Using DSSAT model to simulate water management practices on soybean under different soil types

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Abstract. Water management plays a crucial role in optimizing plant growth and production. The amount of water supplied and the timing of its application are the keys of irrigation management. The right irrigation system will result in optimal crop production and high water use efficiency (WUE). Modeling in DSSAT (Decision Support System for Agrotechnology Transfer) software can simulate the effect of water management on various types of plants. The study in this paper aims to find out the effect of water management systems on soybean in two types of soil with simulation. This study conducted descriptive quantitative methods. Combination between all irrigated systems and Tha tum type soil (AITT000001) obtained the highest yield due to soil texture, loam better than sand on water holding capacity. The highest WUE was reached the automatically irrigation system, both in the Tha Tum and IBSB910015 soil type. It means automatically irrigation system more precise than others.

1. Introduction

Water plays a key role in the crops cultivation, from germination to harvesting. It has several functions to the plant. Water is a basic requirement for all plants is also the main constituent material of the cell protoplasm. In addition, water is a major component in the process of photosynthesis, transporting assimilation the results of this process to the part of the plant is only possible through the movement of water in plants. The role of the above, the amount of water usage by the plant will be correlated positively with the production biomass plants, only a fraction of the water is absorbed will evaporate through the stomata or the process of transpiration.

Good irrigation practices lead to higher yields and incomes for producers, but also increase the demand for water [1]. Water in the plants ranged from 80-90 percent of the dry weight of the plant, this percentage would be even greater in parts of plants that are actively growing. Water absorption by this root is strongly influenced by the state of the environment: water available in the soil, soil temperature, soil aeration, and soil solution concentration. Water deficit would disrupt the chemical balance and in plant photosynthesis resulting in reduced returns or all physiological processes run is not normal. If this situation goes on, the result of which is shown, for example, plant stunting, wilting, low production, quality goes down, etc.

In a community that faces the affects of drought, proper irrigation is extremely important. Irrigation is the artificial application of water to the soil, in the correct amounts and frequency, for optimal soil infiltration and plant growth. To be effective soil type (sand, silt, clay), vegetation, size of the area to be irrigated, water pressure, and local conditions should be considered.
Irrigated agriculture is very important for securing food production for an increasing population over the next decades. Given scarcity of water resources, optimal irrigation management is needed to reduce water while realizing maximal crop productivity [2].

The decision support system for agrotechnology transfer (DSSAT) has been in use for the last 15 years by researchers worldwide. This package incorporates models of 16 different crops with software that facilitates the evaluation and application of the crop models for different purposes [3]. 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) [4]. Two previous papers explain result of (1) climate change simulation on maize [5], (2) interaction weather and soil characteristics on rice use DSSAT model [6]. The study in this paper aims to find out the effect of water management systems on soybean in two types of soil using DSSAT model simulation.

2. Methods
2.1. Soil types
Two types of soil were evaluated in this research, IBSB910015 and Tha tum series. Characteristics data derived from DSSAT soil database and the data were shown in Tables 1 and 2. Texture, bulk density, pH and C organic looks different in those soil.

Table 1. The characteristics of soil type IBSB910015

| Soil Depth (cm) | Texture | Bulk Density (g/cm³) | pH  | NO₃ (ugN/g) | NH₄ (ugN/g) | C-Organic (%) |
|----------------|---------|----------------------|-----|-------------|-------------|---------------|
| 0- 5           | Sand    | 1.36                 | 5.3 | 1.5         | 0.6         | 0.9           |
| 5- 15          | Sand    | 1.4                  | 5.4 | 1.5         | 0.6         | 0.69          |
| 15- 30         | Sand    | 1.46                 | 5.7 | 1.5         | 0.6         | 0.28          |
| 30- 45         | Sand    | 1.46                 | 5.8 | 1.5         | 0.6         | 0.2           |
| 45- 60         | Sand    | 1.47                 | 5.8 | 1.5         | 0.6         | 0.2           |
| 60- 90         | Sand    | 1.43                 | 5.9 | 0.6         | 0.6         | 0.09          |
| 90-120         | Sand    | 1.48                 | 5.9 | 0.5         | 0.6         | 0.03          |
| 120-150        | Sand    | 1.57                 | 5.9 | 0.5         | 0.6         | 0.03          |
| 150-180        | Sand    | 1.79                 | 5.9 | 0.5         | 0.6         | 0.03          |

Table 2. The characteristics of soil type Tha tum

| Soil Depth (cm) | Texture | Bulk Density (g/cm³) | pH  | NO₃ (ugN/g) | NH₄ (ugN/g) | C-Organic (%) |
|----------------|---------|----------------------|-----|-------------|-------------|---------------|
| 0- 5           | Loam    | 1.24                 | 4.6 | 1.5         | 0.6         | 0.67          |
| 5- 15          | Loam    | 1.29                 | 4.76| 1.5         | 0.6         | 0.59          |
| 15- 23         | Loam    | 1.37                 | 5   | 1.5         | 0.6         | 0.48          |
| 23- 34         | Loam    | 1.33                 | 4.7 | 1.5         | 0.6         | 0.35          |
| 34- 44         | Loam    | 1.33                 | 4.7 | 1.5         | 0.6         | 0.35          |
| 44- 55         | Loam    | 1.33                 | 4.7 | 1.5         | 0.6         | 0.35          |
| 55- 66         | Loam    | 1.37                 | 4.8 | 1.01        | 0.6         | 0.24          |
| 66- 76         | Loam    | 1.37                 | 4.8 | 0.6         | 0.6         | 0.24          |
| 76- 87         | Loam    | 1.37                 | 4.8 | 0.6         | 0.6         | 0.24          |
2.2. Simulation steps

This study conducted descriptive quantitative methods. Data were obtained as a result of simulation using DSSAT software. There are three running simulations in this research:

1. Run no 1: select the soybean experiment file UFGA8401.SBX in Gainsville, USA. In which soil file IBSB910015, texture: Milhopper Fine Sand and weather file UFGA 1984 with variety BRAGG in Florence, SC, USA. Create one more treatment with no irrigation application.

2. Run no 2: changes the treatment as follows;
   a. Treatment 1: Decrease time of applications and amount of irrigation from 18 times to 14 times by deleting the 6th application to 9th application.
   b. Treatment 2: Change to automatically irrigation with fixed amount 15 mm and fix the depth of management at 20 cm.
   c. Treatment 3: Change to automatically irrigation with fixed amount 15 mm and fix the depth of management at 40 cm.

3. Run no 3: Run the same treatments from action 3 but change the soil type by using your created soil file: Tha Tum series.

Based on the output file, calculate water use efficiency and interpret critical soil water content which may affect to the growth and yield.

The variable observed in this study is yield (kg/ha), age of crops (days after planting), biomass (kg/ha), evapotranspiration (mm), water use efficiency, water stress, soil depth (cm), texture, bulk density (g/cm$^3$), pH, NO$_3$ (ugN/g), NH$_4$ (ugN/g) and C organic (%).

2.3. WUE calculation

WUE-Yield, calculated as the ratio of harvested biomass to cumulative ET (Evapotranspiration) [7]. The equation to calculate water use efficiency as follow:

\[
\text{Water use efficiency} = \frac{\text{Yield}}{\text{ET}}
\]

However, the denomination in evapotranspiration is mm, thus it has to convert to kg/ha by:

\[
1 \text{ ha} = 10,000 \text{ sqm} \\
1 \text{ mm} = 0.001 \text{ m} \\
1 \text{ ha} = 0.001 \times 10000 \text{ m}^3 \\
= 10 \text{ m}^3 \\
1 \text{ m}^3 \text{ of water} = 1000 \text{ kg} \\
\text{So water 1 mm} = 10,000 \text{ kg/ha}
\]

The results of calculation water use efficiency was presented in Table 4.
3. Results and discussion

3.1. Effect treatments to Soybean yield

![Figure 1](image-url) The yield of soybean in different treatments.

The graph above presents the yield of soybean in different treatments. The combination of all irrigated systems and Tha tum type soil (AITT000001) obtained the highest yield. However, in the same soil type IBSB910015, the main factor affect the value of yield is irrigated treatments. It is clear that the rainfed irrigated system acquire the lowest yield and the irrigated 15 mm 40 cm system obtained the highest value.

According to the above graphs, the main factor determines value of yield is soil type. The characteristics of the soil in the study area are presented in Tables 1 and 2. Texture is the characteristics of soil which it’s influence water availability thus it affects the yield of the crop. Soil moisture was positively and significantly correlated to SOM and soil texture [8]. There are three main components of soil texture ; sand, loam, and clay. It has a different character. Sand has a low capability to hold water, water can easily evaporate and runoff. Loam and clay can hold the water, and clay better than loam. This character is called as water holding capacity. The best soil type is high water holding capacity, thus water difficult to evaporate and runoff. Based on that texture feature, hence the yield in the Tha tum higher than in IBSB910015.

In another word, water holding capacity refers to the amount of water held between field capacity and wilting point. It is useful information for irrigation scheduling, crop selection, groundwater contamination considerations, estimating runoff, and determining when plants will become stressed. Water holding capacity varies by soil texture. According to USDA, medium textured soils (fine sandy loam, silt loam, and silty clay loam) have the highest water holding capacity, while coarse soils (sand, loamy sand, and sandy loam) have the lowest water holding capacity [9]. Medium textured soils with a blend of silt, clay, and sand particles and good aggregation provide a large number of pores that hold water against gravity. Coarse soils are dominated by sand and have very little silt and clay. Because of this, there is little aggregation and few small pores that will hold water against gravity. Fine textured clayey soils have a lot of small pores that hold much water against gravity. Water is held very tightly in the small pores making it difficult for plants to absorb it.

The second factor that affects the yield is irrigated systems. This represents the amount of water gives to the crops. It can be seen from the Table 3 that the amount of water irrigates to soybean. Rain-fed irrigated systems mean the water comes from only the rain, there is no addition by a human.
Therefore, rain-fed irrigated systems obtain the lowest yield value. Moreover, traditional systems gain a lower yield than automatic systems.

| Treatments                        | Rainfall (mm) | Irrigated (mm) |
|-----------------------------------|---------------|----------------|
| Irrigated 1 IBSB910015            | 380.4         | 403            |
| Irrigated 2 IBSB910015            | 380.4         | 259            |
| Rain fed IBSB910015               | 380.4         | 0              |
| Irrigated 14 times IBSB910015     | 380.4         | 333            |
| Irrigated 15 mm 20 cm IBSB910015  | 380.4         | 240            |
| Irrigated 15 mm 40 cm IBSB910015  | 380.4         | 333            |
| Irrigated 14 times AITT0000001    | 380.4         | 210            |
| Irrigated 15 mm 20 cm AITT000001  | 380.4         | 255            |
| Irrigated 15 mm 40 cm AITT000001  | 380.4         | 255            |

Based on the table above, in the same soil type of IBSB910015, the factor determine the yield is the amount of water and irrigation systems. Irrigation systems automatically obtain the yield better than manual system, even the amount of water is less than manually. The concept of automation irrigation is proper irrigation. It can be affect to increase productivity and minimizing environmental impacts caused by excess applied water and subsequent agrichemical leaching.

### 3.2. Water Use Efficiency

The water productivity concept emerged from different fields. In irrigation systems, the term water use efficiency has been used to measure the effectiveness of delivered water to crops and the amount of wasted water through this delivery process. The term water use efficiency is based on the assumption that a plant with high water use efficiency should have greater productivity under water-limited conditions than would a plant with low water use efficiency [10]. The improvement of water use efficiency is a means to improve the drought tolerance of crops. Crop production may be expressed in terms of the total biomass or seeds weight or even in monetary units when production is transferred to monetary units [11]. The more common way of expressing water productivity is as the ratio of yield to water supply or total evapotranspiration (evaporation; the loss of water from the soil, and transpiration: is the loss of water from the plant).

| Treatments                        | Yield (kg/ha) | Evapotranspirasi (kg) | Water Efficiency/ha | Percentage (%) |
|-----------------------------------|---------------|-----------------------|---------------------|----------------|
| Irrigated 1 IBSB910015            | 3456          | 56600000              | 0.0006010601        | 0.061060       |
| Irrigated 2 IBSB910015            | 2210          | 51400000              | 0.000429961         | 0.042996       |
| Rain fed IBSB910015               | 1659          | 42200000              | 0.000393128         | 0.039313       |
| Irrigated 14 times IBSB910015     | 3199          | 54900000              | 0.000582696         | 0.058270       |
| Irrigated 15 mm 20 cm IBSB910015  | 3460          | 53900000              | 0.000641929         | 0.064193       |
| Irrigated 15 mm 40 cm IBSB910015  | 3464          | 51400000              | 0.000673930         | 0.067393       |
| Irrigated 14 times AITT000001     | 3818          | 66400000              | 0.000575000         | 0.057500       |
| Irrigated 15 mm 20 cm AITT000001  | 3842          | 60300000              | 0.000637148         | 0.063715       |
| Irrigated 15 mm 40 cm AITT000001  | 3843          | 62900000              | 0.000610970         | 0.061097       |
According to the Table 4, it is absolutely known that the highest average of water use efficiency in the automatically irrigation system, both in the Tha Tum and IBSB910015 soil type. The value of water efficiency in that treatments (irrigated 15 mm 20 cm and irrigated 15 mm 40 cm) more than 0.06 %. However, the manual irrigation systems obtained water use efficiency less than 0.06 %. Furthermore, the lowest value obtained in rain-fed irrigation system (0.03 %).

It is obvious that irrigation systems influenced water use efficiency. Automation systems obtain the highest value because the water irrigates the soybean based on the sensor system. If the soil moisture is low, automatically water irrigates soybean. Therefore, water loss by evaporation and runoff can minimize. In contrast, manual systems irrigate does not consider soil moisture, thus sometimes water easily run off and evaporate to air. Research in the field of irrigation technology shows promising results in water savings. For example, Dukes et al., also found a 50% reduction in water use in pepper plants using soil water based automatic irrigation system in comparison to daily manually irrigated treatments [12].

3.3. Water stress in growth stage

![Figure 2](image)

**Figure 2.** Soybean water stress in the irrigated 1, irrigated 2 and rain fed (IBSB910015 soil type)

![Figure 3](image)

**Figure 3.** Soybean water stress in the irrigated 14 times, irrigated 15 mm 20 cm and irrigated 15 mm 40 cm (IBSB910015 soil type)
The three graphs above show water stress in different treatments. According to the first graph, rain-fed treatment often obtained water stress, from vegetative until generative stages. Irrigated 2 acquired water stress only in generative stage, and irrigated 1 did not occur water stress during plant growth. The second graph, all of the treatments obtained water stress from 20 to 30 days after planting. Moreover, irrigated 14 times occurred water stress around 60 days after planting. And irrigated 15 mm 20 cm obtained water stress at around 105 days after planting. The last graph described water stress only on irrigated 14 times, it occurred at around 30 and 60 days after planting.

Soybean growth stages are divided into two different broad stages depending on plant development. The first stage is vegetative (V) stages and the second is reproductive (R) stages. The
vegetative stages are numbered according to how many trifoliate leaves are present (0-45 days after planting). The reproductive stages (45–132 days after planting) begin at flowering and also include pod development, seed development, and maturation. Based on those stages, if the crops have occurred water stress, it affected plant growth and productivity.

Figure 6. The effect of water stress to age of crops

Figure 7. The effect of water stress to age of crops
Water stress effect on the age of crops and biomass is expressed in the figure 6 and 7. It is clear that water stress impact to age of crops and biomass. The critical value of water requirements in soybean is flowering stages and seed development. The first time crop initiate to flower requires a lot of energy. The energy comes from photosynthesis, and water is an absolute factor to create photosynthesis. Therefore, if water less than crops requirement, the crops will occur water stress and disturbing biological mechanism. In the seed development also require much water, if water less than requirement, it will reduce pod size and pod weight. Therefore the biomass of soybean lower than water sufficient.

4. Conclusion
According to the results and discussion, it can be concluded : Combination between all irrigated systems and Tha tum type soil (AITT000001) obtained the highest yield, the main factor determine value of yield is soil type, which soil texture is the main characteristic that affect yield, loam better than sand texture on water holding capacity. The highest average of water use efficiency in the automatic irrigation system, because more precise. The critical value of water requirements in soybean is flowering stages and seed development. Water stress in this stage affects age of crops shorter and low biomass. It requires validation of this simulation with field experiments.

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