Simulation of climate change impact on maize growth and yield using DSSAT modeling

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Abstract. Solar radiation, temperature, and CO2 are important climate variables on crop production. Climate change is a very serious threat to the agricultural sector and potentially bring new problems for the sustainability of agricultural production systems. This paper aims to know the impact of climate change on maize growth and production by simulating changes in climate variables. The case study was at Pak Chong District, Nakhon Ratchasima province, Thailand. There are eight treatments simulation and one treatment as a control; (1) no change (control), (2) solar radiation (SR) + 30%, (3) SR – 30%, (4) CO2 + 25 ppm, (5) CO2 – 25 ppm, (6) maximum temperature + 3°C, (7) maximum temperature – 3°C, (8) minimum temperature + 3°C, (9) minimum temperature – 3°C. Simulation use Decision Support System for Agrotechnology Transfer (DSSAT) software. SR adds 30% obtained the highest yield due to the highest on grain number and pod weight. In contrast, SR - 30% reached the lowest.

1. Introduction
Global warming mainly causes climate change which influences direct agriculture as increasing the temperature, changing the rainfall rate, water-preservation and soil fertility [1]. Also, most of the climate change impact on agriculture would appear to be the tropical region of the world. Thailand is located in South East Asia with a total area of 51.36 million hectares, within the tropical belt will be most influenced [2,3]. Intergovernmental Panel on Climate Change defines climate change as “a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.” It means to any change in climate over time, whether due to natural variability or as a result of human activity [4].

Climate change is a very serious threat to the agricultural sector and potentially bring new problems for the sustainability of food production and agricultural production systems in general. Climate change is the condition of some elements of the climate that magnitude and or intensity tends to change or deviate from the dynamics and the average conditions, towards (trend) of certain (increased or decreased). Climate change occurs due to natural processes and or due to human activity is constantly changing the composition of the atmosphere and land use that causes global warming.

Climate change demands extra attention of mankind on earth. There are two keywords relate to climate change, namely (1) mitigation, and (2) the adaptation. These two words are often mentioned in writings on climate change and on the field sometimes not easily distinguished. Mitigation is the effort to reduce emissions or increase GHG emissions from various sources, in controlling or reducing the impacts of climate change. Adaptation is the ability of humans, animals, and plants or organisms to...
adapt to environmental changes, is both micro and macro, either directly or indirectly as a result of climate change, it can perform its biological function properly.

The agricultural sector is the most important sector in life as it relates to the availability of food for all inhabitants on earth. This sector contributes to global warming in an amount less than the industrial and transport sectors, but most was impacted by climate change. Precipitation, temperature, radiation, and CO₂ are climatic factors that influence crop conditions. If these factors change due to global warming will affect the growth and production of plants. Thailand is a developing country whose agricultural sector contributes to global food security.

The impact of climate change is most important to know is on food crops, because these plants are the main energy source. One crop that is used as a staple food for humans and livestock is corn. Corn contains carbohydrates, protein, and fats that are beneficial to humans and livestock. This plant can grow well and produce maximum on certain climatic conditions. If climate change, it will result in the disruption of the physiological plant so that it will affect the growth and production of plants.

Due to climate change, conditions of maize crop will change in the next years. Now the question arises how projected climatic conditions impact on wheat yield. In the past decades, many studies estimated the climate change and its impacts on agriculture on the basis of crop development simulation models. DSSAT model simulates crop growth and crop yield levels by means of different input variables (for example; soil characteristics, daily weather parameters, crop characteristics, cropping system management options) [5]. The DSSAT suit is a software application package that encompasses over 28 crop simulation models [6]. Climate change due to global warming is a reality that must be faced. The perceived impact current and future needs to be anticipated, especially in maize. Therefore it is necessary to do research on the simulation of climate change factor. This paper to address the impact of climate change on maize growth and production in Thailand.

2. Methods

2.1. Study area

Pak Chong is the westernmost district of Nakhon Ratchasima province, northeastern Thailand. Coordinates of this district are 14°42′45″N 101°25′19″E (Figure 1). The weather data were collected from the Thai Meteorological Department (TMD). There were three climate variables that were used in this paper; solar radiation, CO₂ concentration, and temperature (maximum and minimum). The period of the climate data was 1969 to 2007.

![Figure 1. Pak Chong district map [7].](image)
2.2. Data simulation

This research uses descriptive quantitative methods. Data obtained as a result of a simulation using DSSAT software. There were eight treatments simulation and one treatment as a control; (1) no change (control), (2) solar radiation (SR) + 30%, (3) SR – 30%, (4) CO$_2$ + 25 ppm, (5) CO$_2$ – 25 ppm, (6) maximum temperature + 3 °C, (7) maximum temperature – 3 °C, (8) minimum temperature + 3 °C, (9) minimum temperature – 3 °C. Observed parameters in this research were root weight (kg/ha), anthesis day and physiological maturity day (dap), grow degree days, pod weight (kg/ha), grain number (#/m$^2$) and yield (kg/ha). There were 21 steps to obtain simulation data using DSSAT modeling:

1. Click crop management data, then open new file and save it as our project
2. Click simulation options to adjust the treatments that we want to know
3. Open the main view, then select seeral crops on the crops menu and choose maize
4. Select the file that we already safe
5. Click run menu and choose sensitivity options
6. Click run model
7. Select weather on the sensitivity analysis and then enter
8. Select weather modification and then enter
9. Select weather variable that we want to know and then enter
10. Select modification option and then enter the amount
11. Click 0 to return back
12. Enter the name of the result of run model
13. Click enter until obtaining the result of simulation
14. Click yes to run more simulation and repeat step 7 to 13
15. Click no to close the run model
16. Click analysis menu to obtain the result data running
17. Click overview to view all of the results
18. Click summary to see the summarize
19. Click plant growth output and then click plot
20. Click the variables that we want to know and click runs menu and then click next
21. Export the data to excel and save it

3. Results and Discussion

3.1. Results

3.1.1. Root weight

![Figure 2. The effect of solar radiation treatments to root weight.](image-url)
Figure 3. The effect of CO₂ treatments to root weight.

Figure 4. The effect of maximum temperature treatments to root weight.

Figure 5. The effect of minimum temperature treatments to root weight.
Based on Figure 2-5, solar radiation treatments are the treatments that effect more significant than the others. Solar radiation subtracts 30% treatment has root weight lowest than control and the others. Solar radiation adds 30% is the highest level of root weight. One of the factors influences the development of plant organ is photosynthesis. Glucose as a result of photosynthesis transfer to all of the plant organs; leaf, stem, and root. Therefore, it is clear that solar radiation adds 30% treatment produce the highest root weight and solar radiation subtract 30% treatment result in the lowest root weight.

3.1.2. Anthesis day and physiological maturity day (dap)

The Figure 6 illustrates the effect of treatments on anthesis day and physiological maturity day. It is clear that temperature is the key role of age plants. If the temperature add 3 °C (maximum or minimum), the anthesis day will shorter, thus the physiological maturity day will adjust. Otherwise, if the temperature subtract 3 °C (maximum or minimum), the anthesis day will longer, therefore the physiological maturity day will adjust. Therefore the crops age in the high altitude will longer than in low altitude.

3.1.3. Grow Degree Days. The Figure 7 presents the growing degree days on maize in different temperature treatments. The Growing Degree Day, or GDD, is a heat index that can be used to predict when a crop will reach maturity. Each day’s GDD is calculated by subtracting a reference temperature, which varies with plant species, from the daily mean temperature (we ignore values less than zero). The total GDDs over a growing season is related to plant development. The development of plants depends on the accumulation of heat. Since cool-season plants have a lower reference temperature, they accumulate GDDs faster than warm-season plants. The reference temperature for a given plant is the temperature below which its development slows or stops.
3.1.4. Pod weight, Grain number, and Yield

Table 1. Estimation maize yield in different treatment.

| Treatment          | Pod weight (kg/ha) | Grain number (#/m²) | Yield (Kg/ha) |
|--------------------|--------------------|---------------------|---------------|
| No_change          | 15532              | 3821                | 11298         |
| SR_add30           | 20584              | 5056                | 14989         |
| SR_subtract30      | 10127              | 2579                | 7342          |
| CO2_add25          | 15638              | 3847                | 11373         |
| CO2_subtract25     | 15384              | 3760                | 11117         |
| Maxtemp_add3       | 15087              | 4173                | 10515         |
| Maxtemp_subtract3  | 13546              | 3073                | 10066         |
| Mintemp_add3       | 14618              | 4149                | 10123         |
| Mintemp_subtract3  | 13487              | 3076                | 10076         |

The Table 1 shows the pod weight, grain number, and yield of the maize per ha in different treatments. There are two treatments that the yield higher than control, solar radiation add 30% and CO2 add 25 ppm. Moreover, the other treatments lower than control. The highest yield was gained at solar radiation add 30% treatments and the lowest at solar radiation subtract 30%. It is clear that the combination of pod weight and grain number affect yield, higher pod weight and grain number will produce high yield.

3.2. Discussion

According to the results of observation, all of the treatments influence plant growth and production. In general, solar radiation add 30% treatments are the best treatments because it obtained the highest production. It due to the grain number and pod weight are the highest. In contrast, the lowest production obtained solar radiation subtract 30%. It means solar radiation treatments affect more significant than CO2 and temperature treatments. Researcher stated one of the most important factors that influences plants development is the solar radiation intercepted by the crop [8]. The solar radiation brings energy to the metabolic process of the plants. The principal process is the photosynthetic assimilation that makes...
synthesize vegetal components from water, CO2 and the light energy possible. A part of this, energy is used in the evaporation process inside the different organs of the plants, and also in the transpiration through the stomas.

One of the organs that effected by solar radiation is root weight (Figures 2, 3, 4 and 5). The productivity of a crop depends on the ability of plant cover to intercept the incident radiation, which is a function of leaf area available, the architecture of vegetation cover and conversion efficiency of the energy captured by the plant into biomass. Most production strategies are directed towards maximizing the interception of solar radiation. In the case of crops, this implies adapting agricultural practices in such a way as to obtain complete canopy cover as soon as possible. Deficiencies in water and nutrient inputs may reduce the rate of leaf growth, reducing yield below optimum levels due to insufficient energy capture [9].

The second treatment that affects obviously to the production is CO2 treatments, whereas the CO2 add 25 ppm treatment produce more yield than control and CO2 subtract 25 ppm result in lower yield than no change. One of the most consistent effects of elevated atmospheric CO2 on plants is an increase in the rate of photosynthetic carbon fixation by leaves. Across a range of FACE experiments, with a variety of plant species, the growth of plants at elevated CO2 concentrations of 475–600 ppm increases leaf photosynthetic rates by an average of 40% [10]. Carbon dioxide concentrations are also important in regulating the openness of stomata, pores through which plants exchange gasses, with the external environment. Open stomata allow CO2 to diffuse into leaves for photosynthesis, but also provide a pathway for water to diffuse out of leaves. Plants therefore regulate the degree of stomatal opening (related to a measure known as stomatal conductance) as a compromise between the goals of maintaining high rates of photosynthesis and low rates of water loss. As CO2 concentrations increase, plants can maintain high photosynthetic rates with relatively low stomatal conductance. Across a variety of FACE experiments, growth under elevated CO2 decreases the stomatal conductance of water by an average of 22% [10]. This would be expected to decrease overall plant water use, although the magnitude of the overall effect of CO2 will depend on how it affects other determinants of plant water use, such as plant size, morphology, and leaf temperature. Overall, FACE experiments show decreases in whole plant water use of 5–20% under elevated CO2. This in turn can have consequences for the hydrological cycle of entire ecosystems, with soil moisture levels and runoff both increasing under elevated CO2 [11].

The last treatments are manipulation maximum and minimum temperature. All of these treatments result in yield below control, it means control temperature is optimum to plant growth and production. Adding and subtracting the temperature affect the yield decrease. These treatments affect significantly to anthesis day and physiological maturity day. Responses to temperature differ among crop species through-out their life cycle and are primarily the phenological responses, i.e., stages of plant development. For each species, a defined range of maximum and minimum temperatures form the boundaries of observable growth. Vegetative development (node and leaf appearance rate) increases as temperatures rise to the species optimum level. For most plant species, vegetative development usually has a higher optimum temperature than for reproductive development. Simulating maize using DSSAT in Bako and Melkassa explains that rainfall variability and rising temperatures are determining factors explaining yield decrease in Bako and Melkassa [12].

Different components of yield and yield severely decreased due to increase in temperature [13]. The effect of temperature extremes on plant growth and development has not been extensively studied with the major effect during the pollination phase [14]. Exposure of plants to temperature extremes at the onset of the reproductive stage has a major impact on fruit or grain production across all species. One potential strategy to minimize this impact is to select varieties which shed their pollen in the early morning when temperatures are cooler [15]. The synthesis on heat shock from high temperatures demonstrates the need to increase our understanding of the impact of temperatures above the threshold on the ability of the plant to set grain and also change the duration of the grain-filling period. The expectation of greater occurrences of temperature extremes will continue to have increasingly negative impacts on plant production [16].
4. Conclusion
Based on the results and discussion, it can conclude as follow:

a. Maize growth and production response the treatments differentially.

b. Solar radiation add 30% treatments are the best treatments because it obtained the highest production. It due to the grain number and pod weight are the highest. In contrast, the lowest production obtained solar radiation subtract 30%. It means solar radiation treatments affect more significant than CO2 and temperature treatments.

c. CO2 treatment affects obviously to the production, where the CO2 add 25 ppm treatment produce more yield than control and CO2 subtract 25 ppm result in lower yield than no change.

d. Manipulation maximum and minimum temperature result in yield below control, it means control temperature is optimum to plant growth and production. Adding and subtracting the temperature affect the yield decrease. These treatments affect significantly to anthesis day and physiological maturity day.

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