Effect of weather and soil characteristics on rice production using DSSAT modeling: Case study in Thailand

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Abstract. Weather and soil are abiotic factors which have a huge effect on rice production. Precipitation, solar radiation and temperature are the kinds of weather in which significantly affect crops. Meanwhile, soil characteristics have an important role in plant growth and production. Combination of appropriate weather and fertile soil would result in high yield. That combination can be simulated using the Decision Support System for Agrotechnology Transfer (DSSAT). This research used a case study in Thailand, a developing country which is one of the largest rice producing countries. There were four treatments simulation in this research; (1) combination soil characteristic in Sing Buri with DTSP station weather, (2) combination soil characteristic in Sing Buri with PCNM station weather, (3) combination soil characteristic in Tha Tum with DTSP station weather and (4) combination soil characteristic in Tha Tum with PCNM station weather. The combination Sing Buri and DTSP obtained the highest yield and Tha Tum and PCNM reached the lowest yield. It was due to soil fertility in Sing Buri better than Tha Tum, it can be seen from texture, pH, C and CEC (cation exchange capacity) which was more suitable for rice.

1. Introduction

Environment conditions are one of the main factors that influence crops growth and production. Environment refers to the sum total of all the external forces or factors, both biotic and abiotic, that affects the physiological behaviour or performance of an organism or a group of organisms. The biotic environment is the living things that include plants, animals, and bacteria. Furthermore, the abiotic environment is the non-living things that include temperature, water, atmospheric gases, and soil. Two things in the abiotic factor which has a huge impact on plant cultivation are weather and soil.

Precipitation, solar radiation and temperature are the kinds of weather in which significantly affect to crops from germination until post-harvest. Rainfall related to water availability for agriculture area, as we knows that water is absolute factor to plant growth. Plants require solar radiation mainly in the photosynthesis process. Every plant obtains the intensity, quality and duration of solar radiation in a different amount, it depends on the geographic location. In addition, crops also need a specific temperature in the biological mechanism. In different temperature, crop in the same variety will perform in different growth and production.

There are several types in the world, every region has different type depend on parent material and environments. Three main soil characteristics create soil variance; physic, chemist and biology. Texture, structure, depth of soil are the example of soil physic characteristic. It has important role for the plant growth, for instance; soil texture affect root capability to penetrate in soil layer. While, soil chemical characteristic relate to nutrients availability, such as; cation exchange capacity, nitrogen content and
pH. The main function of soil chemical is to provide nutrients for the plant, thus farmer know the amount of fertilizer added to obtain optimum yield. The last characteristic of soil biology plays a role un directly for the plants. Soil microorganism in the soil help in organic decomposition and degradation.

Every area has specific weather and soil type, it will impact on plant growth and production. Interaction between weather and soil type produce a suitable location to gain optimum yield. To examine the effect of those interactions DSSAT programs can be used. 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) [1]. The DSSAT suite is a software application package that encompasses over 28 crop simulation models [2]. Analysis in DSSAT can predict the result from combine treatments between weather and soil type in the same and different region. This research compares two rice areas production in Thailand, Sing Buri and Tha Tum province.

2. Materials and Method
This research uses descriptive quantitative methods. This paper was created at March 2017, which the climate data was taken from 1969 to 2007. Weather data was acquired from DTSP and PCNM station. There are four parameter that include in this research, solar radiation, maximum temperature, minimum temperature and rainfall. Soils data was obtained from Land Development Department (LDD). The number of soil layer Sing Buri different with Tha Tum, it depend on soil depth. Sing Buri has five horizon and Tha Tum has 6 horizon. Soil characteristics data which was included to simulate the programs are soil texture (% clay, % silt, % sand), pH, Nitrogen, Cation exchange capacity (CEC) and C organic percentage. Combination soils and weather data were simualte as the treatments to simulate in DSSAT software. There were four treatments simulation in this research;
1. Combination soil characteristic in Sing Buri with DTSP station weather
2. Combination soil characteristic in Sing Buri with PCNM station weather
3. Combination soil characteristic in Tha Tum with DTSP station weather
4. Combination soil characteristic in Tha Tum with PCNM station weather

The variables that observe as indicator of impact treatments in this research are leaf area index (LAI), tiller number, root depth (m), root weight (kg/ha), grain number (#/m²), grain weight (kg/ha), time harvesting, and yield (kg/ha).

There are several steps to gain simulation data using DSSAT models :
1. Soil Data
   a. Input Sing Buri soil characteristic and save it
   b. Input Tha Tum soil characteristic and save it
2. Weather Data
   a. Input PCNM station weather data and save it
   b. Input DTSP station weather data and save it
3. Crops analysis
   a. Run simulation with selected experimental site in Thailand by using soil files of Sing Buri and match with template weather files of DTSP8502.WTH
   b. Run simulation with selected experimental site in Thailand by using soil files of Sing Buri and match with template weather files of PCNM9001.WTH
   c. Run simulation with selected experimental site in Thailand by using soil files of Tha Tum and match with template weather files of DTSP8502.WTH
   d. Run simulation with selected experimental site in Thailand by using soil files of Tha Tum and match with template weather files of PCNM9001.WTH
4. Export the result of simulation data to excel
3. Results and Discussion

3.1. Results

3.1.1 Soil characteristics

Table 1. Soil Characteristics in Sing Buri

| Depth | Texture   | pH | C (%) | N (%) | CEC  |
|-------|-----------|----|-------|-------|------|
| 0 - 20| Sand : 1.1 | 5  | 2.22  | 0.2   | 32.2 |
|       | Silt : 19.3|     |       |       |      |
|       | Clay : 79.6|     |       |       |      |
| 20 - 56| Clay : 5.8 | 5.8| 0.77  | 0.13  | 31.5 |
| 56 - 110| Clay : 5.8 | 5.8| 0.59  | 0.14  | 31.5 |
| 110 - 130| Clay : 5.3 | 5.3| 0.56  | 0.1   | 34.3 |
| 135 - 160+| Clay : 4.9 | 4.9| 0.36  | 0.06  | 37.6 |

Table 2. Soil Characteristics in Tha Tum

| Depth | Texture   | pH | C (%) | N (%) | CEC  |
|-------|-----------|----|-------|-------|------|
| 0 - 11| Silt loam : 43.6 | 4.6| 0.67  | 3.2   |
| 11-23 | Loam : 33.8  | 5  | 0.48  | 5.9   |
| 23 - 55| Clay : 15.2 | 4.7| 0.35  | 18.9  |
| 55 - 87| Clay : 23.3 | 4.8| 0.24  | 15.9  |
| 87 - 148| Clay loam: 40.7| 4.5| 0.07  | 10.9  |
| 148 - 180| Sand : 91.5 | 4.8| 0.01  | 3.8   |

3.1.2 Leaf area index

The result of simulation using DSSAT tools on leaf area index (LAI) is presented at the below graph.

Figure 1 shows that the impact of treatments for leaf area index in which the value of DTSP8502 station weather higher than PCNM9001 in both soil type. The higher leaf area index was gained by Sing Buri DTSP and the lowest at Tha Tum PCNM. Leaf area index at vegetative growth and decrease at generative stage.
3.1.3 Number of tiller

Figure 2 describes the impact of treatments for number of tiller. The pattern of the results similar with leaf area index in which the value of DTSP8502 station weather higher than PCNM9001 in both soil type. The highest number of tiller was obtained Sing Buri DTSP and the lowest at Tha Tum PCNM. At the vegetative stage, number of tiller reach a peak and decline to slow down after generative growth.
3.1.4 Root depth

The graph above presents the impact of treatments for root depth (m). The figure clearly shows that the depth root was influenced by soil type. Tha tum soil characteristic reaches approximately 1.8 m in both weather station. However, in the Sing Buri soil type, root depth gain 1.6 m from the soil surface.

3.1.5 Root weight

Figure 3. Simulated graph the impact of treatments for root depth (m)

Figure 4. Simulated graph the impact of treatments for root weight (kg/ha)
The result of the impact of treatments for root weight (kg/ha) obviously different from root depth (m). Based on that figure, it can be seen that the highest root weight at Sing Buri DTSP treatment and the lowest root weight at Tha Tum PCNM.

3.1.6 Grain number

The graph above illustrates the impact of treatments for the number of grain (#/m²). The figure clearly shows that the number of grain was influenced mainly by soil type, whereas in the same weather station, Sing Buri has higher number of tiller than Tha Tum. Weather also affects the result of grain number but was not dominant as soil type, weather in DTSP station influence in that variable more than PCNM.

3.1.7 Grain weight

The graph above illustrates the impact of treatments for grain weight (mg). The figure clearly shows that the number of grain was influenced mainly by soil type, whereas in the same weather station, Sing Buri has higher number of tiller than Tha Tum. Weather also affects the result of grain number but was not dominant as soil type, weather in DTSP station influence in that variable more than PCNM.
Impact of treatments for grain weight totally different from grain number. According to the figure, it can be seen that in the same weather station areas, Tha Tum soil type affect more grain weight than Sing Buri. In addition, in the same soil type, PCNM weather influence higher than DTSP weather. The highest treatments were reached by Sing Buri_PCNM and the lowest at Sing Buri DTSP.

3.1.8 Time harvesting and yield

| Treatments            | Time harvesting (days after planting) | Yields (kg/ha) |
|-----------------------|---------------------------------------|---------------|
| SINGBURI_DTSP         | 90                                    | 3136          |
| SINGBURI_PCNM         | 102                                   | 2340          |
| THATUM_DTSP           | 90                                    | 2224          |
| THATUM_PCNM           | 103                                   | 1642          |

Table 3 describes the impact the treatments for time harvesting and yields. It is clear that whether in DTSP station affect time harvesting shorter than the weather in PCNM station. Overall Sing Buri soil types reach higher in the production than in Tha Tu. Moreover, combination Sing Buri soil type and DTSP weather station obtain the highest yield and the lowest at ThaTum_PCNM.

3.2 Discussion

In general, the production of rice mainly is influenced by the characteristics of the soil. Table 3 shows that Sing Buri obtain more yields than Tha Tum. It is due to soil fertility in Sing Buri better than Tha Tum, it can be seen from table 1 and 2. Texture, pH, C organic and CEC (cation exchange capacity) are the key to soil fertility. They are important to result in nutrients availability for the rice.

Based on table 1 and 2, soil texture in Sing Buri dominant clay and varies in Tha Tum. Soil texture is an important soil characteristic that drives crop production and field management [3]. The textural class of soil is determined by the percentage of sand, silt, and clay. Soil texture determines the rate at which water drains through a saturated soil; water moves more freely through sandy soils than it does through clayey soils. Once field capacity is reached, soil texture also influences how much water is available to the plant; clay soils have a greater water holding capacity than sandy soils. In addition, well-drained soils typically have good soil aeration meaning that the soil contains air that is similar to atmospheric air, which is conducive to healthy root growth, and thus a healthy crop.

Soil pH between Sing Buri and Tha Tum are different. Sing Buri pH higher than Tha Tum. The influence of soil pH on nutrients availability is described in figure 7. Plant nutrient availability is strongly tied to the activity of H+, or pH in the soil solution. Decreasing soil pH directly increases the solubility of Mn, Zn, Cu, and Fe. At pH values less than approximately 5.5, toxic levels of Mn, Zn or Al (a non-nutrient element common in soils) may be released. The availability of N, K, Ca, Mg and S tend to decrease with decreasing pH since conditions which acidify the soil such as weathering and plant uptake also result in the removal of these nutrients or in decreased microbial activity. The effects on P and B are primarily indirect as well since the availability of these nutrients depends on the formation of less soluble compounds with Al, Fe, Mn and Ca, which are affected by pH. As a result, P and B availability decrease at both very low and very high pH, with maximum availability in the range of pH 5.5 to 7.0. These reactions bind P much more strongly than B, with the result that available B can be readily leached from soils. These reactions are discussed more fully in the sections dealing with individual nutrients [4].
One of the main essential elements in the soil is C if the C content in soil high it means soil fertility also high. Plants obtain nutrients from two natural sources: organic matter and minerals. C soil content dominant come from organic matter. Organic matter includes any plant or animal material that returns to the soil and goes through the decomposition process. In addition to providing nutrients and habitat to organisms living in the soil, organic matter also binds soil particles into aggregates and improves the water holding capacity of the soil. Most soils contain 2–10 percent organic matter. However, even in small amounts, organic matter is very important. Plant productivity is linked closely to organic matter [5]. Consequently, landscapes with variable organic matter usually show variations in productivity. Plants growing in well-aerated soils are less stressed by drought or excess water. In soils with less compaction, plant roots can penetrate and flourish more readily. High organic matter increases productivity and, in turn, high productivity increases organic matter. According to table 2 and 3, it is clear that C soil content in Sing Buri higher than Tha Tum. The result of previous experiment revealed the highest yield observed in CA maize–cowpea rotation plots could be attributed to a combined effect of multiple factors including reduced pest and weed infestations, improved water use efficiency, good soil quality (higher SOC) and greater biological activity[6, 7, 8].

The CEC affects the way a soil should be managed for crop production and environmental protection. For example, a soil with a low CEC (less than 5 meq/100g) generally has a low clay and organic matter content, has a low water-holding capacity, requires more frequent lime and fertilizer additions, and is subject to leaching of NO3, B, NH4, K and perhaps Mg. Such soils will have lower yield potential than soils with higher CEC under the same level of management, but high productivity can be maintained by intensive management. These soils will usually be easier to cultivate than soils with higher CEC since they drain more rapidly, and added nutrients are highly available for plant uptake. Soils with CEC greater than 20 may have high clay content, moderate to high organic matter content, high water holding capacity, less frequent need for lime and fertilizers (except N), and low leaching potential for cationic nutrients. On the other hand, their physical properties may make it difficult for a farmer to cultivate, irrigate or maintain good aeration. Such soils are also more prone to K fixation unless soil K levels are inherently high [4] (Hodges, S. C, 2009).

The second factor that was used as a treatment in this research is the weather. There are two weather to compare; DTSP and PCNM. The parameter of weather observed in this research are solar radiation, maximum temperature, minimum temperature and rainfall. Based on table 1, weather affects mainly in time harvesting, DTSP harvesting shorter than PCNM. It is due to solar radiation and temperature. It affects photosynthesis to the plant, higher in solar radiation and temperature impact the mature of plants faster than low solar radiation and temperature [9]. Campilo et al stated one of the most important factors that influences plants development is the solar radiation intercepted by the crop [10]. 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.

Figure 7. The influence of Soil pH on Nutrient Availability
It also affects to the production which is the yields of DTSP weather higher than PCNM in the same soil type.

### Table 4. Average value weather parameter

| Parameter                  | Weather station |
|----------------------------|-----------------|
|                            | DTSP | PCNM |
| Solar radiation            | 16.13 | 12.95 |
| Maximum temperature (°C)   | 32.2  | 31.97 |
| Minimum temperature (°C)   | 23.35 | 20.67 |
| Rain (mm/day)              | 2.45  | 2.83  |

### 4. Conclusion

According to the above discussion, it is clear the reasons why the combination Sing Buri and DTSP obtain the highest yield and the combination Tha Tum and PCNM reach the lowest yield. Combination of higher soil fertility and well weather will support in plant growth and obtain high production. It is suggested to do the next research to validate the simulation model.

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