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Investigation of Soil Properties Effect on Crop Yield Performance

Muhammad Aliuddin Bakar[1*], Nur Amalina Ismail[1], Mohd Hudzari Razali[1], Norkhairunnisa Abdul Shukor[1], and Syahrizan Syahlan[1]

[1]Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA Cawangan Melaka, Malaysia.

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ABSTRACT

Soil nutrient is essential for crop growth. Spatial variability of nutrients will have occurred in numerous scales, between regions, a field, particularly in soil properties. A study was carried out to observe the yield performance in an agricultural plot at Semujuk Jasin, Melaka. Using management zone delineation, the area is divided into fifteen smaller 6.8-meter × 6.8-meter plots. A soil sample from each plot was tested in the laboratory to obtain the soil moisture, organic matter, pH level, Phosphorus, and Manganese content. Using ArcGIS software, the result is interpolated using the Kringging method, mapped, and then compared with the crop value from each. Plot A3 generated the lowest yield with a crop yield value of RM6.8. This plot also has the lowest soil moisture content, which is 6.452%. Plot A1 produces only RM65.2 for crop yield, although it has 21.505% soil moisture content, while plot C1 only produces RM47.4 for crop yield value, although it has a higher soil moisture content of 23.265%. Regarding the soil organic matter content for both plots, plot A1 has only 1.455% organic matter content, while plot C1 has lower soil organic matter content, which is 0.823%. Plot B2, with a low pH value (4.51), shows a poor performance of RM52.6 regarding satisfactory readings on other plots. From the analysis made based on the experiment result, the primary limiting factor affecting crop performance is soil moisture content. Soil pH value and Organic Matter also play an essential role in determining crop performance.

Keywords: Crop growth, Precision agriculture, Soil properties, ArcGIS, Yield mapping

1. INTRODUCTION

Soil nutrient is essential for crop growth. The declination of soil fertility, which inevitably leads to low agricultural productivity, is the main cause of the problem [1]. Poor cultivation practices have resulted in declining soil organic matter content and increasing acidic soil occurrence [2]. Soil scientists have developed modern theories to define soil quality [3]. The concept of soil quality is crucial for the success of sustainable agriculture and ecological management [4]. Soil quality is based on soil characteristics or indirect observations. Soil characteristics representing soil quality need to be selected and quantified [5]. These may include biological, chemical, or physical soil characteristics [6]. Thus, soil characteristic mapping is vital in determining problematic soil location remedies and thus ensuring high-yield production.

Precision agriculture is defined as the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production [7]. The concept of precision agriculture is expanding due to technological developments in the last decade. Precision agriculture cover from the integration of information on the agriculture management system, a system designed to improve farm productivity and efficiency. The Precision farming database generally includes crop information such as growth stage, health, nutrient requirement, soil physical, chemical properties, depth, texture, nutrient status, salinity

*Corresponding author: aliuddin@uitm.edu.my

and toxicity, soil temperature, and productivity potential. Precision agriculture can optimise the resources in creating the soil map and finding the relation between soil properties and crop yield performance. As an example, Piro (2017) [8] has conducted research comparing multispectral and hyperspectral data to monitor plant health by looking at the leaf vitality of sugar beef. According to the result, the value of the index increases with healthier and decreases with unhealthier plant conditions. Using ArcGIS, plant health monitoring is conducted using visible, infrared, and microwave wavelengths. The plant's health can be monitored by the Normalised Difference Vegetation Index (NDVI) obtained from the image. In terms of crop management, ArcGIS is widely used throughout the world. By using ArcGIS software, crop management can be done more efficiently and faster, with lower costs, and the decisions made have a higher level of accuracy. In the United Kingdom Plant health office, GIS is used in Windows mobile devices to enable officers to collect and store data in real-time faster and more comfortably [9].

In the Malaysian National Paddy Precision Farming Project initiated by the Malaysian Remote Sensing Agency (MACRES) in collaboration with Universiti Putra Malaysia (UPM), a Fertiliser Recommendation Map software, one of the Spatial Decision Support System (SDSS) is created. The map is created based on input from the sensing system, including soil, water, growth, and yield sensors. From the obtained input, a geographic information system analysis of field information is conducted. From the analysis data, the variable rate applicator used this data for fertiliser, pesticides, seed application and fertigation activity. This is expected to optimise the profitability, maintain the sustainability of agriculture, and protect the environment [10].

From the requirement of knowledge in soil properties and the benefit of precision agriculture in modern farming, a study is conducted to determine the local plot that has an issue or yield problem, finding the governing factor affecting the crop yield performance, and suggest a suitable approach to remediate the problem.

2. MATERIAL AND METHODS

2.1 Location of Case Study

This case study was conducted in Kampung Seri Mendapat, Merlimau Melaka. The agriculture plot is approximately 1.2km southwest of Universiti Teknologi MARA (Melaka), Kampus Jasin. The agriculture plot is 0.5 acres and cultivated with corn. The plot is protected with an electric fence and black net to avoid predators from outside damaging the crop. The corn is planted with a density of 15000 crops per acre.

2.2 Soil Sampling

The study area is divided into plots with sizes 6.8 meters times 6.8 meters. There are 3 lines and 5 columns made up of 15 plots through the study area. The soil sample is taken in the middle of each plot, and the coordinates of the sample are obtained by using Garmin handheld GPS. Figure 1 shows the divided plot in the study area, while Figure 2 shows the soil sample taken in the process.

Figure 1: Division of Subfield.

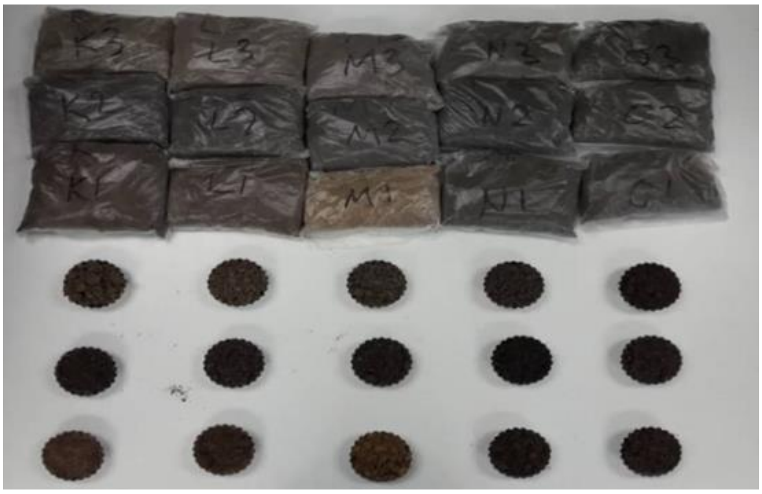

Figure 2: Soil Sample.

2.3 Soil Moisture Content Test

The test is conducted following ASTM D2216-90. The soil sample with the container was first measured its weight with balance. The container is then placed in an oven with a temperature of 105°C to 110°C for 24 hours. After 24 hours, the container is weighed again using balance. The weight of the soil before the drying process minus the weight of soil after the drying process divided by the dry weight minus the container weight is the formula to obtain the soil moisture content.

$$\text{Moisture Content} = \frac{Wet\ Weight - Dry\ Weight}{Dry\ Weight - container} \quad (1)$$

2.4 Soil Organic Matter Content Test

In the soil organic matter content experiment, the experiment was conducted based on ASTM D2974-87, Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Organic Soils. The dry soil from the Soil Moisture Content experiment is transferred to the porcelain dish, weighed and recorded. The soil is then burned at a temperature of 400^0C to 450^0C overnight using a furnace, as in Figure 3. The weight before the burning process minus the weight after burning process device with the weight after the burning process is the formula for obtaining the soil organic matter content.

$$\text{Organic Matter Content} = \frac{Dry\ Weight - Burned\ Weight}{Burned\ Weight - porcelain\ dish\ weight} \quad (2)$$

Figure 3: Muffle Furnace.

2.5 Soil pH Value Test

Soil pH value is obtained by following ASTM D4972. The soil sample is first shieve to obtain particles less than 2mm. The soil is then weighed for 10g, put in a glass container and mixed with 10mL of distilled water. The pH value is taken by using a digital pH meter.

2.6 Soil Macro and Micro Nutrient Test

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is an analytical technique used for element determination. The test is conducted to obtain the value of nutrients from the soil sample. In this study, the value for Phosphorus and manganese is obtained from the ICP test. Figure 4 shows the ICP-MS equipment used for the determination of nutrient content.

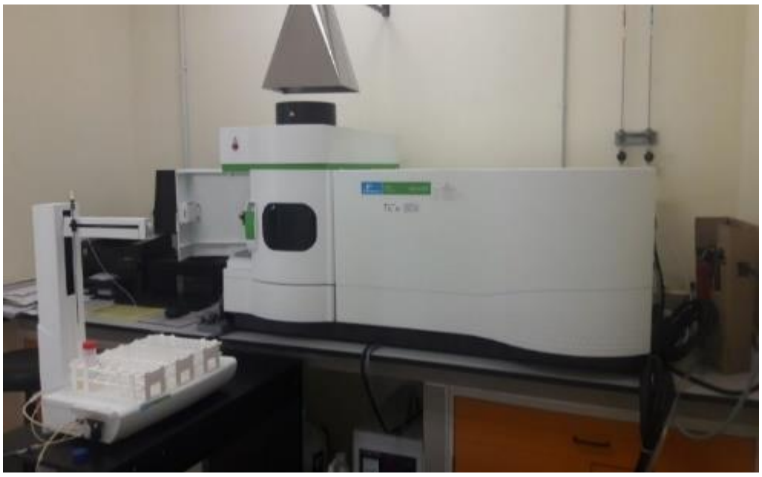

Figure 4: Inductive Coupled Plasma Mass Spectrometry (ICP-MS).

2.7 Soil Structure Determination Test

A soil structure test was conducted to know the specific soil types for each plot. This characteristic will influence the bulk density, porosity, water-holding capacity and aeration. All this contributes to the performance of crop growth and yield performance during the cultivation process. The sample is dried in the oven at 100°C for 6 hours. The door of the oven is open periodically to release the moisture outside. The dried sample is then crushed before being placed in the motorised sieve shaker like in Figure 5. There are eight pans with a mesh of 4mm, 2mm, 1mm, 500µm, 250µm, 125µm, 63µm, and 45µm. The weight of soil collected in each pan is measured using a balance and then recorded. Figure 6 shows the collected soil sample after the test.

Figure 5: Motorised Sieve Shaker.

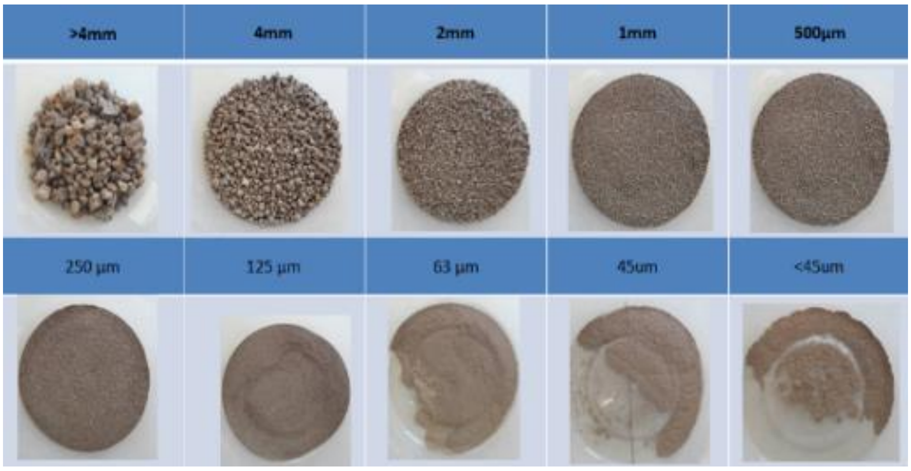

Figure 6: Soil Collected From Sieve machine.

2.8 Soil Characteristic Analysis Using ARCGIS Software

After all the data requisition was completed, the analysis of the soil properties was performed using ArcGIS. ArcGIS is used as it can record and manage the data well, secure in data query, data analysis like interpolation and good data presentation. Figure 7 shows the ArcGIS used in the study.

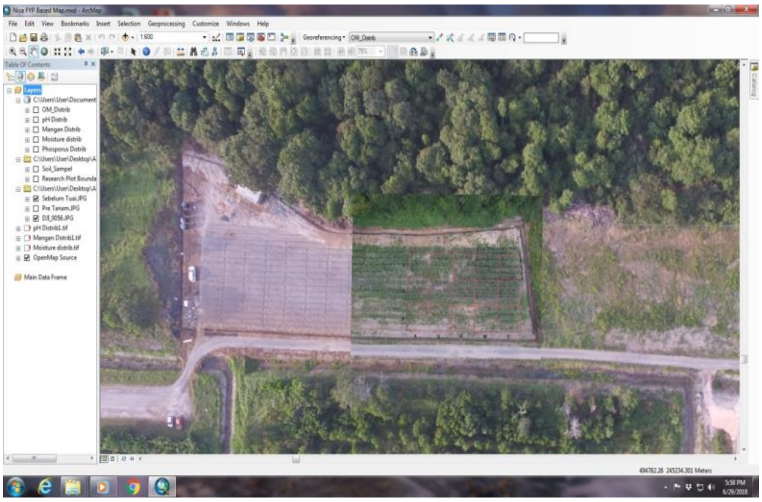

Figure 7: ARCGIS Software.

3. RESULTS AND DISCUSSION

3.1 Crop Yield Value

The crop performance is uneven throughout the case study plot. From Figure 8, we can see that some plots are full of healthy matured corn plants while other plots perform poorly with the stunted plants and are low in density.

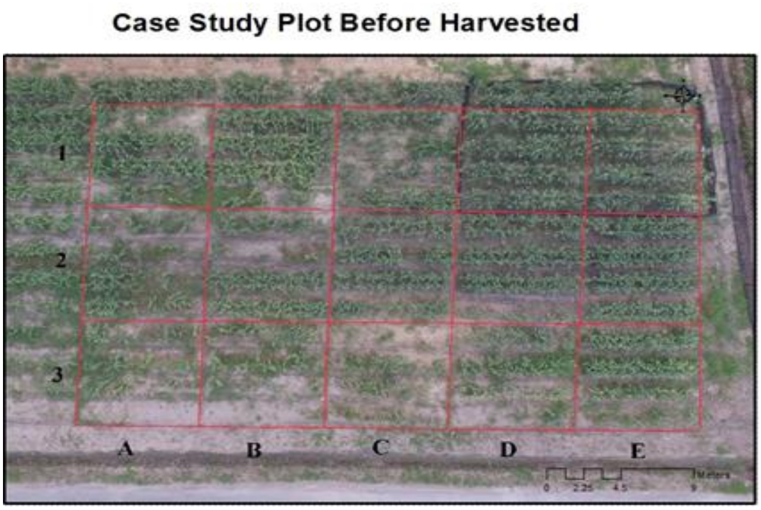

Figure 8: Aerial Photography of Study Plot Before Harvested.

To obtain the measurable value to present as crop performance, the number of corn harvested in each plot is recorded based on the crop grade. The price for grade A corn is RM1; grade B corn is RM0.7, while grade C corn is RM0.5. The number of corn produced in the plot times the price according to the corn grade is used to set a value to determine the crop yield performance. The total value obtained in each plot is shown in Table 1. The highest crop yield performance was scored by plot D1 with RM177.2, while plot A3 scored the lowest with only RM6.8. The average score is RM80.55.

Table 1: Crop Yield Value.

Plot	Crop Yield Value (RM)	Plot	Crop Yield Value (RM)	Plot	Crop Yield Value (RM)
A1	65.2	B3	21.1	D2	109.4
A2	44.4	C1	47.4	D3	27.2
A3	6.8	C2	113	E1	160.8
B1	116.1	C3	16.9	E2	160.8
B2	52.6	D1	177.2	E3	89.4

3.2 Soil Properties Distribution

Table 2 shows all the recorded values for soil properties analysis conducted for the whole plot.

Table 2: Soil Properties Experiment Result.

Plot	Soil Moisture Content (%)	Soil Organic Matter Content (%)	Soil pH Value	Soil Structure
A1	21.53	1.46	6.23	Coarse Sandy Loam
A2	12.08	8.35	5.64	Loamy Sand
A3	6.45	10.69	4.96	Loamy Coarse Sand
B1	25.55	9.89	5.44	Loamy Coarse Sand
B2	20.67	18.44	4.51	Fine Sandy Loam
B3	10.10	14.22	4.47	Sand
C1	23.25	0.88	5.58	Loamy Coarse Sand
C2	22.81	9.68	5.55	Loamy Coarse Sand
C3	8.36	13.42	5.11	Loamy Coarse Sand
D1	25.59	10.48	6.25	Coarse Sand
D2	24.13	9.51	5.34	Loamy Coarse Sand
D3	9.08	9.45	5.51	Loamy Sand
E1	21.98	10.47	5.67	Loamy Coarse Sand
E2	29.52	10.25	5.67	Loamy Coarse Sand
E3	20.19	10.61	4.81	Loamy Sand

From Figure 9, there is a pattern in the soil moisture distribution in the study area. The lower left area (A3) has a low soil moisture content, and it increases gradually to the upper right area (E1). The lowest value of soil moisture content is recorded at plot A3 with a reading of 6.45%, while the highest value recorded for soil moisture content is at plot E2 with 29.52%. The organic matter distribution throughout the study area is shown in Figure 10. Plot B2 has the highest organic matter content, 18.44%, while plots A1 and C1 have the lowest organic matter content, 1.46% and 0.88%. The average soil organic matter content through the study area is 8.25%.

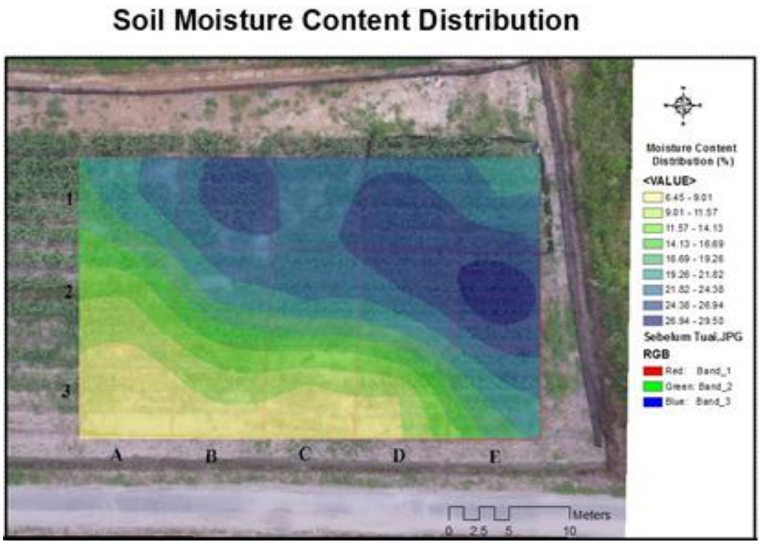

Figure 9: Soil Moisture Content Distribution.

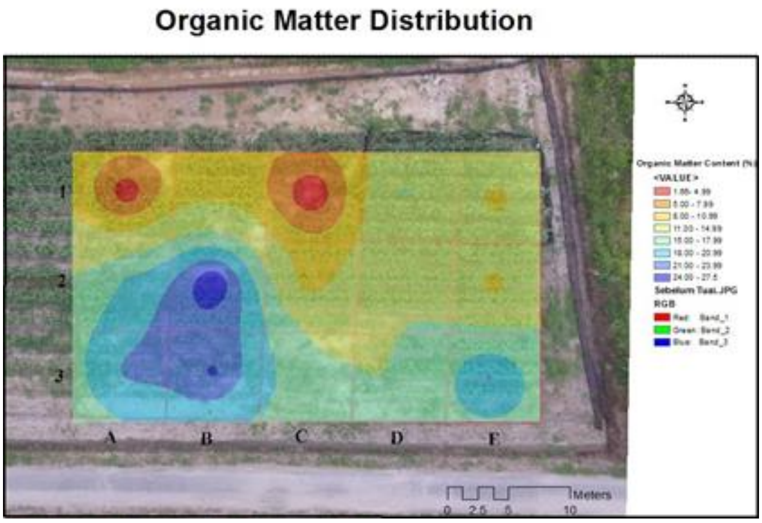

Figure 10: Soil Organic Matter Content Distribution.

In the soil pH experiment, the pH value ranged from 4.51 to 6.25. This shows that the soil in the study area is slightly acidic. The most acidic plot in the study area is at plot B3, with a pH value of 4.47, and the second lowest is recorded at plot B2, with a pH value of 4.51. The upper part of the study area (line 1) has a higher pH value compared to the study area at the lower part (line 3). Acidic soil is unsuitable for plant growth as it disrupts the crop nutrient intake process. The less acidic soil was recorded at plots A1 and D1 with pH values of 6.23 and 6.25, respectively. A higher pH value means a lower acidic rate, and the plant can absorb nutrients better and thus have better growth and yield performance. Figure 11 shows the soil pH distribution through the study area.

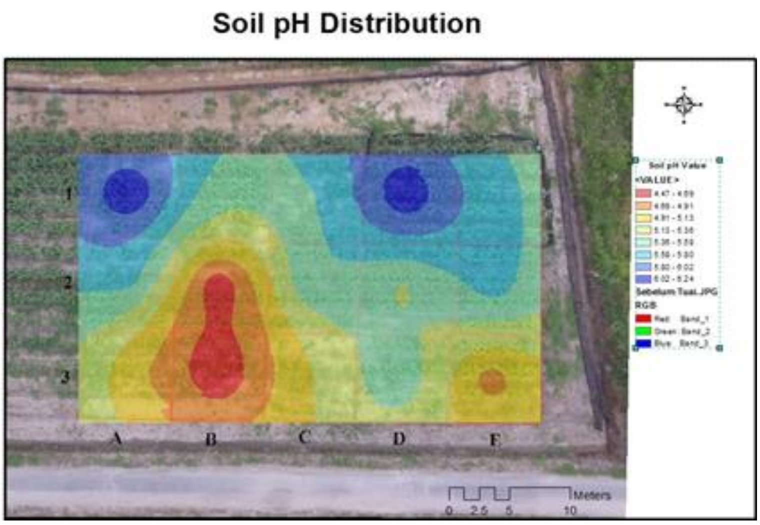

Figure 11: Soil pH Value Distribution.

From the result of the soil structure experiment, the soil structure for all the divided plots is shown in Table 5. Most of the soil structure in the study area is Loamy Sandy Loam, with eight plots or more than 50% of the total area falling under this type of soil texture. The second familiar texture is Loamy Sand, with three plots with this soil texture. For coarse sandy loam, fine sandy loam, sand, and coarse sand, only one plot is each for the sand texture. Sandy loam is approximately made of 60 percent sand, 30 percent silt and 10 percent clay. Loamy sand is ideal for agricultural activities as it can retain sufficient nutrients and water while allowing excess water to drain away. Sandy loam soil texture has the same characteristics as loamy sand texture. The soil texture through the study area can be said to be suitable for cultivation activities. Any bad performance of crops planted in this study area can be concluded because of another factor soil texture.

3.3 Determination of Problematic Plot

From the result obtained from ArcGIS and related to the crop yield performance, soil moisture is the primary factor affecting the crop yield performance. The lower left area with low moisture has poor performance compared to the upper right area with higher moisture content. Figure 12 shows the relationship between crop value and soil moisture when plotted against one another.

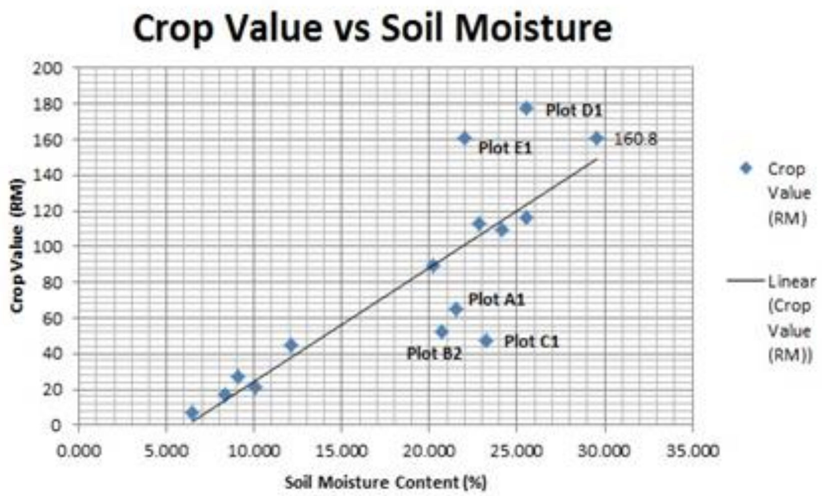

Figure 12: Graph of Crop Value versus Soil Moisture Content.

Based on the planting distance and plot size, each plot can be planted with approximately 160 corn trees. Assuming each plant produces one grade A cob, with a market price of RM1 per cob for grade A, the yield value for each plot is RM160, assuming 100% performance in yield. Any plot producing less than 50%, which is RM80, is considered problematic. From Figure 4.7, there are eight plots that generate less than RM80 in yield. Plot A2, A3, B3, C3, and D3 fall within the line of crop value versus soil moisture content. The average moisture content for this plot is 9.2%, far from the standard soil moisture content suitable for crop growth, which is 25%. The lowest yield was generated by plot A3 with a crop yield value of RM6.8. This plot also has the lowest soil moisture content, which is 6.452%. The second and third lowest yield performances were scored by plots C3 and B3 with crop yield values of RM16.9 and RM21.1. Both plots also have a low soil moisture content of 8.37% and 10.096%. For plot A1, B2 and C1, they perform poorly in crop yield value, although they have a sufficient soil moisture value above 20%. A further investigation of other factors shows that for plots A1 and C1, the organic matter content for both plots is shallow compared to the average content suitable for crop growth. Plot A1 produce only RM65.2 for crop yield, although it has 21.505% soil moisture content, while plot C1 only produce RM47.4 for crop yield value, although it has a higher soil moisture content of 23.265%. When referring to the soil organic matter content for both plots, plot A1 has only 1.455% organic matter content, while plot C1 has lower soil organic matter content, which is 0.823. This shows why plot C1 performed lower compared to plot A1 despite having a higher moisture content. This also shows why these two plots performed severely compared to another plot with sufficient soil moisture content. Plot B2 performed below average despite having sufficient soil moisture and organic matter content. Studies on other factors show that this plot has a low pH level of 4.51. Low pH values will result in difficulties for the plant in absorbing the required nutrients.

4. CONCLUSION

From the case study, we can see how using ArcGIS software can reduce the difficulties in determining crop performance, knowing the problematic plot and analysing the limiting factor for crop performance. From the analysis made based on the experiment result, the primary limiting factor affecting the crop performance is soil moisture content. Soil pH value and Organic Matter also play an essential role in determining crop performance. By using ArcGIS, the process of determining all the factors is faster, more comfortable, and more accurate.

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