Lecture Note on

Input Environment and Techniques of Monitoring Plant Environment

PLANT GROWTH MODELLING AND SIMULATION

SWE 606 (3+0)

Topic Covered:

1. Plant environment & growth
2. Monitor plant environment – Historic weather data
3. Monitor plant environment – Derived & generated weather data
4. Crop development phases
5. Modeling morphological development in Rice
6. Basic module to simulate crop growth
7. Input yield models
8. Generalized agriculture simulator

1. PLANT ENVIRONMENT & GROWTH

Increase in the size of living organisms is commonly called ‘growth’. Many physiological processes play an important role during growth of plants and animals. In plants seed germinates and develops into a seedling and later it assumes the shape of an adult plant. Plants show indefinite and diffuse growth while animals show fixed and uniform growth.

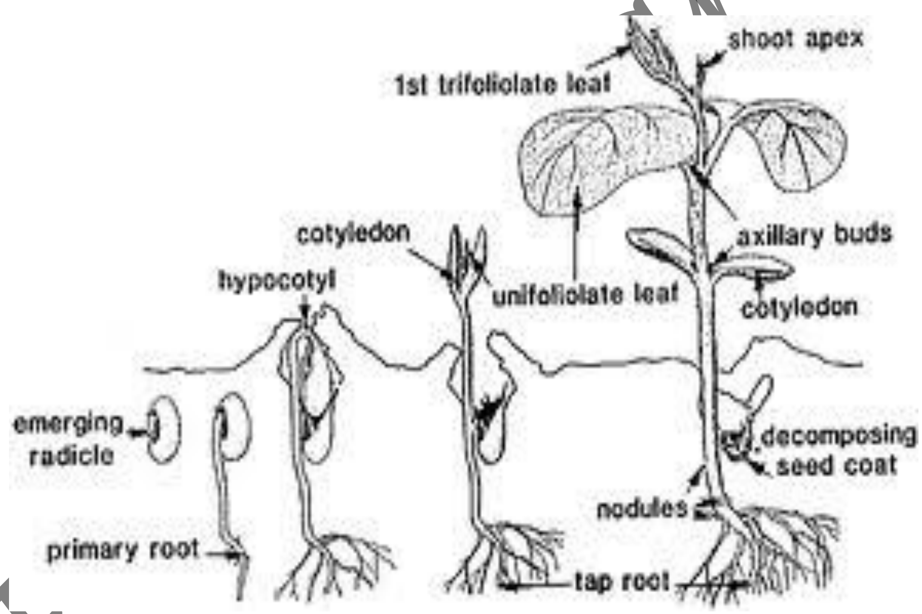
Growth may be defined as an irreversible permanent increase in size, volume or mass of a cell or organ or whole organism accompanied by an increase in dry weight. In other words we can say that the progressive development of an organism. Usually expressed as dry weight (total of the part we're interested in such as grain), height, length, and diameter.

Types of growth

1. ***Primary and secondary growth-***. The mitotic division of meristematic cells present at the root and shoot apex increases the length of the plant body. This is called the primary

growth. The secondary meristem increases the diameter of the plant body and it is called the secondary growth.

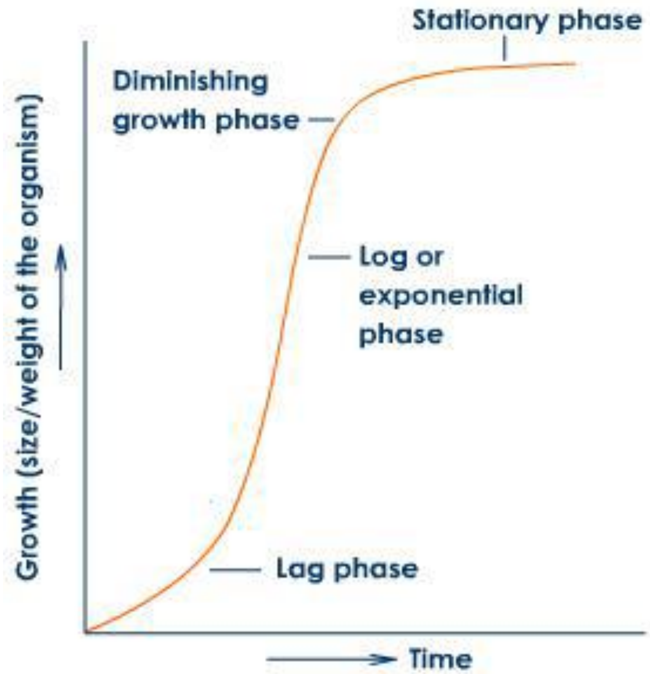
2. ***Unlimited Growth***- The root and the shoot system of plants grow continuously from germination stage to the death or throughout the life span of the plant. It is called ‘Unlimited’ or ‘indeterminate’ type of growth.
3. ***Limited growth*** - The leaves, fruits and flowers stop growing after attaining certain size. This is called ‘limited’ or ‘determinate’ type of growth.
4. ***Vegetative growth***- The earlier growth of plant producing leaves, stem and branches without flowers is called ‘vegetative growth’/ Phase.
5. ***Reproductive growth***- After the vegetative growth, plants produce flowers which is the reproductive part of the plant. This is called reproductive growth/phase.



Stages of growth-seed germination to a complete plant

Growth curve

It is an ‘S’ shaped curve obtained when we plot growth against time. It is also called ‘sigmoid ‘curve. This curve mainly shows four phases of growth- 1.initial slow growth (Lag phase), 2. the rapid period of growth (log phase/grand period of growth/exponential phase) where maximum growth is seen in a short period and 3. The diminishing phase where growth will be slow and 4. Stationary / steady phase where finally growth stops.



Above figures shows the growth curve- growth plotted against time.

Factors Affecting Plant Growth

Growth related to the factors affecting it.

$$G = f(X_1, X_2, X_3 \ldots X_n)$$

G = measure of growth

Xi = growth factors

The factors that affect plant growth can be classified as genetic or environmental.

A. Genetic Factor

1. Field crops - Yield potential is determined by genes of the plant. A large part of the increase in yield over the years has been due to hybrids and improved varieties. Other characteristics such as quality, disease resistance, drought hardiness are determined by the genetic makeup. Corn hybrids are an example of a dramatic yield increaseresulting from genetics. Genetic engineering is now becoming an important tool in changing a plants potential.

2. Nursery crops andturf:Not interested in total growth as much as appearance. Ex. is Bermudagrass

3. Coastal bermudagrass: As a forage the grower is interested in yield and feed quality.

4.Tifdwarf:Golf greens - interested in appearance, cover, wear resistance not how much total growth occurs.

5. *Variety and Plant Nutrient needs*: Hybrid corn producing 200 bu/ac requires more plant nutrients than a hybrid producing 100 bu/ac. As potential crop yields are increased, the plant nutrients required are increased. Current research in the Soil Science and Genetics department is concerned with developing corn hybrids that use nitrogen more efficiently - Produce more grain per pound of N - fertilizer.A producer has control over the genetic factor by his choice of variety.

Field crops - highest yielding, disease resistant, etc.Nursery - Best appearance - dwarf vs larger shrubs

B. Environmental Factors

All external conditions and influences affecting the life and development of an organism.

The following are regarded as the most important environmental factors

i. Temperature
ii. Moisture supply
iii. Radiant energy
iv. Composition of the atmosphere
v. Soil aeration and soil structure
vi. Soil reaction

vii. Biotic factors
viii. Supply of mineral nutrients
ix. Absence of growth-restricting substances

Each can be a limiting factor in plant growth. These environmental factors do not act independently example - inverse relationship between soil moisture and air.

a. Temperature - A measure of the intensity of heat. Plant growth occurs in a fairly narrow range - 60 - 100 degrees F

i. Temperature directly affects photosynthesis, respiration, transpiration - loss of water, absorption of water and nutrients.
ii. The rate of these processes increases with an increase in temperature. Responses are different with different crops.
iii. Temperature also affects soil organisms. Nitrifying bacteria inhibited by low temperature. pH may decrease in summer due to activities of microorganisms.
iv. Soil temperature affects water and nutrient uptake.

b. Moisture supply - Plant growth restricted by low and high levels of soil moisture1. It can be regulated with drainage and irrigation. Good soil moisture improves nutrient uptake. If moisture is a limiting factor fertilizer is not used efficiently.

c. Radiant energy.

Quality, intensity and duration of light are important. *Quality* can't be controlled on a field scale - Feasible on specialty crops. *Intensity* of light (brightness) is an important factor.

Duration - Photoperiodism - Plant behavior in relation to day length.

Long day plants - flower only if days are longer than same critical period - 12 hours for grains and clovers

Short day plants - flower only if days are shorter than a critical period soybean.

Indeterminate - flower over a wide range of day lengths. Tomato, cotton, buckwheat

d. Composition of the atmosphere

CO_2 makes up 0.03 per cent of air by volume. Photosynthesis converts CO_2 to organic material in the plant. CO_2 is returned to atmosphere by respiration and decomposition. In a corn field or closed greenhouse CO_2 level may drop and become a limiting factor in growth.Increasing CO_2 can increase crop yields respiration of plants and animals - decomposition of manure or plant residue may release CO_2

Greenhouse crops- Plant growth and quality can be enhanced by supplemental CO_2. Growth responses have been shown with tomatoes, lettuce, cucumbers, flower crops, greens, peas, beans, potatoes

Air Quality-Air pollutants in sufficient quantities are toxic to plants sulfur dioxide - provides sulfur at low levels

e. Soil aeration

Compact soils of high bulk density and poor structure are aerated poorly. Pore space is occupied by air and water so the amount of air and water are inversely proportional to the amount of oxygen in the soil. On well drained soils, oxygen content is not likely to be limiting to plant growth. Plants vary widely in their sensitivity to soil oxygen. Paddy rice vs tobacco.

f. Soil reaction

pH influences availability of certain nutrients ex phosphate availability low on acid soils. Al is toxic to plants, diseases affected by pH, Potato scab controlled by keeping pH below 5.5.

g. Biotic factors

Disease - heavier fertilization may increase vegetative growth and susceptibility to disease. Root knot nematodes reduce absorption so more fertilizer is necessary.

h. Plant Nutrients

Essential Plant Nutrients - Those elements that are needed for higher plants to complete all life functions, and that the deficiency can be corrected only by the application of the specific element causing the deficiency.

Non-mineral nutrients (from water and air)carbon, hydrogen, oxygen

Macronutrients-Primary nutrients,nitrogen, phosphorus, potassium

Secondary nutrients- calcium, magnesium, sulfur

Micronutrients- copper, manganese, zinc, boron, molybdenum, chlorine, iron, nickel

Mineral Elements beneficial to some plants- cobalt, vanadium, sodium, silicon, selenium

i. Absence of growth - restricting substances, high concentrations of plant nutrientsaluminum, nickel, lead - associated with sewage disposal, wastes from industry, mines, etc.organic compounds - phenols, oil.

2. MONITOR PLANT ENVIRONMENT – HISTORIC WEATHER DATA

The nature and precision of weather variables required for crop growth modelling. These variables are:

At Production Level 1: daily values of solar radiation, maximum and minimum temperature and air humidity;

At Production Level 2: in addition to variables at Production Level 1: daily precipitation values, air humidity and wind speed.

Solar radiation is by far the most important weather variable for crop growth simulation at Production Level 1, but air temperature can also be crucial. Air humidity is important in very dry weather for some crops. For simulation at production Level 2, precipitation is an essential input; solar radiation, temperature, and air humidity are also important, but wind speed has little impact on transpiration.

Weather data can be obtained from national meteorological services, from the Food and Agricultural Organization (FAO) and from the institutes within the Consultative Group on International Agricultural Research (CGIAR)

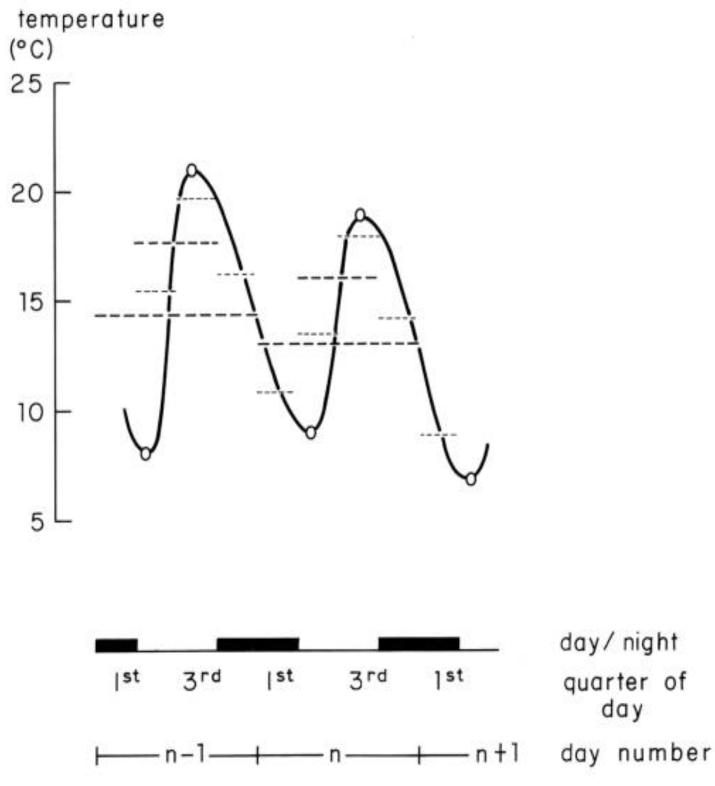
Different historic weather data are;

1. *Solar radiation*

Solar radiation is a key meteorological variable and its values should be obtained as accurately as possible. Daily values of the 'total global radiation should be obtained, if possible. Solar radiation can be partitioned in two ways: according to wavelength in photosynthetically active radiation (PAR, 400-700 nm wavelength) and near infrared (700-1300 nm), and according to direction in direct (from a point source) and diffuse radiation. PAR is always about 50% of the total solar radiation and this fraction varies little with radiation intensity (Monteith, 1973). But the fraction diffuse of the total radiation depends strongly on the daily total. The relation between the fraction diffuse and the daily total radiation relative to the extraterrestrial radiation at that location and date appears to be constant in temperate regions.

2. *Minimum and maximum temperatures*

Temperature affects the rate of most physiological processes. Maximum and minimum temperatures are not used as such in simulation, but are replaced by an effective temperature which is calculated from them. The effective temperature for processes that continue during the complete 24-hour time period is the average of the maximum and minimum temperatures. The effective temperature for photosynthesis is assumed to be the average day temperature. Only in the quarter-day time period module (L1Q) is the effective temperature for each time period and for all processes calculated from a fixed, asymmetric pattern over the whole day, by using the nearest maximum and minimum temperatures.



3. *Precipitation*

Rain is a particularly important driving variable in the semi-arid and sub-humid tropics, but is also important in temperate zones during in dry periods. Its value can change more from day to day than any other meteorological variable. The spatial variability of precipitation is also quite large. Its value must be determined at the field for which the study is undertaken whenever precipitation is a key variable for simulation. Though the quality of data of the nearest official meteorological station may be better, less accurate data from the field for which the simulation is performed can be more relevant.

4. Humidity

Air humidity affects transpiration and evaporation, and reduces photosynthesis in some crops when its value is very low. Good air humidity measurements are not easy to obtain, but are not of overriding importance in crop simulation. Air humidity can be measured in several ways and expressed in different units. The absolute concentration, expressed as the water vapor pressure inkPa (1 kPa= 10 mbar), is preferred.Relative humidity changes a lot during the day and should be avoided as a basic measurement of humidity.

5. Wind speed

Canopy transpiration is only sensitive to wind speeds up to 1-2 ms^{-1} ,Wind speed is measured directly as a rate and averaged over 24 hours, or obtained as a daily wind run and expressed in ms^{-1}. It is often measured at 2 m over a low grass sward at a standard meteorological station.

6. Carbon dioxide

The CO_2 concentration fluctuates very little during the year and usually does not change significantly inside the canopy. Its value at sea level is specified with a parameter. The volumetric CO_2 concentration decreases by 12% per 1000 m elevation.

3. MONITOR PLANT ENVIRONMENT – DERIVED & GENERATED WEATHER DATA

1. *Clear sky and overcast radiation*

Maximum amount of daily total global radiation can be computed accurately for any day and latitude. The starting point is the solar constant (about 1400 J $m^{-2}s^{-1}$), i.e., the intensity of solar radiation measured outside the atmosphere and perpendicularly to the solar rays. Radiation at sea level on a perfectly clear day is about 25% lower than the solar constant due to absorption and reflection by water vapour and dust in the atmosphere.

Clear sky radiation at sea level can be used as a yardstick for monitored radiation and their ratio is the relative amount of radiation received. Observations taken at sea level are usually between 0.15 and 0.75 times the value for extraterrestrial radiation at the same location and the same date, but are less on very heavily overcast days and up to 0.9 times extraterrestrial radiation under extremely clear skies.

2. *Daylength*

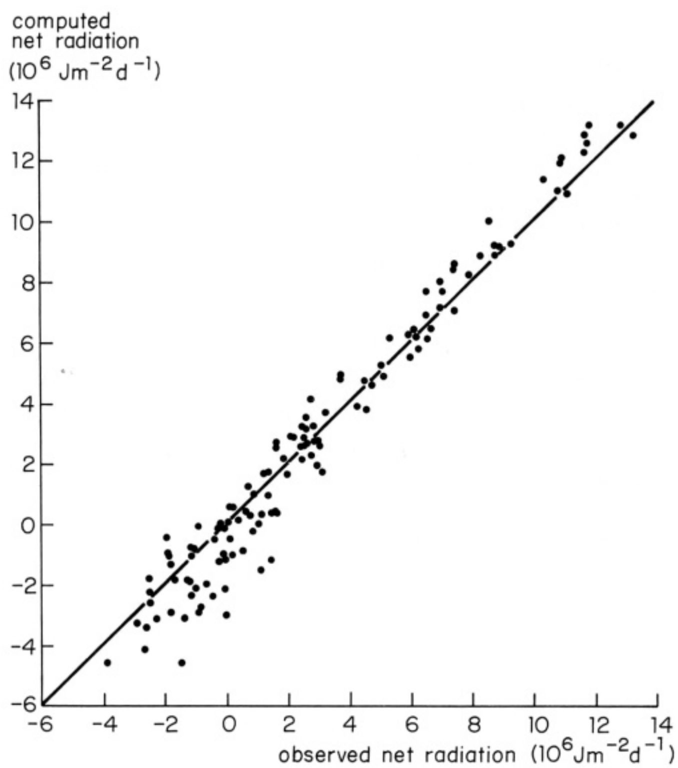
Astronomical day length is input for the photosynthesis computation in the FUPHOT function and SUPHOL subroutine and in calculating evaporation in the SUEVTR subroutine. Daylength provides the basis for splitting each 24-hour period into day and night fractions. Its value is accurately obtained from a set of mathematical equations in the SUASTR subroutine, using latitude and date as inputs.

To compute daylength for photoperiod-sensitive species, it must be realized that, even when the sun is still below the horizon the light level is high enough to trigger the photoperiodicity mechanism.

3. *Net radiation*

Net radiation (all wavelengths included) is the balance of incoming short wave radiation (wavelength 400-1400 nm) minus its reflection and outgoing thermal radiation (>3000 nm), plus incoming thermal radiation (about 12.000 nm). Its calculation is part of the computation of the energy balance for evapotranspiration. Reflection of short wave radiation is about 0.2-0.3 for crops.

Reflection from a soil surface (i.e., its albedo) is 0.1-0.4. Reflection increases strongly at low inclinations of the sun, but this is unimportant as the light level is then low. Net thermal radiation is computed according to the Brunt equation from surface temperature (as an indicator of the outgoing long wave radiation) and from cloudiness and air humidity.



Measured and observed values of daily total net radiation on each third day for a full year

4. *Potential evapotranspiration*

Potential evapotranspiration is a useful variable when characterizing a climate. At meteorological stations it is sometimes determined as the rate of transpiration of a standard grass sward well supplied with water and nutrients. As many variables as possible are then fixed. However, it seems easier, and for many purposes at least as good, to compute such rates rather than to measure them.

5. *Generating weather data*

It is not often that weather data for more than a few full years is available from a single meteorological station. This is insufficient to test the stability of crop yields over a 10-25-year period using simulation. The next best alternative to a large set of historical weather data, is a large set of weather data generated from observations taken over a few years. These can be generated by using information contained in the historical data: the relations between values of variables on successive days and between the values of all variables on individual days.

When generating new weather data, twelve monthly precipitation totals plus the number of wet days for each month appear to be just as good as taking 365 daily values. This requires at least 10 times less data than taking daily values and means that sufficient rainfall data to support crop simulation can be collected from remote areas without frequent measurements. This not only spreads resources, but is particularly helpful because rain varies more than any other meteorological variable over short distances and requires a denser recording network than other weather characteristics.

4. CROP DEVELOPMENT PHASES

Many changes occur as a crop grows. Some changes, such as those of weight and leaf area, are easy to quantify, while others, such as plant age and phonological development, are more difficult. Nevertheless, it is essential to quantifycrop phenology because the important process of partitioning of new biomassdepends directly on this expression of age.The 'development stage' of a crop quantifies its physiological age and isrelated to its morphological appearance.

Development stage is a state variablein crop growth models. The development stage cannot be expressed simply aschronological age, because several environmental factors, such as temperatureand waterstress, can speed up or reduce the rate of phenological development.Daylength is crucial in some crops to induce flowering. Contrary towhat is suggested by intuition, the rate of crop growth per se has no effect onthe rate of phenological development, as long as the growth rate is not verylow. The concept of development stage is used to characterize the whole crop;it is not appropriate for individual organs. The development stage has thevalue of 0.0 at emergence, 1.0 and 2.0 at maturation. It is dimensionlessand its value increases gradually. The development rate has the dimensiond^{-1}. The multiple of rate and time period yields an increment in stage.

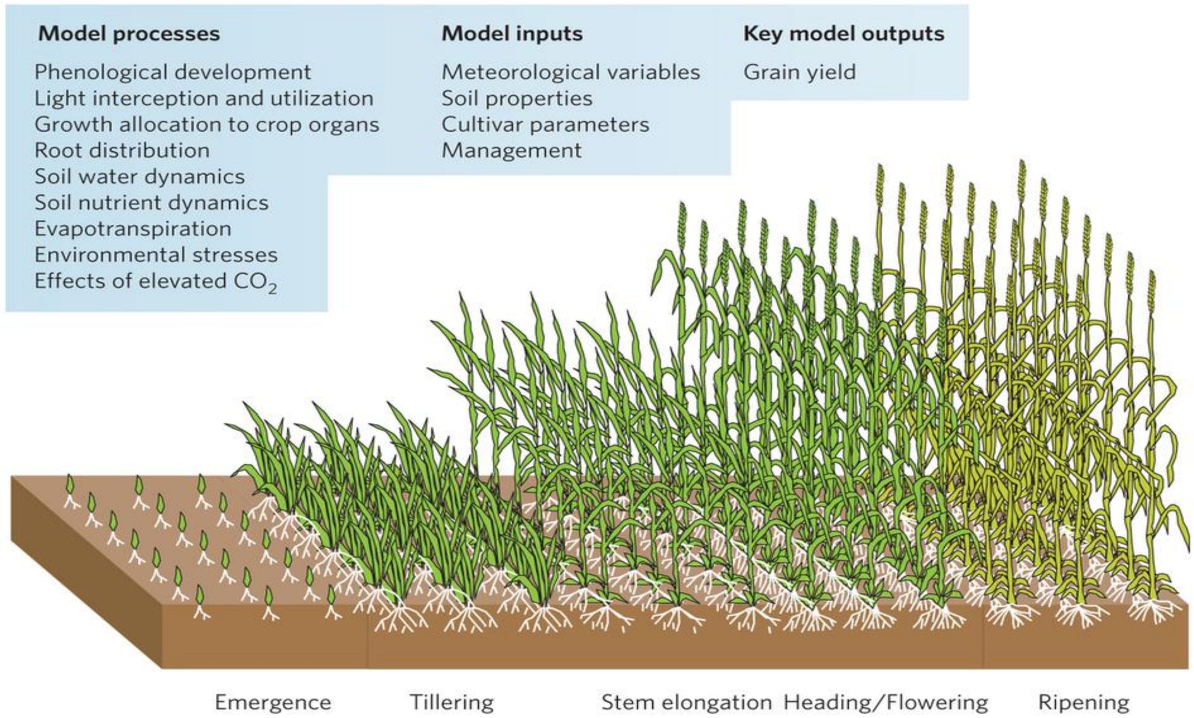
The rate of phenological development can be affected by temperature differentlyin the vegetative stage than in the reproductive stage. Daylength hasan effect only in the vegetative stage.

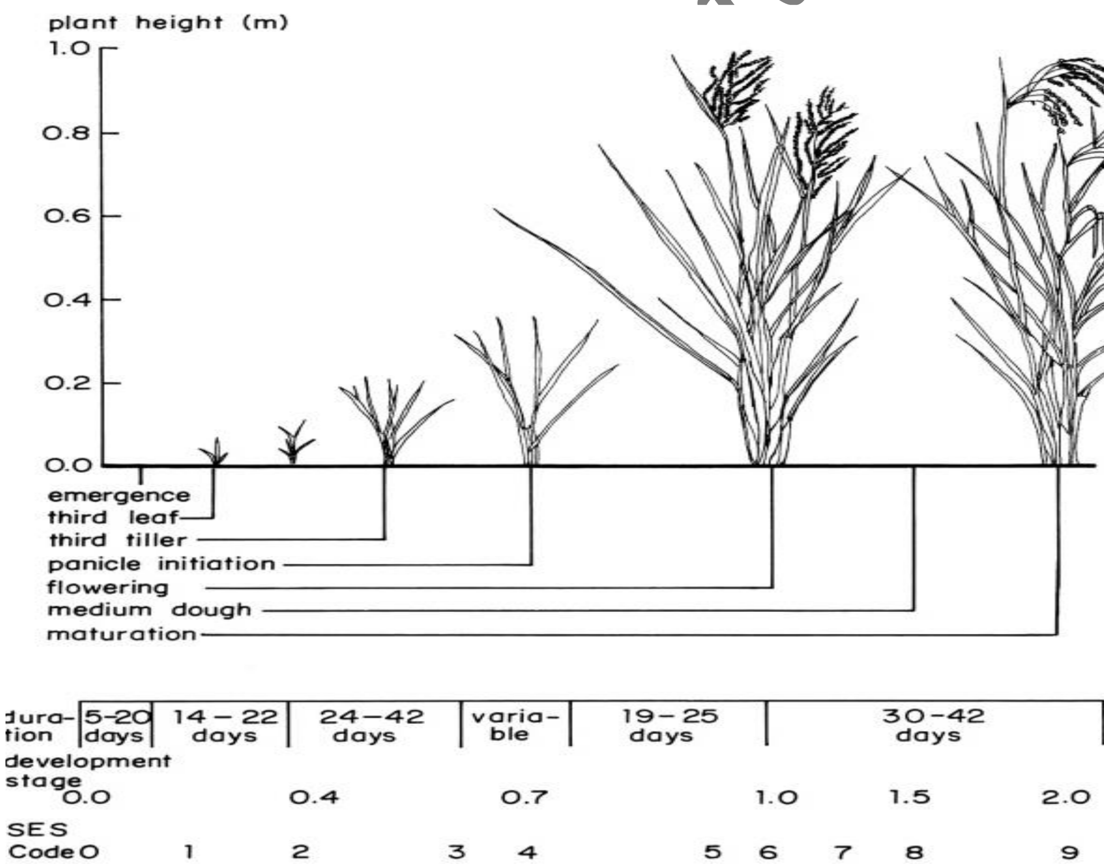
The objective of the Crop Development research focus area is to improve cultivars. Gene frequencies are constantly manipulated to develop new genotypes that will produce more efficiently under existing or potential environmental conditions. The germplasm collection is the heart of the breeding programme and is constituted from sources throughout the world. New cultivars that combine characteristics such as yield, quality, disease and pest resistance are continuously being developed. With a few exceptions in plants, a single-celled zygote forms after fertilization, or syngamy, in which a haploid nucleus in the egg cell within the embryo sac (female gametophyte or megagametophyte) fuses with a haploid sperm nucleus from a germinated pollen. This zygote soon undergoes growth through a series of cell division and cell enlargement and ultimately transforms into a multicellular embryo in the seed.

This embryo is likened to a miniature plant within the seed. It possesses all the potential for developing into a mature plant, but is temporarily in dormant or arrested growth. Just like a mature plant, it has a root and shoot. Called the radicle, this root is described as an embryonic root because it is a part of the embryo. It is also referred to as a rudimentary root, from the root word “rudiment” which means small or tiny, a mere blob of a structure that is imperfectly developed. The embryonic shoot, called epicotyl, is likewise described as rudimentary.With all the necessary environmental requisites, a small and relatively simple seed germinates. With time, it completes various stages of development and transforms into a complex mature plant having multiple organs. Finally, its overall size and weight could be several hundred or thousand times more than that of the seed, or even more.

In rice, a seed germinates and produces a seedling, the seedling continues to increase in volume, height and complexity and ultimately becomes mature, the mature plant produces inflorescences (panicle) and spikelet’s, and each spikelet transforms into a fruit (caryopsis) which encloses a seed. When the seeds mature in the annual crops, the entire plant soon dies.

Physiological or biochemical methods of characterizing and measuring the developmentstage of the crop are yet unknown. Phenological development isstill not understood enough to provide an explanatory model of this process,hence, descriptive modelling is used here.





Above figure shows the Development stage of Rice.

1. Vegetative phase

A first approximation of the development rate in the vegetative stage is theinverse value of the duration of the period between emergence. This value is equal to the development rate constant, when temperature hasbeen constant and daylength has had no effect. Temperature is often the dominant factor influencing plant development intemperate climates. The development stage can then be expressed as a temperaturesum (degree.days, sum of average temperatures above a lowerthreshold. The temperature that affects the phenological development process can betaken as equal to the daily average air temperature at the height of the shoot'sgrowing point.

Only when day or night temperatures regularly reach valueswhere the response is non-linear, is another procedure of weighing temperaturerequired or should shorter time periods be taken. The temperature ofthe growing point can be higher or lower than the air temperature at twometers due to insolation, transpiration from the growing point and heat transferfrom the soil.

2. Initialization

The development stage begins at 0.0 when simulation starts at seedlingemergence. Often, however, simulation starts when young plants are alreadywell established using observed or assumedquantities of leaves and roots as initial values. Values of 0.1-0.25 for the initialdevelopment stage of field crops are common, and as high as 0.5 for transplantedrice. The effect of transplanting in rice can be approximated by reducingits development stage by 0.2. For winter wheat in a temperate climate,simulation may start in spring at development stage 0.33. No generally validinitial values can be given, because they depend strongly on the experimental situation and on local management practices.

3. Reproductive phase

The reproductive period is defined here as the period after flowering untilmaturity. Simulating this development process proceeds in the same manneras that of the vegetative period. The development rate constant for the reproductiveperiod and for the vegetative period are numerically different, as is theeffect of temperature. Daylength has no effect.

5. MODELLING MORPHOLOGICAL DEVELOPMENT IN RICE

Carbohydrate production in cereals can be limited by the capacity of the grains to use them. In the case of rice this is easy to understand, as the size of grains is physically restricted by the size of the hull. The maximum size of the grain is a variety-specific characteristic. To simulate this effect, the 'sink size' of the grains must be quantified (i.e., their capacity to absorb available carbohydrates). It is thenessential to keep track of the number of grains. Grain setting is the end resultof a series of events, so that the processes of tillering and floret formation mustbe considered.

Tillers dying is only approximated as a dynamic simulation of age groups with different light interceptions is not justified. A module formorphological development in rice is presented to simulate the phenomenonthat is often referred to as the sink-source relationship. This approach,developed by van Keulen& Seligman (1987) for wheat also facilitates model-ling damage by pests and diseases.

In the module TIL, the formation rate of plant parts, such as tillers, floretsand grains, is assumed to depend on the net carbohydrate supply to the crop.The larger this supply, the higher the organ formation rates, so long as theirnumbers do not exceed certain limits. Formation rates of organs, in numbers per hectare per day, are equal to the difference between potential number andcurrent number, divided by an appropriate time constant. Thetime coefficient is 15 days for tiller formation, 7 days for floret formation, and 3days for grain initiation. The time coefficient for tillers dying is set at 14 days, assuming that tillers only die slowly and when carbohydrates arelacking. Each type of organ forms during a restricted developmental period.

The potential numbers of these plant parts at any moment, equals the carbohydrate supply of that day, divided by the daily requirement of carbohydratesfor forming and maintaining one tiller, one floret and one grain. The carbohydrate required for florets and grains is a constant. The older the plant andthe larger most of the early tillers, the more carbohydrates are required toinitiate new tillers. This effect is mimicked by making the carbohydrate required for initiating new tillers a function of the development stage of the crop. The number of tillers that will be formed in a rice crop in a specific simulation depends on environmental conditions. The maximum number ofgrains equals the number of florets.The sink size of the storage organ equals the number of grains multiplied by the maximum growth rate of one grain. The maximum growth rateper individual grain is estimated to be the weight of mature kernels of thatvariety, divided by half the grain filling period. Hence, if sufficient grains havebeen formed sink size will rarely limit growth.

6. BASIC MODULE TO SIMULATE CROP GROWTH

1. *Introduction*

The major components are combined in two modules (L1D, listing 3 and L1Q, listing 4) which can be used to simulate the growth of annual crops. The first module is basically the sum of the simplest approaches. The time period for this module is one day (24 hours) and since it simulates at Production Level 1, it is called L1D. The second module (L1Q) includes some of the more detailed approaches and its time period is a quarter of a day.

L1D and L1Q must be supplemented with data sets for a crop and weather. Not all crop characteristics in this data set are required for all modules, but including more data than is required causes no problems. The simulation program is to be completed with module T12, which contains several special functions. The modules contain a number of constants. They are not combined as each represents a single process: 1.467 stands for g CO_2 produced per g of glucose, 0.682 is its inverse; 0.053 refers to the fraction of glucose sacrificed during intercellular transport to provide energy for this process, 0.947 is its complement; 1.111 represents the yield in glucose from starch hydrolysis, 0.900 is its inverse; 0.2727, 0.400, and 0.444 are the carbon fractions in CO_2, glucose and starch respectively. The small value 1.E-10 is added in some cases to avoid division by 0.0, which would halt the simulation. The function AINT is used to truncate values; the output of the function AMOD is equal to its first input except when it exceeds the second input; the second input is then subtracted a number of times until a value between zero and the second input remains.

Data in CSMP AFGEN functions should cover a range of values that is wider than the range in which inputs are expected. This ensures that extrapolation outside the data, causing unexpected results or irrelevant warnings, does not occur.

2. *Basic crop growth module with one-day time periods (L1D)*

Module L1D (Listing 3) can be used when growth limited by sink size does not need to be considered and when environmental conditions for crop growth are favourable. Hence, it will often be appropriate. L1D should not be used when environmental conditions are unfavourable (e.g., when day or night temperatures considerably exceed the range where the temperature response curves for photosynthesis, respiration and phenological development are more or less linear). It is comparable with the SUCROS models. Careful reading and practice are required to become familiar with this module.

The module contains an initial and a dynamic part. Before the initial section starts memory is reserved (Lines 3, 4) for the weather data. Line 2 specifies that the value of IDATE is an integer number. IDATE, an integer, is the truncated value of DATE, and ranges from 1 to 365. DATE is the sum of TIME elapsed since simulation started and DATEB, a parameter representing the Julian date at which simulation starts. The initial section (Lines 5-11) is followed by the dynamic section starting in Line 12. Three dummy variables are introduced (Lines 8-10) and used (Lines 40, 51, 97) to ease combining this with other modules.

Actual weather data are read from tables using IDATE as input (Lines 103, 105, 106) and standard weather data are derived (Line 104). Ensure that manipulating DATE does not lead to values lower than 1 or higher than 365: CSMP does not reject an instruction to select data outside the TABLES, but results will be nonsense. The initial value of TIME (Line 113) should be 0.0. The FINISH TIME of 1000 is never reached: simulation always stops when either the FINISH conditions of maturity (DS = 2.0), or that of severe carbohydrate shortage (CELVN = 3.0) is reached. For meaning and implications of the TITLE, PRINT, PRTPLOT and PAGE statements, for the TIMER variables DELT, PRDEL, OUTDEL and FINTIM, and for run control statements, such as FINISH, refer to the CSMP manual.The last variables (Lines 120-125) are solely for convenient presentation of output.

3. Crop growth module with quarter-day time periods (L1Q)

Module L1Q (Listing 4) can be used for simulating crops in situations where temperature fluctuates a great deal, when the dynamics of plant reserves are important and when tillering and grain formation in cereals is under study.This module is organized in the same way as L1D. Module L1Q should not be combined with water balance modules L2SU and L2SS. To incorporate the module TIL (which simulates tillering and grain formation) into L1Q, substitute TIL for Line 36. Formation and use of available carbohydrates (WAR) is programmed in Listing 4 Lines 14, 29, 30, 51. The rate of use is derived from the growth rates of the organs (Lines 52-56), these being equal to potential growth rates based on carbohydrate availability unless a reduction occurs, such as that resulting from sink size limitation (Line 35).

In each 24-hour cycle (i.e., sunrise to sunrise) the time period for integration (DELT) is equal twice to half the daytime (0.5 · daylength) and twice to half the nighttime (0.5 · (24h – daylength)). Though DELT itself remains equal to 0.25, all rates in integrals are multiplied with a correction factor for daylength, FADL (Line 144). This factor is larger than one, if the day part is longer thansix hours, and vice versa. Simulation starts at 0.00 h, and output is printed at midnight (when PRDEL is a whole number). Printed rates shows their mid-night values (so that photosynthesis is always 0.0). (In LlD, printing time corresponds with sunrise.) The variable DTIME indicates the starting time of the fraction of the day that the simulation has reached (first quarter: DTIME = 0. second quarter: DTIME = 0.25, etc.). The variable NIGHT signals whether it is day or night for calculating radiation intensity (Line 131). Temperatures at different times during the day are reconstructed from the minimum and maximum temperatures by the function FUTP. The INTEGRAL function is used for various state variables to compute the running average of a variable (Line 47; Subsection 1.4.4) and to retain the maximum value that a variable reached (Line 46). The daily total of a rate can also be calculated with an INTEGRAL function; the content of such integrals is reset to 0.0 each new day (Lines 65, 66).

7. INPUT YIELD MODELS

1. APSIM-A MODEL DESIGNED FOR FARMING SYSTEMS SIMULATION

The Agricultural Production Systems Simulator (APSIM) is a modular modelling framework that has been developed by the Agricultural Production Systems Research Unit in Australia. APSIM was developed to simulate biophysical process in farming systems, in particular where there is interest in the economic and ecological outcomes of management practice in the face of climatic risk. This module also include a diverse range of crops, pastures and trees, soil processes including water balance, N and P transformations, soil pH, erosion and a full range of management controls. Reports of APSIM testing in a diverse range of systems and environments are summarized. An example of model performance in a long-term cropping systems trial is provided. APSIM has been used in a broad range of applications, including support for on-farm decision making, farming systems design for production or resource management objectives, assessment of the value of seasonal climate forecasting, analysis of supply chain issues in agribusiness activities, development of waste management guidelines, risk assessment for government policy making and as a guide to research and education activity.

Agricultural Production Systems Simulator (APSIM) is a modelling framework that allows individual modules of key components of the farming system (defined by model developer and selected by model user) to be 'plugged in'(McCown et al., 1996). APSIM has been developed by the Agricultural Production Systems Research Unit (APSRU), a collaborative group made up from CSIRO and Queensland State Government agencies. The initial stimulus to develop APSIM came from a perceived need for modelling tools that provided accurate predictions of crop production in relation to climate, genotype, soil and management factors, whilst addressing long-term resource management issues in farming systems. APSIM was designed at the outset as a farming systems simulator that sought to combine accurate yield estimation in response to management with prediction of the long-term consequences of farming practice on the soil resource (e.g. soil organic matter dynamics, erosion, acidification etc.).

Overview of the APSIM system and its components. The APSIM modelling framework is made up of;

a) a set of biophysical modules that simulate biological and physical processes in farming systems,

b) a set of management modules that allow the user to specify the intended management rules that characterize the scenario being simulated and that control the conduct of the simulation

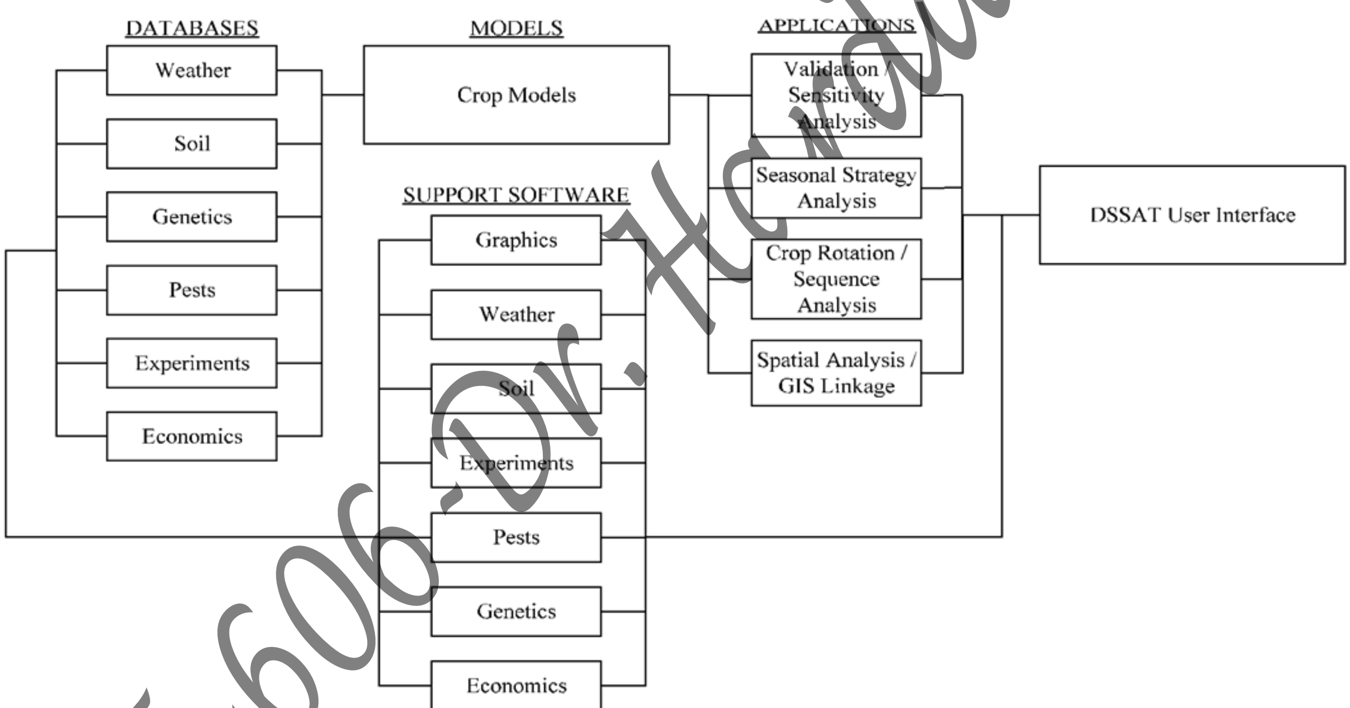
c) various modules to facilitate data input and output to and from the simulation,

d) a simulation engine that drives the simulation process and controls all messages passing between the independent modules.

2. THE DSSAT CROPPING SYSTEM MODEL

The decision support system for agro technology transfer (DSSAT) has been in use for the last 15 years by researchers worldwide. This package incorporates models of 16 different crops with software that facilitates the evaluation and application of the crop models for different purposes. Over the last few years, it has become increasingly difficult to maintain the DSSAT crop models, partly due to fact that there were different sets of computer code for different crops with little attention to software design at the level of crop models themselves. Thus, the DSSAT crop models have been re-designed and programmed to facilitate more efficient incorporation of new scientific advances, applications, documentation and maintenance. The basis for the new DSSAT cropping system model (CSM) design is a modular structure in which components separate along scientific discipline lines and are structured to allow easy replacement or addition of modules. It has one Soil module, a Crop Template module which can simulate different crops by defining species input files, an interface to add individual crop models if they have the same design and interface, a Weather module, and a module for dealing with competition for light and water among the soil, plants, and atmosphere. It is also designed for incorporation into various application packages, ranging from those that help researchers adapt and test the CSM to those that operate the DSSAT-CSM to simulate production over time and space for different purposes.

The DSSAT is a collection of independent programs that operate together; crop simulation models are at its center (Fig.). Databases describe weather, soil, experiment conditions and measurements, and genotype information for applying the models to different situations. Software helps users prepare these databases and compare simulated results with observations to give them confidence in the models or to determine if modifications are needed to improve accuracy. In addition, programs contained in DSSAT allow users to simulate options for crop management over a number of years to assess the risks associated with each option. Below flow diagram mentioned for DSSAT.



Overall description of the DSSAT cropping system model

The DSSAT- CSM simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, carbon, and nitrogen that take place under the cropping system over time. The most important features of our approach are:

a. It separates modules along disciplinary lines,
b. It defines clear and simple interfaces for each module,

c. It enables individual components to be plugged in or unplugged with little impact on the main program or other modules, i.e. for comparison of different models or model components,
d. It facilitates documentation and maintenance of code,
e. It enables modules written in different programming languages to be linked together,
f. It allows for easy integration into different types of application packages due to the well-defined and documented interface to the modules,
g. It allows for evolution to integrate other components, such as livestock and intercropping, through well-defined module interfaces, and
h. It facilitates cooperation among different model development groups where each can focus on specific modules as building blocks for expanding the scope and utility of the CSM.

3. QUEFTS, MODEL TO ANALYSE THE EFFECT OF NITROGEN PHOSPHORUS AND POTASSIUM LIMITATION ON CROPS GROWTH

QUEFTS can be used for quantitative evaluation of the native fertility of tropical soils, using calculated yields of unfertilized maize as a yardstick. The procedure consists of four successive steps. First the potential supplies of nitrogen, phosphorus and potassium are calculated, applying relationships between chemical properties of the 0-20 cm soil layer and the maximum quantity of those nutrients that can be taken up by maize, if no other nutrients and no other growth factors are yield-limiting. In the second step the actual uptake of each nutrient is calculated as a function of the potential supply of that nutrient, taking into account the potential supplies of the other two nutrients. Step 3 comprises the establishment of three yield ranges, as depending on the actual uptakes of nitrogen, phosphorus, and potassium, respectively. Next, these yield ranges are combined in pairs, and the yields estimated for pairs of nutrients are averaged to obtain an ultimate yield estimate.

The QUEFTS model works only for a maize crop. The generic version of QUEFTS is called CROPFERT and can be used for all type of crops, for which the nutrient concentrations are given in the file NUTRIDAT.dat

Applications & Use:

QUEFTS can be used to calculate the nutrient limited yields for crops growing under tropical conditions. This requires either soil chemical data or representative crop experiments to derive the base nutrient supply of unfertilized soils. This base nutrient supply is used to calculate the actual crop nutrient uptake and yields for the main crops. If fertilizer nutrients are applied, the resulting increases in crop nutrient uptake and yields can next be calculated.

4. CROP MODEL STICS

STICS is a model that has been developed at INRA (France) since 1996. It simulates crop growth as well as soil water and nitrogen balances driven by daily climatic data. It calculates both agricultural variables (yield, input consumption) and environmental variables (water and nitrogen losses). From a conceptual point of view, STICS relies essentially on well-known relationships or on simplifications of existing models. One of the key elements of STICS is its adaptability to various crops. This is achieved by the use of generic parameters relevant for most crops and on options in the model formalizations concerning both physiology and management that have to be chosen for each crop. All the users of the model form a group that participates in making the model and the software evolve, because STICS is not a fixed model but rather an interactive modelling platform. The data required to run the model relate to climate, soil (water and nitrogen initial profiles and permanent soil features) and crop management. The species and varietal parameters are provided by the specialists of each species. The data required to validate the model relate to the agronomic or environmental outputs at the end of the cropping season.

From a conceptual point of view, STICS is made up of a number of original parts relative to other crop models (e.g. simulation of crop temperature, simulation of many techniques) but most of the remaining parts are based on conventional formalizations or have been taken from existingmodels. Its strong points are the following:

a. Itsrobustness: ability to simulate various soil climate conditions without considerable bias in the outputs.
b. Its‘conceptual’ modularity: possibility of adding new modules or complementing the system description (e.g.: ammonia, symbiotic nitrogen fixation, plant mulch, stony soils, many organic residues, etc.). The purpose of such modularity is to facilitate subsequent developments.
c. The external communication created by the model among the users and developers, whichdrives the model advancement.

Data required-

i) Minimum data to run the model
   Climate
   Soil
   Management
   Genetic Parameters
ii) Validation of the model

Limitations of the model

The type of mechanisms simulated partly defines the model’s validity range; certain environment*management combinations are therefore excluded from its range of applications. For example, since the model does not simulate phosphorus or potassium dynamics in the soil-plant system, any reduction in yield related to the plant being deficient in these elements, as well as the management aimed at rectifying these deficiencies, are beyond the validity range. Although the number of main output variables is limited, the number of subsidiary variables is much higher and consequently it is useful to consider validation for these subsidiary variables. However, given the simplicity of the model formalizations and the irregular sensitivity of these variables this would not make much practical sense.

For instance, LAI could be over-estimated for values of over 3 or under-estimated during a period of low radiation, but this would have little effect on the related functional output variablessuch as biomass production and water transpiration. Nevertheless, these subsidiary variables mustnot be ignored because they make it possible to make a diagnosis on the model’s performance. Also, there is a difference between the scales expected for the results of the model and the scalesrequired for describing the processes. For example, the coupled water and nitrogen balances in the soil are solved at the scale of 1 cm, but soil characterization and thereafter the assessment of water and nitrogen profiles are based on dividing the soil into a maximum of 5 horizons. The model is still a simplification of reality that is justified by the reasons for which it is to be used and that must be respected. In the scientific fields where biology has an important role, models must not be considered to be ‘simulators’ of reality such as in the field of physics, but simply as tools for interpreting a highly complex reality.

8. GENERALIZED AGRICULTURE SIMULATOR

A General System Simulation Approach We view the general system simulation approach as a flexible, iterative problem-investigating process that includes problem formulation, mathematical modeling, testing and refinement of the model and problem solution in close consultation with decision makers. We view it as flexible with respect to (1) types and sources of data, (2) estimation and approximation procedures and (3) techniques. Therefore, we use the adjective "general" to describe this approach. All specialized techniques are regarded as potential contributors to our approach if, when and as appropriate. Included are: LP, NLP, equilibrium simultaneous equations with parameters estimated statistically from time series data; input/output table analyses; cost/benefit, internal rate of returns and net present value analyses; other techniques such as program planning and budgeting (PPB) and project evaluation and review techniques (PERT) and still other unnamed techniques. The approach is a process involving creative design of alternative courses of action to help provide solutions to the development problems at policy, program and project levels.

These problems and alternatives partially determine the model structure and level of aggregation. The flexibility of this approach allows for (1) sequential changes in model structure, parameters and objectives, leading to better models with a broader range of outputs and (2) utilization of any appropriate technique. The "output" of a simulation is a set of system performance variables associated with each set of policies and/or development strategies indicating the attainment of various benefits and the incurrence of various damages at different points in time from alternative policies, programs and projects. These estimates can be compared through interaction with policy makers for different alternatives in choosing the alternative which best solves the problem under consideration. Again, this interaction may lead to feedbacks and modification of the model. While this sequence of steps can be followed in using specialized techniques for solving real-world problems, we feel that the general system simulation approach has a flexibility advantage which particularly suits it to this iterative process; i.e., because it can use any specialized technique as appropriate and because it can use information of any kind and source, it has the strengths of all techniques available but can reject any on the basis of its disadvantages.

The generalized system simulation approach- The formalized problem-solving process contains three distinct phases: specification of needs and definition of the problem, identification of a set of feasible solutions, and selection and implementation of a solution. Generalized system simulation contributes to all phases of this process with the construction of a mathematical model of the problem and the use of computer simulation techniques to generate numerical solutions of the model under various assumptions and policy conditions. The process--including problem definition and model building, testing, validation, and application-- is iterative in nature rather than strictly unidirectional that is, information gained at later stages may (probably will) indicate a need to return and repeat earlier stages before continuing. Central to the whole approach are the interactions among decision makers, researchers, consultants, and modelers and simulators. These creative interactions are essential not only to properly define the most relevant development problems to be considered by planners and policy makers but also to specify meaningful policy simulation experiments and to interpret the results. As decisions are made through these interactions, both normative and non-normative (positive) information will be brought to bear. Where it is felt such information is deficient, new information will be sought. Mathematical Modeling Mathematical modeling, although in principle not absolutely necessary to the problem-solving process, in practice is almost indispensable, particularly if there is any degree of complexity to the problem.

Mathematical models may be constructed and used as either analytical models or simulation models. However, as the number and the nonlinearity of differential equations increase with the complexity of the model, analytical solutions become impossible given the present state of the mathematical art. Therefore, taking advantage of the capabilities of large-scale digital computers, researchers have turned to simulation as a means of generating numerical solutions and, hence, of providing policy makers with information about the likely consequences of alternative resource allocations, including the vector of criterion variables needed to evaluate alternative development strategies. For an economic development model, a vector of relevant performance criteria might include such elements as levels and growth rates of gross domestic product, employment, total and per capita income, nutrition, tax revenues, income distribution, trade balances, investments, etc. The approach is generalized on two accounts. First, models may include, but are not limited to, such specialized techniques as linear and nonlinear programming, dynamic programming, program evaluation and review techniques (PERT), and (as commonly used in econometric models) sets of statistically estimated simultaneous equilibrium equations. Secondly, there is flexibility in the data sources which can be tapped. That is, although time series and cross-sectional data, where available, may be used to estimate parameters, the approach is not limited to this source and may rely heavily on estimations by technical experts, perhaps via the Delphi method, or on "guesstimates." As regards mathematical programming techniques, effective use for public policy prescriptions is precluded at least until the problems discussed earlier have been overcome. Programming models may, however, have application in representing the private decision-making process. At the latter level, interpersonal validity is not a problem and it may be possible to specify a meaningful and realistic objective function or set of priority-ordered objective functions, although aggregation problems do remain if one wishes to model a sector or region rather than an individual decision-making unit. In spite of their problems (e.g., aggregation, choice of objective functions, computer execution time), such models may be the only feasible way to determine the simultaneous allocation of several resources to a large number of activities subject to a large number of resource and behavioral constraints.