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Research Article

# Design and Development of Smart Agricultural Greenhouse

**Uzuazokaro Nathaniel ASIBELUO[a] ID, Ovuakporaye Godwin EKRUYOTA[b*] ID**

[a]*Department of Electrical Engineering, Delta State University of Science and Technology, Ozoro, NIGERIA*
[b]*Department of Computer Science, Delta State University of Science and Technology, Ozoro, NIGERIA*

*(*): Corresponding Author: g.o.softsystem@gmail.com*

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## ABSTRACT

*Food insecurity across the globe has necessitated the need to optimize crops productivity through automation and Internet of Things (IoT). This research was carried out to develop a smart greenhouse system where the soil nutrient level, air temperature and soil moisture content can be closely monitored through sensors and the Internet. The sensors – major input components of the structure – sent information to a NodeMCU ESP8266 microcontroller for interpretation, configuration and necessary actions by the output components of the smart structure. The output components of the smart structure are the liquid-crystal display (LCD), water pump, fan, heater and relay modules, while the C++ programming language was used. Remarkably, the intelligence aspect of the smart greenhouse is built on the smart algorithm. Based on the performance evaluation of the various system units, the irrigation, cooling, heating and fertilization units have an accuracy of 85%, 90%, 90% and 85% respectively. Interestingly, the performance rating of the prototype was very encouraging, which makes this smart system a reliable material to combat global food insecurity.*

**Keywords:** *Algorithm, Food security, Programming language, Sensors, Smart greenhouse*

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## INTRODUCTION

Agriculture is a major contributor to several countries' Gross Domestic Product (GDP), accounting for about 24% of Nigeria's GDP and 14% of Africa's cumulative GDP (Statista, 2022). Food crisis has become a major global problem due to inequality between food production and increment in human population. According to Ballard (1996), substantial variation between farm product production and consumption has caused a severe demand-supply mismatch, which has resulted in food insecurity leading to hunger and malnutrition. Crop protection (weeding, fertilizers application, irrigation and pest control) which is one of the essential aspects of crop production, is a tedious and time-consuming operation; hence the application of advanced techniques have played a very essential aspects in avoiding crop failure (Ekruyota and Uguru, 2021; Sahni *et al.*, 2021).

Modern technologies have not only improved the industrial sector but also the agricultural sector. This has improved the rate of food production and supply chain for farm products, thus mitigating the problem of food insecurity (Cao, 2022). Among these technologies are automation and smart technology (Artificial Intelligence) which help produce healthy farm products in appreciable qualities and quantities. These technologies used configured sensing devices to carry out basic agricultural activities, thus bridging the food production gaps created by insufficient human power (Ramirez-Asis *et al.*, 2022). Within the past two decades, the application of artificial intelligence (AI) and cloud have helped to enhance agricultural activities logistic to be more proficient and reliable (Srivastava *et al.*, 2018; Ben Ayed and Hanana, 2021).

Though some scientists have developed smart systems for agricultural production activities (Goap *et al.*, 2018; Ogidan *et al.*, 2019; Nurhasanah *et al.*, 2021), related literature starch reviewed that there is not integrated smart greenhouse that can monitor the soil moisture, air temperature and quality within the green house. Therefore, this research was aimed at developing a prototype of smart greenhouse where the soil water and nutrients content, together with the air temperature can be closely monitored for the benefit of crops production.

## MATERIALS and METHODS

### The study area

This research was conducted Ozoro community of Delta State, Nigeria. The area is located within the tropical rainforest region with dense vegetation, characterized by high temperatures and high humidity. Ozoro has two basic climatic seasons – wet and dry climatic seasons, experiences about 1800 mm per annual and temperature of 39±70°C. The rainy (wet) season is associated with high humidity, while the dry season is characterized by reduced rainfall and lower humidity (Uguru *et al.*, 2022).

## Smart system architecture

The block diagram of the smart greenhouse structure is presented in Figure 1.

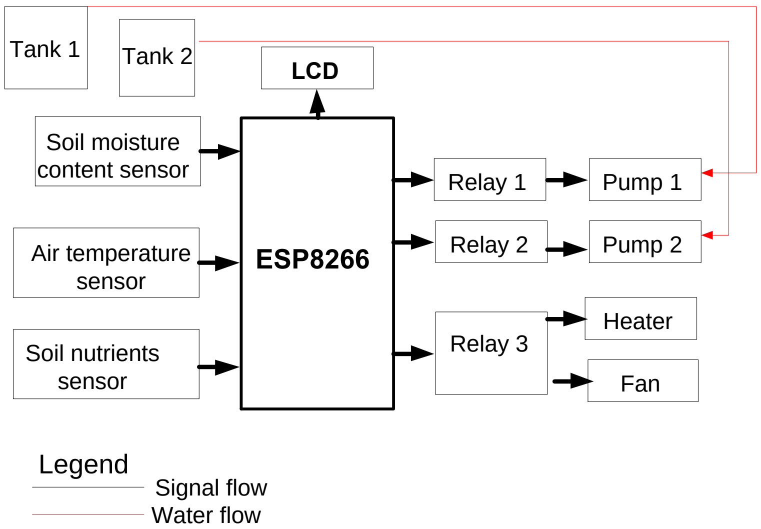


*Figure 1. The block diagram of the smart system.*

Essential components and their specifications

The components used for the automation are presented as follows:

## Microcontrollers

A NodeMCU ESP8266 (32-bit RISC CPU Xtensa LX106) with a Wi-Fi module that has an operating voltage of 3.3V, SRAM of 64 KB, clock speed of 80 MHz and input voltage that ranges from 7 V to 12 V direct current (DC), was used for the construction of the greenhouse prototype. The Arduino was also used as a supportive microcontroller to run some of the applications in the smart green house.

## Soil moisture sensor

A corrosion-resistant soil moisture sensor with an operating voltage ranging between 3.3 V and 5 V direct current, an operating current of 15 mA and PCB Size of 3.2 cm x 1.4 cm was used for the construction of the prototype. The corrosion- resistant probe was selected for the design because of some corrosive agricultural chemicals that will be applied to the soil during crop cultivation.

## Temperature and humidity sensor

The DHT11 temperature and humidity sensor module with voltage range of 3 V to 5 V, power rating of 2.5 mA and temperature accuracy of ±2°C was used for the design of the smart structure. The DHT11 sensor can measure temperature within the range of 0°C to 50°C and humidity of 20% to 80% (±5%), which are consistent with the crop's environmental requirements.

## Soil nutrient (NPK) sensor

The JXCT Soil NPK sensor with Modbus RS485, having a voltage range of 9 V to 12 V DC, operating environmental temperature that varied from 5°C to 45°C, and measuring range of 0 to 1999 mg $kg^{-1}$ was selected during the design of the smart greenhouse. This sensor gives high-speed measurement, while appreciable accurate results (Sensors, 2023).

**Water pump**

A water pump with the following specification: operating voltage ranging from 2.5 V to 6 V, operating current of 220 mA, water flow rate of 120 L $h^{-1}$ and maximum head of 110 mm. Two of these pumps were used for the design; one controls the irrigation line, while the other controls the fertigation line.

**Peripheral Component Interconnect (PCI) fan and heater**

A waterproof PCI fan (model: TFD-12025H12B/KW(RB)) with these specifications 12 V DC, power rating of 0.33 A, speed of 2200 RPM and airflow rate of 113.2 $m^3$ $h^{-1}$ was used for the design. The waterproof fan was selected due to the moist environment of the greenhouse resulting from the irrigation process. Also, a 12 V space air heater with a power capacity of 50 W, which can heat up to 100±10°C was used for the design and development of the prototype.

**Programming language used**

The C++ language programming language was used to design and develop the smart greenhouse. The C++ language was used because it is elegant, flexible, safe and object-oriented (O'Reilly, 2021). The graphical user interface (GUI) was developed with the Blynk application for Android. Blynk app is highly compatible with several IoT applications and can easily interact with the Arduino microcontroller (Idama and Ekruyota, 2023).

**Router module**

A 3-port 10/100 Mbps wireless router module, with voltage a rating of 5 V, CPU frequency of 650 MHz, and 2.4G Wi-Fi transmission rate of 300 Mbps was used to connect the greenhouse to the internet.

**The workflows**

The flowcharts and algorithms of the smart greenhouse are presented in Figures 2, 3 and 4. Figure 2 shows that the soil moisture sensor reads the soil moisture level and transmits the data to the microcontroller for interpretation. Then the microcontroller determines if it is relevant to activate/deactivate the relay module in charge of pumping machine 1, which is in charge of irrigation based on the pre-set soil moisture content range. Then, in Figure 3, the DHT11 sensor detects the greenhouse air temperature and transmits the data to the microcontroller to determine whether to activate/deactivate the relay connected to the heater or the fan based on the pre-set temperature range. Also, figure 3 revealed that the soil nutrients sensor will measure the soil nutrients level and transmit the same to the microcontroller for interpretation. Then, the microcontroller will initial the process of activating the relay module in charge of pump 2 if the nutrient levels are below the pre-set values, if the nutrient level matches the upper limits of the plant's requirement, the relay will deactivate pump 2 and the fertigation procedure will terminate automatically.

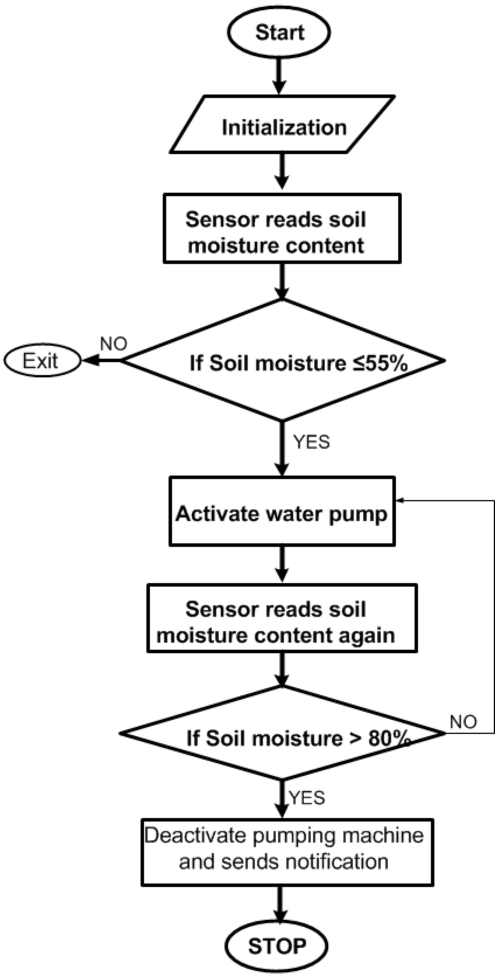


***Figure 2.*** *The flowchart of the irrigation unit.*

**Algorithm of the irrigation unit**

STEP 1: START
STEP 2: Initialized the system.
STEP 3: Sensor reads the soil's moisture content.
STEP 4: If the moisture content is less than 55% go to step 5, else go to step 9
STEP 5: Activate the water pump for irrigation.
STEP 6: Sensor reads the soil's moisture content again after one hour.
STEP 7: If the moisture content is greater than 80% go to step 8, else go to step 5
STEP 8: Deactivate the pumping machine for irrigation.
STEP 9: STOP

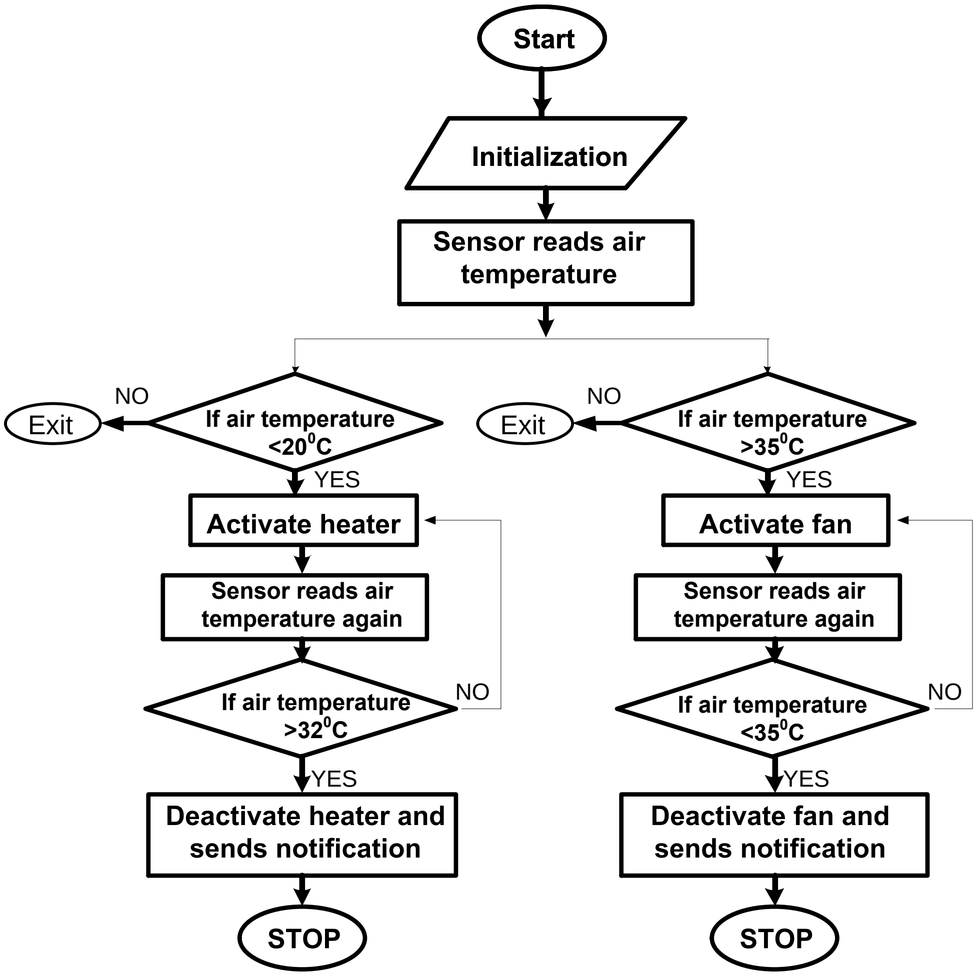


***Figure 3.*** *The flowchart of the cooling and heating units.*

**Algorithm of the cooling and heating sub-systems**

STEP 1: START
STEP 2: Initialized the system.
STEP 3: Sensor reads the air temperature content
STEP 4: Check for input command (Low temperature, High temperature)
STEP 5: If low temperature go to step 6, else if high temperature go to step 10, else go to Step 15.
STEP 6: Activate the heater and send notification.
STEP 7: Sensor reads the air temperature again.
STEP 8: If the temperature is greater than 32°C go to next step 9 else go to step 6.
STEP 9: Deactivate the heater and go to step 15.
STEP10: If the air temperature is greater than 35°C go to step 11 else go to step 15
STEP11: Activate the fan.
STEP12: Sensor reads the air temperature again.
STEP13: If the air temperature is less than 35°C go to step 14 else go to step 11
STEP14: Deactivate the fan and send notification.
STEP15: STOP

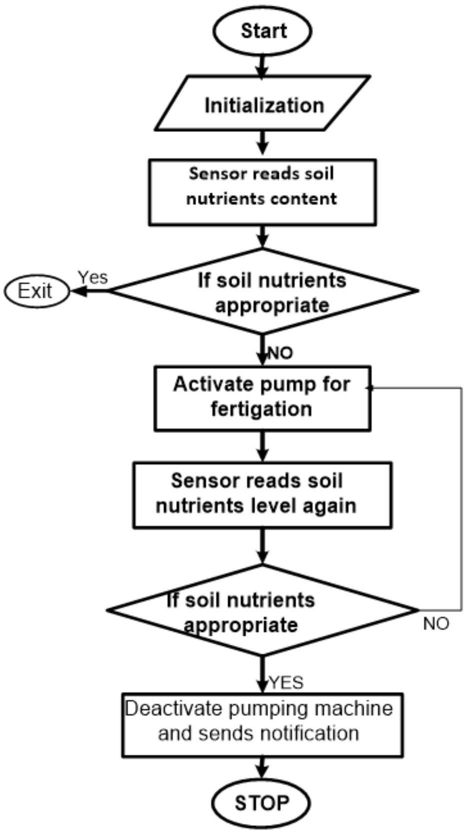


***Figure 4.*** *The flowchart of the fertigation sub-system.*

**Algorithm of the fertigation unit**

STEP 1: START
STEP 2: Initialized the system.
STEP 3: Sensor reads the soil's nutrients level.
STEP 4: If the soil nutrients levels are not appreciated go to step 5, else go to step 9
STEP 5: Activate the pump for fertigation.
STEP 6: Sensor reads the soil's nutrients levels again after one hour.
STEP 7: If the nutrients levels in the soil are within the recommended level go to step 8, else go to step 5
STEP 8: Deactivate the fertigation pumping machine.
STEP 9: STOP

**Testing**

The system was tested for 20 hours, starting with fresh leached oven-dry soil (moisture content of about 10%). The greenhouse was placed under the sun between 9 am to 6 pm for two days. To evaluate the accuracy of the smart greenhouse, a digital handheld thermometer and soil meter were used to determine the temperature and soil moisture content of the greenhouse.

The interior temperature of the greenhouse was programmed to range between 240°C to 300°C, the moisture content was programed to vary from 60% to 80% and the nutrient values were programmed to range from 150 mg $kg^{-1}$ to 400 mg $kg^{-1}$. Therefore, if any parameter designed for the smart system falls outside the pre-programmed values, a sensor will trigger the relay to start or stop the water pump, fertigation pump, fans or heater to regularize the situation. Additionally, the GUI allows the user to Switch “ON” and “OFF” the systems if the need arises if there is a reliable internet network.

The temperature, soil moisture content and soil nutrient level of the greenhouse environment will be programmed according to the environmental requirement of the intended planted crop inside the greenhouse. According to Nurhasanah *et al.* (2021) reports, most vegetables and fruits require soil moisture content that ranges from 60% to 80% and environmental temperature that ranges from 240°C to 300°C. Environmental conditions outside the optimal range of a crop severely affect its production and performance (Ma *et al.*, 2016; Xue *et al.*, 2017; Awad *et al.*, 2022).

## RESULTS AND DISCUSSION

The test results of the smart greenhouse are presented in Table 1. The findings revealed that the heating and watering of greenhouse crops can be done through automation and smart process, which is further confirmation of the researches carried out by Goap *et al.* (2018) and Nurhasanah *et al.* (2021). The increment observed in the greenhouse air temperature during the test running period can be linked to the external atmospheric conditions. It was noted from the results that pump 2 is rarely started when compared to pump 1; pump 2 was switch ON only three times (with 2 false positive), as against 10 times recorded in pump 2. This can be linked to lower nutrients depreciation rate in the soil, when compared to water under the same environmental conditions. Xue *et al.* (2017) stated that water consumption by plants tends to be higher than nutrient consumption. Since water is more volatile than most plants nutrients, therefore its ability to evaporate is higher than those plants’ nutrients. A similar high-water consumption rate during automated irrigation was noted by.

*Table 1. Results obtained from the greenhouse testing and evaluation.*

| | Soil moisture | Air Temperature | Nutrient level | Irrigation system | Heater | Fan | Fertigation |
|---|---|---|---|---|---|---|---|
| 9:00 AM | 12.6 | 20.6 | Low | ON | ON | OFF | ON |
| 10:00 AM | 18.9 | 21.9 | Low | ON | ON | OFF | ON |
| 11:00 AM | 24.1 | 24.6 | Low | ON | ON* | OFF | ON |
| 12:00 PM | 30.7 | 26.5 | Low | ON | OFF | OFF | OFF* |
| 1:00 PM | 51.3 | 28.1 | High | ON | OFF | OFF | OFF |
| 2:00 PM | 67.4 | 32.8 | High | ON | OFF | ON | OFF |
| 3:00 PM | 75.4 | 31.2 | High | ON | OFF | ON | OFF |
| 4:00 PM | 88.2 | 26.8 | High | OFF | OFF | ON* | OFF |
| 5:00 PM | 83.1 | 25.3 | High | OFF | OFF | OFF | OFF |
| 6:00 PM | 82.8 | 24.1 | High | OFF | ON* | OFF | OFF |
| 9:00 AM | 79.5 | 21.7 | High | OFF* | ON | OFF | OFF |
| 10:00 AM | 73.9 | 23.3 | High | OFF* | ON | OFF | OFF |
| 11:00 AM | 68.2 | 25.4 | High | OFF | OFF | OFF | OFF |
| 12:00 PM | 62.8 | 27.9 | High | OFF | OFF | OFF | OFF |
| 1:00 PM | 55.6 | 32.2 | High | ON | OFF | ON | OFF |
| 2:00 PM | 60.3 | 31.6 | High | ON | OFF | ON | OFF |
| 3:00 PM | 68.1 | 30.4 | High | ON | OFF | ON | ON* |
| 4:00 PM | 77.3 | 27.2 | High | OFF* | OFF | OFF | ON* |
| 5:00 PM | 83.5 | 25.6 | High | OFF | OFF | OFF | OFF |
| 6:00 PM | 81.8 | 24.8 | High | OFF | OFF | ON* | OFF |

* = false results

## Performance evaluation of the system

### The irrigation unit

It was observed that the irrigation system gave false results in 3 outputs out of the 20 outputs.

Therefore, the performance of the smart irrigation system = $\frac{17}{17+3} \times 100 = 85\%$

### Heating unit

It was observed that the heater gave false results in 2 outputs out of the 20 outputs.

Therefore, the performance of the automated heating system = $\frac{18}{18+2} \times 100 = 90\%$

### Cooling unit

It was noted from the experimentation that the fan gave false results in 2 outputs out of the 20 outputs.

Therefore, the performance of the automated cooling system = $\frac{18}{18+2} \times 100 = 90\%$

### Fertigation unit

It was noted from the experimentation that the fertigation system gave 3 false results out of the 20 outputs.

Therefore the fertigation system performance = $\frac{17}{17+2} \times 100 = 85\%$

**Overall performance**

The overall performance of the smart greenhouse = $\frac{85+90+90+85}{4}$ = 87.5%

Based on the results presented in Figure 5, it was observed that the soil moisture sensor has 85% accuracy, the DHT11 sensor has 90% accuracy and the soil nutrient sensor has 85% accuracy. The findings of this study that the smart greenhouse performance was above average; therefore, there was strong correlation between the hardware and the software. This indicates that the three sensors and the programming used in the development of the greenhouse can keep the air temperature, soil moisture and soil nutrients properly for proper growth and development of the crops planted inside the greenhouse. These achievements in the automation and using IoT to control essential parameters inside the greenhouse are similar to works done by Goap *et al.* (2018), Ogidan *et al.* (2019) and Nurhasanah *et al.* (2021). Therefore, this smart system will enhance the greenhouse production of fruits and vegetables, mainly by incorporating the soil nutrients analyzer into the smart system.

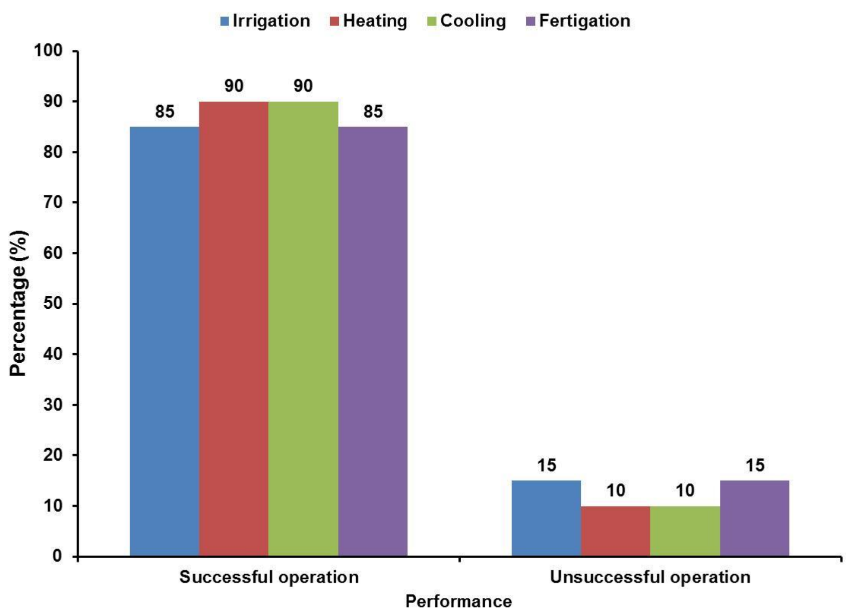


***Figure 5.*** *The performance of the smart system.*

## CONCLUSION

This system was developed to use automation and IoT to enhance crop production. The input components of the smart greenhouse include soil moisture sensor, soil nutrients sensor and temperature sensor; the process (microcontroller) components consist of the ESP8266 and associated Arduino; the output components comprise liquid-crystal display (LCD), water pump, fan, heater, and the relay modules, while the C++ programming language was used. Results obtained from the experimentations of the prototype structure revealed that the performance rating of the greenhouse was above average (87.5% efficiency). This depicted that the sensors, hardware devices and coupled with the IoT can guarantee constant monitoring of a greenhouse soil nutrient level, moisture content and the environmental air temperature and condition. This will enhance the crops productivity and alleviate the problem of food insecurity ravaging Nigeria.

## DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest.

## CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.
**Ovuakporaye Godwin Ekruyota:** Data analysis and review of the original draft.
**Uzuazokaro Nathaniel Asibeluo:** Designed the research Methodology and writing of the original draft.

## ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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