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Effects of rainfall on selected soil physico-chemical properties of marginal soil cultivated with MD2 pineapple crop

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Abstract

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This study assessed the effects of rainfall on soil physico-chemical properties (pH, moisture, temperature, Nitrogen value, Phosphorus value and Potassium value) of MD2 pineapple cultivation on marginal soil, and also investigated correlation between rainfall and soil physico-chemical properties based on IoT-based monitoring. Agromon Smart Agriculture and NPK Sensors (Agromon) that is equipped with a Sigfox-based wireless transmitter was used to provide real-time marginal soil properties data from an experimental MD2 pineapple field plot in UiTM Sarawak. Rainfall data between March and July 2021 for Samarahan Rainfall Station were obtained from Department of Irrigation and Drainage, Sarawak (DID). Soil properties data were transmitted from field plot gateway to the nearest Sigfox base station in Santubong, and subsequently to SATU dashboard server in order to be accessible to all users. Agromon demonstrated the capability of IoT system in monitoring selected soil properties across favored and unfavored weather conditions. Pineapple farmers can make timely and cost-effective farm operation decision anywhere to optimize plant vigor and therefore, improve yield.

Keywords: IoT; soil nutrient; soil pH; soil temperature; soil moisture; rainfall; leaching

Introduction

Soil fertility is the key factor to produce optimum crops yield. Soil nutrient deficiency will significantly affect crops health and growth, especially on marginal soil. However, fertility of marginal soil can be improved by suitable agricultural input management practices (Hubanks et al., 2018). Optimal and timely application of input such as fertilizer will avoid overfertilization and minimize the expenditure on fertilizer (Lavanya et al., 2020). Internet of Things (IoT) system provides the avenue for constant monitoring of soil chemical properties by conducting real-time processing of field data, presented them in the form of user-friendly infographics, and utilize cloud storage to provide high accessibility to time-series field data. Accessibility to real-time and time-series data provides farmers with necessary input for timely decision-making, and not solely relying on time-consuming and costly laboratory-based soil analysis (Ojha et al., 2015). The values of Nitrogen (N), Phosphorus (P) and Potassium (K) macronutrients, and other soil physical properties such as soil pH, soil moisture, and soil temperature can be easily monitored from the IoT dashboard on mobile devices or desktop web browser. Prompt remedy actions is becoming more significant now as climate change effects on agriculture yield has already affected many regions globally. The quest to produce sufficient yield from depleting agricultural land bank and soil fertility in the midst of worsening climate change effects, calls for a more efficient, accessible, and affordable agricultural field monitoring. High rainfall in the tropical region exacerbates soil fertility decline, especially on marginal soil cultivation that is driven by arable land shortage. Therefore, this study explored the potential of IoT-based monitoring of marginal soil properties on agricultural field. The latter setting is highly significant to both agricultural researchers and farmers to better understand climate change effects on yield.

Literature Review

Numerous studies have discussed IoT applications in agriculture (Gómez-Chabla et al., 2019). While IoT is implemented using various methods and platforms, the vast majority of researchers have opted for the open-source platforms that are more cost effective and easier to develop from the off-the-shelf controllers and sensors. IoT is also made possible by the specific communication protocol for data transport or delivery, and it can be classified into two big categories namely short-range and long-range communication.

Codeluppi et al. (2020) presented the development of a low-cost, modular, and Long-Range Wide-Area Network-based IoT platform, known as LoRaWAN-based Smart Farming Modular IoT Architecture (LoRaFarM). The system is dedicated to improving farm management in a highly customizable way. The system mainly captures farm management sensor data such as soil moisture of the field and humidity value of a greenhouse, and forwarded them to the Cloud using LoRa communication protocol. On the other hand, Sigfox protocol employed by our study is capable of handling long-range transmission of minimum 40 km distance using a single Base Station (Islam et al., 2021).

Soil NPK is not a commonly discussed IoT sensor. The alternative methods of capturing NPK values have been highlighted by (Lavanya et al., 2020; Fenila Naomi et al., 2019; Kapse et al., 2020; Goutham Chand et al., 2018). These literatures mainly focused on optical-based NPK sensing, and incorporated the colorimetric properties of a Light Dependent Resistor (LDR) and Light Emitting Diodes (LED) with a microcontroller unit to analyze the acquired value via fuzzy logic.

Another soil chemical property of interest in our study is soil pH. In comparison to the NPK sensor, a specific type of probe-based pH sensor is more widely available in the market and used by numerous studies. Oliveira Jr et al. (2020) used a DFRobot SEN0249 analogue spear tip pH sensor for semisolid material, while Ruslan et al. (2021) connected a similar analogue pH sensor to TTGO LoRa module based on ESP32 microcontroller for IoT soil monitoring.

Two of the most common agricultural soil physical property parameters are soil moisture and soil temperature. Doshi et al. (2019) and Balamurugan et al. (2021) presented an IoT system incorporating an ESP32s Node MCU with a generic analog soil moisture sensor based on the principle of electrical resistance. While our study utilized a different type of sensor, both adhere to the basic operation principles.

Peat soil as a type of marginal soil is associated with low nutrient availability, a factor that delimits its agricultural capability. Betong and Samarahan are two largest pineapple producing divisions in Sarawak, Malaysia (DoA Sarawak, 2019) that practice cultivation on peat soil. Nutrient depletion is significantly attributed to crop nutrient uptake, leaching, and readily fixed in peat soil (Boll Kassim, 2016; Codeluppi et al., 2020). Pineapple-cultivated peat soil recorded higher N, available P, and exchangeable K depletion rates than in undisturbed peat, in spite of NPK fertilizer application; and NPK depletion in peat soil is further exacerbated by rainfall incidence (Boll Kassim, 2016). K is more important than N in pineapple cultivation (Malézieux & Bartholomew, 2003). Leaching of K in peat soil reduces the rate of K recovery, causing lack of K availability for plant uptake (Ahmed et al., 2005), and subsequently affect pineapple fruits yield and quality (Mahmud et al., 2018). Soil pH is affected by NO3 leaching where growing H+ accumulation in the soils will increase soil acidity (Bolan & Hedley, 2003), and soil acidification is influenced by high rainfall incidence (NRCS, 2019). Increasing soil acidity is also contributed by long-term fertilizer application (Mahmud et al., 2018; Han et al., 2016). On the other hand, excessive K availability may reduce micronutrient uptake by pineapple plant during vegetative growth (Zubir et al., 2020). Therefore, constant monitoring of nutrient content in peat soil is necessary to ensure sufficient nutrient is available throughout the crop cycle, and IoT system provides the monitoring platform for various soil chemical properties.

Data and Methodology

Data

Soil physico-chemical properties data were acquired using Agromon Smart Agriculture and NPK Sensors (Agromon) (Wondernica Research, 2021) from the experimental field plot in Universiti Teknologi MARA Sarawak Samarahan campus. DID (Department of Irrigation and Drainage Sarawak, 2021) provided rainfall data for DID Samarahan rainfall station. Six physico-chemical properties, namely pH, moisture, temperature, and macronutrient values for N, P, and K were selected based on sensor availability (*see IoT System*). The data collection period between March and July 2021 was influenced by IoT system availability and functionality.

Study Area and Rainfall Station

An IoT gateway was installed on an experimental field plot at the Universiti Teknologi MARA Samarahan Campus farm in Samarahan division in Sarawak, Malaysia (1.446359° N, 110.451986° E) (Figure 1). Data were transmitted to the nearest Sigfox base station located within approximately 28 km radius in Santubong, Kuching Division. Data of daily rainfall were obtained for DID Samarahan rainfall station, the nearest station located within 4.5 km radius from the study area.

MD2 pineapple crops (*Ananas comosus* var. MD2) were cultivated with planting distance of 0.9 m to minimize nutrient leaching. Malaysian Pineapple Industry Board recommended distance of 0.3 m for single row commercial cultivation (MPIB, 2020). All plant beds were installed with plastic

Fig. 1. Study Area and Rainfall Station

mulching sheet to minimize fertilizer runoff, nutrient leaching, and crop-weed nutrient uptake competition (Mohammaddoust-e-Chamanabad et al., 2007). 20 grams per crop of compound NPK 12:12:17 fertilizer, the recommended rate at reproductive stage (MPIB, 2020), were applied on soil surface around the crops in March 2021.

IoT System

Agromon (Wondernica Technologies, Penang, Malaysia) is comprised of electrochemical and dielectric smart sensors and WT-AGRO-3S interface Wireless Transmitter (Figure 2) with the latter serving as gateway connecting sensors to Sigfox base station.

Fig. 2. Agromon Wireless Transmitter (WT-AGRO-3S)
Source: Wondernica Research, 2021

pH Sensor

The sensor is able to detect pH values within the range between 3.0 and 9.0, with accuracy statement of ±0.3 (Figure 3). The power consumption during usage is at approximately 150 mW. The operating voltage for the pH probe is 5V. Its analogue signal output voltage varies within the range of 0 and 3V.

Fig. 3. Soil pH sensor.
Source: Wondernica Research, 2021

Pre-usage calibration is required, involving submersion of probe into pH 4 and pH 7 buffer solutions to set the slope equation in order to obtain pH level within the standard 25°C room temperature calibration environment. The equations involved are as follows:

$$slope = (7.0 - 4.0) / ((neutralVoltage - 1500.0) / 3.0 - (acidVoltage - 1500.0) / 3.0) \quad (1)$$

$$intercept = 7.0 - slope * (neutralVoltage - 1500.0) / 3.0 \quad (2)$$

$$pH = slope * (voltage - 1500.0) / 3.0 + intercept \quad (3)$$

The *neutralVoltage* and *acidVoltage* values in equation (1) are obtained from the two-point calibration process. The constant floating value of 1500.0 refers to the voltage reading of pH 7 buffer at 25°C ambient temperature in milli-volt unit. *Slope* (equation 1) and subsequent *intercept* (equation 2) values are next derived from the graph. Finally, *pH* value can be interpolated using equation (3).

Soil Moisture and Temperature Sensors

The ranges of readable moisture and temperature (Figure 4) are between 0 and 100% with ± 3%accuracy tolerance, and between -30°C and +70°C with ±0.2°C accuracy, respectively. The operational power consumption rate is 200 mW.

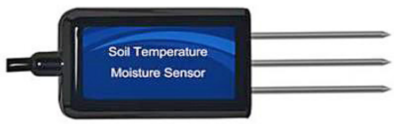

Fig. 4. Soil moisture and temperature sensors
Source: Wondernica Research, 2021

Soil NPK Macronutrient Sensors

The soil NPK sensors feature readable macronutrient range between 0 and 1999 mg/kg, with ±2% FS and highest resolution of 1 mg/kg (mg/L). The operational power consumption rate is 150 mW. Soil macronutrient detection and measurement capabilities of NPK sensors (Figure 5) are partially attributed to its stainless-steel probe's resistance to electrolysis, salt, and alkaline corrosion due to long-term insertion into soil. Probe shell is also vacuum-potted and completely waterproof. The probe is suitable for macronutrient detection in soil types of alkaline, acid, substrate, seedling bed and coconut bran (Kumar, 2021).

Fig. 5. Soil Nitrogen, Phosphorus, and Potassium (NPK) sensors
Source: Wondernica Research, 2021

The smart sensors were inserted into plant bed, next to the crop, prior to fertilizer application (Figures 6 and 7), and remained in the same location throughout data observation period. All field physico-chemical property values were transmitted via Sigfox network. Users are able to view real-time and time-series data through SATU Dashboard (SAT. ASIA, Malaysia) (Figures 8 and 9) from any computing device.

Fig. 6 and 7. Field setup of IoT System

Results and Discussion

This study is focused on daytime soil physico-chemical properties data. According to Albornoz et al. (2014), plant electrical conductivity rate is higher during the day, therefore higher nutrient uptake in plants is enabled by higher uptake from soil. Hence, more detectable changes in soil properties values occur during the day. While IoT data were measured on hourly basis, not all sensors were able to produce field data consistently. Here, observations with at least three variables with non-nil value are considered for statistical assessment, amounting to 28. Daily rainfall value is shared among same-day soil physico-chemical properties observations. A summary of observational data collected between March and July 2021 is shown in the following Table 1.

Mean daily rainfall at the experimental plot is 7.6 mm. While the highest rainfall was recorded at 60 mm, both lowest and median values are at 0. This study was conducted during the monsoon transition phase (March-May 2021) and southwest monsoon (May-September 2021) involving heavy rainfall in a short period of time in late afternoon or evening, and more days without rain, respectively (MetMalaysia, 2021a; 2021b). Soil moisture level was consistent at approximately 21%. The southwest monsoon's less day with rain also significantly influenced the highly positively skewed rainfall distribution, and subsequent highly negatively skewed soil moisture. The latter echoes the possibility of negative correlation between rainfall and soil moisture by (Sehler et al., 2019). Temperature between 25.7 and 30.4°C is optimum for pineapple growth (Crane, 2020). Mean soil pH of 5.5 corresponds with the acidic nature of marginal soil, the dominant soil type in Samarahan division (Maas et al., 1986). Marginal soil naturally contains low macronutrients. The highest value for N, P, and K macronutrients in this study are respectively 7.0. 9.0, and 25.0 mg/kg. N and K are very significant macronutrients for pineapple growth (Mahmud et al., 2018). Plant N uptake is the highest among all macronutrients prior to fruiting stage; while K that is most required for fruiting, retained the highest content reserve in

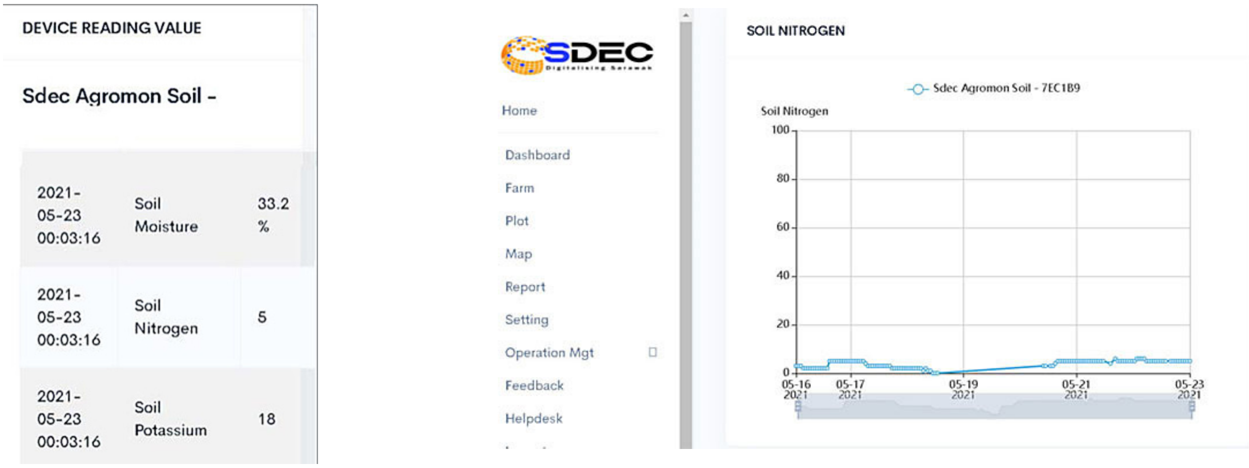

Fig. 8 and 9. Excerpts of SATU Dashboard Screen

Table 1. Descriptive statistics of Rainfall and Soil Physico-Chemical Property Variables

	Rainfall (mm)	Moisture (%)	Temp (°C)	pH	N (mg/kg)	P (mg/kg)	K (mg/kg)
Mean	14.268	22.204	26.814	5.204	2.714	3.393	9.643
Min	0	3.9	21.7	4	0	0	0
Median	4.25	22.95	27.05	5.05	2.00	3.00	8.50
Max	60.0	27.5	30.4	7.2	6.0	8.0	21.0
Std Dev	20.128	4.914	2.370	0.728	2.052	2.767	7.035
Skewness	1.355	-1.902	-0.539	1.023	0.444	0.248	0.294
Obs	28	28	28	28	28	28	28

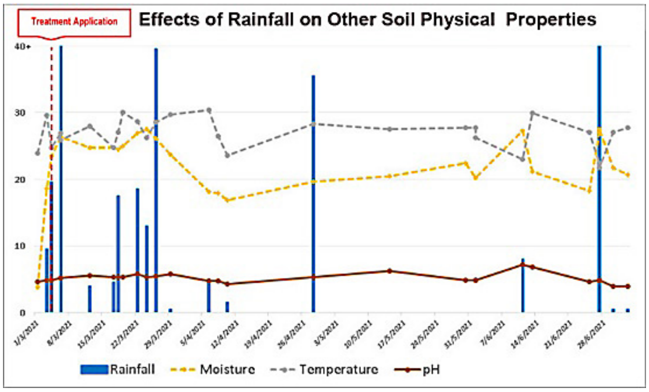

Fig. 10. Time Series Values of Rainfall, Moisture, Temperature, and pH

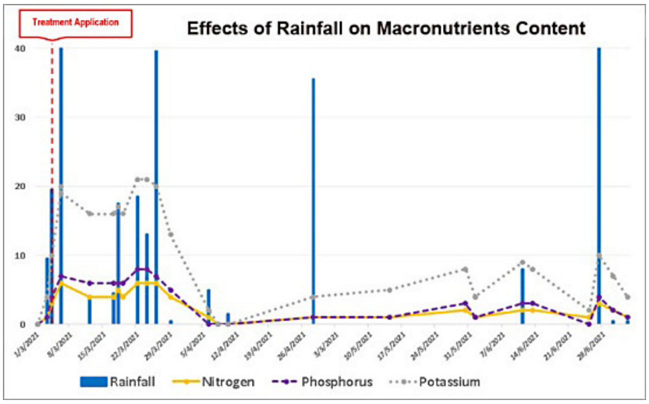

Fig. 11. Time Series Values of Rainfall, Nitrogen, Phosphorus, and Potassium

the soil until fruiting commences. P is the least important among the three macronutrients.

This study also examined time series changes of soil physico-chemical properties values, especially post fertilizer application. 20 grams per crop of NPK 12:12:17 compound fertilizer was applied in the first week of observation, as shown in the following Figures 10 and 11. Correlations between rainfall and soil chemical properties are summarized in Table 2.

Table 2. Variable Correlation

	Rainfall	Temperature	Moisture	pH	N	P	K
Rainfall	1						
Temperature Sig. (1-tailed)	-0.264 0.087	1					
Moisture Sig. (1-tailed)	0.600** 0.000	-0.218 0.133	1				
pH Sig. (1-tailed)	0.183 0.176	0.262 0.089	0.547** 0.001	1			
N Sig. (1-tailed)	0.595** 0.000	0.059 0.383	0.860** 0.000	0.567** 0.001	1		
P Sig. (1-tailed)	0.569** 0.001	0.024 0.451	0.877** 0.000	0.610** 0.000	0.981** 0.000	1	
K Sig. (1-tailed)	0.573** 0.001	0.037 0.427	0.883** 0.000	0.635** 0.000	0.987** 0.000	0.994** 0.000	1

*** Correlation is significant at the 0.01 level (1-tailed)*

Spearman Rank Correlation analysis is chosen due to the small number of observations and non-normal data distribution.

Rainfall is strongly correlated with soil moisture content in this study (rho = 0.600). High rainfall especially in March promoted high moisture content within the month. The lowest moisture content recorded in mid-April (16.9%) is significantly influenced by lack of rainfall two weeks prior (7 ml).

Leaching of soluble calcium bicarbonate from the soil, where the former's formation is attributed to rainfall, increases soil acidity (NRCS, 2019). Few rain incidences during the observation period has led to non-drastic changes in soil pH, as demonstrated by weak rainfall-soil pH correlation of *0.183* in Table 2. For example, the period up until 26 day after treatment (DAT) (29 March) received the highest cumulative rainfall, recorded pH range was just between 4.9 and 5.8. The subsequent two-month period saw an increment from 4.3 to approaching 7.2 (maximum pH) while recording only two days with rain. Therefore, low rainfall contributed to a decrease in soil acidity.

Rainfall generally inversely affects soil temperature. The usage of plastic mulching sheet in this study is a measure that conserves soil temperature (Abdul Kader et al., 2017). Correlation coefficient of -0.264 also reflects low soil temperature's association with trapped moisture, with the latter increasing with rainfall.

As shown in Figure 9, N, P, and K contents are at the lowest at 1 mg/kg, 1 mg/kg, and 4 mg/kg respectively prior to treatment application. An increase in NPK availability in the soil occurred between 14 to 21 DAT prior to plant nutrient uptake. Content decrement was detected between 6 and 17 DAT, post maximum rainfall on 3 DAT, before peaking on 18 and 19 DAT. Rainfall is strongly correlated to N, P, and K content (Table 2), therefore days with low rainfall recorded low nutrient content due to higher plant nutrient uptake, while being affected by nutrient leaching and fertilizer runoff from previous higher rainfall episode. N, P, and K contents deplete with time as no additional fertilizer application took place. Unfortunately, sensor error occurred between 36 and 38 DAT, where NPK sensors (Figure 5) were unable to record any content reading in spite of healthy plant growth. As a result, the IoT system under calculated nutrient content in the soil between 36 and 38 DAT.

Conclusion

Utilization of IoT-based sensors such as Agromon (Wondernica Research, 2021) is able to provide agricultural stakeholders with real-time soil chemical and physical properties data, especially post unfavorable weather conditions such as heavy rainfall and dry season. On the other hand, any field-based IoT system is exposed to technical challenges such as sensor error that may affect the consistency of data collection. At the moment, Agromon is able to provide estimation of soil chemical and physical properties under various weather conditions. As precision agriculture calls for application of good ratio of nutrients to optimize plant vigor (Zubir et al., 2020), reliance of robust field-based IoT system will support more efficient farm operations, such as precision fertilization, in order to improve global food security in the midst of worsening climate change effects.

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