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Original Research Article

Influence of Soil Moisture on Soil Temperature of Harumanis Mango Trees Under Controlled Environment

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Abstract: Soil moisture and temperature plays an essential role in plant growth and development. They are the main environmental variables controlling soil respiration and photosynthesis. For Harumanis mango grown in a controlled environment, these two variables are important in regulating the overall condition to imitate the required condition, particularly during vegetative growth. In this study, we aimed to investigate the influence of soil moisture on soil temperature in the Harumanis mango tree greenhouse. Two types of sensors: soil moisture and soil temperature sensor, were installed at 15 cm depth to monitor the in-situ readings at three specific locations in the selected greenhouse. Soil moisture and soil temperature were monitored for 20 days continuously at 10-minutes intervals. The results of linear regression indicated that an increase in soil moisture decreases the soil temperature, although there is a variation in data regarding the sampling locations. This information could help growers plan the irrigation efficiently (i.e. water amount) to initiate preferable dry conditions to induce flowering of these mango trees

Keywords: soil parameters; soil condition; soil sensor; greenhouse; vegetative stage key

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1. Introduction

Harumanis mango, scientifically known as Mangifera Indica, is a very popular mango in Malaysia. The mango is unique to the northern state of peninsular Malaysia, Perlis, considering the climate condition and soil type. The growth of this tree requires a long dry season for the trees to grow fully and produce fruit. This specific dry condition or environment is crucial, particularly to induce flowering during the vegetative stage of the tree. Furthermore, the environment will affect and determine the quality of fruit produced. In a study conducted by Abdul Talib *et al.* (2020), it was discovered that Harumanis fruits grown in hot and dry environments produced a higher yield and better quality compared to those grown in less hot and dry conditions.

The mango is well-known for its sweet taste and aroma, differentiating it from other mango types (Abdul Talib *et al.*, 2020; Nasron *et al.*, 2021). Harumanis mango has a high demand in both local and export markets and the demand is expected to increase due to these mango's characteristics (Nooriman *et al.*, 2018; Uda *et al.*, 2020). It helps boost the economy in Perlis and has become the source of income for most people in the state.

Due to the high demand, some growers have planted their mango trees inside a greenhouse. Planting the trees in a greenhouse may produce high-quality fruits while reducing other risks such as pests, diseases and bad weather. For instance, high-intensity rainfall may cause flowering to fail (Mad Saad *et al.*, 2014). The growers can control the parameters of the greenhouse to create an environment that favours the trees' growing conditions and stages. To avoid the failure of flowering and fruiting inside the greenhouse, it is essential to fully understand the flower-inducing conditions. As such, growers can simulate the environment in an open area.

Among factors that influence the flower induction of Harumanis trees, soil moisture and soil temperature play major roles. Both soil parameters are key controls for soil respiration and plant photosynthesis (Baldocchi *et al.*, 2006; Sun *et al.*, 2017). A study showed that controlling the soil moisture through soil water deficit lasting to five weeks can promote earlier and more intense flowering in mango trees of both 'Kensington' and 'Irwin' cultivars. Furthermore, the final fruit yield was higher in the water-stressed trees (Bally *et al.*, 2000). The growth of both the vegetative and reproductive parts of mango is significantly impacted by soil temperature, which is influenced by the surrounding temperature (Yusof *et al.*, 1969). Hence, it can be inferred that the regulation of shoot growth in mango due to environmental factors may be partially attributed to soil temperature (Makhmale *et al.*, 2016).

In this study, we aim to investigate the two key factors that influence the flower induction of Harumanis trees. The main objective of this paper is to monitor and evaluate the influence of soil moisture on soil temperature inside the selected areas of the greenhouse. Understanding this may help growers and decision-makers properly plan the irrigation inside the greenhouses to a better-controlled environment and successfully create a favourable condition to induce the flowering of Harumanis mangoes.

2. Materials and Methods

2.1. Study Area

This study was conducted in Greenhouse-03 at the Institute of Sustainable Agro-Technology (INSAT), Universiti Malaysia Perlis, located at 6°39'45.439''N and 100°19'17.994''E. The greenhouse has a dimension of 84 m length by 24.2 m width, consisting of 216 Harumanis mango trees (Figure 1). The average air temperature in the greenhouse is 25.1°C, and the relative humidity is at 80.7%.

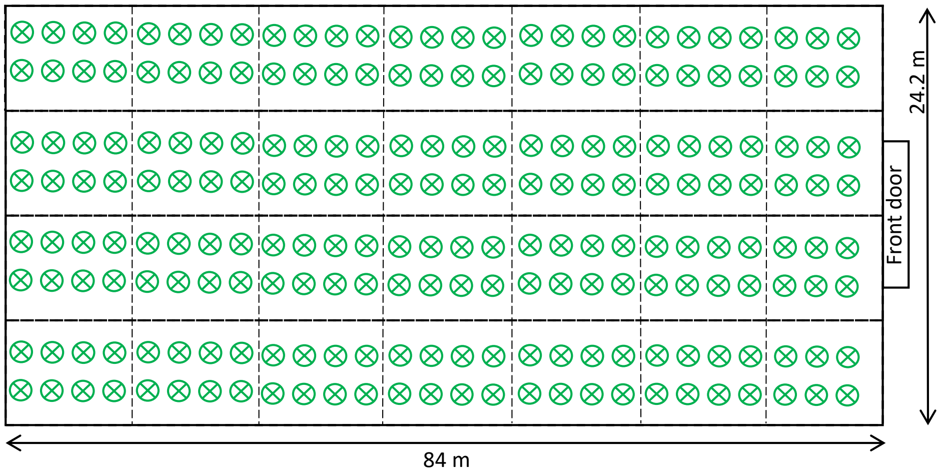

Figure 1. Flowchart of research methodology used in the study

2.2. Method Overview

The flowchart of the research methodology used in this study is shown in Figure 2. There were five main processes involved: plant samples selection, sensor calibration, sensor installation, data collection, and analysis. The details of each process are explained in the following subsections.

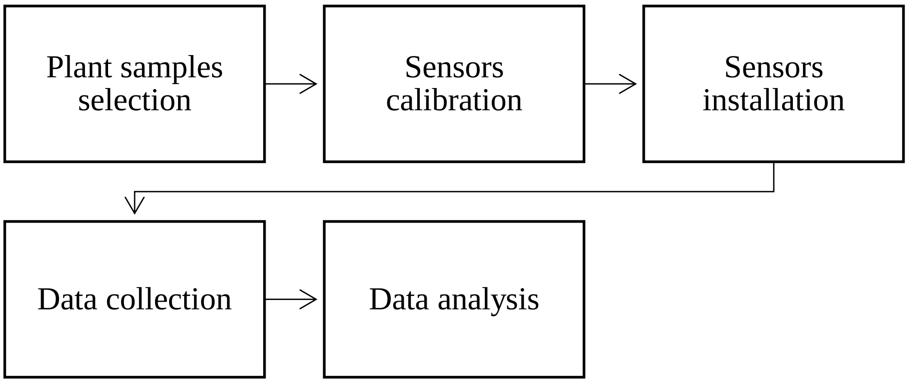

Figure 2. Flowchart of research methodology used in the study

2.2.1. Sampling location

This study selected three locations in the greenhouse based on the random grid method applied to the planting layout of Harumanis trees. In addition, tree conditions were also considered to ensure a par comparison between locations. The selected trees were confirmed to have similar age, canopy proportion and height. Only three trees were selected to represent the greenhouse's soil moisture content and soil temperature following the availability of sensors, cost, and time constraints. The sampling location was named after the sensor type and the tree's number. For soil moisture sensor: SMS14, SMS15 and SMS16. Similarly, for the soil temperature sensor: STS14, STS15, and STS16.

2.2.2. Sensor's calibration

Sensor calibration was performed on all sensors prior to the installation using the gravimetric soil moisture protocol. Figure 3 shows the process of calibration conducted in the laboratory. For this purpose, the soil was first collected from the greenhouse. Then, several soil samples were prepared in a cylindrical container by mixing soil (100 g) and water at varying volumes (100, 150, and 200 ml). After the preparation was done, each sensor was placed inside the container for a few hours before connecting it to the Arduino board for data reading. The data displayed from the Arduino board were the estimated moisture in percentage and sensor value in the ohm (Ω) unit. The reading in ohm showed that this sensor used the principle of electrical resistance (McRoberts, 2013). Three measurements were recorded for each soil sample and sensor.

After measurements were taken and the sensors were removed, the thermometer was used to measure the soil temperature. Then the soil water content of the soil samples was measured using the oven drying method. Samples were placed in the oven at 105℃ for 24 hours. The samples were weighed before and after the drying process. The moisture content in the soil was calculated using equation 1. The w1 and w2 in the equation refer to the weight of soil before and after oven drying, respectively.

$$Moisture\ content = \frac{(W_1 - W_2)}{(W_2)}\ x\ 100\% \tag{1}$$

Both measurements from sensors and laboratory procedures were compared, and adjustments were made to the sensors' reading.

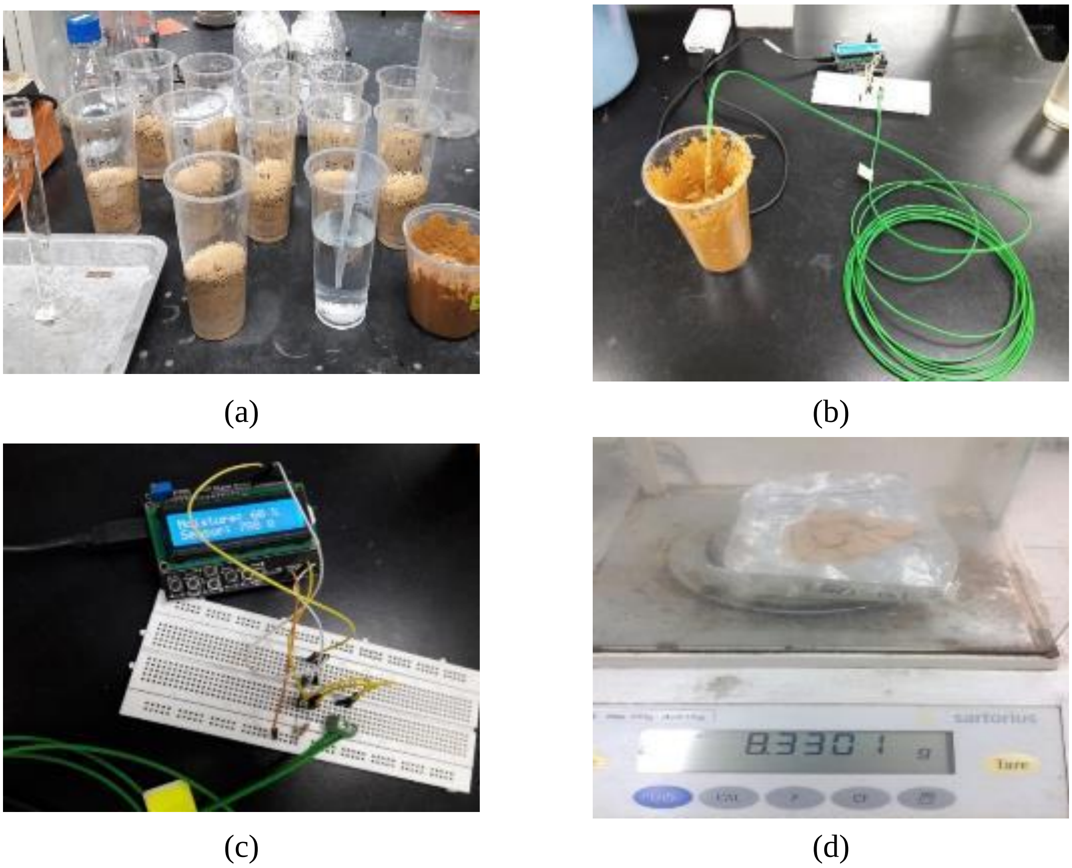

Figure 3. (**a**) Preparation of soil samples; (**b**) Connection setup from soil sensor to Arduino board; (**c**) Data reading displayed from the board; (**d**) Soil sample weighing after the oven drying process

2.2.3. Sensors installation

The soil auger was used to dig two holes to install the sensors for each location. The sensors were placed 15 cm below the soil surface within the canopy perimeter's position and near the micro sprinkler's irrigation. This is the active root zone area. Figure 4 shows the installation of soil moisture and soil temperature sensors at one location and the connection board connecting all sensors to the Arduino board for processing and sending data to the cloud. Note that all sensors were attached to the PVC pipe to protect and facilitate the installation and removal process. The soil moisture sensors were soaked in the container filled with water for 2 hours and dried for 24 hours before installation, following the procedure suggested by Cobors and Chambers (2010). The procedure was repeated twice to improve the sensor reading. The sensor must be wet for installation to remove the air inside the sensor and shall be fully contacted with the soil particle.

(a) (b)

Figure 4. (**a**) The installation setting of soil moisture and soil temperature sensor at the selected tree; (**b**) Connection from soil moisture and soil temperature sensor to the connection board

2.2.4. Data collection

The data from each sensor were automatically collected and sent to the data cloud. The reading was taken every hour for 19 days, from 21st March to 8th April. This specific period was selected as it is when stress was exposed to the plants to induce flowering. The flowering phases of Harumanis are best illustrated using photos from a study conducted by Hazis *et al.* (2018). The data cloud can be accessed directly through a smartphone or laptop with the presence of the internet. To avoid any data losses due to technical glitches, we downloaded the data on a daily basis.

2.2.5. Data analysis

For data analysis, we calculated the daily average of soil moisture and soil temperature for each sampling location. The mean was used to represent the soil moisture and soil temperature graph over the study period, separately. The linear regression has been applied to evaluate the relationship of the two variables within datasets at three sampling locations.

3. Results and Discussion

There were 768 measurements taken for each variable studied: soil moisture and soil temperature. For the purpose of analysis and graph visualization, the daily mean soil moisture and soil temperature were calculated as aforementioned.

3.1. Soil Moisture Content and Soil Temperature

Figure 5 shows the daily average of soil moisture over the study period. It can be seen that the soil moisture data shows a decreasing trend for all sampling locations. The soil at trees 16 recorded the highest moisture, starting at 42.5% and maintained to be highest throughout the period, although it showed decreasing trend. The other two sampling locations, SMS15 and SMS16 have the initial reading at 37% and 32%, respectively. However, the final recorded soil moisture of these locations are very close at approximately 25%.

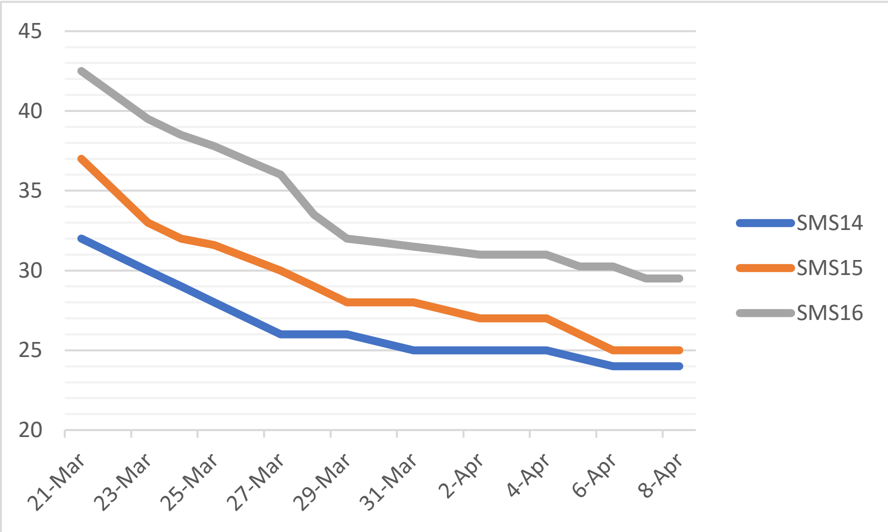

Figure 5. Soil moisture data over the study period at three sampling locations

Figure 6 shows the daily average of soil temperature data recorded over the study period at three sampling locations. The recorded temperature ranged between 27ºC and 32ºC. It can be seen that the temperature data at all locations exhibit an increasing trend. The temperature recorded by STS14 has the highest temperature throughout the study period. Although the increment is almost similar between locations, a high increase was observed for STS16 between 1st and 4th of March.

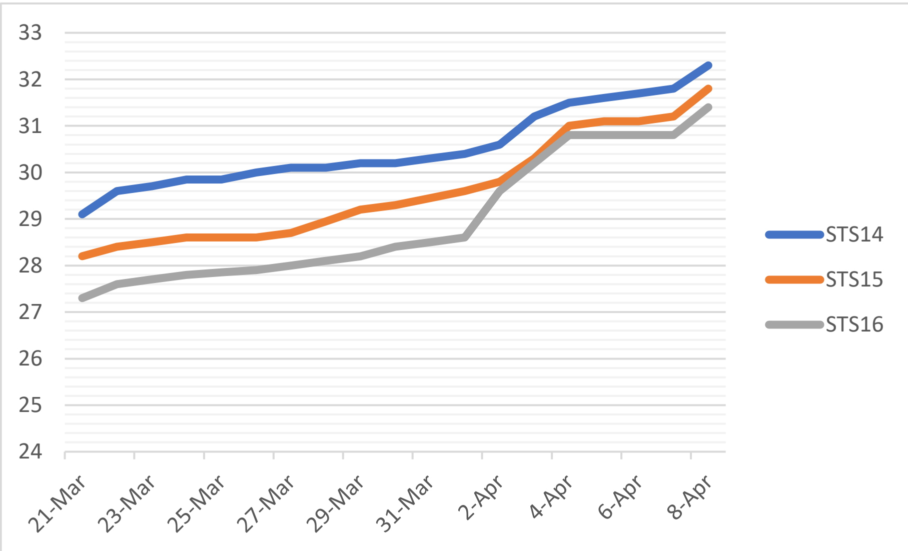

Figure 6. Soil temperature data over study period at three sampling locations

The decreasing trend in soil moisture and increasing trend in soil temperature have been expected due to the management schedule. The trees were intentionally not being irrigated to create enough dry period to induce flowering. The variations in the soil moisture measurement of different locations can be due to several soil condition factors such as the soil texture, porosity and slope (Mohanty & Skaggs, 2001). Soil texture affects soil moisture because it determines the water-holding capacity of the soil and the rate at which water can infiltrate and move through the soil (Abdallah *et al.*, 2021; Abdu *et al.*, 2008). Soils with a high proportion of fine particles, such as clay, have a high water-holding capacity, but they also tend to have low infiltration rates, which can lead to waterlogging and slow drainage. Soils with a high proportion of coarse particles, such as sand, have a low water-holding capacity, but they also tend to have high infiltration rates, which can lead to rapid drainage and lower soil moisture levels (Haghnazari *et al.*, 2015). Slope can also affect soil moisture by influencing the amount of water that enters the soil, the rate of water movement through the soil, and the distribution of soil moisture within the soil profile (Elnaker & Zaleski, 2022; Wang *et al.*, 2013). On slopes, water tend to flow downhill, leading to areas of higher soil moisture content at the base of the slope and lower soil moisture content at the top of the slope. However, other factors such as soil compaction during installation may also contribute to the variations recorded.

3.2. Relationship Between Soil Moisture and Soil Temperature

Figure 7 illustrates the general relationship between soil moisture and soil temperature of the greenhouse from three sampling locations. Linear regression is fitted based on the data points plotted to investigate how soil moisture influences soil temperature. The soil temperature is negatively correlated to the soil moisture. It was shown that the soil temperature increased as the soil moisture was being reduced. A one per cent increase in the soil moisture reduces the soil temperature by 0.2408ºC. The increase in soil temperature promotes root growth due to the increased metabolic activity of root cells and the production of lateral roots (Brownmang onwuka, 2018). In general, the result suggests that a decrease in soil moisture will increase the soil temperature, resulting in stressful conditions for trees to grow. This condition is needed to induce the flowering of the trees.

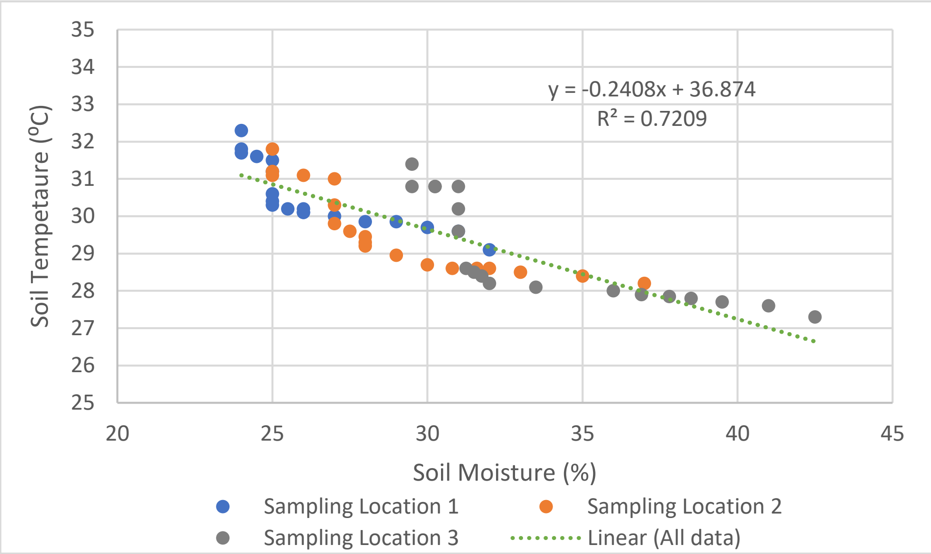

Figure 7. Scatter plot showing the relationship between soil moisture and soil temperature across all trees or sampling locations

4. Conclusions

This study monitors the soil moisture and soil temperature of Harumanis mango trees during the vegetative stage. The data collected were used to study the relationship between these two soil parameters. The results demonstrate that the decrease in soil moisture causes an increase in soil temperature. Despite the limitation in the sensors' quantity and sampling locations, the information gained from this study can help growers to plan irrigation scheduling. Further studies should extend the study period to be able to get a whole overview of the stress condition process for flower induction of Harumanis trees.

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Conflicts of Interest: The authors declare no conflict of interest.

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