CHAPTER 3

CROPGRO- Soybean MODEL

3.1 History of CROPGRO- Soybean model

Crop models are available for almost all economically important crops and one many occasions they have been successfully used in research. In the future, models may be useful for improving the efficiency of agricultural systems and could be a tool for farers trying to improve the profitability of their farms (Jacobson *et al.*, 1995). Soybean crop models have been available since the 1980s when the original version of SOYGRO V.4.2. (Wilkerson *et al.*, 1983) was released. Subsequently, the model was improved (SOYGRO V5.0) with the incorporation of the Richie (1985) water balance and a preliminary phenology model (Wilkerson *et al.*, 1985). In order to improve the code and be compatible with the standard input and outputs for mats of the IBSNAT project (IBSNAT, 1989), SOYGRO V5.4 was released (Jones *et al.*, 1987) and tow years later the model the model was further modified as Version 5.42 (Jones *et al.*, 1989) for release with the version 2.1. of the DSSAT (IBSNAT, 1989). The next major improvement of the soybean model was the inclusion of soil N balance, N uptake features and an N_2 fixation sub-model. This version was released under the name CROPGRO, a generic model to simulate three-grain legumes crops: Soybean (*Glycine max* L.), common bean (*Phaseolus vulgaris* L.), and peanut (*Arachis hypogaea* L.) Boote *et al.* (1998) described the most recent CROPGRO version released in December 1996 (CROPGRO V3.1.). The structure of the soybean model included in the DSSAT program is very flexible, so the adaptation of the model to a new climatic area is less time consuming than the design of a new model. During the last few years, skepticism has been slowly changing into widely accepted view that crop model are highly useful tools for scientist with DSSAT package (IBSNAT, 1989).

CROPGRO-soybean model (Hoogenboom *et al.*, 1994; Boote *et al.*, 1998) embedded in the Decision Support Systems for Agro-technology Transfer (DSSAT) (Tsuji *et al.*, 1994) is a process - oriented dynamic and generic crop simulation model, having options such as simulating yield for cropping season; crop carbon balance, crop and soil N balance, and soil water balance (Tsuji, 1998), operates on the daily time step, and simulates crop growth and development of four legumes (soybean, peanut, common bean, chickpea) based accounting for the effects of the weather variables and the main limiting factors as water and nitrogen.

It was found that CROPGRO-soybean model has many current and potential uses for answering question in research, crop management, and policy. Models can assist in synthesis of research understanding about the interactions of genetics, physiology, and environment, integration across disciplines, and organization of data. It can assist in preseason and in-season management decisions on cultural practices, fertilization, irrigation, and pesticide use. Crop models can assist policy makers by predicting soil erosion, leaching of agri-chemicals, effect of climatic change, and large area yield forecast (Boot *et al.*, 1996).

3.2 Inputs and outputs of CROPGRO - soybean model

Similar to other crop models, the CROPGRO - soybean model have the following processes in the Table 3.

In detail, the CROPGRO - soybean model requires the following inputs:

i. Daily weather date at least for the duration of the growing season. This includes solar radiation; maximum and minimum air temperatures and precipitation.

ii. Soil initial conditions and properties which include drainage and run off coefficients, evaporation ad radiation reflection coefficients, rooting preference factors, soil water content, nitrogen and organic matter details at several depth layers, and information on the initial and saturated soil water content.

iii. Management practices such as varieties, plant density, sowing depth, planting depth, irrigation (date of application and amount), and nitrogen fertilization (date of application and amount).

iv. Latitude information of the production area. This information s required in order calculating day length during the cropping season.

v. Genetic coefficients, the CROPGRO -SOYBEAN model requires variety specific coefficients that account for genotypes differs in their response to environmental factors. There are 15 genetic coefficients for soybean.

Table 3.1 General process diagrams for CROPGRO-soybean model.

INPUTS	PROCESS	OUTPUT
<u>Controllable inputs</u> ▪ Variety seeds ▪ Plant spacing ▪ Date of sowing ▪ Date and amount of irrigation water ▪ Date and amount of N fertilizer ▪ Types of fertilizer ▪ Genetic coefficients ▪ Types of residue	▪ Plant growth ▪ Phasic development ▪ Morphological development	▪ Grain yield ▪ Yield components ▪ Above ground biomass ▪ Date of phasic ▪ Developmental change
<u>Non-controllable inputs</u> ▪ Daily weather data ▪ Day length ▪ Soil properties and initial conditions		

Source: Tsuji *et al.*, 1994.

3.3 Features of CROPGRO-Soybean model

The CROPGRO - Soybean model takes account into the following:

- Phenological prediction or duration of each stages as affected by environmental conditions and genotype features
- Biomass expansion and partitioning
- Root, stem, pod addition
- Effect of soil water deficit and nitrogen deficiency on the photosynthesis partitioning in the plant system.

3.4 CROPGRO soybean simulation

Then scientists from several institutions have been developing and testing the models of various crops, and the results are being widely used in modern agriculture in crop management with several approaches such as cereals, legume, root crops and others crop model, in which, include CROPGRO for soybean crop. These models can simulate based on different management information such as planting date, plant density, irrigation, but it also has some limitations such as it can not simulate very well on nitrogen management (Tsuji *et al.*, 1994).

Over the time, CROPGRO soybean has improved ability of phenology prediction based on new-optimized coefficients, and a more flexible approach that allow crop development during various growth phases to be differentially sensitive to temperature, photoperiod, water deficit, and N stress and improved graphic and sensitivity analysis. Sensitivity of growth processes and seed yield to climatic factors i.e. temperature, CO_2, irradiance, and water supply, and cultural management e.g. planting date and row spacing (Boote *et al.*, 1998) could be analyzed easily in the model. And the CROPGRO soybean model (Hoogenboom *et al.*, 1994) was used to simulate yield for cropping season. The CROPGRO soybean model is process - oriented and simulates crop carbon balance, crop and soil N balance, and soil water balance. Measured weather and soil data, and actual management practice data were used as inputs to model. Weather data required by the model, including daily incoming solar radiation, maximum and minimum air temperature and precipitation, were collected of site by an automatic weather station. The weather was assumed to be constant over the field, although some spatial variation in precipitation might have occurred. Management practices (crop variety, planting date, planting depth and chemical applications) were constant over the field (Wilkerson *et al.*, 1998).

Soybean growth and yield models require good predictions of vegetative and reproductive development stages, as a function of specific environment variables. This is a basic requisite for crop growth models (Egli and Bruening, 1992). Hodges and French (1985) described a soybean phenology model that computes daily development rate as a product of three variables: water stress, photoperiod and temperature. Model includes seven phases, encompassing sowing to maturity, and include a juvenile phase to account for the period of time following emergence when plants are assumed not to respond to photoperiod. Wilkerson *et al* (1983) developed a phenology model for integration into SOYGRO (a growth and yield model for soybean) that have some features similar to the Hodges and French (1985). In detail, plant growth models may be the only way to integrate over many processes that plant physiologists may study in isolation in their laboratories. When considered in the holistic picture of crop growth, some previous highly studied processes, such as single-leaf photosynthesis or N_2 - fixation efficiency, assume a lesser level of importance (Boot *et al.*, 1996). More mechanistic leaf photosynthesis and stomatal conductance response to CO_2 as well as an hourly energy balance option appeared in CROPGRO model released in 1994 (Boote and Pickering, 1994; Pickering *et al.*, 1995) compared the more mechanistic, photosynthesis -energy balance approach, to SOYGRO which has empirical adaptation of photosynthesis and evapotranspiration (ET) to CO_2 and temperature. Season long effects predicted yield, biomass, and ET show little relative difference between two models, except where water stress and irrigation demand were computed.

Simulation in CROPGRO soybean model also includes leaf level, hedgerow, canopy photosynthesis based on a sunlit and shaded leaf approach, with hourly time-step, and use algorithm of Spitters *et al.* (1986) for computing fraction diffuse and fraction direct sunlight. Simple and comprehensive modeling approaches were used to compare daily canopy assimilation responses to temperature (Pickering *et al.*, 1995). Daily assimilation versus temperature for the mechanistic leaf hedgerow canopy photosynthesis mostly confirmed the simple function at midrange temperature, although mechanistic model predicted higher daily assimilation in quite warm temperatures. Controlled environment chamber studies confirmed that canopy assimilation remains high a quite temperature (Pan *et al.*, 1994). Mathematic equations were applied in the model with dataset recorded from an experiment, for soybean, improved phonological parameter values were derived from field data set. Grimm *et al.*, (1993, 1994) used simplex optimization algorithm to solve for base temperature, optimum temperature, critical minimum and maximum day length and cumulative threshold durations, based on extensive data available on time to flowering, beginning seed, and physical maturity of any soybean cultivars grown over wide range of climatic sites.

The model assumes complete control of growth limiting factors such as weeds, pest, diseases and other management variables. Some options of CROPGRO - Soybean model showed as follows:

Development processes calculations

Carbon balance processes include leaf area expansion, pod addition, seed addition, shell growth rate, seed growth rate, nodule growth rate, senescence, and the model calculated carbohydrate mobilization. And crop development in CROPGRO soybean used a flexible approach, allowed the use of difference equations shapes for each function as well as different cardinal temperatures. The species file for each crop defines those equation shapes and cardinal temperatures (base temperature, first optimum, second optimum, and maximum temperature. It also defines the thirteen phases (Tsuji, 1994).

The model simulates the growth stages for soybean according to the stages defined originally based on the descriptions of stages for soybean (Fehr and Caviness, 1977). Only the stages with variables name identified are explicitly included in the model. In vegetative period, there are 4 stages: VE, V1, V2, V(n) and in reproductive period, there are ten stages namely R00, R0, R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, detail of the stages are shown in the Table 3.3.

Table 3.2 Development stages of soybean.

Stage	Stage description
Vegetative	
VE	First day with 50 percent of plants with some part visible at soil surface
	First day with 50 percent of plants with completely unrolled leaf at unifoliate node.
V_1	First day with 50 percent of plants with completely unrolled leaf at first node above the unifoliate node.
V_2	First day with 50 percent of plants with 2 leaves above the unifoliate on the main stem.
V(n)	First day with 50 percent of plants with n leaves above the unifoliate on the main stem.
	Day on which last main stem node formed.
	Day when leaf expansion ceased (often on branches).
Reproductive	
R00	Day when juvenile phase ends and plants first become sensitive to photoperiod.
R0	Day when floral induction occurs.
R1	Day when 50 percent of plants have at least one flower at any node on the plant.
R2	Day when 50 percent of plants have one peg at any node (for peanut only)
R3	Day when 50 percent of plants have at least one pod formed (at least 0.5 cm in length) and ready to grow

(Cont'd)

Stage	Stage description
R4	Day when 50 percent of plants have at least one filly expanded pod.
R5	Day when 50 percent of plants have pods with seeds beginning to grow.
R6	Day when 50 percent of plants have at least one pod containing a full-sized green seed.
R7	Day when 50 percent of plants have at least one pod that yellowing, physiological maturity.
R8	Day when 50 percent of plants have at least 95 percent of pods brown, harvest maturity.

Source: Fehr and Caviness, 1977

Photosynthesis and evapotranspiration calculations

Currently it can calculate hourly values of canopy photosynthesis using a hedgerow right interception model and leaf-level photosynthesis parameters. The model also has several evapotranspiration (ET) options that may be selected, including the Priest-Tailor and the FAO –Penman methods (Boote *et al*., 1994).

Growth and maintenance respiration

Growth and maintenance respiration requires approximate estimates of tissues composition in six types of compound: protein, lipid, lignin, carbonhydrate-cellulose, organic acid, and minerals for soybean by Wilkerson *et al*. (1983) and Jones *et al*. (1989). The model calculates composition for new tissues prior to computing growth conversion efficiencies for each day's growth. Composition values are entered in the species file, except that protein concentration of newly –synthesized vegetative tissue depends on N balance/deficit (Boote *et al.*, 1994).

Carbon balance and assimilate partitioning algorithm

The approach for C balance in CROPGRO is modified from SOYGRO v5.42, PNUTGRO V1.02, and BEANGRO 1.0. The model is essentially a source – driven model except under three circumstances: (i) during early V stage development, potential leaf area expansion and sink strength can be limiting, thus reducing growth and photosynthesis; (ii) when severe N deficit limits growth of vegetative or seed components, then carbohydrates accumulate in vegetative tissue; and (iii) after a full seed load has been added and if the crop is past a critical seed addition period, then it is possible for reproductive sink strength to be limiting (Boote *et al*., 1994).

Nitrogen uptake, balance, and fixation with respect to carbon balance

A nitrogen fixation component has been incorporated into CROPGRO. When N uptake is deficient (less than N demand) for growth of new tissues, carbohydrate can be used for N_2- fixation to the extent of the nodules mass and the species –defined nodule specific activities (Boote *et al.*, 1994).

Mobilization of nitrogen and carbohydrate, senescence, and maturity

In CROPGRO, carbon hydrates accumulate in leaf and stem tissues under several situations: N deficiency that limits growth, insufficient sink during early sink, limited growth after a full seed load is set. Senescence of leaf and petioles is dependent on protein mobilization and is enhanced by drought stress (Boote *et al*., 1994).