CHAPTER 2

LITERATURE REVIEW

System Simulation and Modeling

System analysis is a study of the status of a system at a certain moment and its behavior as a function of time. A system, which can be defined as a limited part of reality that contains interrelated elements; may be too complex to study directly. However a model, which can be defined as a simplified representation of a system that contains the elements and their relations that are considered to be major important for the system behavior, may be easier to study (Leffelaar and Ferrari, 1984). Simulation is the study of a system and the computation of its behavior using a dynamic model (Penning de Vries et al., 1989). Dynamic simulation models are based on the assumption that changes in the state can be described by mathematical equations: rate or differential equations. This leads to models in which state, rate, and driving variable can be distinguished (Leffelaar and Ferrari, 1984). State variables in a model represent quantities, which may be tangible (such as weight), or abstract (such as development stage). Rate variables represent amount of change of state variables. Driving variables is the environmental factors that drive or causes changes in the system behavior (Penning de Vries et. al, 1989). When differential equation, which summarize existing knowledge of a system, are formulated, and when the state of the model at a certain period of time is known, its state in the future can be calculated (Leffelaar and Ferrari, 1984). Modeling is both science and art of building a model of a system. Define the objectives and system boundary is the first step of

building a model or modeling. The clearly defined problems and objectives will make clear exactly what problems the model will be used to solve and to what degree of detail information is required to form the model. After the objective is being set, the next step is to identify the specified system in term of its properties i.e. system variables, and their relationship, which are adequate for objective of the study (Jongkaewwattana, 1995). Each relationship among variable as defined must be quantified. Sufficient theory and data are needed to quantify them. Literature review and analysis of data is a very important step for better understanding of the system. The next step is termed model development. This step involves a key step where the modeler summarized the quantitative relationship among key system's elements defined in the previous step into a computer language. The developed computer model must be verified or tested to ensure that they perform as intended by the developer. It frequently happen that models, as first developed, fail to simulate some aspect of the real system. To make the model work correctly, some of the parameter in the equations and even some of the relationship have to be adjusted. This process is called model calibration. Then, the verified model would be validated. Validation is a process in which model's users conduct a comparison of the predictions of a verified model with experimental observations other than those used to build and calibrate the model, and identification and correction of the errors in the model until it is suitable for its intended purpose. The validated model is used to help researcher to be better to predict responses of the system when an individual input variable changed and holding all others constant, this is called sensitivity testing. The most sensitive variable is the variable which its change most affect the system outputs (Whisler et al., 1986). System analysis also helps researchers

to better understanding interaction between system variables. Final step is the application of the model, which is the use of the validated model to predict responses of the system when key elements of the system are changing, which assist decision making (Jintrawet, 1998).

Modeling Potential Crop Production

In modeling crop production systems, crop biomass may be viewed as a product of growth and phenology processes. Separating the two processes is important because they are affected by different environmental variables (Penning de Vries et al., 1989; and Ritchie et al., 1998). At the production level I, the crop receives ample water and nutrients and its growth rate depends only on the current state of the crop and on current weather conditions, particularly radiation and temperature (Penning de Vries et al., 1989). The rate of growth or rate of biomass accumulation is principally influenced by the amount of light intercepted by plant leaf area over an optimal temperature range. The duration of each event in the life cycle of a plant or phenology for a particular varieties, however, is highly dependent on its thermal environment and to some extent the photoperiod before floral induction (Ritchie et al., 1998). The phenology process are more difficult to quantify and more variable over space and time than the growth process (Ritchie et al., 1998). Despite that, it is essential to quantify because partitioning of biomass between root, leaves, stems and storage organ is strongly related to the physiological age or phenological stage of the crop (Penning de Vries et al., 1989).

Principle of Phenology Model

Development stage may be defined as a state variable in crop growth models. The development stage of a crop quantifies its physiological age and is related to its morphological appearance. The developmental rate is the conversion version of the duration of a particular stage. The driving variable which influences the development rate is temperature and photoperiod for photoperiod sensitive plant (Penning de Vries et al., 1989).

Development Stages

In order to be able to measure plant development, development scales have been designed which, however, are different for each plant species. These development scales assign a number to phenological milestones in the plant's life, such as flowering, and ripening. Typically, a development scale is one-dimensional, and progress on the scale is irreversible (Goudriaan and van Laar, 1994). In the simple and universal crop growth simulator SUCROS1, the developmental stage can be conveniently expressed in a dimensionless variable, having the value 0 at seedling emergence, 1 at flowering and 2 at maturity (Goudriaan and van Laar, 1994). With increasing knowledge of a crop, its development scale can be specified with a larger degree of resolution and an increasing number of intermediate values.

The development stage is principally calculated as the integral of the development rate. A complicating is that the influence of climatic factors on development rate can also change with development stage itself. For example, daylength is often important for flower induction, but it has not importance for ripening. Sensitivity to temperature can also drift significantly.

Development Rate and Environmental Factor

Temperature

In general, it is temperature that has the largest effect on development rate. Development rate is found to be roughly linearly related to temperature over a large range, although there is usually a maximum in the response curve, above which development rate will decrease again. The temperature, at minimum in the response curve which development rate is assumed to be zero, is called the base temperature (T_b). During maximum and base temperature, the development rate is practically proportional to T_a-T_b (T_a being the air temperature). Provided temperature T_a lies between T_b and the optimum temperature, the development stage can be predicted using sum of temperatures in degree-days (Goudriaan and van Laar, 1994). The simplest and most useful definition of degree-days is growing degree day (GDD), which is the product of daily mean air temperature and its base temperature (T_b) as follow;

$$GDD_i = \overline{T_a} - T_b \qquad \text{.....(2.1)}$$

SUMGDD is the summation of growing degree days for a phenological stage (°Cd) used to determine a particular duration of growth stage. CUMGDD is used only in output to indicate the total GDD that has accumulated since emergence (Jones and Kiniry, 1986). A commonly used simulation method is to keep track of the number of accumulated degree-days in summation, and then read off the associated development stage (Goudriaan and van Laar, 1994).

Daylength

Sensitivity of a crop to daylengths can change during its vegetative phase. Thus, it is necessary to separate its vegetative phase into pre-inductive phase (others similar term such as basic vegetative phase, juvenile phase, and photo-insensitive phase) and inductive phase (others similar term such as eliminate phase and photosensitive phase) (Major, 1980; Summerfield et al., 1991; and Vergara and Chang, 1985). Pre-inductive phase is insensitive to (and its length is independent of) photoperiod, whereas the inductive phase is sensitive to (and its length is depend on) photoperiod (Summerfield et al., 1991). The duration of the juvenile stage or pre-inductive phase is almost totally controlled by temperature and varies with cultivars (Ritchie et al., 1998).

The degree of sensitivity to daylengths, which varies with cultivars, is also different with daylengths. Based on the degree of sensitivity to daylength, daylengths can be separated into optimal and non-optimal photoperiods (Major, 1980). Optimal photoperiod of short- and long-day plants may be defined as photoperiods at which plants show no delay in floral initiation stage. Under optimum photoperiods, if temperature is not a limiting factor then, flowering occurs in a constant number of days that consist of the days required for the end of juvenile and the minimum inductive cycles (Major, 1980). The end of the juvenile phase is usually about five days before floral initiation in maize, a phenomenon that can be determined with special experiments in which plants are interchanged between long days and short days during late juvenile and floral induction phases. Photoperiod exchange experiments with all crops in CERES models have demonstrated a similar pattern to maize with a similar minimum induction period (Ritchie et al., 1998).

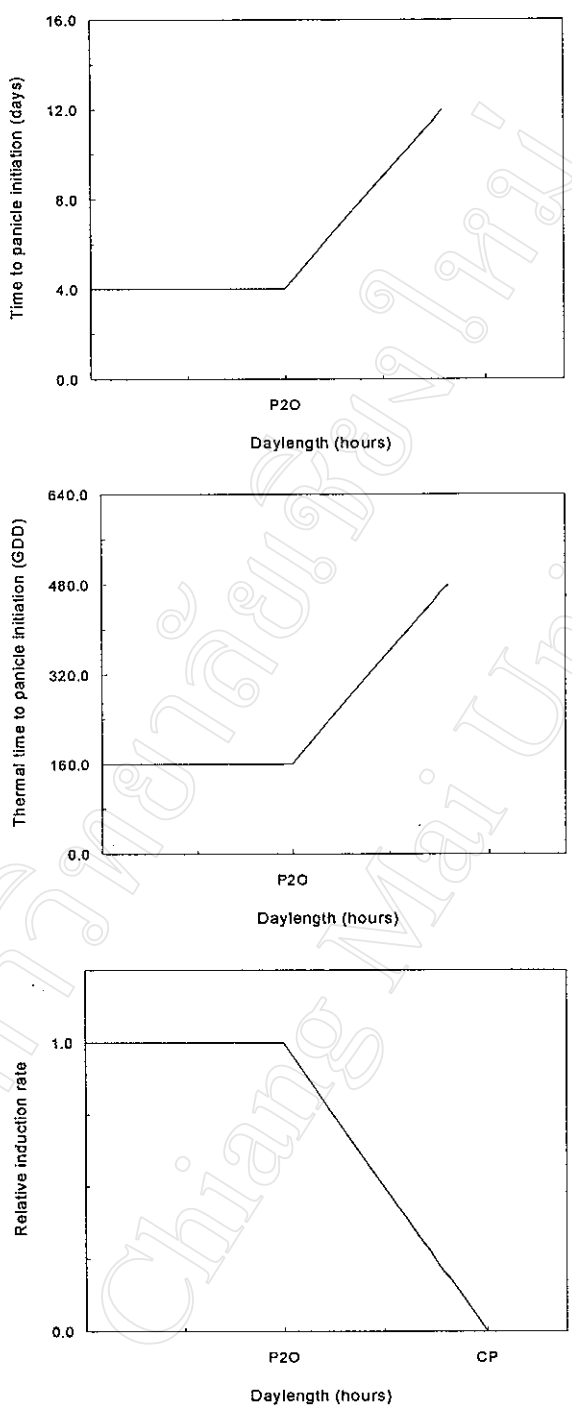
Non-optimal photoperiod is defined as photoperiods that have a delaying effect on initiation time (Major, 1980). The extra time taken for floral induction to occur for photoperiod longer (for short day plant) or shorter (for long day plant) than an optimum photoperiod is used to calculate a cultivar specific rate of photo-induction (Ritchie et al., 1998). The photoperiod, which is the threshold between optimal and non-optimal photoperiods, is expressed as a cultivar specific coefficient (P2O) in CERES models (Ritchie et al., 1998). For maize as a short day plant, it P2O value is about 12.5 hours, below which no further delaying effect of photoperiod (initiation occurs in constant number of day) and above which its coefficient (P2) for delaying reproductive growth is in unit of number of days delay per hour increase in photoperiods (equation 2.2). For rice, sorghum, and millet, the optimum (P2O) varies with cultivars, ranging between 11 to 15 hours, below which no further delaying effect of photoperiod (initiation occurs in constant growing degree days, P22) and above which its coefficient (P2R) is in growing degree days delayed per hour increase in photoperiods (equation 2.3) (Tsuji et al., 1994). In the ORYZA model, the effect of photoperiod is expressing the response as a rate rather than duration. The function can be characterized by the maximum optimum photoperiod (same as threshold photoperiod, P2O), and the relative response of developmental rate slowed per hour increase in photoperiod (*S*) above P2O, under which the relative rate is equal to 1 (equation 2.4) (Kropff et al., 1994). The relationships, which are used to generate the equation 2.2, 2.3 and 2.4, show in Figure 2-1A, Figure 2-1B, and Figure 2-1C, respectively. It is expressed variously because understanding about the photoperiods respond functions is unclear (Ritchie et al., 1998).

$$\#\,days = 4.0 + P2 \times (DL - P2O) \quad \text{.....(2.2)}$$

$$^{\circ}Cd = P22 + P2R \times (DL - P2O) \quad \text{.....(2.3)}$$

$$RATE = 1 - S \times (P2O - DL) \quad \text{.....(2.4)}$$

For both short- and long-day plants, absolute and quantitative daylength sensitivity. is distinguished. In case of absolute daylength sensitivity, a particular value is required before development to flowering can proceed at all, whereas for quantitative daylength sensitivity it takes longer only (never prevent) if the length of the day is somewhat unfavorable (Goudriaan and van Laar, 1994). For a quantitative short-day plant, above a particular photoperiod its floral induction duration reaches a maximum number of days. For an absolute short-day plant, induction never occurs above a particular photoperiod. Conversely, in long-day plants below a particular photoperiod floral induction never occurs for absolute sensitivity and maximal delay is achieve for quantitative sensitivity (Major, 1980; and Summerfield et al., 1991). However, only some genotypes has the particular photoperiod where abrupt changing of sensitivity occurs (Major, 1980). Major (1980) called the particular photoperiod as the critical photoperiod. But Summerfield et al. (1991) defined the word "critical photoperiod" as a photoperiod at which the threshold between optimal and non-optimal photoperiod, and called the critical photoperiod in meaning of Major as "ceiling photoperiod". CERES models did not incorporate the particular photoperiod, at which prevent or maximal delay floral induction, into the models and did not demonstrate prediction of the genotypes whose sensitivity sharply change at the particular photoperiod. However, for ORYZA model, the relative induction rate could be zero (induction never occurs) at a photoperiod that is determined by the cultivar specific coefficient (*S*).



(A)

$$\#\,days = 4.0 + P2 \times (DL - P2O)$$

(B)

$$^{\circ}Cd = P22 + P2R \times (DL - P2O)$$

(C)

$$RATE = 1 - S \times (P2O - DL)$$

Figure 2-1 Responses of short-day plant to daylength as function of number days (A), growing degree days (B), and relative induction rate (C).

Another problem is that photoperiod is not the same as calculated astronomical daylength. Astronomical daylength is defined as the period between sunset and sunrise. The latter occur when the upper edge of the sun's disk appears to be on horizon with an unobstructed horizon and normal atmospheric refraction (Whisler et al., 1986). It was found that photoperiod can exceed daylength by up to an hour. Civil twilight, which light intensity is about 4 Lux, can induce or delay of flowering in some rice cultivars, but not all (Vergara and Chang, 1985). The CERES crop models use the daylength include civil twilight in phenological model (Forsythe et al., 1995). There are a daylength simulation model called CBM model, which allow user to select a daylength definition from 6 definition upon the position of the sun with respect to horizon (Forsythe et al., 1995).

Previous Research about Sugarcane

Sugarcane Simulation Models

There are two main sugarcane simulation models currently in use throughout the world, APSIM and CANEGRO models, developed by the Australian and South African Scientist, respectively. The CANEGRO has been included into the Decision Support System for Agrotechnology Transfer (DSSAT v3.5) suite for model as CANEGRO 3.1 (Hoogenboom et al., 1999). ThaiCane 1.0 model was developed and based on CANEGRO 3.1 model and designed to be applicable for Thai condition and variety. These models predict only vegetative stages using growing degree days (GDD) concept. However, these models do not predict flowering date or maturity date (O'leary, 1999), at which sugarcane stop growth, begin to senescence and cause a decrease in yield (Moore and Osgood, 1989).

These models end simulation at harvesting date, but in reality growth ends since flowering occurs. Jintrawet et.al. (1997a) reported that duration of vegetative growth stage and leaf interval of two Thai sugarcane cultivar can be predicted using growing degree days concept. However, Chanmueng (1997) and Siri et al. (1997) suggested that thermal time alone may not be sufficient to the prediction of the panicle initiation and panicle emergence stage of sugarcane varieties. Their research demonstrated that cumulative growing degree days since emergence to panicle initiation is different with different planting dates. Both of them suggested that it may be the effect of photoperiods on rate of change from vegetative to reproductive phases, but they did not demonstrate how photoperiods could be incorporated to accurately predict the development rate.

Sugarcane Flowering and Environmental Effects

Flowering in sugarcane is controlled by photoperiod but is influenced by low temperatures (Singh et al., 1988). At the early growth stages, the sugarcane plant is photoperiod insensitive. Clement (1975) reported that the plants were ready for photoperiod induction when it showed four fully-exposed internode, which was observed at the 14th leaf position (Jintrawet, 1997).

Daylength

Previous research found that most sugarcane clones have narrow range of optimum photoperiod between 12 and 12.5 hours (Clements, 1975; James, 1969; James and Smith, 1969; and Levi, 1985). At Pingtung Taiwan, Lee and Lin (1950) found that blossoming time of a native *S. spontaneum* at 12 hours photoperiod and natural daylength, but the 9- and 15- hour photoperiod delayed blossoming

(Clements, 1975). Similar respond found in several clones (*Saccharum spp.*) at Canal Point, but its number of panicle violently reduced at 9-, 11- and 14- hour photoperiod as compared to 12.5 hour, where panicle emergence delayed without reduced (James and Smith, 1969). The narrowness of range of inductive photoperiod was demonstrated by a Hawaiian clone (H73-1933), which blossomed readily under controlled conditions with daylength of 12:28, slightly at 12:02, and not at all above 13:02 or below 11:34 photoperiod (Clements, 1967). Under controlled conditions, flowering has been induced with decreasing or constant photoperiods, but increasing photoperiods failed to induce flowering or reduced it substantially (Clements, 1967) and the flowers initiated under increasing photoperiod fail to emerge (James and Smith, 1969). Most of cane clones could be successfully induced to produce blossom by imitating its favorable daylength, which normally were the daylength of their natural environment (Clements, 1975).

An interruption given after midnight with 21.53 Lux (0.070 Wm^{-2}) of incandescent light was sufficient to inhibit flowering in a Hawaiian sugarcane clone, H37-1933 (James and Smith, 1969). It was reported that both incandescent and fluorescent light were effective, whereas light from mercury lamps or far-red had no effect on flowering in H37-1933 (Julien and Soopramanien, 1975).

Temperature

Low night temperature during the photoperiod induction phase prevented sugarcane cultivars to enter their blossoming phase. Research conducted on two sugarcane varieties reported that Nco310 and H37-1933 varieties failed to develop flower if the minimum temperature during photoperiod induction dropped below 12°C

and strongly delayed at 13-16 °C during floral induction under a fixed photoperiod (Clements, 1967). The best average minimum temperature during the induction period of *S. officinarum* under a controlled condition were 21.1 and 22.6 °C in November and March, respectively (Levi, 1985). Under natural condition, those nights with a minimum temperature below 18.3 °C were non-inductive, with flowering declining were the proportion of non-inductive night increase during the photo-induction period (Berding, 1981). Minimum and maximum temperatures in the range of 18 – 31 °C or not differ more than 13 °C were favorable for flowering condition (Carlucci et al., 1990; and Pereira et al., 1983).