IST-Africa 2019 Conference Proceedings
Paul Cunningham and Miriam Cunningham (Eds)
IIMC International Information Management Corporation, 2019
ISBN: 978-1-905824-63-2

Long Range Low Power Sensor Networks for Agricultural Monitoring - A Case Study in Kenya

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Abstract: This paper describes the development of a sensor system capable of monitoring parameters of interest in greenhouses and open fields with the aim of improving efficiency in food production. The sensors we deploy measure soil moisture, soil temperature, ambient temperature and relative humidity and transmit these parameters to a server over a Long Range wide area network (LoRaWAN) which exploits the long range low power LoRa protocol. We report the results of a field test conducted in central Kenya and show that our system can accurately measure parameters of interest and provide alerts to farmers.

Keywords: Internet of things (IoT), precision agriculture, Long range wide area network (LoRaWAN)

1. Introduction

Food security is a pressing challenge in Kenya and other developing countries [1]. As population increases, the pressure on available land and other resources necessary for food production such as water and energy is also increasing. It is therefore important to explore the role technology can play to make food production more efficient to ensure nations are able to feed themselves now and in the future.

Precision agriculture is a promising technology which has the potential to increase agricultural efficiency and improve food production [2]. Precision agriculture relies on the integration of sensor systems within the farm to monitor environmental conditions, determine the appropriate inputs and guide decisions. Precision agriculture goes hand in hand with the internet of things (IoT) which refers to the interconnection of sensors over the internet to enable the acquisition of data. In agricultural applications, IoT enables the collection of data related to several parameters that affect food production and the application of inputs.

Examples of the use of IoT in agriculture include production of greenhouse crops which grow in controlled environments. If the conditions are not monitored and controlled meticulously, yields reduce significantly. In addition, due to climate change, weather patterns are becoming unpredictable and field crops must be irrigated. This creates a need for monitoring of field conditions so that plants are irrigated only when necessary so as to conserve water [3].

This paper describes the development of sensor systems to monitor environmental conditions within greenhouses and in open fields so as to guide the application of farm inputs and improve food production [4]. The system developed was deployed at the Dedan Kimathi University of Technology farm in Nyeri, Kenya. The farm has several greenhouses growing crops such as tomatoes and onions. In addition, coffee and vegetables such as cabbage are grown on open fields.

The system monitors parameters such as temperature, humidity, soil moisture and soil temperature via the use of sensors connected to a microcontroller (MCU). The MCU is connected to a long range low power (LoRa) radio which transmits data to a cloud server via a gateway connected to the internet. By exploiting LoRa, we can install our sensors as far as one kilometre away from the gateway. The microprocessors used are able to run on battery power and since data acquisition is done at intervals of up to one hour, we exploit power management strategies to ensure the devices can run for long periods on batteries.

This project gives farmers the potential to own an affordable efficient greenhouse monitoring system. This paper also addresses the need to reduce cost and conserve water used in irrigation as well as the energy used. Farmers in Kenya also receive low incomes from crop production and here we explore the use of technologies that can cut costs.

This paper addresses the role of precision farming using sensor systems and LoRa radio for data transmission to monitor greenhouses. The data infrastructure is set up to receive, store and analyse the data in real time and later give feedback for corrective action based on environmental parameters [5]. This is aimed at creating conducive conditions for crops to thrive in as they grow, increase crop yields. Conserve key resources such as water and energy as well as boosting agricultural businesses for sustainability and food production.

The rest of the paper is organised as follows. Section 3 presents the methodology used to design the sensor system and describes the main components of the system. Section 4 describes the technologies used to obtain data from the sensors and create visualisations for data interpretation. Section 5 presents results of a test deployment of the system while section 6 describes the business benefits of the system. Section 7 concludes the paper

2. Objectives

The main objectives of this work are:

1. To design a sensor system to monitor environmental conditions within greenhouses and open fields.
2. To integrate the sensor system and LoRaWAN radio for long range low power wireless transmission of sensor data.
3. To develop data infrastructure to visualize and store sensor data.

3. Methodology

The sensor system design is based on the Nucleo-F446RE development board from ST[1] which is ideal for rapid prototyping. These microcontrollers are programmed using the mbed[2] platform which allows development of software in C/C++ and provides drivers for the peripheral sensor devices connected to the MCU. Data transmission is via LoRa radio. We employ a custom LoRaWAN transceiver shield and a Multitech gateway. Figure 1 shows the development board, transceiver and gateway used in our work.

Data transmission relies on a network server able to decode LoRa packets and forward them to a database for storage and analysis. The network server we use is provided by The Things Network[3] (TTN). Through the use of the Node-red open source tool, data is fetched from TTN and stored in the influxDB. The data can then be used for predictive analytics [6]. The data from the database is now channeled to another open source tool, Grafana, for visualization. In addition, data from node-red can be sent to the farmer directly via SMS, email or tweet notification. The alert notifies the farmer to take relevant action. Figure 2 shows a diagram schematic of the system.

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[1] https://www.st.com/en/evaluation-tools/nucleo-f446re.html

[2] https://www.mbed.com/en/

[3] https://www.thethingsnetwork.org/

Figure 1: The Nucleo-F446RE development board (left), custom LoRaWAN transceiver shield (middle) and MultiTech gateway.

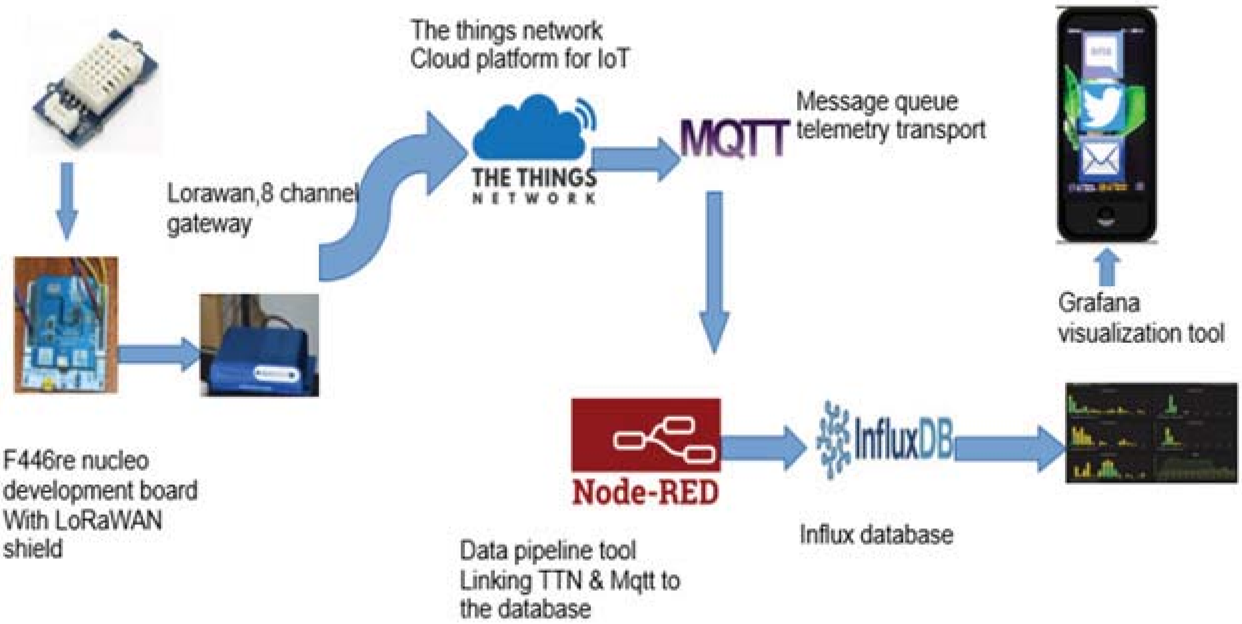
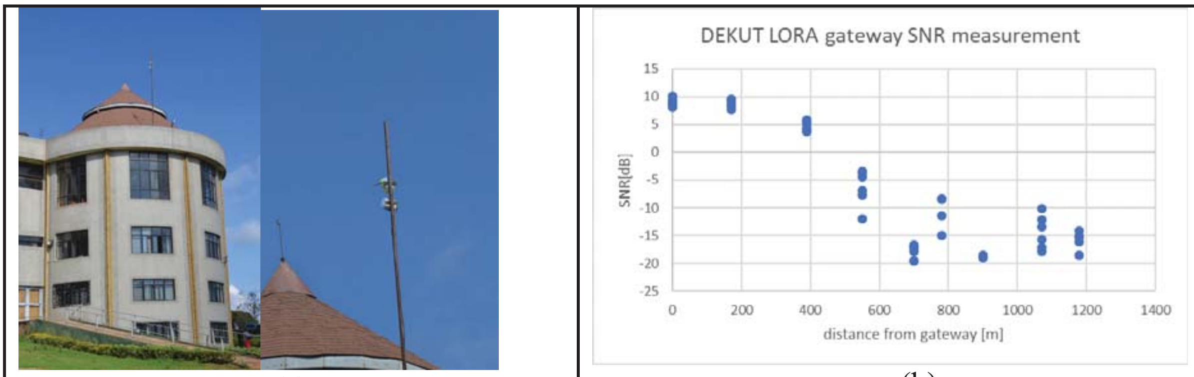


Figure 2: Schematic diagram of the system.

3.1 Gateway Installation and Radio Mapping

A MultiTech gateway was configured and installed on the roof of a centrally located building at Dedan Kimathi University of Technology at a height of approximately 40 meters [7]. This provided adequate radio coverage to the greenhouses located approximately 1.2 kilometers away and to the coffee farm approximately 500 m away. Figure 3 (a); shows the installed gateway.



(a)

(b)

Figure 3: (a) The gateway mounted at Dedan Kimathi University of Technology.(b) Received SNR as a function of distance from the gateway.

An experiment to determine the received signal to noise ratio (SNR) as a function of distance from the gateway was conducted to determine how far we could place our sensors and whether we could reliably obtain data from the greenhouses. Figure 3 (b) shows a plot of the received SNR as a function of distance from the gateway.

3.2 Sensors

Table 1 show all the sensors used in this study.

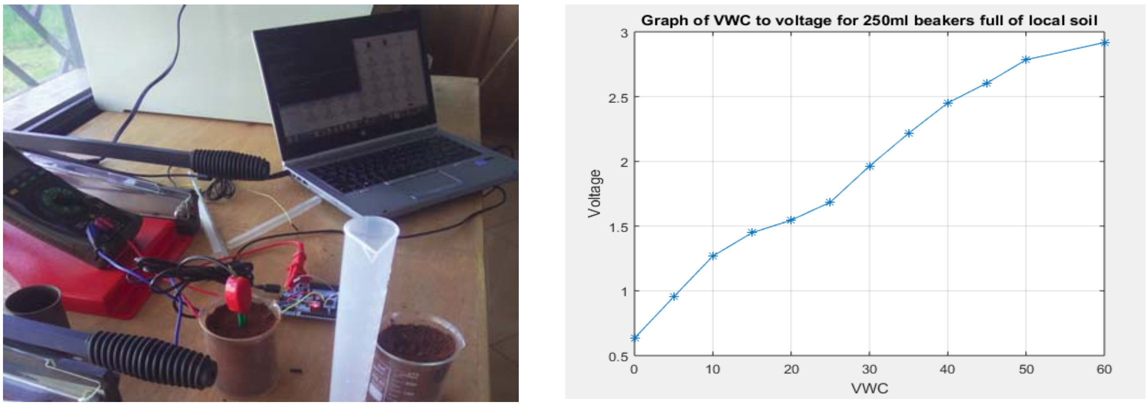
#	Sensor	Price (USD)	Link
1.	Vegetronix H400 soil moisture sensor.	$39.95	https://www.vegetronix.com/Products/VH400/
2.	Vegetronix soil temperature sensor THERM200-	$33.95	https://www.vegetronix.com/Products/THERM200/
3.	Grove DHT Humidity & temperature sensor.	$9.90	http://wiki.seeedstudio.com/Grove-Temperature_and_Humidity_Sensor_Pro/

Table 1: Types of sensors that were used and their prices.

3.2.1 Sensor Calibration

The vegetronix sensors we use to monitor soil temperature and moisture were calibrated in the laboratory using soil samples from the coffee farm. The soil moisture and temperature sensors produce an output voltage between 0 and 3V in response to changes in soil moisture and temperature respectively. To calibrate the soil temperature sensor, a soil sample was heated in a crucible as the output voltage was measured and soil temperature recorded using a mercury thermometer.A voltage-temperature plot was obtained.

Soil moisture is measured using the Volumetric Water Content (VWC) metric which is the ratio of the volume of water to volume of soil. Starting with dry soil of a given volume, we added water to vary the VWC from 5% to 60% in steps of 5%. For each sample the corresponding output voltage was recorded. Figure 5 (b) shows a plot of sensor voltage versus VWC.



(a) (b)

Figure 5: (a) Shows soil moisture sensor calibration laboratory set up. (b) Voltage vs VWC plot.

3.3 Programming

Mbed enabled boards such as the Nucleo-F446RE development board we use in this study can be programmed in several ways including using an online program compiler[4] and the offline mbed command line interface[5] (CLI). We used both online and mbed CLI to compile our programs. Code used in our experiments is available in the following GitHub repository https://github.com/ciiram/nyeri-coffee which is based on work by Jan Jongboom. https://github.com/janjongboom/dsa2018-greenhouse-monitor.

3.3.1 Energy Conservation

We take advantage of the power management scheme available in mbed OS which allows devices to be placed in a low power sleep mode between data acquisitions [8]. In our setup, we acquire data at 30 minute intervals and put the device to sleep in between these sampling times. Also, the sensors are only connected to the MCU when measurements are being made to prevent them from draining the battery. This setup results in considerable power savings. In particular, the board draws 42mA when in sleep mode and 111mA when taking measurements and transmitting data. The data acquisition period lasts for between 11-13 seconds.

4. Technology Description

This project uses the Long-Range Wide Area Network (LoRaWAN) Multitech 8 channel conduit which is a programmable Gateway for the internet of things (MTCDT Series) for data transmission. Each device which consists of a Nucleo-F446RE development board, a custom LoRaWAN shield and the connected sensors is registered on The Things Network platform which will retrieve data from the device and forward it to the database for storage. The Things Network provides credentials for device authentication which ensure the security of data transmissions.

4.1 Node Red

This is a programming tool that links hardware devices, softwares, online services and APIs to realise real time streaming of data resources. Node-red pellets have nodes that represent the various components in the communication pipeline and allow interconnection of these nodes to ensure seamless flow of data in and out of the platform [9].

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[4] https://os.mbed.com/compiler

[5] https://os.mbed.com/docs/v5.7/tutorials/quick-start-offline.html

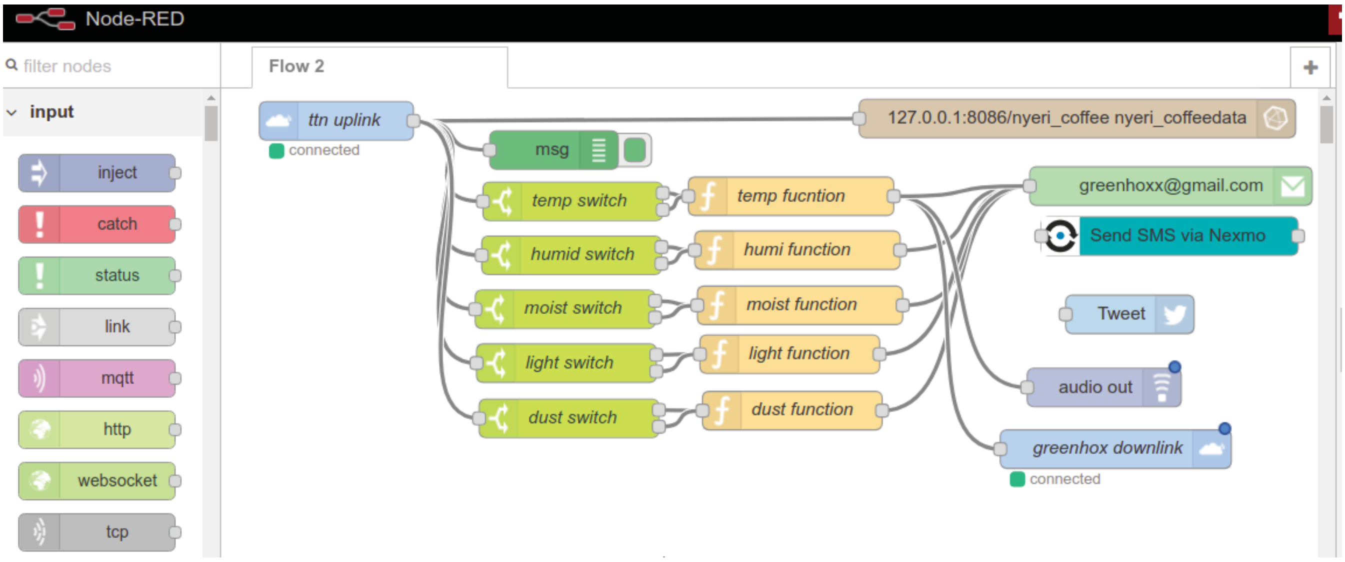
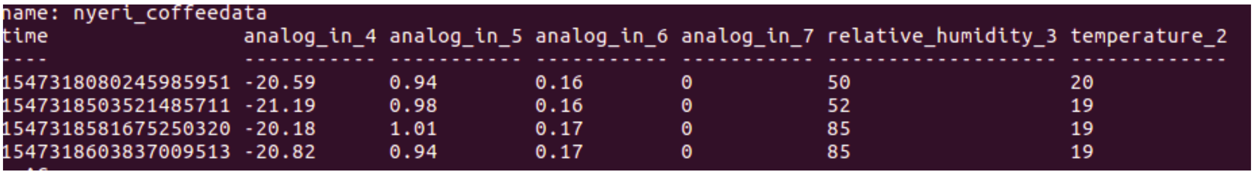


Figure 6: shows a node-red dashboard.

4.2 InfluxDB

This is an open source database tool that is installed on local machines or cloud based. It is a nosql platform for storage of data metrics and events (time series data)[10]. It can be integrated with other tools such as grafana and the node-red data pipeline that handles data. The influxdb installed on the local host just stores IoT data, but the cloud based database has other tools that aid in analytics, delivering insights and value in real time. The ease to scale out and clustering to eliminate point of failure is also attributed to cloud based influxDB.



```
name: nyeri_coffeedata
time                analog_in_4 analog_in_5 analog_in_6 analog_in_7 relative_humidity_3 temperature_2
----                ----------- ----------- ----------- ----------- ------------------- -------------
1547318080245985951 -20.59      0.94        0.16        0           50                  20
1547318503521485711 -21.19      0.98        0.16        0           52                  19
1547318581675250320 -20.18      1.01        0.17        0           85                  19
1547318603837009513 -20.82      0.94        0.17        0           85                  19
```

Figure 7: shows window snippet of data stored in influxDB.

4.3 Grafana

For data to make meaning to the user after analysis, it has to be visualised. Grafana is a data visualization and monitoring tool that supports other tools such as influxdb, graphite, prometheus elasticsearch among others. It has different versions from enterprise, cloud and open source with extensive flexibility for plugins with other platforms. The tool has appealing dashboard, easy to use and important features [11].

5. Results

A prototype system capable of recording soil moisture, soil temperature, ambient temperature and humidity was deployed in the coffee farm for approximately five days in October 2018. Figure 11 shows the plots of these parameters visualised using Grafana. The periodic nature of both ambient and soil temperature is visible from the plots. In addition, after a downpour on 6th October, 2018, the soil moisture level is seen to increase from approximately 25% to 60%.

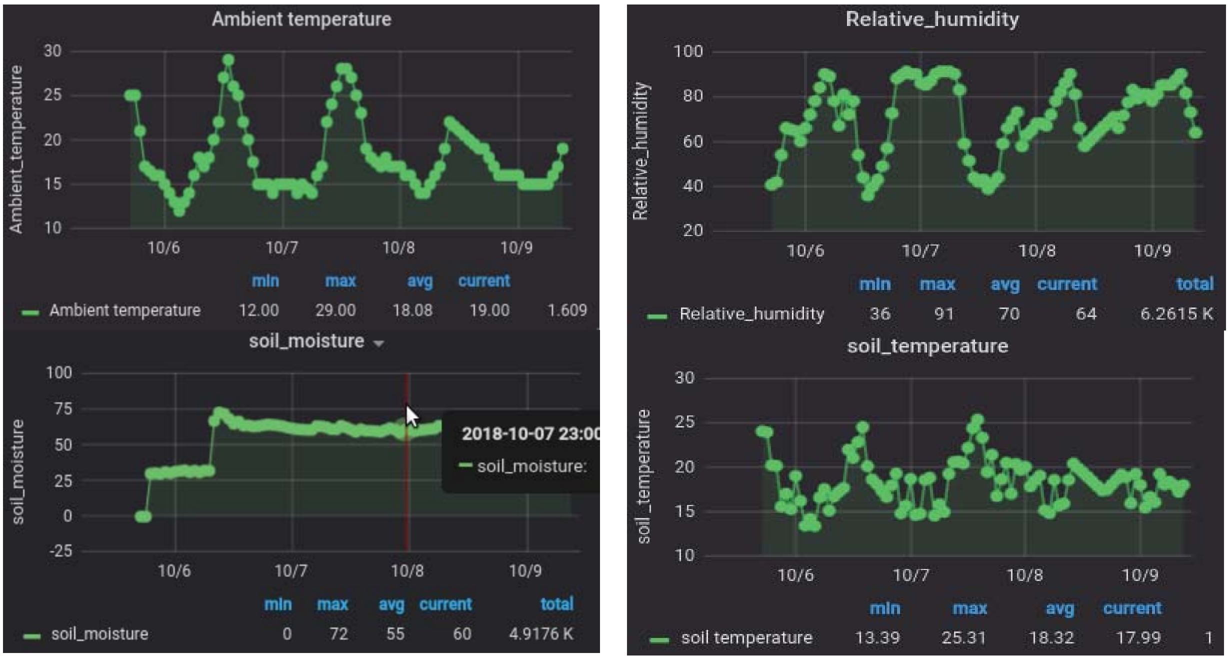


Figure 8: Plots on grafana visualization tool with ambient temperature (top left), relative humidity (top right), soil temperature (bottom right) and soil moisture.

The system was also able to send feedback to mobile gadget via SMS, tweet or email.

6. Business Benefits

The system we describe has the potential to reduce costs and improve production by controlling the application of farm inputs and also quickly detecting potentially adverse conditions on the farm and recommending corrective measures. For example, watering crops only when there is need and relying on feedback from sensors to stop irrigation can cut both electricity and water costs. Also, as more data is collected, insights can be drawn relating farm inputs, farm conditions and yield. This would guide the farmer to enable effective use of resources for maximum output.

The agro based businesses will benefit with increased crop yields and production patterns will be structured wisely. The sensor network will have more accurate sensors that will monitor the parameters more accurately, even extending to monitor other vital agricultural parameters. In addition, this will open a new avenue to better and new ways of monitoring greenhouses to increase crop production. Through this project the various pesticides manufacturing companies will use this as good way to know patterns and trends of different crop pests and diseases and device the best formula for them.

The system has the potential to greatly reduce costs with projected annual savings of approximately 25% -30% on energy and water. For example, for a small scale greenhouse (9m by 18m) in Nyeri, Kenya, the cost of energy can amount to approximately KES 17,000 per month assuming 6 electric fans, a water pump and electric lights [12]. A saving of between 25%-30% translates to approximately KES 57,000 annually on greenhouse energy.

Costs on water depend on whether the water is bought or pumped from a river. A small scale greenhouse can spend up to KES 20,000 on water bought from vendors and pumped by gravity. With approximate 25% to 30% water conservation this translates to approximately KES 66,000 on water annually.

7. Conclusions

This paper has demonstrated real time monitoring of greenhouse and field conditions at a coffee farm by leveraging long range low power radio networks. In particular we use

LoRaWAN for communication, Nucleo-F446RE development boards and sensors, cloud computing services such as TTN, node-red and databases. The system is able to collect temperature, relative humidity, and soil moisture data from the greenhouse and open fields, visualise and provide alerts seamlessly and in real time.

Future work will focus on analysis of the data acquired to provide meaningful predictions and alerts to farmers. In addition, we intend to develop web and android applications interfaced with the cloud services for easier management.

Acknowledgements

We would like to thank ARM for the generous donation of equipment, expertise and time which made this study possible. Special thanks to Damon Civin, Jan Jongboom and Gen-Tao Chiang. In addition we thank the DeKUT farm manager, Mr. Peter Mwirigi, and the Horticulture Supervisor, Purity Wanjiku Thumbi, for their help during the project. We also acknowledge funding from the ESRC DigDev network of the University of Sheffield.

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