CHAPTER II
LITERATURE REVIEWS

1. Peanut production areas and drought stress in Thailand

Peanut is an important cash crop in the world, and it is used largely for human consumption. Recently, people have a lot of concern on the health benefit from foodstuffs. Peanut can meet these requirements as it is a good source for protein and oil nutrients for human life, and peanut seeds contain benefit compounds such as arginine, oleic and linoleic acids (Andersen and Gorbet, 2002). Harvest area of 23.5 million hectares worldwide are devoted to peanut with a total production of 35.5 million tons in shell and average pod yield of 1.5 tons per hectare (FAOSTAT, 2009). In Thailand, peanut is planted on 65,000 hectares providing 0.14 million tons in shell and average yield of 1.7 tons per hectare (FAOSTAT, 2009). As peanut is grown largely in rain-fed areas, drought is a recurring problem for peanut production. More than 80% of world peanut production areas (Wright and Nageswara Rao, 1994) including 60% of peanut production areas in Thailand (Patanothai et al., 1987) is under rain-fed conditions. Rainfall in Thailand is bimodal from the middle May to late November, and there is a cool and dry season from November to middle March. In these situations, drought usually occurs at any crop growing stage and any growing season and can limit peanut productivity in Thailand. Therefore, yield loss due to drought is an important problem. A clear knowledge on the crop when it encounters drought conditions is very important and useful for improving the crops under drought environments.

2. Mechanisms of drought resistance

A better understanding on the mechanisms of plant adaptation to drought is important for improving drought resistance and provides a solution to drought problem and effective use of water in agriculture. However, plant responses to drought are complex. The mechanisms of drought resistance are under different genetic controls and the ability of plants to adapt to stress environments is also different. The mechanisms of drought resistance could be categorized into three

groups as drought escape, dehydration tolerance and dehydration postponement (Turner, 1986). Plants use either one or more than one mechanism at a time for resisting drought.

2.1 Drought escape

Drought escape is the ability of plants to develop and complete their life cycle before the onset of drought. Plants are never affected by drought. Once good rain or good soil moisture is terminated, the plants escape drought by rapid development of phenology in order to mature prior to the occurrence of drought. Crops having drought escape adaptation usually result in a shorter crop cycle from planting to harvest when the crops encounter drought environment than under well-watered conditions (Sobardo and Turner, 1986). However, plant with drought escape adaptation demonstrates good drought tolerance depending on the synchronization of the period of growth and the availability of soil water (Turner, 1979). Mild water stress increase earliness by decreasing the time to flowering in determinate plants (Angus and Moncur, 1977).

The decreased time to flowering induced by mild water deficit is likely to result from warmer shoot temperature and so higher day-degree in plants in which the stomata are partially close by water stress. Early flowering thus appears to be a consequence of water-conservation mechanisms induced by water shortage rather than an adaptive mechanism. Therefore, the role of roots in sensing some water deficit appears to have a little result to the mechanism of drought escape. However, this process has a negative effect on high productivity due to short life cycle of plants usually reduces the time to accumulate yield.

2.2 Dehydration tolerance

The ability of plants to endure drought periods without significant rainfall and withstand low tissue water status is dehydration tolerance. The two major mechanisms of dehydration tolerance are turgor maintenance and desiccation tolerance, when the plants encounter with drought stress.

(i)   Maintenance of turgor

Osmotic adjustment is a powerful mechanism for adapting to drought stress of plant, it is the accumulation of solutes under water limit conditions thereby decreasing the osmotic potential and so increasing the turgor pressure of cells. Osmotic adjustment of shoots has been observed to maintain stomatal opening (Turner et al., 1978; Ludlow et al., 1985) and photosynthesis (Ackerson et al., 1980), to lower leaf water potentials, and to defer leaf rolling (Henson, 1982; Hsiao et al., 1984) and leaf death (Hsiao et al., 1984) until lower leaf water potentials are reached. Plants subjected to drought environments accumulate osmotic active compounds such as amino acids, sugars and ions inside their cells (Zhang et al., 1999), resulting in a decrease in cell osmotic potential and then in maintenance of water absorption and cell turgor pressure (Turner, 1986). Similar to shoots, the adjustment of osmotic compounds in roots plays an important role in maintenance of root turgor. Osmotic water potentials in several roots of the crops planted under water stress conditions are lower than those in leaves (Sharp and Davies, 1979). Osmotic adjustment and desiccation tolerance are both the choices for adaptation to drought of crop.

(ii)   Tolerance of desiccation

Desiccation tolerance appears to depend on the ability of the cells to withstand mechanical injury, the ability of the membranes to resist degradation and the ability of the membrane and cytoplasm to endure denaturation, and of proteins (Gaff, 1980). Plants differ in desiccation tolerance, the capacity of the cell membrane to prevent electrolyte leakage at decreasing water content, or cell membrane stability (Tripathy et al., 2000). Plants with poorly developed dehydration postponement characteristics such as increase in stomatal and cuticular resistance and reduction in leaf area appear to have the greatest development of desiccation tolerance. Furthermore, osmotic adjustment also appears to increase ability of plants to tolerate desiccation (Blum and Ebercon, 1981).

2.3 Dehydration postponement

The ability of plants to endure the periods without significant rainfall whilst maintaining a high water status is dehydration postponement. The two major

mechanisms of dehydration postponement are reducing water loss or maintaining water uptake, when the plants encounter drought stress.

(i) Reduction of water loss

Reducing water loss by decreasing stomatal conductance and decreasing leaf area is the process that can lower crop productivity under water deficit conditions (Turner, 1979). The process might efficiently enhance water use efficiency as the reduction of water loss at critical time of the day while vapour pressure deficits is large. However, when vapour pressure deficits are less severe, the process allows photosynthesis to continue in early morning or late afternoon. In addition, the reduction in photosynthesis and water use early in the life cycle of the plant may enable a greater grain yield to be achieved by conserving water for the period after anthesis (Passioura, 1977).

Stomatal closure appears to be under the control of both abscisic acid and cytokinins. Moreover, the vapour pressure deficit of the air has an effect on the stomatal conductance independent of any changes in the bulk of mesophyll leaf water potential (Turner, 1986). Another tool for reducing water loss is a reduction in leaf area. The process appears to be largely affected by soil water status and by root hydration. Insufficient water situation can induce the decrease in leaf turgor, resulting in reduced leaf growth. Nevertheless, the loss of growth can be quickly compensated for when stress is removed (Acevedo et al., 1971). Hence short-term drought changes in leaf growth are unlikely to have any long-term drought influence on leaf growth. Adaptation of above-ground part is one mechanism of plant response to drought stress by dehydration postponement, and adjustment of water uptake by roots is also another mechanism of adaptation.

(ii) Maintenance of water uptake

Drought resistance can be increased by improving the ability of the plant to extract water from the entire soil profile (Wright and Nageswara Rao, 1994). The increase in root growth such as root depth and density is therefore an important response of plants to increase drought tolerance. Some plants such as peanut with higher root length density in deeper soil layers are more tolerant to drought and have

higher pod yield and harvest index under drought conditions (Pandey et al., 1984; Songsri et al., 2008a).

The plants can explore a greater volume of soil for water in deeper soil layers as high osmotic adjustment allows the plant to continue root growth at low water potentials. Osmotic adjustment of roots to shoots can increase the amount of extractable water and, thus, has similar benefits to those of deep roots. Moreover, osmotic adjustment in leaves also have a strong effect on water uptake (McGowan et al., 1984). Although the plants have a greater root length and take up a greater amount of deeper water, the plants with leaf osmotic adjustment mechanism can exploit the advantage of deep roots more than the plants without this mechanism. In addition, the hydraulic resistance to water flow in the plant is a factor that influence water uptake by plant roots. The interaction between root and shoot highlights the importance of the hydraulic resistance. High hydraulic resistance between soil and the shoots can induce relatively lower water potentials in the leaves than roots compared with a low hydraulic resistance (Turner, 1986).

An understanding on the mechanisms of crop responses to drought environments will be useful for crop breeding for drought resistance program. Furthermore, it is necessary to get insight into the responses to varying drought conditions occurring at different growth stages as yield loss due to drought is erratic in nature depending on timing, intensity and duration.

3. Effect of timing drought on yield

Drought can occur at any plant development stage. The effect of drought timing has a major influence on yield, i.e., how much yield is lost or gained with varying drought timings. Most frequent drought patterns can be categorized in to three types such as pre-flowering drought, mid-season drought and terminal drought.

3.1 Pre-flowering drought

Water stress during the vegetative or early flowering stages is not detrimental and sometimes actually increases yield of peanut (Nageswara Rao et al., 1985; Nautiyal et al., 1999). The reason why peanut subjected to early drought stress can increase yield is not clearly understood. The adaptation of plants for physiological and

morphological traits such as chlorophyll concentration, stomatal conductance, photosynthesis and relative growth rate (RGR) increased after re-watering might contribute to yield increase (Awal and Ikeda, 2002). Furthermore, some traits such as vegetative growth, crop growth rate (CGR), pod growth rate (PGR) and reproductive development are significantly associated with increased yield after pre-flowering drought stress (Nautiyal et al., 1999). In addition, Nageswara Rao et al. (1989) assumed that the promotion of root growth during drought stress is an important character contributing to the increased yield. Rooting traits and the ability to uptake water under early water stress in peanut have not been reported in previous studies. Hence, the investigations of these traits might reveal the mechanisms underlying yield increase.

3.2 Mid-season drought

Pod yield of peanut is very sensitive to severe mid-season drought. Water deficit during the reproductive stages can reduce pod yield by 56-85% (Nageswara Rao et al., 1989). The reduction in soil water content can have detrimental effect on flowering, pegging and pod development owing to the subterranean fruiting of peanut. Number of reproductive parts such as number of flower, pegs and mature pods is reduced due to water deficit at flowering phase and results in the reduction in pod yield (Nautiyal et al., 1999). Water stress reduced not only number of pegs but also peg elongation which is turgor dependent. Pegs fail to penetrate effectively into air dry soil (Wright and Nageswara Roa, 1994).

3.3 Terminal drought

The end of season drought is a single event of drought that occurs at pod setting until maturity stage (Nageswara Rao et al., 1989). Pod yield is affected by decreasing pod growth and development (Reddy et al., 2003), number of mature pods, pod size, resulting in substantial reduction in yield   (Chapman et al., 1993; Songsri et al., 2008b). In addition, late-season drought can significantly affect physiological processes such as plant water status, stomatal resistance (Wright and Nageswara Roa, 1994) and photosynthesis (Williams and Boote, 1995). Photosynthetic activity was reduced by water stress through metabolic changes (Ritchie et al., 1990). Moreover, it

also predisposes the production of aflatoxin contamination and consequently lowering the quality of the seeds produced (Holbrook and Stalker, 2003). Aflatoxin deteriorates the quality of peanut kernels and its products rending them unfit for human and livestock consumption and causes economic and trade problems at almost every stage of marketing of peanut (Diener et al., 1987).

Effects of drought on peanut are different in different traits. Thus, the research on drought resistance is needed to understand the responses of individual traits which involve in productivity of peanut, including the comprehension on the relationships among the traits. The knowledge should increase the progress of peanut breeding for drought resistance and can explain the associations among these traits.

4. Effects of pre-flowering drought and mid-season drought

Drought affects not only physiological and morphological characters but also growth and yield of peanut (Turner, 1986). However, the responses of peanut to drought depend on development stages attacked by drought.

4.1 Effect of drought on peanut yield

Drought during the vegetative phase has only small effects on growth and yield of peanut due to the ability of peanut to recover from early season drought by initiating a flush of reproductive growth after the relief of the stress (Nageswara Rao et al., 1988; Awal and Ikeda, 2002; Nautiyal et al., 1999). Nageswara Rao et al. (1988) reported that peanut genotypes grown under early season drought are able to postpone days to flowering, and the number of flowers and pegs are reduced by early water stress. Low number of flowers during stressed period is compensated by flush flowering after re-watering. Hence, the number of flowers between early drought and non-water stress are not different. In addition, pre-flowering drought can decrease plant height, resulting in increased mature pod because the distance for stabbing pegs is shorter (Awal and Ikeda, 2002). Spanish-type peanuts can increase pod yield when irrigation is withheld at vegetative development and then resumed at pod filling development (Nautiyal et al., 1999). However, different peanut genotypes differ in their responses under early drought stress (Puangbut et al., 2009).

Drought stress at pegging, pod development and seed development could reduce pod yield, seed weight and harvest index substantially (Pallas et al., 1979; Nautiyal et al., 1999; Reddy et al., 2003). The number of pods per plant can be low due to the increase in soil resistance caused by prolonged drought (Sharma and Sivakumar, 1991) Orcutt and Hopkins (1988) found that shoot dry weight, pod dry weight, number of branches and pegs were greatly reduced when peanut was subjected to induced drought stress by diniconazole from 41 days after emergence to harvest. Peanut genotypes reduced pod, leaves and stem weights when they encountered drought during 20-50, 50-80 and 80-110 days after planting (DAP) (Meisner and Karnok, 1992).

4.2 Effect of drought on top growth

Water deficits can reduce leaf growth, stem growth, the number of leaves per plant, individual leaf size, leaf longevity and leaf area due to the reduction in plant water status, leaf expansion and photosynthesis. Water stress results in fewer and smaller leaves. Leaf area expansion is decreased by lower leaf turgor and high temperature (Chung et al., 1997). Furthermore, water stressed peanut plant has shorter main axis and branches than normal conditions. Soil water deficit reduces inter-nodal length, number of branches and number of internodes, implying that drought stress has effects on cell division (Nageswara Rao et al., 1988). Peanut genotypes planted under pre-flowering drought conditions reduced plant height, the number of leaves and leaf area (Boote, 1983; Wright and Nageswara Rao, 1994). Nautiyal et al. (1999) reported that peanuts grown under early drought conditions are able to increase number of leaves, leaf area and leaf dry weight after the drought stress. Moreover, Nageswara Rao et al. (1985), and Nautiyal et al. (1999) found that vegetative growth, CGR, PGR and reproductive development are associated with increased yield after pre-flowering drought stress, but drought during mid-season can reduce leaf and stem dry weight and leaf area (Meisner and Karnok, 1992).

Harvest index (HI), partitioning efficiency, have been identified as a drought resistance mechanism in peanut (Nigam et al., 2003, 2005). Generally, HI is calculated as the ratio of total pod yield and biomass including pods at final harvest. Hence, HI is directly related to yield. The ability to partition dry matter into pod yield

under limited water supply is an important trait for the peanut genotypes with resistance to drought (Chapman et al., 1993; Nigam et al., 2005).

Transpiration efficiency (TE) or water used efficiency (WUE) defined as grams of dry matter produced per kilogram of water transpired, and peanut genotypes are different in this trait (Wright et. al., 1994). WUE is used to express the amount of total biomass produced per unit of water use in evapotranspiration (Teare et al., 1982). The trait is rather fair for comparison of peanut genotypes which considerably vary in total biomass and water use. However, the selection through this process is difficult or even unsuccessful due to genotypes and environmental variations (Arunyanark et al., 2008). The identification and use of surrogate traits for WUE that are simple and have low environmental variations under drought conditions would be more effective and efficient.

In addition, the responses of top growth were assumed to be very closely related to the responses of root growth. Hence, the research on drought stress response needs to be intensively studied in the responses of a below ground part (root) for explaining the adaptation of peanut grown under drought conditions.

4.3 Effect of drought on root growth

Drought resistance might be increased by improving the ability of the crop to extract water from the entire soil profile (Wright and Nageswara Rao, 1994). Rooting depth, root distribution, root mass and root length density (RLD) have been identified as drought avoidance traits (Passioura, 1983; Turner, 1986; Matsui and Singh, 2003; Taiz and Zeiger, 2006). Under field conditions, peanut root was established both deeply and laterally in the soil profile early in the growth season, and RLD significantly increased at each depth increment with DAP until 80 DAP under sufficient water conditions (Ketring and Reid, 1993). Boote et al. (1982) found in Florunner peanut genotype that roots grew deeper into the soil at the rate of 2.2 to 2.8 cm per day during emergence to 130 DAP. When peanuts encountered drought conditions, root growth rate was reduced due to the harder soil (Boote, 1983). Dhopte and Ramteke (1991) found that root growth rate of drought tolerance genotype (JL-24) was three times higher than that of drought susceptible genotype (ICGS11) in both non-stressed and stressed conditions. Peanut frequently has the highest root

distribution at 0-30 cm soil depth (Boote, 1983), and the distribution was moved towards deeper soil layer under drought conditions (Wright and Nageswara Rao, 1994; Devies et al., 1989).

Rucker et al. (1994) found that some peanut genotypes that had a large root system (root dry weight) under non-stressed conditions produced higher yields under drought conditions and they suggested that these genotypes could possess drought avoidance traits. Del Rosario and Fajardo (1988) investigated root mass responses to drought stress of 12 peanut genotypes under greenhouse conditions and found that root dry weight of peanut was reduced by drought condition but it could increase root to shoot ratio. Nevertheless, the response of root mass to drought conditions occurred in some genotypes, but not all genotypes.

Peanut genotypes with higher RLD at lower soil depth enhanced drought tolerance and higher RLD in deeper soil layers in response to long term drought can contribute to high pod yield and harvest index. These peanut genotypes were classified as drought responsive (Songsri et al., 2008a). Pandey et al. (1984) reported that RLD of a peanut genotype (Kidang) was increased in the lower soil profile by drought stress. In contrast, Robertson et al. (1980) showed that RLD of a peanut (Florunner) was not affected by differential water managements.

So far the information on root response of peanut under pre-flowering drought conditions has been very limited in the literature. Awal and Ikeda (2002), who only studied one peanut genotype grown in containers, reported that drought significantly enhanced the root to shoot ratio which accelerated post-stress recovery. Meisner and Karnok (1992), who investigated root growth of a peanut genotype in a rhizotron chamber, found that the root growth rate was significantly reduced during stress from 20 to 50 days after planting (DAP) compared to non-stressed conditions under sufficient irrigation. After recovery, early drought-stressed peanut had more root growth than did the non-stressed peanut of the control treatment. Root traits may be associated with differential yield responses to pre-flowering drought stress. However, the mechanisms underlying yield responses of these peanut genotypes have not been well understood because there was no information on rooting traits under these conditions. The information on the responses of root characteristics of diverse peanut genotypes to pre-flowering drought under field conditions is still lacking and further

investigations are necessary. In addition, so far previous reports have been limited to the experiments under chamber conditions, and more previous studies investigated in a few peanut genotypes. Especially, there is a lack of information on classification of root distribution patterns for many peanut genotypes under drought, which could be useful for peanut drought breeding programs.

Moreover, the adaptation of peanut genotypes for top growth, root growth and other physiological traits would clearly explain the responses of yield under drought conditions. Several physiological traits that contribute to crop productivity under drought conditions are useful for improving drought resistance in peanut. Hence, a better understanding in the responses of physiological traits under water-limited situations is important for peanut breeding for drought resistance.

4.4 Effect of drought on physiological traits

Drought stress significantly induces the change of physiological traits of peanut such as water status in plant, stomatal conductance, specific leaf area (SLA), and chlorophyll content. Relative water content (RWC) is often used to determine plant water status. Stomatal conductance is defined as transpiration of plant. Chlorophyll content is indirectly detected by the soil plant analysis development (SPAD) chlorophyll meter reading (SCMR).

RWC is a proportion of amount of water in fresh leaf into amount of water in turgid leaves, and it is frequently used as a tool for detecting water status in peanut (Bennet et al., 1984; Nautiyal et al., 2002). RWC in leaves is higher in initial stages of leaf development and declines as the dry matter accumulates and leaf matures (Jain et al., 1997). Obviously, stressed plants had lower RWC (30%) than did non-stressed plants (85-98%) (Babu and Rao, 1983). Nevertheless, RWC completely recovered within 1-3 days of re-watering and some peanut genotypes tended to have higher RWC compare with non-stressed treatment (Pallas et al., 1979). This could be due to the vigorous response of peanut genotypes for stomatal conductance during recovery following the stress period (Awal and Ikeda, 2002). Rapid recovery after irrigation within only one hour was also reported (Meisner and Karnok, 1992).

Soil moisture deficit can reduce stomatal conductance (Wright and Nageswara Rao, 1994). As moisture stress increases, stomata start closing as a mechanism to

reduce transpiration. As a consequence, the entry of carbon dioxide is also reduced (Reddy et al., 2003). The decrease in stomatal conductance due to moisture stress results in low conductance of carbon dioxide and a reduction in photosynthesis. The main effect of a soil water deficit on leaf carbon exchange rate is exerted through stomatal closure. Nageswara Rao et al. (1988) found that drought is able to reduce stomatal conductance. However, stomatal conductance has higher value after re-watering compared with non-stressed plant. Moreover, stomatal conductance in peanut is closely related to water status (Bennet et al., 1984).

SLA can be easily and inexpensively measured, and it is being used in a large-scale screening program for improved drought resistance in Australia and India (Wright and Nageswara Rao, 1994). Lower SLA value means that plants have thicker leaves and higher chlorophyll density than the plants with higher SLA, indicating that the plant have a greater photosynthetic capacity (Arunyanark et al., 2008). SLA is highly correlated with water use efficiency (Wright et al., 1994). Soil moisture deficit is able to decrease SLA (Wright et al., 1994; Craufurd et al., 1999). Nautiyal et al. (2002) reported that peanut with low SLA under drought conditions can maintain high values of RWC, carbon exchange rate (CER), stomatal conductance and harvest index (HI) compared with peanut having a high SLA.

SCMR was used for rapidly assessing drought tolerance in peanut (Nageswara Rao et al., 2001; Arunyanark et al., 2008). It is an indicator of the photosynthetically active light transmittance characteristics of the leaf, which is dependent on the unit amount of chlorophyll per unit leaf area (Richardson et al., 2002). Positive correlations between SCMR and chlorophyll content (Akkasaeng et al., 2003) and chlorophyll density (Arunyanark et al., 2008) has been reported. Leaf photosynthesis is usually correlated with chlorophyll content per unit leaf area and, hence, the SCMR is able to provide a useful tool to screen for genotypic variation in potential photosynthetic capacity (Nageswara Rao et al., 2001).

The increase in canopy temperature is not unexpected. There were higher canopy temperature under drought stress conditions than under well-irrigated conditions in wheat (Siddique et al., 2000) and rice (Dennis and O'Toole, 1995). The peanut genotypes with lower canopy temperature are preferable because they have higher transpiration and, therefore, have higher carbondioxide exchange rate than the

genotypes with high canopy temperature. Rucker et al. (1994) found that peanut canopy temperatures were correlated with visual drought stress rating and yield. In plant breeding program, the interest is in finding genotypes that maintain low canopy temperature under field conditions.

Clearly, drought affects several traits of peanut. However, the investigation on rooting traits so far had been limited due to lack of comprehension and technique to access root sample, along with the process for collecting root are complicated and difficult. Thus, the establishment of reliable root sampling procedure is a must for drought resistance research, as it makes possible to obtain accurate and acceptable root information.

5. Rooting investigation methods

Measurement of root system is a procedure to obtain information on root architecture, root characteristics, root volume and root development. However, soils are optically opaque so that continuous visual observation of growth is impossible, and roots also respond differently to a wide variety of soil environments. This is extremely difficult to select appropriate methods for assessing root growth and activity. The consequence is a variety of techniques each best suited to particular purpose (Gregory, 2006). A summary of methods for examining roots is provided by Bohm (1979).

Although there are several methods to measure rooting traits in the fields, but all methods are destructive, laborious and time-consuming. Some methods require many instruments, and some tools are substantially complex and complicated. However, rooting parameters are considerably important for understanding the responses of peanut under drought conditions. Bohm (1979) proposed eight methods for observing roots, including Excavation, Monolith, Auger, Profile wall, Glass wall, Indirect, container and other methods. Nevertheless, this research focuses on a few of the methods involving with root mass and length.

Methodological difficulties associated with observing and measuring belowground biomass and distribution makes root study preclude the use of these methods. Many studies have compared the measurement accuracy of root biomass from different methods including core method, in-growth cores, monolith method,

minirhizotrons, trench profile wall and core break methods (Vogt et al., 1998; Park et al., 2007). Monolith and core methods are two efficient methods for providing acceptable root information such as root biomass and root length density (RLD) (Bohm, 1979; Ping et al., 2010).

5.1 Monolith methods

Monolith method is to dig a soil block containing all roots in the soil, and the soil block is washed in water to remove soil and debris (Bohm, 1979). The method is suitable for the crops with a small size of stem, and it is used to examine root amount, root distribution and root mass. The sample sizes can be varied from 0.3 m^2 to 1.2 m^2 (Bormann et al., 1993; Heijmans et al., 2001). Ping et al. (2010) found that, by using monolith method, sampling error can be reduced greatly with increased sample size (larger block). Furthermore, they also found that washing damage and soil lost during extraction might be the major factors controlling the measurement accuracy of total root biomass by method with small sample size. Certainly, the larger sample area is, the better monolith method would be (Park et al., 2007).

5.2 Auger methods

RLD is used for the study of root responses to drought. An auger method is more convenient in terms of less time and labor and often used for study RLD. Three steps are involved in this method including taking soil cores, separating roots from soil cores and calculating RLD (Bohm, 1979). The design of the coring tube was recommended by Welbank et al. (1974). Briefly, the tube is made of steel with 7.62 cm in the internal diameter, 3.18 mm in thickness and 120 cm in length and fitted with cutting tips of heat-treated special steel which stands up well to hammering through stones of flint, lime stones and compactable material.

The disadvantages of core method are that the roots are not recovered completely, partial roots are recovered randomly from random positions and there is soil compaction during core sampling. The roots therefore are generally overestimated (Vogt and Persson, 1991). Increase of core diameter can reduce the effect of soil compaction (Campbell and Henshall, 2001; Park et al., 2007). Park et al. (2007) found that soil compaction resulted in about 10% overestimation of root biomass. Ping et al.

(2010) found that the small core method (3.8-cm-diameter) significantly underestimated total root biomass compared with the large core method (10-cm-diameter), and washing damage and soil lost during extraction might be the major factors controlling the measurement accuracy of total root biomass by core method with small sample size.

In addition to sampling of roots, other tools are also necessary to assist root investigation for development of drought resistant peanut varieties. Simulation model is very useful to assist breeding for drought resistance program, and it is benefit for the future research on the traits with difficulty to measure such as rooting traits. However, the simulation can be effective and efficient, if accurate inputs can be obtained. The model requires input data including environmental conditions, management practices, and characteristics of cultivar-specific genetic coefficients (Boote et al., 1998). Before the application of the CSM-CROPGRO Peanut model, it is necessary to first determine the cultivar coefficients if the cultivars are new breeding lines or local cultivars that have not been used previously with the model. Hence, finding the tool to calibrate accurately the fit values of cultivar coefficients is needed.

6. Crop simulation model

A computer model is a simplification of a real-world system, even though so far it is not provided all environmental factors. There are different types of models, ranging from simple models that are based on an equation to extremely advanced models including thousands of equations (Hoogenboom et al., 2000). Crop simulation models are computer software programs that provide the dynamic simulation of crop growth by numerical integration of constituent processes with the aid of computers (Sinclair and Seligman, 1996). These models have been used in massive agronomic disciplines for nearly 40 years (Hoogenboom et al., 2004). Crop models were originally developed as research tools, and probably have had their greatest usefulness so far in being part of the research process (Matthews, 2002).

The general goal of crop simulation model is to simulate and explain crop development and behavior, yield and quality as a function of environmental and management conditions or of genetic variation (Sinclair and Seligman, 2000).

Moreover, the simulation models can be used to help in synthesis of research understanding about the interactions of genetics, physiology, and the environment, in integration across disciplines, and in organization of data (Boote et al., 1996). Many advantages of integrating crop simulation model approaches into a research programme were given by Seligman (1990), including i) identification of gaps in our knowledge, ii) generation and testing of hypotheses and an aid to the design of experiments, iii) determination of the most influential parameters of a system (sensitivity analysis), iv) provision of a medium for better communication between researchers in different disciplines and v) bringing of researchers, experimenters and producers together to solve common problems. Furthermore, Sinclair and Seligman (1996) considered models as a tool for obtaining knowledge in an organized, logical and dynamic framework, thereby allowing the identification of faulty assumptions and providing new insights.

7. The CSM-CROPGRO-Peanut Model

The Cropping System Model (CSM) CROPGRO-Peanut is one of the crop simulation models that encompass the Decision Support System for Agrotechnology Transfer (DSSAT) (Tsuji et al., 1994; Hoogenboom et al., 1999; Jones et al., 2003; Hoogenboom et al., 2004). The model is process-oriented and designed to simulate growth and development on a daily basis, using carbon, nitrogen, and water balances, reaching to simulated yield of peanut cultivars under diverse management scenarios and for a range of environmental conditions (Singh et al., 1994; Boote et al., 1998; Banterng et al., 2004; Suriharn et al., 2008; Phakamas et al., 2008; Putto et al., 2008). The simulation model is useful for marking appropriate management decisions and for providing farmers and others with alternative options for their farming systems (Hoogenboom, 2000).

7.1 Data requirement for model operation

The CSM-CROPGRO-Peanut model requires inputs data that refer to minimum data set for the model operation. The minimum data set has been determined by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) (Hunt and Boote, 1998). The data requirements consist of

environmental conditions such weather and soil data, management practices, and characteristics of cultivar-specific genetic coefficients (Boote et al., 1998). The input data sets that are accurate in particularly specific location could be obtained and would give a precise result. Therefore, the model investigation in any research programme should be concerned on input data.

Weather data is a powerful factor which affects the output data of the model. Daily information of solar radiation, maximum and minimum air temperatures and precipitation is used as weather data input (Hunt and Boote, 1998). The minimum weather data has been kept as simple as possible, and all required weather data should be for a particular site and particular time period.

The information on minimum soil data can often be obtained from classification taxonomic system, basic profile characteristics by soil layer as saturated, drained upper limited, lower limited, bulk density, organic carbon, pH, root growth factor, drainage coefficient, organic nitrogen, phosphorus and potassium (Hunt and Boote, 1998). Obtaining all the soil data needed for model operation is often quite difficult. Hence, ISBNAT has endeavored to specify a minimum soil data set, and to make available procedures by means of which surrogate values can be obtained by calculation from more readily available data (Ritchie et al., 1990). This minimum data set does not include the information on specific adverse aspects of the soil such as sodium content, salinity, and heavy-metal content, the need for which could increase attempts are made to apply models in more marginal agricultural regions (Hunt and Boote, 1998).

In all experimentations, attention should be paid to the details of how experiments are conducted so as to increase precision in output data. All aspects of crop management factors including planting date, harvesting date, planting depth, planting method, row spacing, plant population, fertilization, irrigation, irrigation method, water management, watering date and inoculate applications were proposed by IBSNAT. The requirements for the IBSNAT minimum data set cover most significant aspects (Hunt and Boote, 1998).

Crop cultivar information required for model operation also varies greatly among models. The IBSNAT models have been developed to use input data that identify the characteristics of the genotypes involved, and the term of such data are

cultivar coefficients. The cultivar coefficients required for the CSM-CROPGRO-Peanut model include 15 growth and development characteristics describing each peanut cultivar (Hoogenboom et al., 1994). The seven coefficients determining the life cycle development characteristics include the critical day length for photoperiod (CSDL), the sensitivity to photoperiod (PPSEN), the photothermal days from emergence to first flower (EMFL), the photothermal days from first flower to first pod (FLSH), the photothermal days from first flower to first seed (FLSD), the photothermal days from first flower to end of leaf expansion (FLLF) and the photothermal days from first seed to physiological maturity (SDPM). The eight coefficients that define the growth characteristics are four vegetative traits and four reproductive traits. The vegetative traits consist of the maximum leaf photosynthetic rate (LFMAX), specific leaf area (SLAVR), the maximum size of a full leaf (SIZLF) and the maximum fraction of daily growth that is portioned to seed and shell (XFRT), and four reproductive traits comprise individual seed size (WTPSD), seed filling duration for an individual pod cohort (SFDUR), average seed per pod (SDPDV) and the photothermal time required for reaching final pod load (PODUR) (Boote et al., 2003).

7.2 Output data

The output data provides an overview of input conditions and crop performance, and a comparison with observed data if available. This file presents the information that uniquely describes the simulated data set, a summary of soil characteristics and cultivar coefficients, the crop and soil status at the main developmental stages, a comparison of simulated and measured data for major variables, and information on simulated stress factors and weather data during the different developmental phases. Moreover, output file also provides a summary of outputs for use in application programs with one line of data for each simulation run, while subsequent files contain detailed simulation results, including simulated seasonal growth and development, carbon balance, and mineral nutrient aspects.

8. Determination of the cultivar coefficients of peanut genotypes

The cultivar coefficients are the values for crop characters that define the development, vegetative and reproductive growth of individual genotype (Hunt et al., 1993; Boote et al., 2003). Before the application of the CSM-CROPGRO Peanut model, it is necessary to first determine the cultivar coefficients if the cultivars are new breeding lines or local cultivars that have not been used previously with the model. The experimental conditions for determining cultivar coefficients must be absolutely optimum environment, having no abiotic and biotic stresses (Boote, 1999). The CSM-CROPGRO-Peanut model uses the concept of cultivar coefficient to characterize genotypes or cultivars (Boote et al., 1998, 2003).

8.1 Data collection for determination of cultivar coefficients

Determination of cultivar coefficients with data from particular specific experiment requires the sampling of growth and development data for each cultivar at regular intervals throughout the crop cycle. For many models, the input data are the time of occurrence of the major stages of plant development, the dry weight of the major organs at various times throughout the growing season, the final yield and its components, the number of branches, leaves, fruits and other organs and the main stem and branch height (Hunt and Boote, 1998). Procedures for collecting data on plant development traits of several crops are described in the IBSNAT technical manual (IBSNAT, 1990). Data from detailed experiments grown in two seasons are sufficient to determine cultivar coefficients for peanut cultivars of the CSM-CROPGRO-Peanut model (Banterng et al., 2004), and the minimum data required for the determination of cultivar coefficients of the CSM-CROPGRO-Peanut model are two development stages, e.g., first flowering (R1) and harvest maturity (R8) (Anothai et al., 2008a). Growth observations collected during phenological development stages as dry matter accumulation of different plant parts, leaf area index (LAI), and specific leaf area (SLA) at different growth stages are also required (IBSNAT, 1988).

8.2 Methodology for determination of cultivar coefficients

The approach and order for manual calibration follow the procedures described by Boote (1999). The first step, the coefficient for duration of EMFL and

SDPM are adjusted until the simulated dates of flowering and maturity matched the observed data. The next step involves the simulation of the rate of dry matter accumulation by adjusting the values of soil fertility factor (SLPF) in the soil file to obtain a good fit for the mean value of top dry weight and pod for all cultivars. Then LFMAX is adjusted to account for the residual differences in top dry weight and pod within a cultivar. Next, the WTPSD and SDPDV are adjusted until the simulated and observed values for final seed size and seeds per pod are well matched. Then, the coefficients for pod and seed development (FLSH, FLSD and PODUR) are calibrated. The onset of pod at maturity are used for adjusting FLSH, the onset of seed and seed harvest index are used for adjusting FLSD (Anothai et al., 2008a), and the onset of pod, seed, pod harvest index and seed harvest index are used for adjusting PODUR. After that, the SDPM is readjusted to ensure that the maturity date is correct. Also, the WTPSD and SDPDV are re-calibrated as seed size and seeds per pod might have been changed because of the alterations of parameters affecting timing. Then, SFDUR is adjusted until a good fit for shelling percentage as well as pod, seed and seed harvest index is obtained. Next, the WTPSD, SDPDV and PODUR are again re-calibrated as in the previous steps. Then, the XFRT is calibrated to produce a good match for biomass, pod, seed and seed harvest index. Finally, LFMAX is readjusted to obtain the correct of top dry matter, pod and seed dry weight. If the fit is good, it is determined that the calibration is finished.

The Genotype Coefficient Calculator (GENCALC) is a software package that facilitates the calculation of cultivar coefficients for use in existing crop models (Hunt et al., 1993) and a new version of this software is currently under development for incorporation into the DSSAT (Hoogenboom et al., 2004). The value for a given cultivar coefficient is varied, relative to one or more simulated and observed crop measurements. The algorithm searches the crop model output file based on the difference between simulated and actual target variables. Yield testing before releasing a new peanut cultivar is a routine process in peanut breeding. Such tests often record dates of first flower and harvest maturity, final pod yield, final seed yield, final biomass, seed size, pod harvest index, seed harvest index and shelling percentage. Furthermore, the trials are generally conducted over several seasons and

multiple locations. Using the data collected during yield testing, the program GENCALC might help the determination of the cultivar coefficients.

A new method for estimation of cultivar coefficients, the Generalized Likelihood Uncertainty Estimation (GLUE) methodology (Beven and Binley, 1992), was developed as a method for calibration and uncertainty estimation of models based on generalized likelihood measures. The GLUE program is used to estimate genotype-specific coefficients for the DSSAT crop models. It is a Bayessian estimation method that uses Monte Carlo sampling from prior distributions of the coefficients and a Gaussian likelihood function to determine the best coefficients based on the data that are used in the estimation process (He et al., 2010). Generally, the run would want to estimate all parameters. The GLUE program should make 3,000 simulation runs for phenology coefficient and another 3,000 runs for growth coefficient. The program randomly generates parameters either phenology or growth data. The model outputs are used to select the parameter set with the maximum likelihood value based on comparison of simulated and observed data, first for phenology parameters, then for growth parameters. The GLUE method can be used, without intervention by users, to produce a set of estimated coefficient.

8.3 Evaluation for determination of cultivar coefficients

In evaluation for cultivar coefficients of yield performance, the cultivar coefficients of the individual peanut lines obtained from the model calibration data are firstly validated to simulate growth and development of the same lines for the independent experiment. Model evaluation for cultivar coefficients are conducted by comparing the simulated values of development and growth characteristics of the individual peanut lines with their corresponding observed values for the independent experiment, and by obtaining the values for statistical fit observation such as the normalized root mean square error (RMSEn) and the index of agreement (d) (Willmott, 1982). The RMSEn is desired to be low. The d has values between zero to one, with one being the best fit.

9. Application of crop simulation models

The ability of crop simulation models to predict growth, development and yield as influenced by growing environmental conditions, agronomic practices and cultivar traits makes them to be an attractive tool for crop researching (White, 1998). There are three areas of application of crop simulation models in crop improvement proposed by Matthews (2002), consisting i) identification and evaluation of desirable plant characteristics, ii) environmental characterization and iii) genotype by environment interactions. Furthermore, the model can also be used in assisting in multi-environment evaluation of crop breeding cultivars (Banterng et al., 2003). Several researches that reveal the application of crop simulation models get along with the Matthews's proposed. The instances of the applications are ample such as identification and evaluation of desirable traits leading to the design of a crop ideotype for a particular environment (Boote et al., 2001), potential contributions of crop models to the crop improvement process include assisting with multi-location evaluation of crop breeding lines (Banterng et al., 2006; Suriharn et al., 2008) understanding the nature of genotype by environment interactions (Chapman et al., 2002; Phakamas et al., 2008; Putto et al., 2008), estimating the impact of climate change on agricultural production and food security (Alexandrov and Hoogenboom, 2000; Mall et al., 2004), evaluating cultivar performance (Boote et al., 2003; Banterng et al., 2006; Suriharn et al., 2008), assessing the adaptation of a new cultivar to a region (White, 1998; Chapman et al., 2002) and predicting crop yield before harvest (Nain et al., 2004; Mercau et al., 2007; Soler et al., 2007).