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Simulation of Climate Variability for Assessing Impacts on Yield and Genetic Change of Thai Soybean

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***Abstract*—**This study assessed the effects of climate change on Thai soybeans under simulation situations. Our study is focused on temperature variability and effects on growth, yield, and genetic changes in 2 generations of Chiang Mai 60 cultivars. In the experiment, soybeans were exposed to 3 levels of air temperature for 8 h day^{-1} in an open top chamber for 2 cropping periods. Air temperature levels in each treatment were controlled at 30-33°C (± 2.3) for LT-treatment, 33-36°C (± 2.4) for AT-treatment, and 36-40 °C (± 3.2) for HT-treatment, respectively. Positive effects of high temperature became obvious at the maturing stage when yield significantly increased in both cropping periods. Results in growth indicated that shoot length at the pre-maturing stage (V3-R3) was more positively affected by high temperature than at the maturing stage. However, the positive effect on growth under high temperature was not found in the 2nd cropping period. Finally, genetic changes were examined in phenotype characteristics by the AFLPs technique. The results showed that the high temperature factor clearly caused genetic change in the soybeans and showed more alteration in the 2nd cropping period.

***Keywords*—**simulation, air temperature, variability, Thai soybean, yield , genetic change

I. INTRODUCTION

CLIMATE is the primary factor for agricultural production. Agriculture is one sector which is important to consider in terms of climate change. The changes in global climate related parameters such as temperature, precipitation, soil moisture, and sea level [1] are expected to alter crop productivity due changes in climate, weather events, and patterns of pests and diseases. Many research studies have shown the impacts of climate variability on yield loss or the alteration of physiological mechanisms on cereal crops [2]. Increased air temperature is one of important climate change indicator that causes heat stress on plants. Heat stress is a serious threat to crop production worldwide. There is a strong scientific consensus (such as IPCC) that global mean surface temperatures will increase from the present by 1 °C to 3.5 °C by the year 2100 [3]. Hence, the climate change conditions due to global warming are likely to affect future global agricultural production through changes in nutrition and genetics [4] -[5].

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Soybeans [*Glycine max* (L.) Merrill] rank as one of the most important agricultural crops of the world. A recent study revealed that unfavorable environmental conditions (temperature variability, rainfall variability, and relative humidity variability) during seed growth and development in the field can reduce germination and vigor of soybean seeds [6]. Therefore, the climate change condition is likely to have a substantial impact on biomass, production, or nutritional value of soybeans in Asian countries such as Japan, India, and Thailand [5], [7].

Considerable future temperature changes in Thailand, will be high enough to cause adverse effects on soybeans. However, the possible adverse effects of temperature change on soybean production in the growing season or genetic change is not well understood in Thailand. Thus, in this study we carried out an experiment to assess the impacts of air temperature variability to understand how increased and decreased air temperature in the growing season affect growth yield and genetic change of Thai soybeans.

II. MATERIALS AND METHOD

A. Field study

The study area was a suburban area located at coordinates 16 degrees and 44.003 minutes north of the equator, and 100 degrees and 11.810 minutes east of Prime Meridian (Fig.1). The field study was carried out at the agricultural crops field in Naresuan University, Phitsanulok, Thailand. The total study area covered about 200 m^2.

B. Soybean planting and experimental design

Thai soybeans (Glycine max (L.) Merr.) Chiang Mai 60 cultivar were used in this experiment. They were planted for 2 cropping periods (2 generations) during 2009 to 2010. Three replications of a Randomized Complete Block Design (RCBD) were used in three treatments with different levels of air temperature. Soybean seeds were obtained from the Agricultural Research and Development Center in Phitsanulok, Thailand. The soybean seeds were planted with a 20 x 50 cm spacing. At the vegetative growth stage (V-satge), the soybeans in all three treatments were exposed to temperature variability for 8 hr exposure (9.00 am – 5 pm) in open top chambers until harvest. In the experiment, the 1st generation seeds were planted to yield the 2nd generation Therefore, there were 2 cropping periods under air temperature variability.

Fig. 1 Field study area in Phitsanulok, Thailand Cited from Google (2011)

C. Temperature control

The cylindrical open top chamber (internal volume = 6.3 m^2) was constructed out of transparent plastic (Fig.2). Ventilation fans were equipped on the front of the chamber to facilitate air circulation and to equilibrate the temperature difference between inside and outside of the chamber. Three levels of air temperature: ambient level (AT-treatment), lower than ambient level (LT-treatment), and higher than ambient level (HT-treatment) were set up. Water was released via an electrical control system (opening-closing) to control air temperature in the open top chamber. Mean air temperature levels (± S.D) for 8 hr for each treatment were 30-33 °C (± 2.3) for the LT-treatment, 33-36 °C (± 2.4) for the AT-treatment, and 36-40 °C (± 3.2) for the HT-treatment, respectively.

D. Growth and yield determination

During the experimental period, soybean plants were sampled to determine shoot length (height) at 7 different growth stages for the growth and reproductive stages:

Growth stage

V1(first node)

V2(second node)

V3(third node)

Reproductive stage

R1(beginning bloom)

R3(beginning pod)

R6(full seed)

R8(full maturity)

Soybean seeds were harvested and the No. of total seed/plant from the experimental field were determined at the harvest stage (95 days). The shoot length (height) of the soybean plant samples were determined for the total No. of seed/plant.

Fig. 2 Open top chamber in experiment with electrical control system

E. Genetic change

The genetic changes were examined in phenotype characteristics. Soybean leaves at the end of the V3 stage in both cropping periods were sampled and analyzed. The AFLPs technique (Amplified fragment Length Polymorphism) with 6 primers was used in the experiment.

F. Statistical analysis

The growth parameters and grain yield data were analyzed statistically with analysis of variance (ANOVA). Significant differences of parameters were reported at $p<0.05$ by DMRT.

III. Results and Discussion

A. Shoot length at different growth stages

Exposure of soybeans to different air temperature levels was carried out in an open top chamber. In the 1st cropping period, we observed that the high temperature in the HT-treatment resulted in a significant increase in shoot length at the V1, V2, V3, R1, and R3 stage. In contrast, a significant decrease in shoot length was observed in the LT-treatment (low-temperature). Further increase or decrease in air temperature variability in the growth stage did not result at the full seed stage (R6) and the full maturing stage (R8) (Fig. 3). However, we did not find any correlation between temperature levels and shoot length of soybeans for all growth stages in the 2nd cropping period (Fig.4). Fig. 5 and Fig. 6 compare the percentage of height (cm) increase at different growth stages between the HT-treatment and the LT-treatment, and the HT-treatment and the AT-treatment, respectively.

High temperature evidently induced an increase in shoot length at initial growth (by approximately 27%), especially at the V2 stage in the 1st cropping stage (by approximately 80%). While in the reproductive stages, the percentage of height (cm) increase was approximately 20% less.

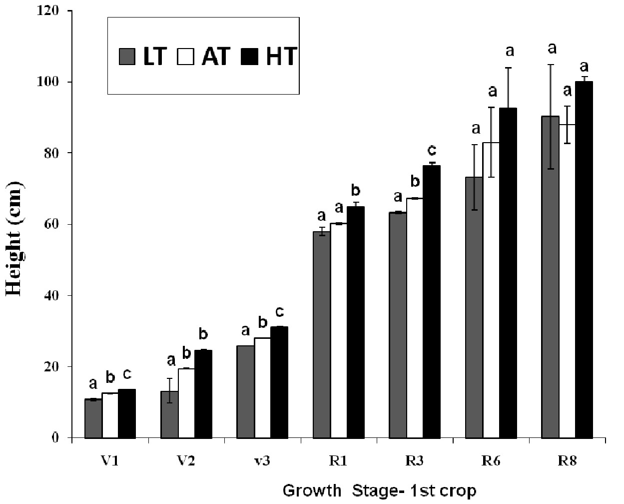

Fig. 3 Height (cm) of Thai soybeans (Chiang Mai 60 Cultivar) under 3 air temperature variability treatments at different growth stages (1st-crop)

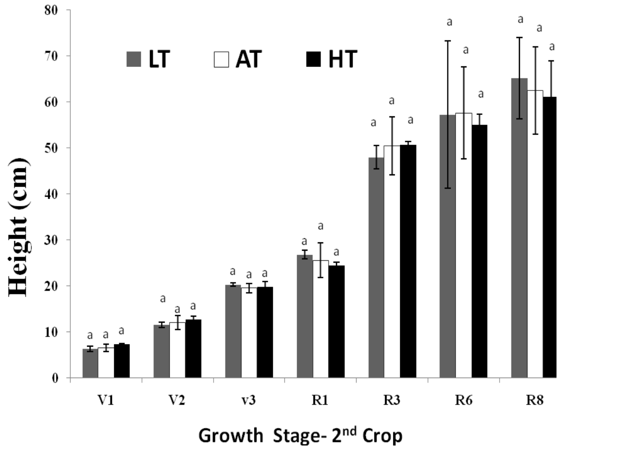

Fig. 4 Height (cm) of Thai soybeans (Chiang Mai 60 Cultivar) under 3 air temperature variability treatments at different growth stages (2nd crop)

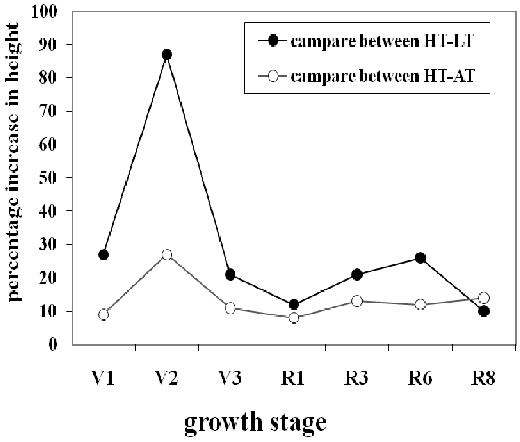

Fig. 5 Percentage of height (cm) increase at different growth stages of Thai soybeans, compared between HT-treatment and LT-treatment, and HT-treatment and AT-treatment in the 1st cropping period.

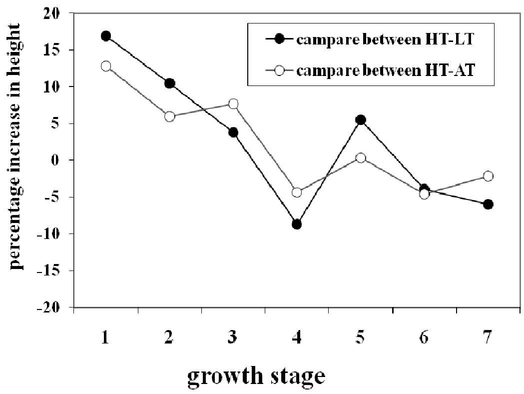

Fig. 6 Percentage of height (cm) increase at different growth stages of Thai soybeans, compared between HT-treatment and LT-treatment, and HT-treatment and AT-treatment in the 2nd cropping period.

B. Soybean yield

In the experiment, grain yields of Chiang Mai 60 cultivars in 3 treatments were examined for No.of total seed /plant at the maturity stage. The results revealed that high temperature (HT-treatment) strongly increased the No. of total seed/plant in both cropping periods (by 28.9 %and 30.62%, respectively) (Fig.7). While, exposure to low temperature did not significantly affect seed yield in soybeans in either cropping periods.

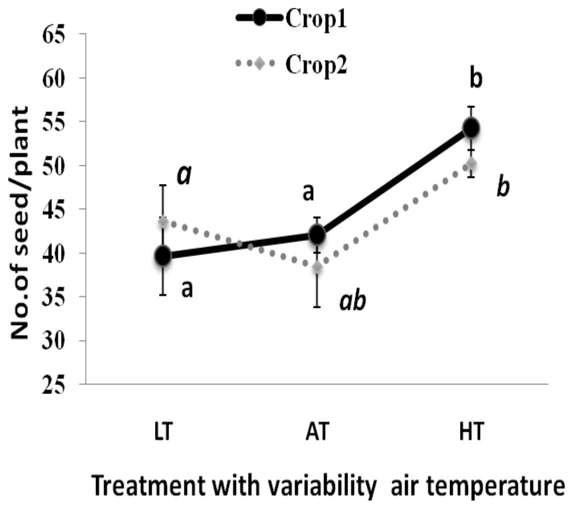

Fig. 7 No.of seed/plant of Thai soybeans (Chiang Mai 60 Cultivar)under 3 air temperature variability treatments

The grain growth of cereal crops depends on the production of carbohydreates and the translocation of assimilates from the source organs to the grains. If the source activity exceeds the sink activity (grain filling) of the grains, excess carbohydrate is stored in the stem or leaves [8]. The support of photosynthetic activity under high temperature may be one of the important mechanisms that induced a increased seed yield in Chiang Mai 60 cultivar [8]. Similar results were found in wheat [9]. High temperatures increased the rate of grain growth and promoted grain size but decreased the duration of grain filling. .

However, the results of the experiment are not consistent with some data concerning temperature stress during the crop period. Many reports suggest that temperature extremes during seed development affect soybean seed quality. Freeze injury before physiological maturity caused large reductions in germination and vigor [6]. Many seeds produced by soybean plants exposed to excessively high temperatures during seed filling are shriveled or abnormal (flattened and wrinkled with depressions in the seed coat), and the quality of these seeds is often much lower than seeds with no visible imperfections [6]. Hence, further monitoring on the effects of temperature extremes on yield and nutritional value in Thai soybean seeds is needed.

C. Phenotype characteristics

We analyzed phenotypic changes by the Amplified Fragment Length Polymorphisms (AFLPs) technique. The effects of temperature variability on phenotype characteristic changes of soybeans for 2 cropping periods are shown in Fig.8-F.g.9. Six primer sequences of DNA indicated that soybeans under 3 levels of temperature in the growing season could be categorized into 2 groups: AT treatment and the LT treatment. The results indicated that the high temperature factor clearly caused genetic changes in soybeans. Moreover, we found that the continuous high temperature exposure through 2 cropping periods caused more alteration in phenotype characteristics in the HT-treatment (Fig.9).

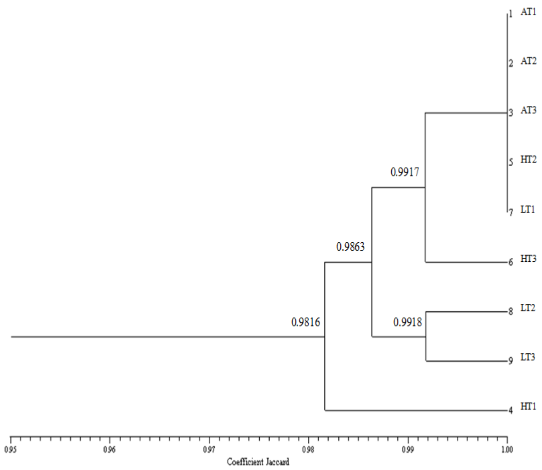

Fig. 8 Phylogenetic tree of soybeans in 3 treatments in the 1st cropping period

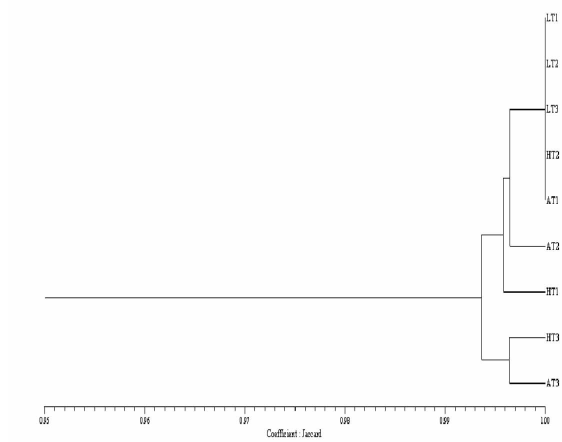

Fig. 9 Phylogenetic tree of soybeans in 3 treatments in the 2nd cropping period

The genetic change in the high temperature treatment may be caused by alterations in mechanisms, such as inhibition of protein synthesis which led to DNA changes. Direct injuries due to high temperatures include protein denaturation and aggregation, and increased fluidity of membrane lipids. Indirect or slower heat injuries include inactivation of enzymes in chloroplast and mitochondria, protein degradation, and loss of membrane integrity [10]. Heat stress also affects the organization of microtubules by splitting and/or elongation of spindles and the formation of microtubule asters in miotic cells [11]. Moreover, after exposure to high temperatures changes occur at the molecular level altering the expression of genes and accumulation of transcripts, thereby leading to the synthesis of stress related proteins as a stress-tolerance strategy [12]. These may be the reasons why the genetics were altered by the high temperature. The characteristics of responses varied according to temperature levels, growth stages, and parameters. The results suggest that the high temperature in the growing season in this experiment (36-40 °C), which could appear in future in Thailand, causes a significant alteration in physiological mechanisms and genetics of Thai soybeans.

However, more field studies to assess impacts on nutritional values need monitoring to quantitatively estimate the effects of climate variability on crop productivity in Thailand.

IV. Conclusion

The results of this study demonstrated that exposure to air temperature variability under a climate change situation (simulation) led to alteration in growth, yield, and genetics of Thai soybeans, Chiang Mai 60, cultivars. High temperature caused obvious genetic changes but induced an increase in shoot length and seed yield.

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