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Assessing Changes in Soil Moisture Distribution for Before and After Irrigation in a Harumanis Greenhouse

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ABSTRACT

Soil moisture is an essential factor in determining the quality of crop production in farming areas, particularly in a greenhouse. It is important to ensure that the irrigation in the greenhouse can provide ample water needed by trees. This study aims to assess the status of soil moisture and map its distribution in a greenhouse following the irrigation supply. Soil samples were collected at forty randomly chosen locations at two different intervals of before and after irrigation supply. The soil moisture content is determined by the gravimetric method in the laboratory. Two soil moisture distribution maps were developed using soil moisture data and the coordinates of the sample locations. Based on the maps, the soil moisture distribution of before irrigation was classified into two classes: low and moderate at about 50% coverage each, while 100% of the greenhouse area was within the high soil moisture class for after irrigation. The statistical results demonstrate that both soil moisture data before and after irrigation are different, with the mean soil moisture content increased by 8.73%, thus proving that irrigation systems installed in the greenhouse work effectively by providing ample water to the soil to achieve high soil moisture content in the greenhouse.

Keywords: ArcGIS, greenhouse, irrigation, mango tree, soil moisture mapping.

1. INTRODUCTION

Traditionally, agriculture mostly prospered in natural conditions. As time progressed, the demand for high-quality produce with higher economic value rose. To meet these requirements, farmers started using greenhouse technology for agricultural cultivation. Greenhouses offer an environmental modification management system that enables crop growth across various climates and seasons [1-3]. In greenhouse cultivation, maintaining a dependable and steady supply of irrigation water is crucial for regulating the environment and soil, given the absence of rainfall.

Irrigation, the process of controlling water supply to crops at specific intervals, emerged as a critical determinant of greenhouse success. Various irrigation methods, such as surface, micro, drip, and sprinkler irrigation, influenced how water was delivered to crops. Effective irrigation has an impact on crop growth, which significantly influences yield and quality. Inefficient irrigation can lead to reduced crop yield, increased vulnerability, excessive water usage, and environmental concerns due to runoff [4-6].

Maintaining consistent soil moisture within a greenhouse can be challenging, particularly when using field soil. Various factors such as temperature, humidity, and air circulation contribute to fluctuations in the soil moisture [7,8], thus making it hard to ensure uniformity across the

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greenhouse, which is crucial for accurate interpretation of results. This uniformity in soil moisture is critical in promoting consistent plant growth, optimizing nutrient uptake, and preventing issues like uneven development or water stress among the plants. In this study, the water supply for the Harumanis trees is highly dependent on soil moisture, which is solely provided through irrigation. The trees within the greenhouse have shown an observable disparity, with certain trees exhibiting delayed or stunted growth compared to others. Thus, ensuring that the trees have sufficient water supply is crucial. This can be achieved by assessing the soil moisture status before and after irrigation.

One of the best ways to investigate the soil moisture uniformity in the greenhouse is by mapping the soil moisture distribution. This could be performed by utilizing the Global Positioning System (GPS) technology in combination with soil moisture data. By collecting soil moisture data at various sampling locations within the greenhouse and integrating them with GPS coordinates, it is possible to generate a detailed spatial map of soil moisture levels. This information enables farmers and researchers to visualize patterns of moisture distribution, identify potential problem areas, and implement targeted irrigation adjustments or other management strategies to ensure consistent and sufficient soil moisture levels across the greenhouse. This study aims to map the distribution of soil moisture at two time intervals: before and after irrigation supply. The objective is to assess changes in soil moisture levels within the greenhouse to determine if the water supply is sufficient, particularly in cases where certain trees have exhibited delayed or stunted growth.

2. MATERIAL AND METHODS

This study was carried out in Greenhouse 19 at the Institute of Sustainable Agrotechnology (INSAT) (N6.65203, E100.260908), Universiti Malaysia Perlis (UniMAP), Padang Besar, Perlis, Malaysia. The estimated area of the greenhouse is 2016 m^2, with 24 m width and 84 m length. It consists of 212 Harumanis trees, all aged three years. The greenhouse is located at 6°39'45.439" N and 100°19'17.994" E. The average air temperature in the study area is approximately 27°C, and the relative humidity is 80%.

Figure 1 shows an overview of the study framework. The study started with sample preparation and location selection. The sample locations were picked based on the tree's layout in the greenhouse. The soil sample was then taken at the location with the set procedure and tested in the laboratory on the same day. The coordinates data were collected for all trees' locations. Once both data were collected, soil moisture maps were created for both conditions, before and after the irrigation supplies. Afterwards, statistical analysis was performed on both sets of data to evaluate it. A detailed explanation of the data collection, mapping of the soil moisture distribution, and statistical data performance are discussed in the following subsections.

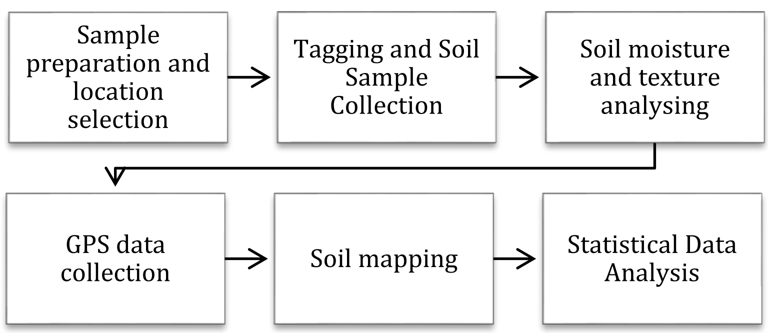

Figure 1: A flowchart of the overall study framework.

2.1 Data Collection

Two types of data were collected in this study: soil moisture and coordinates data. Using random grid sampling techniques, 40 tree locations were selected as samples out of a total of 212 Harumanis trees in the greenhouse. The locations of the samples taken were labeled with A1 until A40.

2.1.1 Soil Sampling

In soil sampling, the most common method to take the soil samples is using a bucket auger at a depth of 0 -15 cm within the canopy radius. This is a typical depth and location where the active root zone is located for most trees. Following this method, the soil samples in this study were taken around the canopy radius at a depth of 15 cm. The soil samples were collected at two intervals: (1) before the irrigation supply and (2) after the irrigation supply. The soil samples after irrigation should be taken after roughly 2 hours. This was to ensure the water supply was infiltrated until the soil absorbed the subsoil. The soil samples were replicated three times following the irrigation schedule; thus, the total soil samples taken from the greenhouse were 240.

A total of 50 g of soil samples were collected for each sample. The samples were tested in the laboratory for soil moisture content analysis using the gravimetric method [9] on the same day. Samples were placed in containers and weighed in a drying oven. Samples were dried at a constant temperature of 105°C for 24 hours. Then, it was weighted again. The soil moisture content was calculated based on the formula:

$$Moisture\ content\ (\%) = \frac{W_2 - W_3}{W_3 - W_1}\ x\ 100 \qquad (1)$$

where;
W_1= Weight of empty cans (g)
W_2= Weight of moist soil+can(g)
W_3= Weight of dried soil+can(g)

2.1.2 Coordinates

The coordinates data, including latitude, longitude, and elevation, were collected using the Real-Time Kinematic (RTK)-GPS tool. A Topcon GR-5 instrument is a compact, high-performing GNSS receiver suitable for static and kinematic applications. The measurement accuracy is 3mm (horizontal) and 10mm (vertical). The coordinates data were taken at all trees inside the greenhouse once, performing it on a bright sunny day.

2.2 Soil Mapping

The soil moisture distribution map was produced using geostatistical analysis in ArcGIS software. The interpolation method of Inverse Distance Weight (IDW) was chosen in this study. IDW is a deterministic interpolation method that determines the cell using a linear-weighted combination of sample set points [10]. IDW is the best choice when the sample point is dense enough to capture for analysis [11]. Soil moisture maps were generated based on two collected data: the average soil moisture data from soil sampling and data collected using RTK-GPS tool, which consists of latitude and longitude. For mapping the soil moisture, five soil moisture class ranges were created: very low (0.00-5.00), low (5.01-10.00), moderate (10.01-15.00), high (15.01-20.00), and very high (20.01-25.00). These classes were established based on several related sources and are determined by the type of soil present in the greenhouse, specifically clay. [12-14]. Further, the high soil moisture class of 15.01 to 20.00 % soil moisture was divided into smaller classes (High

I, High II, High III, High IV, and High V) to help with mapping visualizations following the soil moisture results.

2.3 Statistical Data Analysis

A simple statistical data analysis of mean, minimum, maximum, mean standard deviation, skewness, kurtosis, 1st quartile, median and 3rd quartile was performed to assess the distribution of soil moisture data. Furthermore, one-way ANOVA was run to evaluate the effect of irrigation on the soil moisture distribution for the greenhouse.

3. RESULTS AND DISCUSSION

In this section, soil moisture distribution maps for before and after irrigation were presented and discussed, focusing on the changes following the irrigation supplies. Then, statistical results were displayed and examined.

3.1 Soil Moisture Spatial Distribution and its Changes

The frequency of soil moisture data in each class is presented in Table 1. The 40 soil moisture data represented are an average of three replications for both before and after irrigation treatment. It can be seen that, before irrigation was supplied, 19 soil samples were classified as low, while the remaining (21) soil samples were in the moderate soil moisture class. After irrigation, all 40 soil samples have soil moisture between 15.01 and 20.00%, which is classified in the high soil moisture class. The results of soil moisture content after irrigation were then refined into five subclasses from High I to High V. There are one, 13, 18, and 8 soil moisture samples were classified into High II, High III, High IV, and High V, respectively for the soil moisture after the irrigation was supplied.

Table 1: Frequency of soil moisture data before and after irrigation supplied based on soil moisture classes.

Soil Moisture Class	Map Colour	Range (%)	Frequency (Before Irrigation)	Frequency (After Irrigation)		
Very Low		0.00-5.00	0	0		
Low		5.01-10.00	19	0		
Moderate		10.01-15.00	21	0		
High		15.01-20.00	0	40	Refined;	
					High I: 15.01-16.00	0
					High II: 16.01-17.00	1
					High III: 17.01-18.00	13
					High IV: 18.01-19.00	18
					High V:19.01-20.00	8
Very High		20.01-25.00	0	0		

Figure 2 shows two soil moisture maps created for this study. Figure 2(a) is for before, and Figure 2(b) is for after irrigation. The black spot in both maps indicates the location of trees in the greenhouse. Figure 2(a) used the general five classes legend (very low, low, moderate, high, and very high), while Figure 2(b) used the refined classes legend (High I, High II, High III, High IV, and High V).

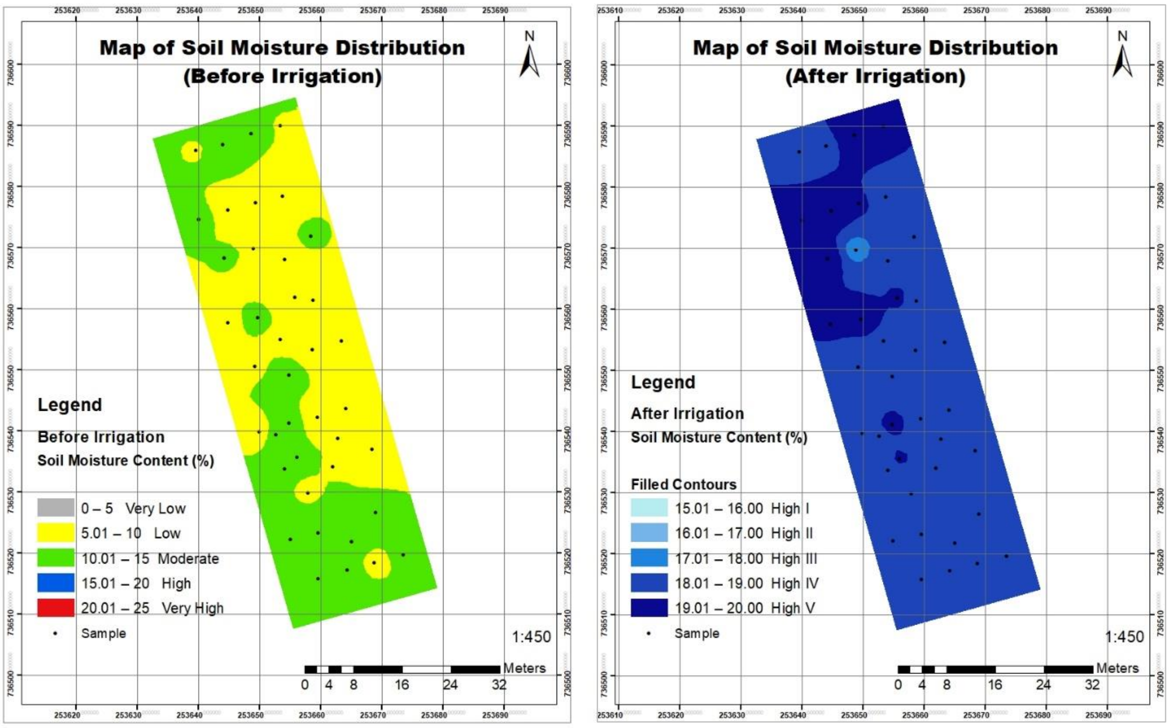

Figure 2: Soil moisture distribution maps for (a) before irrigation and (b) after irrigation was applied.

It can be observed that the soil moisture map before irrigation (Figure 2(a)) is displayed in two scheme colors: yellow and green, indicating the low and moderate soil moisture contents. The north and south regions of the greenhouse have moderate soil moisture ranging between 10.01% and 15%. On the other hand, the central regions have a low soil moisture content between 5.01% to 10%. These variations, although not distinct, could be due to several factors. These factors include topography (slope direction, slope, elevation, etc.) [15], soil properties (particle composition, bulk density, porosity, and organic matter content, etc.) [16], plant uptake [17], and the efficiency of the irrigation system.

The soil moisture map for after irrigation (Figure 2(b)) is presented in blue color, revealing that all soil moisture content of the samples taken has a high soil moisture content between 15.01% and 20.00%. Due to all data being within the same class, it was divided into five subclasses, which are High I, High II, High III, High IV, and High V, for variation purposes using five different blue shades. Most of the greenhouse area, approximately 75%, in the eastern, western, and southern regions exhibits a soil moisture content ranging from 18.01% to 19% (High IV). While the remaining 25%, particularly in the north region, falls in the soil moisture range between 19.01% and 20% (High V). It can be remarked that the provided irrigation water is sufficient to enhance soil moisture levels, and the distribution of the irrigation system within the greenhouse is notably uniform.

Both soil moisture distribution maps exhibit varying class ranges yet demonstrate nearly identical patterns. The soil moisture data for all classes shifted from initially having low and moderate moisture content to higher levels following the irrigation supply. The variations among the five subclasses within the high moisture content class may arise from factors such as tree size, tree canopy, soil composition, evaporation, filtration rates, and the presence of grass in proximity to certain soil sample locations. Different water intake would be observed in trees of different sizes [18], while the tree canopy influences the soil temperature and evaporation under the trees [19].

Both distribution maps offer insights into the soil moisture levels before and after irrigation application. These findings are crucial for enhancing regions with previously low soil moisture, ensuring uniformity and consistent soil moisture levels within the greenhouse. Maintaining uniform soil moisture through efficient irrigation reduces water loss and improves crop productivity [20,21]. In this study, various approaches, including inspecting the irrigation systems (nozzles, piping, etc.), assessing soil leveling, and adjusting water supply as needed, can be implemented to improve overall soil moisture uniformity.

3.2 Statistical Comparison of Soil Moisture for Before and After Irrigation Supply

The data in Table 2 presents statistical measures for soil moisture levels before and after irrigation. For the "before irrigation" condition, there were 40 data points, with a minimum soil moisture content of 12.79%, a maximum of 6.57%, and an average of 9.95%. The standard deviation was 1.4298, indicating moderate variability, while skewness was -0.27599, suggesting a slight negative skew. The kurtosis value of 2.9738 showed a distribution with slightly heavier tails than a normal distribution. The 1st quartile (25th percentile) was 9.11%, the median (50th percentile) was 10.085%, and the 3rd quartile (75th percentile) was 10.86%.

In contrast, the "after irrigation" condition also had 40 data points, with a minimum soil moisture content of 20%, a maximum of 17%, and an average of 18.68%. The standard deviation was 0.70188, indicating relatively low variability, while skewness was 0.21605, suggesting a slight positive skew. The kurtosis value of 2.5057 showed a distribution with slightly lighter tails than a normal distribution. The 1st quartile (25th percentile) was 18.1%, the median (50th percentile) was 18.505%, and the 3rd quartile (75th percentile) was 19.2%. These statistics provide valuable insights into the changes in soil moisture levels before and after irrigation, highlighting the impact of the irrigation process on the greenhouse environment.

Table 2: Statistical data comparison in soil moisture between before and after irrigation.

Measurement	Soil Moisture (Before Irrigate)	Soil Moisture (After Irrigate)
Count	40	40
Minimum	12.79%	20.00%
Maximum	6.57%	17.00%
Mean	9.95%	18.68%
Standard Deviation	1.430	0.702
Skewness	-0.276	0.216
Kurtosis	2.974	2.506
1st quartile	9.110	18.100
Median	10.085	18.505
3rd quartile	10.860	19.200

The mean of the soil moisture increased by 8.73%, and the standard deviation decreased by 0.728 following the irrigation. In summary, the analysis demonstrates that irrigation had a profound and beneficial impact on the soil moisture distribution within the Harumanis greenhouse. The data exhibited higher moisture levels, reduced variability, and a more symmetric distribution after irrigation, underscoring the effectiveness of the irrigation process in improving soil moisture content, which is crucial for plant health and growth in a greenhouse environment.

Table 3 presents the results of an Analysis of Variance (ANOVA) conducted on two groups: soil moisture levels before and after the supply of irrigation. This statistical analysis assesses the variation in soil moisture between these two conditions.

Table 3: Analysis of Variance (ANOVA) results on two groups: soil moisture before and after irrigation supplied.

Source of Variation	SS	df	MS	F	p-value
Between Groups	1	1552.8	1552.9	1170.4	0.00
Within Groups	78	101.5	1.30		
Total	79	1624.4	20.56		

"Between Groups" refers to the variation in soil moisture levels attributed to the difference between the two groups (before and after irrigation). The Sum of Squares (SS) for this source of variation is 1552.8, with 1 degree of freedom (df), resulting in a Mean Square (MS) of 1552.9. The calculated F-statistic is 1170.4, indicating a highly significant difference between the two groups. The p-value for this comparison is exceptionally low at 0.00, confirming the statistical significance of the difference in soil moisture levels before and after irrigation.

The primary focus of this ANOVA analysis is on the "Between Groups" source of variation, which compares soil moisture levels before and after irrigation. The highly significant F-statistic and extremely low p-value indicate a significant difference in soil moisture between these two conditions, suggesting that irrigation has had a substantial impact on soil moisture levels in the greenhouse. It can be concluded that the supplied water through drip irrigation in the greenhouse causes an increase in soil water content. In general, irrigation increases soil moisture [22,23]. In the area where plants draw the most water, drip irrigation supplies water to a small area of soil, minimizing losses from deep percolation and surface evaporation [24].

4. CONCLUSION

This study examines the fluctuations in soil moisture content both before and after the introduction of irrigation. Before irrigation, the maps indicated that soil moisture levels were relatively low, with an average of 9.95% based on 40 samples. This categorization divided the greenhouse area into low and moderate soil moisture content classes. However, following the application of irrigation, the soil moisture content within the greenhouse increased significantly, transitioning into the high soil moisture content class with an average of 18.68% and displaying a more uniform distribution. The ANOVA statistical analysis indicates a significant difference in soil moisture levels between these two conditions, implying that irrigation has substantially influenced the soil moisture inside the greenhouse. Mapping and comprehending soil moisture levels within greenhouses is particularly important for farmers. It optimizes crop growth by enabling precise irrigation adjustments, conserves water resources, enhances cost efficiency, promotes crop health by preventing stress and disease susceptibility, and reduces the environmental impact through responsible soil moisture management.

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