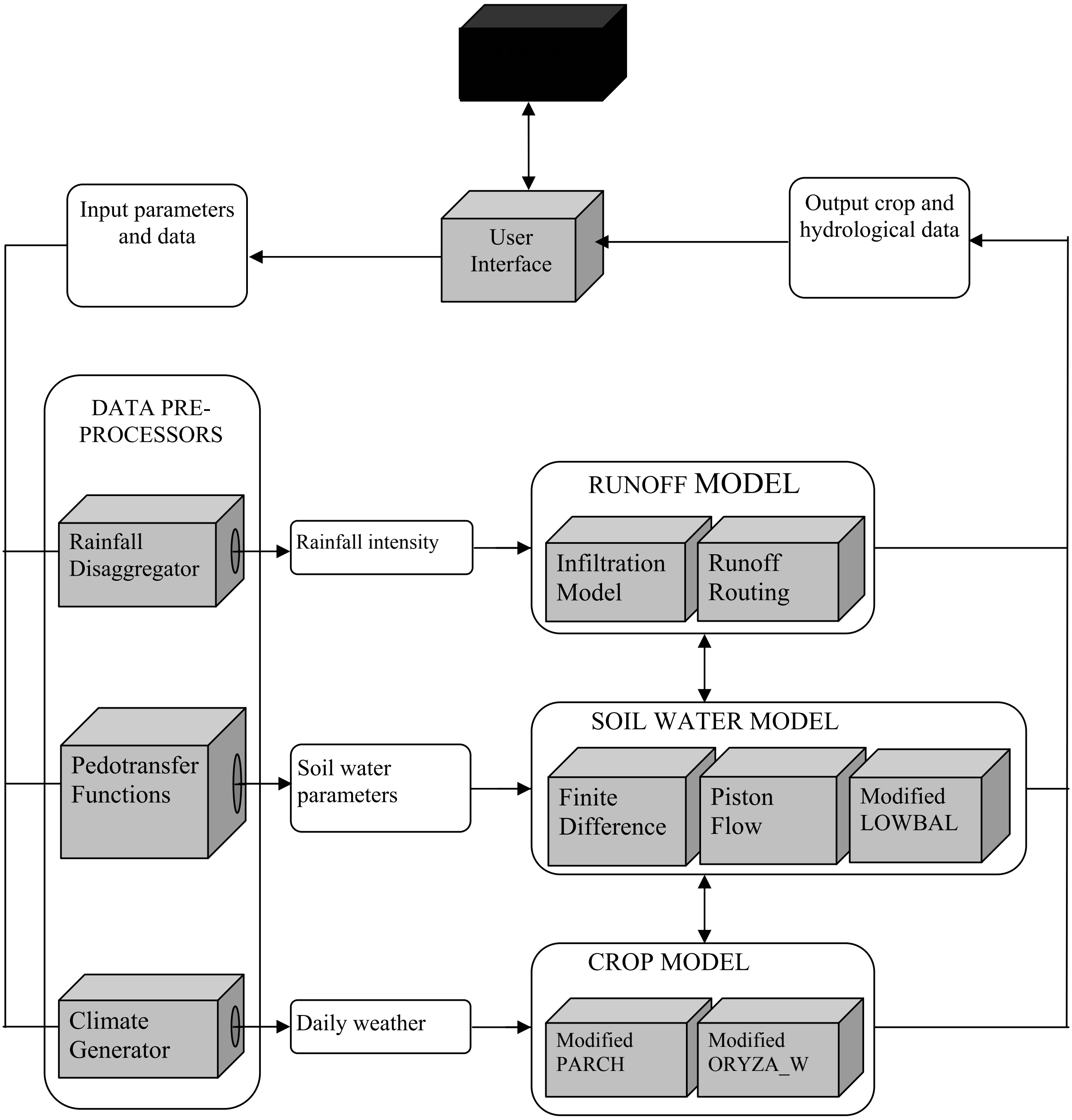

Figure 3.2. Components of the PT software

3.8.2 Input data

The PT model is driven by daily rainfall and other agro-meteorological data. In order to provide for simulation of long-term performance, the PARCHED-THIRST Climate Generator can be used to extend the available historical data. Daily rainfall values are then converted by the rainfall disaggregator into intensity data which are required by the infiltration model. The rainfall-runoff process is simulated as an infiltration excess with infiltration being determined by the Green-Ampt infiltration calculator. Because of the cost and difficulty of measuring soil hydraulic properties in the field, pedotransfer functions are included to allow for their prediction from readily-available soils data. The modified PARCH model adds soil-water redistribution and crop growth simulation routines which complete the system. RWH is simulated by having two profiles running simultaneously with runoff from the upper becoming an input for the lower of the two. Except for climate and soil texture, each profile can have different characteristics.

The crop growth model (PARCH), a sub-model of the PT model, uses a daily time step for the simulation of crop growth. On each day, the resources of light, water and nutrients are `intercepted' or `extracted' and converted into assimilated dry matter. Depending upon the availability of these resources and the crop's ability to sequester them, its growth is considered as light, water, or nutrient `limited'. An index of crop stress is calculated in terms of the ratio of light to water or nutrient limited growth. This stress index is then used to control a number of the crop's stress responses, such as leaf rolling or increased partitioning to roots. Partitioning of resources between crop organs is calculated by empirically derived fractions which are adjusted according to growth stage and level of stress. Resources partitioned to the leaf canopy and root system add to leaf area and root length thereby feeding back into subsequent calculations for light interception and water and nutrient uptake.

3.8.3 Output data

The PT model has the ability to simulate the following:

- Crop growth
- Rainfall
- Crop yield
- Runoff
- Evaporation
- Evapotranspiration
- Drainage

In the following exercise, the PT Model was used to study maize growth and development under different ecological scenarios.

Exercise 1

Determining the effects of planting dates on yields

ii. Double-click on the PT v2.3 model icon on desktop or from the start task bar go to programs and from the program list click PT v2.3. The PT v2.3 main window and welcome screen will appear. ,On the welcome screen click on the icon *experienced user* to be taken straight to the main system window of PTv2.3

iii. On the system Menu open Kilosa system (Kilosa.stm). The system will look like the Figure 3.3.

iv. Then click on the system properties and the system properties window will appear as Figure 3.4.

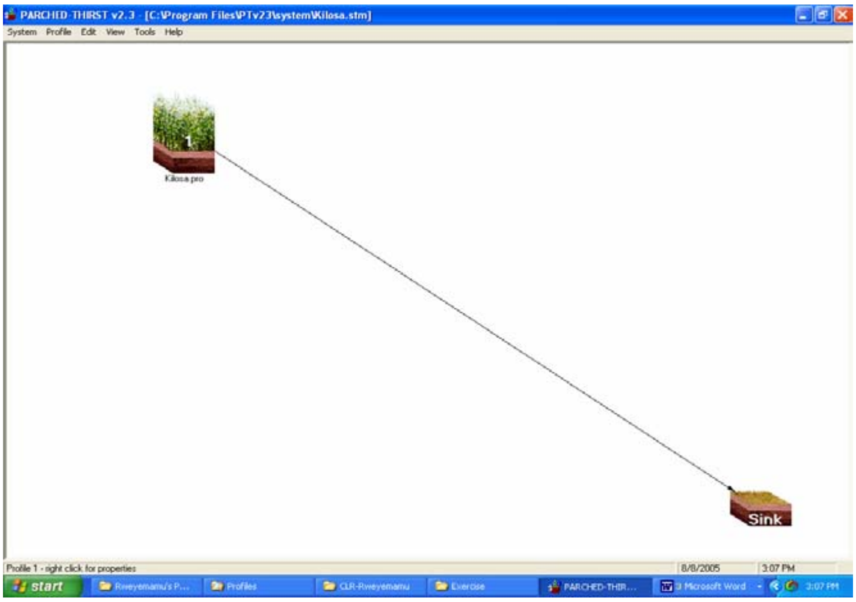

Figure 3.3: The rainfed systems

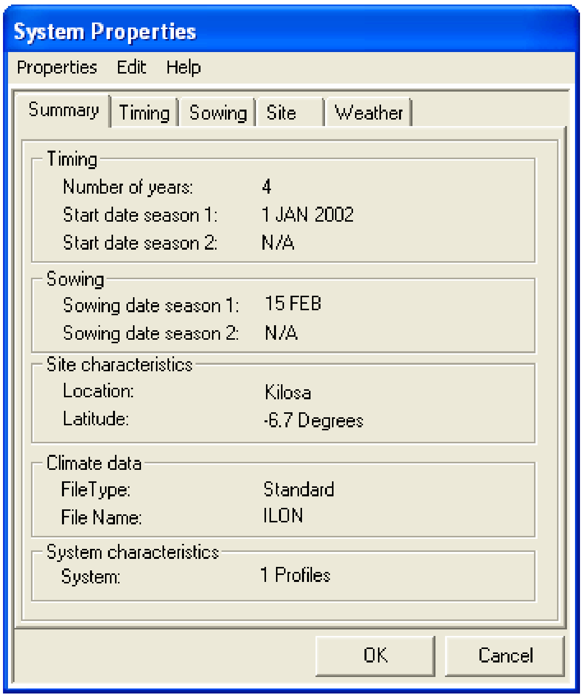

Figure 3.4. System properties window

- v. Click on the Timing Tab, and on the Number of years window writes 4,
- vi. Choose one Season per year, and season start date choose 1st January 2002
- vii. Click on the sowing Tab and the sowing window will appear.
- viii. On the sowing decision click on defined button.
- ix. On sowing date season 1 select 15th February, 2002 and click ok.
- x. On the System menu click RUN you will be prompted for a filename in which to save simulation output (Summary and Daily outputs)

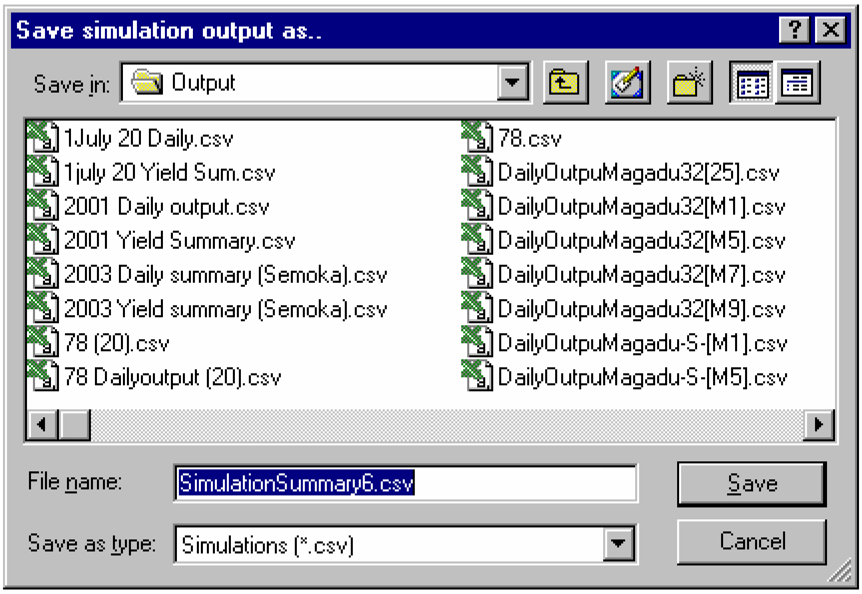

Figure 3.5. Saving output window

xi. Save the Simulation summary files as Kilosa15-Feb Sum and daily output files as Kilosa 15-Feb Daily.

xii. After saving your Summary and daily output files, you will be asked if you want to see runtime simulation graphics during the simulation, click yes.

xiii. Then you will be asked to select speed of simulation check either the slow, medium or fast option button. After selecting the speed then you will have to click run and the Model will start running simulation as shown in Figure 3.5

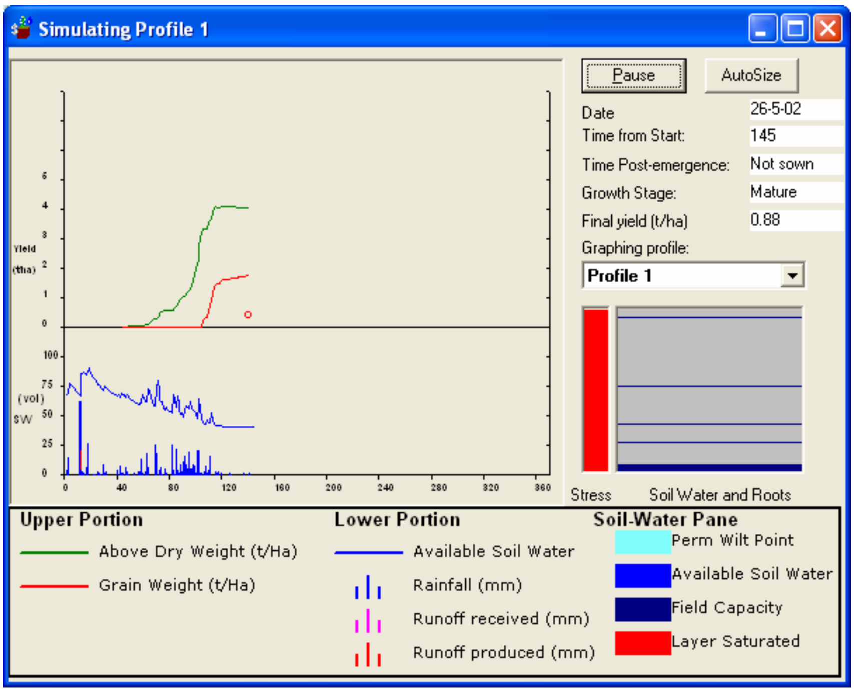

Figure 3.6. Runtime simulation graphics

xiv. Click ok when the model display "End of simulation" and you will view simulation graphics. On the Simulation output summary window, click on the yield Tab to view the simulated yields (t/ha) as the Figure 3.6 bellow.

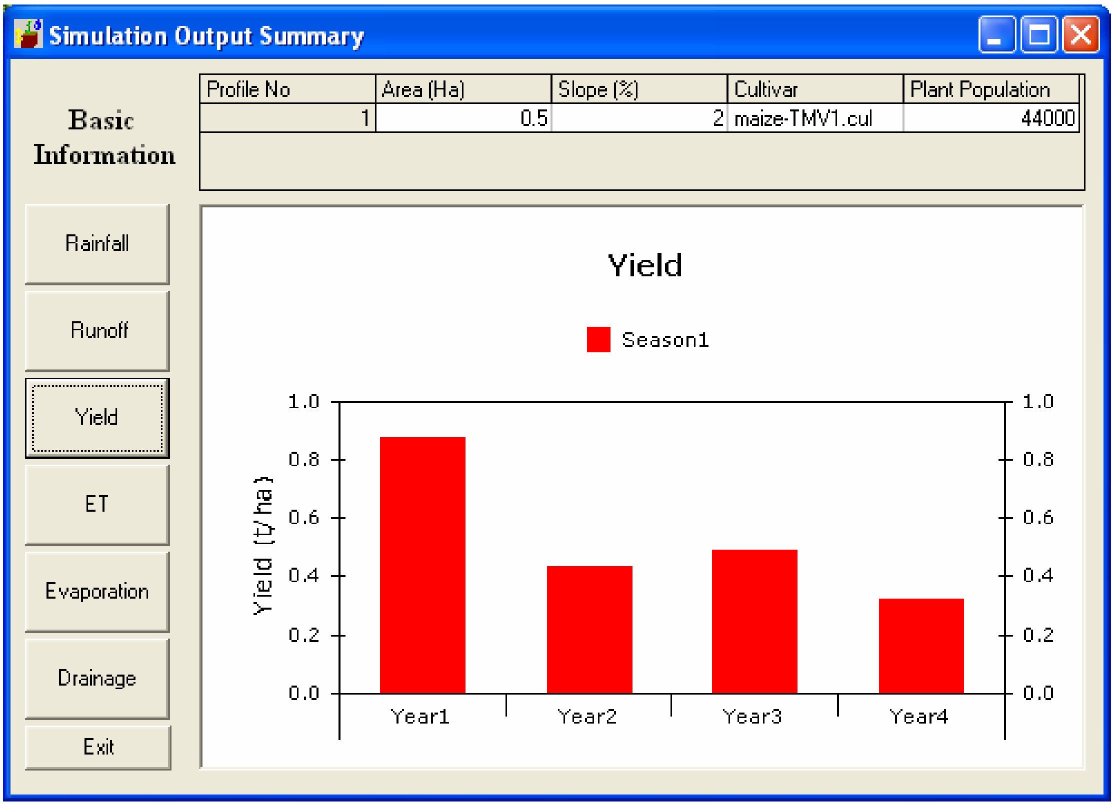

Figure 3.7. Maize yields (t/ha) for 4 years under rain-fed system

Repeat the same procedures for 20th, 25th, 28th, February and 1st and 5th March, 2002,

Results

From the simulation summary files e.g. *Kilosa15-Feb Sum* located at C:\Program files\PTv2.3\output\ click on Kilosa15-Feb Sum. The file will open and you will view the simulated maize yield (t/ha). Open all the files and copy all simulated yields in Excel worksheet for the following dates: 20th, 25th, 28th, February and 1st and 5th March, 2002. Draw the Table indicating simulated maize yield Vs Planting dates as shown in Table 2.

Table 3:2. Simulated maize Yields (in t/ha) Vs Planting dates

Years	Planting dates					
	15-Feb	20-Feb	25-Feb	28-Feb	1-Mar	5-Mar
2002	0.87	0.94	0.83	0.86	0.82	0.72
2003	0.43	0.39	0.41	0.70	0.63	0.31
2004	0.49	0.35	0.49	0.24	0.30	0.27
2005	0.32	0.30	0.53	0.56	0.53	0.54

Exercise2.

Studying Dry matter partitioning in Maize Using PT Model
Among the outputs produced by the Model are: Total dry weight (t/ha), leaf weight (t/ha), stem weight (t/ha), Root weight (t/ha), haulm weight (cob (t/ha), and grain weight (t/ha).

From the Daily output simulation files e.g. "Kilosa15-Feb Daily" "*Located at C:\Program files\PTv2.3\output\ click on Kilosa15-Feb Daily*. Open the file and copy all simulated, total dry weight (t/ha), leaf weight (t/ha), stem weight (t/ha), Root weight (t/ha), haulm weight (cob (t/ha), and grain weight (t/ha) from their respective columns and put them in any Excel Worksheet. Then plot the graphs which show how Dry matter is partitioned at different parts of the plant as shown in Figures 3.7 and 3.8.

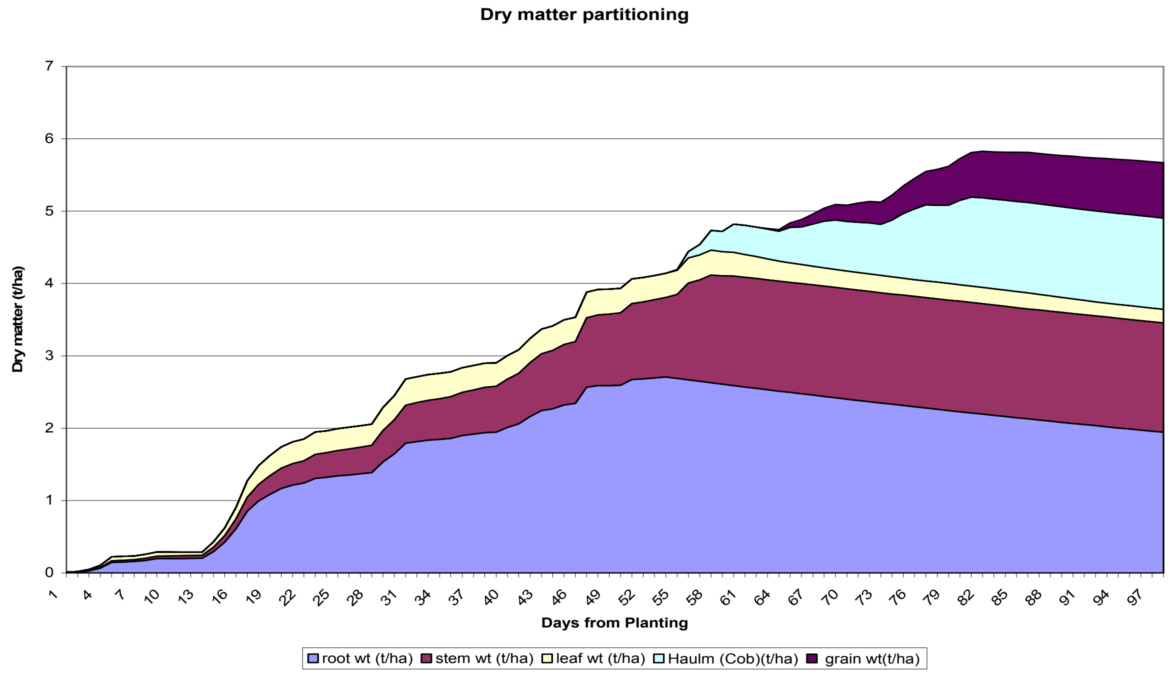

Figure 3.8. Dry matter partitioning in different parts of maize plant

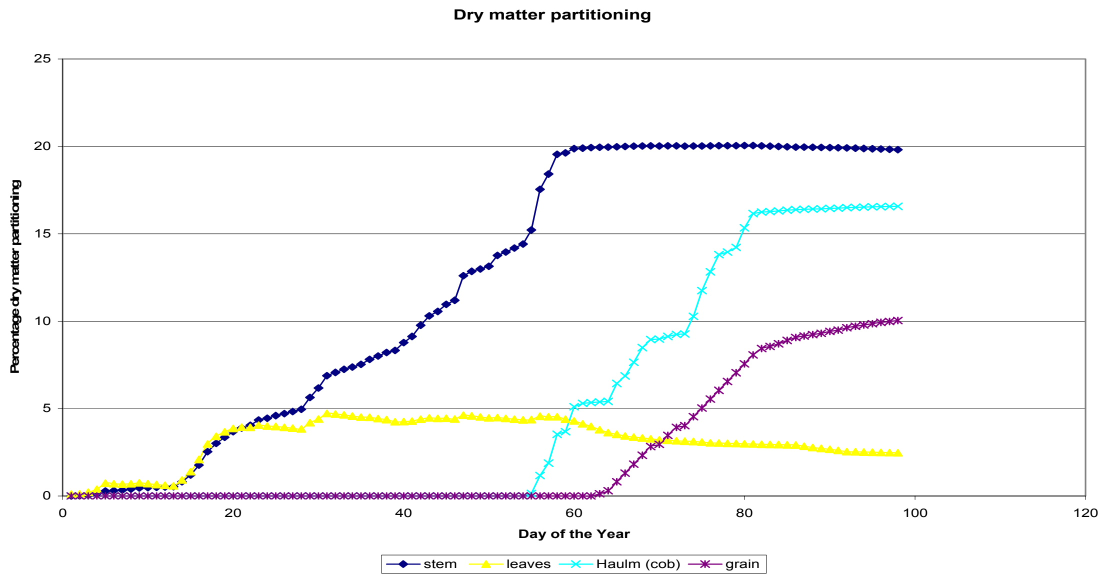

Figure 3.9. Percentage dry matter partitioned in different parts of maize plant

Exercise 3

Compare the Leaf Area Indices from the Daily output simulation file "*Kilosa15-Feb Daily"* by plotting LAI Vs Date from planting and relate them with their dry matter and grain yield for the years 2002 and 2003 (Figure 3.10)

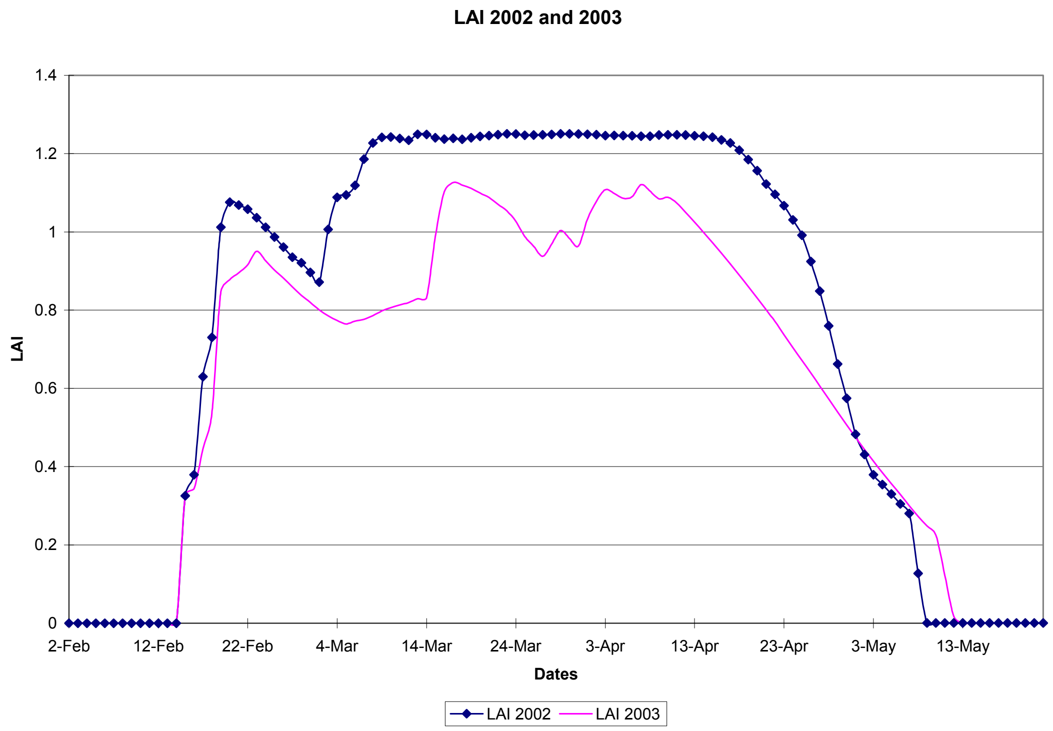

Figure 3.10. Leaf Area Indices for the years 2002 and 2003 for Kilosa (Msimba Seed farm)

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