STOP-AND-GO SOIL FERTILITY MEASUREMENT BY USING ALL TERRAIN VEHICLE FOR IN-SITU NITRATE MEASUREMENT

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ABSTRACT

Agriculture is the main source of food, and it plays an important role in economic growth. The chemical fertilizer that is not absorbed by the plant becomes chemical waste in the soil and flows into underground water, causing water pollution, soil pollution, and acidic rain. The waste of fertilizer in agriculture activities should be minimized to prevent the degradation of the environment. Hence, this project describes the design and development of on-the-go and real-time measurements for soil fertility by using an all-terrain vehicle (ATV). Conventionally, the soil sample needs to be sent to a laboratory for lab analysis, which takes about 2-3 months. Therefore, the device that can measure and analyze soil fertility is a stop-and-go device to determine fertilizer recommendations. The Ion selective electrode (ISE) for nitrate (NO3-) micronutrient with the GPS device will be installed on the ATV device and can be easily changeable. This paper aims to design and develop a soil proximal sensory-based soil collecting system with GPS that can analyze the concentration of the micronutrients contained in the soil and form a fertility mapping. The percentage of error for the sensor will be evaluated before the starting the soil sampling. The soil sample will be done in palm oil field, the depth of the soil collected in 20 cm and 42 samples collected in distance of 10 m between each sample in area of 4 acres. The correlation of the soil sensor and the lab analysis will be done. In the end, the soil mapping and the recommendation map to the farmer based on the result will be developed.

Keywords: Precision Agriculture, All-Terrain Vehicle, Ion selective electrode, soil fertility, soil micronutrient

INTRODUCTION

Agriculture stands as a cornerstone of the global economy, tasked with the monumental challenge of feeding a projected population of 9.7 billion by 2050. This sector, vital for supplying food, fuel, and raw materials, is grappling with formidable challenges such as climate change, water scarcity, soil degradation, and pestilence, which threaten its (Rozenstein *et al.*, 2024). The escalating demand for food necessitates a significant enhancement in agriculture.

The advent of data-driven agriculture has ushered in a new era of precision farming, particularly through the utilization of soil sensors that measure critical parameters such as pH, temperature, electrical conductivity, and humidity. These parameters are pivotal in assessing soil health and informing farming decisions (Ratshiedana *et al.*, 2023). The integration of this data through advanced data fusion techniques equips farmers with actionable insights, enabling informed decisions that optimize crop management and productivity (Kumar, Raghvendra and Souvik, 2021).

Data fusion, a method that amalgamates information from various sources, has been instrumental in providing a comprehensive view of the agricultural landscape. By employing MQTT for efficient data transmission and Grafana for effective data visualization, intelligent systems can offer precise recommendations for irrigation, fertilization, and pest control (Mandal, Ali and Saha, 2021). This approach not only improves crop yields but also reduces operational costs, representing a significant leap from traditional farming methods (N. S. Abu *et al.*, 2022).

The application of data fusion in agriculture is well-established, with studies demonstrating its effectiveness in enhancing crop management. For instance, electromagnetic techniques have been used to measure soil electrical conductivity and moisture, providing valuable data for irrigation management in arid environments (Kitchen, 2008). Similarly, dielectric properties-based methods have refined soil water content measurements, essential for precision agriculture.

Beyond immediate crop management, the data collected through these systems can be analyzed by agronomists and researchers to refine agricultural practices and aid in the development of new crop varieties (Melo, Báez and Acuña, 2021).This integration of data sources assists farmers in improving yields and profits and contributes to the advancement of sustainable agricultural practices.

This paper introduces a novel decision support system that leverages data fusion, focusing on rock melon crops. The system is designed to empower farmers with the information needed to make more informed decisions, thereby improving crop yields, increasing profitability, and conserving vital resources. The methodology includes data collection, fusion techniques, real-time recommendations, system testing, data analysis, and system enhancement. The performance evaluation of the system is discussed, highlighting its impact on sustainable agriculture and its potential as a model for future agricultural decision support systems.

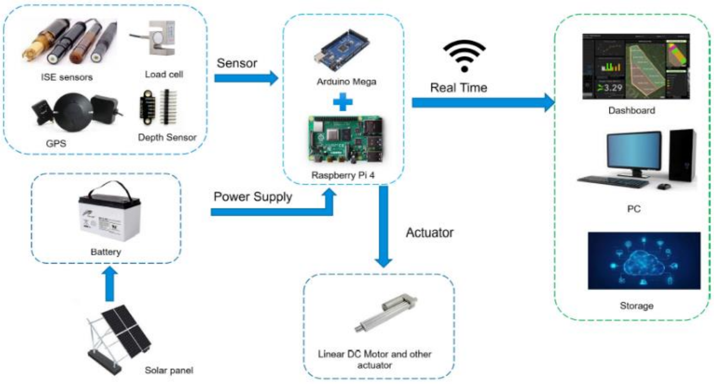
MATERIALS AND METHODS

System Configuration

Figure 1 illustrates the block diagram for the system configuration proposed for agricultural decision support systems. In this system configuration, the data will flow from the input, which is located in the agricultural field, up to the output, which is located remotely, such as in the plantation office or headquarters in the urban area. The input data from the agricultural sites are collected based on multiple sensors based on soil, crops, and environmental monitoring through developed cutting-edge sensor systems (N.S. Abu *et al.*, 2022). In terms of site security, the PIR sensor and integrated CCTV camera can be used to detect any unknown movement through artificial intelligence methods and send the data to the microprocessor such as the ESP32 microcontroller (Kassim, A.M., Jaafar, et al. 2013). The battery level which is supplied inside the sensor is also very important to ensure the sustainability of real-time data collected in the agricultural field (Azam, M.A. et al. 2021).

Moreover, the connection between both areas is through the Internet of Things, where data are transferred to the cloud by using the MQTT gateway. The communication can be done by using WiFi or LoRa transmission such that it can be cover long-range and wide-range communication, which perfectly applied in the plantation and agricultural sites (Kassim, Kamarudin, *et al.*, 2022). On the other hand, the output will be displayed and monitored by the supervisor of the top management and can be viewed through the personal computer and mobile phone dashboards (Kassim, A.M., Jamri, M.S., et al. 2012). The data will be collected and stored through USB and SD cards as hardware storage and in cloud storage, such as an AWS cloud server (Hasim, N., et al. 2012).

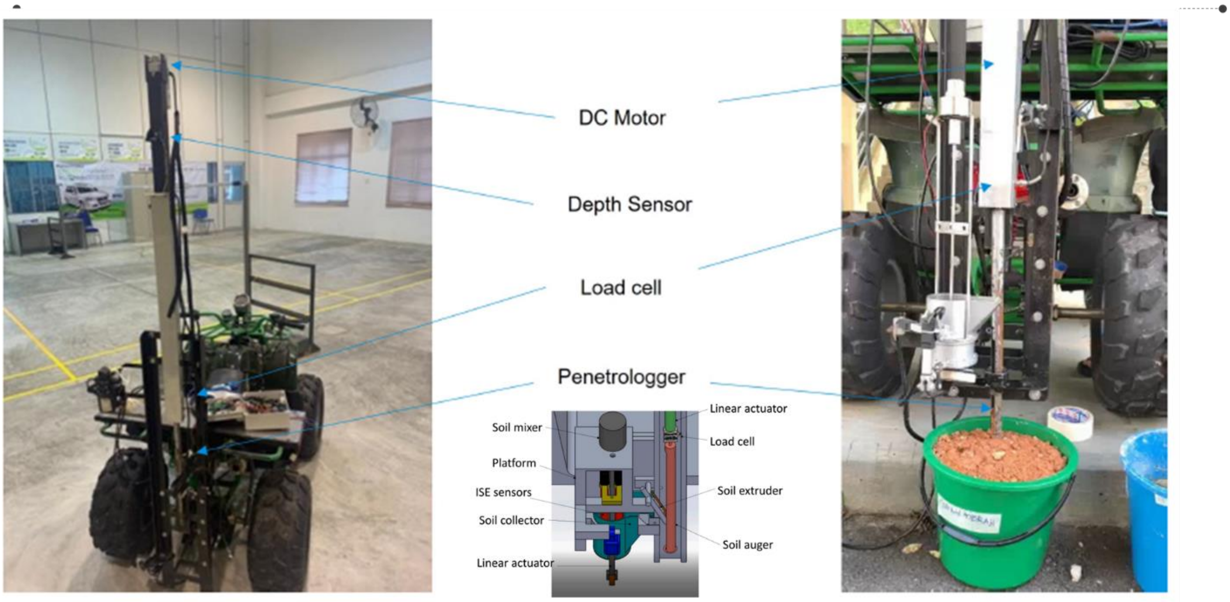
Figure 1. System configuration for agricultural decision support systems



Data Collection

The foundational phase entailed the systematic collection of soil data, focusing exclusively on four critical parameters: pH, temperature, electrical conductivity (EC), and humidity. Data acquisition was automated through soil sensors, with operators using mobile devices to collate data from various points within the rock melon farm (Kassim, Sahak, *et al.*, 2022)The MQTT protocol was harnessed to transmit this data efficiently, ensuring real-time updates and seamless communication between the sensors and the central system (Bin Mohamed Kassim, A., et al. 2015). Figure 2 depicts the Stop—Measure-Go device using ATV, illustrating the journey from the soil sensor during soil collection to the central decision support system.

Figure 2: Stop- Measure-Go device using ATV



Ion-selective electrode sensor (ISE)

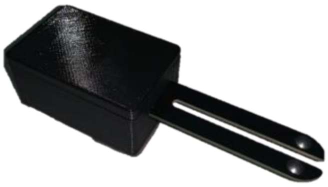
Two experiments will be conducted using an ISE sensor but with a different type of detection. The detection that will be tested is the concentration of soil potassium and nitrate content. The sensor model that will be used is a Vernier ion-selective electrode. This experiment will validate the measurement accuracy of the sensor reading to develop a site-specific soil measurement system. The sensor measured the concentration of both mixtures at the same time and sent the data to the Raspberry Pi via the serial port. The Vernier ISE sensor used in this project is shown in Figure 3.

Figure 3. Ion-selective electrode (ISE)

Soil electrical conductivity (EC) measurement

An electrical Conductivity sensor will be used to measure the nutrient in the soil. The sensor that will be used is a developed multi-soil environment sensor. Figure 4 shows the diagram of the sensor. This sensor is used to validate the accuracy of the sensor and to obtain the correlation between ISE and EC sensor.

Figure 4. Developed multi soil environment sensor



System Testing

The system underwent rigorous testing within the operational environment of a rock melon farm. The evaluation focused on the system's capacity to yield actionable insights and its consequential influence on farming outcomes, particularly in terms of irrigation scheduling, fertilization optimization, and pest management strategies (Kassim, Nawar and Mouazen, 2021). Figure 5 illustrates the deployed soil sensor in the field.

Figure 5. Deployed multi-soil and environment sensor on the field

System Performance Analysis

After the system's design is completed, the system's analysis will be assessed to verify that the data collected is valid. A simple experiment setup will be used to conduct the evaluation. The performance of the ISE sensor and GPS was assessed.

Evaluation of ISE sensor

To determine the ISE sensor's error percentage, it was immersed in a known concentration aqueous solution. Low-concentrated sodium nitrate (NO3-), NaNO3 (1.00 mg/L), high-concentrated sodium nitrate (NO3-), NaNO3 (50.00 mg/L), low-concentrated potassium(K) chloride, KCl (1.00 mg/L), and high concentrated potassium(K) chloride, KCl (50.00 mg/L) were used to make the aqueous solution. The sensor will be soaked in each solution, and the readings and the sensor's percentage of error will be recorded. The experiment will be done three times to determine the valid results. The formula for the percentage error is:

$$\text{Percentage of error} = |(\text{Actual value} - \text{Observed value})| / (\text{Actual value}) \times 100\% \quad (1)$$

Evaluation of GPS

For the GPS, the NMAE sentence reading in (Gpgll) format was exported to the NMAE decoder online, and the sensor's geographical location reading was shown on a Google map. Then, QGIS software will be used to generate the map based on the data that will be measured.

Data Analysis

The data will be analyzed using the linear regression approach. Linear regression is a data mining analysis approach for predicting group membership given a set of data. The relationship and structure between the input and output variables are also expressed using linear regression. Multiple linear regression predicts more than one data category than linear regression. Since there are many input variables, multiple linear regression is utilized, and it can be defined as follows:

$$Y = \beta_0 + \beta_1 X_I + \beta_2 {X_I}^2 + \epsilon_I \quad (2)$$

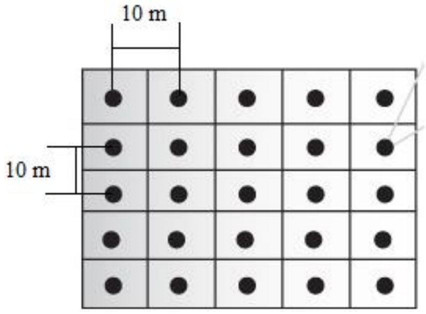
where Y is the output value, X is the observed value, 0 is the data curve, and I is the error The data from the ISE sensor and the EC measurement were compared using linear regression. However, because the units are different, some calculations must be performed before the comparison.

$$\mathrm{mg/L} = \mathrm{ppm} = (\mu\mathrm{S/cm}) * 0.64 \quad (3)$$

Soil Sampling

Soil samples were taken in the UiTM palm oil field in Jasin. A total of 42 soil samples were taken at a depth of 20 cm. The sampling area was 1 acre, and the sampling strategy was grid point sampling with a 10-meter separation between samples, as shown in Figure 6. 42 soil samples were gathered for lab testing to determine the sensor's validity. ISE sensor-based real-time and on-the-go soil nutrient analyses were also performed during sampling, and a soil nutrient table was developed.

Figure 6. Soil sampling grid



RESULT AND DISCUSSION

ISE sensor analysis

To assess the ISE sensor's performance, the percentage of error was analyzed. The results are shown in Table 1 and Table 2.

Table 1: Percentage of Error of ISE soak in LOW (1 mg/L) concentration Sodium Nitrate (NO3-) solution

Sodium Nitrate (NO3-)	LOW		
	1	2	3
Concentration (mg/L)	1.0062	0.9852	0.9544
Percentage of error (%)	0.62%	1.48%	4.56%

Table 2: Percentage of error of ISE soak in HIGH (50 mg/L) concentration Sodium Nitrate (NO3-) solution

Sodium Nitrate (NO3-)	HIGH		
	1	2	3
Concentration (mg/L)	50.79	50.18	50.05
Percentage of error (%)	1.58%	0.36%	0.09%

Tables 1 and 2 show a low percentage of errors recorded based on the test that was carried out. This will result in the ISE sensor being suitable to be used in measuring soil nutrients. The accuracy of a sensor is the most important element in choosing a parameter for measuring data to get an accurate result. Because the economic and/or environmental risk of applying the incorrect treatment to the crop might be significant, accurate measurements are critical in determining the appropriate management treatment.

Soil Sampling and data analysis

The linear regression graph was formed by comparing the concentration of nitrate (NO3-) with the EC. The graph of linear regression is shown in Figure 7. According to Figure 7, the linear regression of Nitrate (NO3-) is lower than the linear regression of the EC value obtained in the field, with R2(NO3-)= 0.0243 versus R2(EC)=0.3325. Figure 8 shows the relationship between Nitrate and EC. The correlation of nitrate to EC is R2 = 0.9616. The correlation for nitrate is the nearest to the value of 1, which is the most accurate.

Figure 7: Linear regression relationship between Nitrate and EC

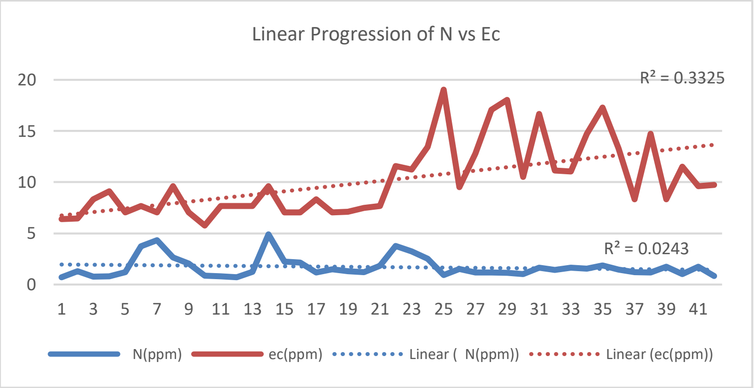
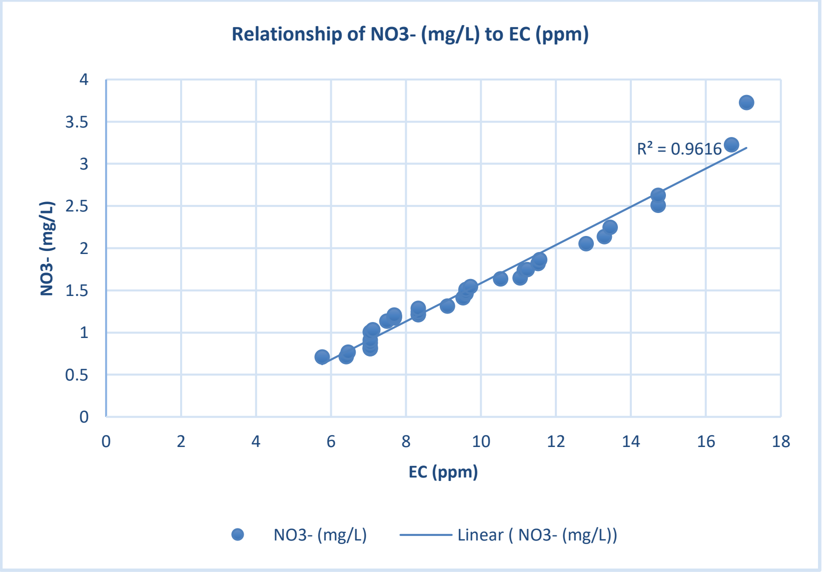


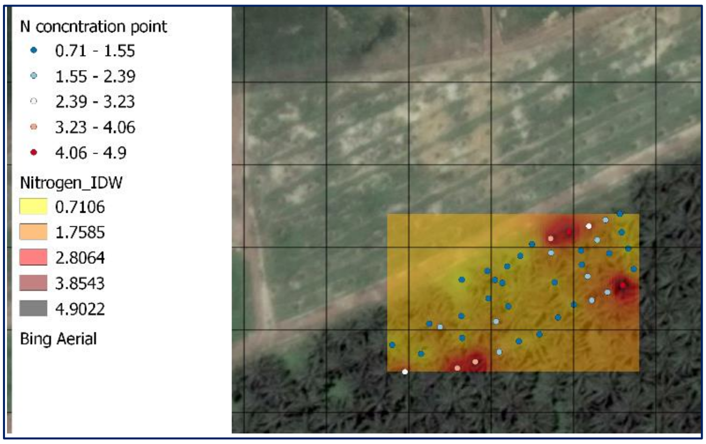
Figure 8: Relationship of nitrate to EC



Soil Mapping Analysis

The data collected were used to construct the fertility mapping of the palm oil field. Figure 9 depicts the field's fertility mapping in terms of nitrate (NO3-). A color legend was added to the fertility mapping of soil nutrients to identify the soil's nutrient level. Figure 9 depicts 42 samples with various color indicators. The content of nitrate ranges from 0 to 5 mg/L. This indicates that there is a lag of nitrate (NO3-) in the soil, as the most optimum nitrate (NO3-) for plant growth is between 10 and 20 mg/L. The system can also keep track of the information gathered through the user interface. The user interface may track the sensor's real-time GPS location, soil nutrient levels, and battery life.

Figure 9: Fertility Mapping of Nitrate (NO3-)



CONCLUSION AND FUTURE WORKS

In this paper, the efficiency of the ion-selective-electrode to be developed as a site specification nutrient measurement was evaluated in this study. Nitrate ISE is used as a nutrient in soil, and the measurement of nitrate (NO3-) is used as a composition for nitrogen. Each sensor shows an accurate reading based on the test that has been carried out. However, when comparing the result for the ISE sensor with the EC, it has a different reading; EC only detects the moisture of the soil and changes it into the form of conductivity. Compared to ISE, it will directly detect the nutrients in the soil. The correlation R2 value for the ISE sensor shows a high value which is nearest to 1. This means the sensor is accurate in reading the measurement of the soil nutrient. An accurate sensor needs to be used to develop a site specification soil nutrient measurement to replace the laboratory method for analyzing soil nutrients, which takes a long time to get the result.

ACKNOWLEDGEMENT

This research is financially supported by Ministry of Higher Education Malaysia through PRGS 2024-1 (PRGS/1/2024/FTKE/T00031). Deeply acknowledgement goes to Universiti Teknikal Malaysia Melaka, UTeM for providing equipment and facilities.

REFERENCES

Abu, N.S. *et al.* (2022) 'Automated Agricultural Management Systems Using Smart Based Technology', *International Journal of Emerging Technology and Advanced Engineering*, 12(5), pp. 123–131.

Abu, N. S. *et al.* (2022) 'Internet of Things Applications in Precision Agriculture: A Review', *Journal of Robotics and Control (JRC)*, 3(3), pp. 338–347.

Ahmad Anas Yusof *et al.* (2022) 'Land Clearing, Preparation and Drone Monitoring using Red-Green-Blue (RGB) and Thermal Imagery for Smart Durian Orchard Management Project', *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 91(1), pp. 115–128.

Azam, M.A., et al. (2021) 'Structural characterization and electrochemical performance of nitrogen-doped graphene supercapacitor electrode fabricated by hydrothermal method', *International Journal of Nanoelectronics and Materials*, 14(2), pp. 127–136

Bin Mohamed Kassim, A., et al. (2015) 'Performance analysis of wireless warning device for upper body level of deaf-blind person', *2015 54th Annual Conference of the Society of Instrument and Control Engineers of Japan, SICE 2015*, pp. 252–257, 7285379

Hasim, N., et al. (2012) 'Development of fuzzy logic water bath temperature controller using MATLAB', *Proceedings - 2012 IEEE International Conference on Control System, Computing and Engineering, ICCSCE 2012*, pp. 11–16, 6487107

Kassim, A.M., Jaafar, et al. (2013) 'Performances study of distance measurement sensor with different object materials and properties', *Proceedings - 2013 IEEE 3rd International Conference on System Engineering and Technology, ICSET 2013*, pp. 281–284

Kassim, A.M., Jamri, M.S., et al. (2012) 'Design and development of obstacle detection and warning device for above abdomen level', International Conference on Control, Automation and Systems, pp. 410–413

Kassim, A.M., Sahak, S., *et al.* (2022) 'Design and Development of Handheld Soil Assessment by Using Ion-Selective Electrode for Site-Specific Available Potassium in Oil Palm Plantation', in, pp. 210–221.

Kassim, A.M., Kamarudin, N.A., *et al.* (2022) 'Performance Analysis of Developed Multi Soil Sensor System for Smart Farming System', in, pp. 1165–1177.

Kassim, A.M., Nawar, S. and Mouazen, A.M. (2021) 'Potential of On-the-Go Gamma-Ray Spectrometry for Estimation and Management of Soil Potassium Site Specifically', *Sustainability*, 13(2), p. 661.

Kitchen, N.R. (2008) 'Emerging technologies for real-time and integrated agriculture decisions', *Computers and Electronics in Agriculture*, 61(1), pp. 1–3.

Kumar, P., Raghvendra, P. and Souvik, K. (2021) 'Soil health monitoring and management using Internet of Things (IoT) and data fusion techniques', *IEEE Access*, 9, pp. 66781–66789.

Mandal, S., Ali, I. and Saha, S. (2021) 'IoT in Agriculture: Smart Farming Using MQTT Protocol Through Cost-Effective Heterogeneous Sensors', *International Conference on Frontiers in Computing and Systems*, pp. 903–913.

Melo, O., Báez, N. and Acuña, D. (2021) 'Towards Sustainable Agriculture in Chile, Reflections on the Role of Public Policy', *International Journal of Agriculture and Natural Resources*, 48(3), pp. 186–209.

Mohamed Kassim, A., et al. (2016) 'Conceptual design and implementation of electronic spectacle based obstacle detection for visually impaired persons', *Journal of Advanced Mechanical Design, Systems and Manufacturing*, 10(7)

Nawar, S., et al. (2022) 'Fusion of Gamma-rays and portable X-ray fluorescence spectral data to measure extractable potassium in soils', *Soil and Tillage Research*, vo. 223

Ratshiedana, P.E. *et al.* (2023) 'Determination of Soil Electrical Conductivity and Moisture on Different Soil Layers Using Electromagnetic Techniques in Irrigated Arid Environments in South Africa', *Water (Switzerland)*, 15(10).

Rozenstein, O. *et al.* (2024) 'Data-driven agriculture and sustainable farming: friends or foes?', *Precision Agriculture*, 25(1), pp. 520–531.