Design of a system for acquiring and measuring thermal, hydric, chemical and mineralogical properties of cultivated land, ambient temperature and relative humidity

Sahi Roland DIOMANDE, Kouamé Norbert N'GUESSAN, Edoe Fernand MENSAH and Yao N'GUESSAN

Abstract— **The lack of reliable information on the properties of agricultural land in real situations and in real time drives up the cost of equipment and measurement techniques. This creates real problems for growers in managing land, water and crop nutrient resources. To give every grower the chance to have accurate information about his farming environment that could help him achieve a good yield, we designed a system for acquiring temperatures, soil and ambient air humidities, phosphorus, calcium and nitrogen contents, electrical conductivity and hydronium potential of cultivated land, and carried out measurements in the Sikensi region over the course of a week. Arduino Uno technology using JXBS-3001-SCY-PT soil sensors is employed. The results showed that the acquisition system designed was simplified and could be implemented by anyone at a low cost. Experimental results showed that mineral content, pH and soil moisture are higher in the subsurface than at depth. In the first 20 cm, calcium content ranged from 6 to 56 mg/kg, with an average of 27.89 mg/kg; nitrogen content varied from 2 to 18 mg/kg, with an average of 9.67 mg/kg; phosphorus content varied from 3 mg/kg to 23 mg/kg, with an average of 12.78 mg/kg; pH varied from 5.40 to 7.46, with an average of 6.25 mg/kg; electrical conductivity varied from 9 to 253, with an average of 157.67; and soil temperature rose from 23.84°C to 29.1°C. Ambient temperature ranged from 25°C to 35°C, with an average of 28.40°C, while relative humidity varied from 50% to 90%, with an average of 75.63%.**

***Index Terms* —** Data acquisition system, soil calcium content, soil pH, soil phosphorus content, soil nitrogen content.

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I. INTRODUCTION

The evolution of information technologies has opened the way to resolving many of the impossibilities [1] of today's world. These technologies provide accurate, reliable information in real time for efficient resource management. The involvement of cutting-edge technologies such as artificial intelligence, the Internet of Things, and mass data analysis, has gained momentum in all fields of application [2], such as medicine [3], agriculture [4], education, industry, etc. [4, 5].

In agriculture, access to reliable data (soil and ambient air temperatures and humidities, mineral salt content, hydronium potential (pH), solar radiation, etc.) [6] in real time via low-cost data acquisition systems [7], remains a challenge. These parameters are an integral part of crop health and well-being. Knowledge of these parameters enables farmers to forecast and prepare their crops against climatic scourges to increase Gross Domestic Product (GDP) and food security [8]. This farming practice also spares crops from the damage caused by modern agriculture's regulated chemical and phytosanitary products [9] and enables them to cope with thermal stress. In addition, the acquisition of accurate, stable data on agricultural environments enables harvest decisions to be made, agricultural products to be marketed, and agriculture to be controlled [10]. The development of a system for acquiring the vital properties of agricultural land therefore contributes to optimizing agricultural quality and production [11], the sustainability of agriculture, and the rational management of land and water resources, as well as decision-making processes [10, 11].

A number of studies have been carried out to investigate the properties of agricultural soils. For example, Placidi et al., (2023) [14] proposed a bifunctional system based on a modified commercial capacitive sensor and an AD5933 impedance converter IC to simultaneously measure salinity, volumetric water content and the electrical conductivity of sandy-siliceous soils. Kojima et al., (2016) [15] have developed a capacitive sensor based on a copper polyethylene terephthalate film substrate. By integrating NCP18WF104J03RB thermistor temperature sensors, they measured moisture and temperature at 10 cm, 20 cm and 30 cm soil depths. The sensor network system developed includes an integrated wireless communication module for data collection. Lekshmi *et al*., (2014) [16] evaluated soil moisture measurement techniques, their associated limitations and the influence of soil mineralogy, salinity, porosity, ambient temperature, the presence of organic matter and matrix structure on soil moisture content. Arunaganesan et al., (2013) [17] realized a data acquisition system based on an Intel 8051 microcontroller that used the LM35 temperature sensor to measure temperature. The data was recorded by the computer via an RS-232 interface..

In previous studies, two options for acquiring the above-mentioned parameters of interest were considered. These include the acquisition of soil surface temperature and moisture data using high-cost probes or sensors, as these are purchased separately [4, 6], with unit prices ranging from US$150 to US$5,000, or sensors for simultaneous measurement of soil water content and electrical conductivity, such as Time Domain Reflectometry (TDR) sensors costing US$3,000 or more [15], or DS18B20 temperature sensors in laboratories [12, 13], and the acquisition of chemical and mineralogical soil properties in the laboratory. Unfortunately, fluctuating soil temperature, humidity, and chemical and mineralogical properties have a huge influence on crops, which can exceed the first fifteen centimeters of soil depth in real-life situations. As for laboratory data, it is limited by the fact that they do not reflect actual farming conditions.

This topical subject has therefore prompted contributions from a number of researchers who have used analog sensors [7], electrochemical, electrical and electromagnetic sensors, optical and radiometric sensors [16]. However, the correct operation of these sensors requires complex calibration [20] and presents communication difficulties [2], resulting in significant data errors. To circumvent these difficulties, electronic sensing by data acquisition systems using Arduino modules have become attractive approaches [11]. The use of high-precision soil-specific sensors is strongly recommended. As for conventional systems for measuring meteorological parameters in the ambient air, not only are they composed of a set of expensive instruments whose use requires skilled labor for maintenance, but also, weather stations are sometimes installed in areas of great influence and far from agricultural production sites. On the other hand, the soil property acquisition systems used in previous studies have considered simple sensors for measuring a single or two items of information (soil temperature and/or moisture or water content). This makes the systematic acquisition of several pieces of soil information in record time very difficult and costly [15].

The main objective of the study is to design a system for acquiring the temperature and humidity of cultivated land and ambient air, pH, chemical and mineralogical properties of soils using a single type of sensor, with high accuracy and accessible to all at a low purchase cost.

Specifically, this involves:

i) designing a system for acquiring soil and ambient air properties using appropriate sensors;

ii) measuring variations in soil and air temperature and humidity; and, measuring the chemical (pH) and mineralogical (nitrogen, phosphorus, calcium content) properties of soils.

II. Materials and Methods

A. *Presentation of the study area*

Submit your manuscript electronically for review. Among the regions of Côte d'Ivoire's Lagunes district, the Agnéby-Tiassa region was created in July 2011 by the Ivorian government, and its constituency registers Sikensi as one of its departments. In its legislative representation, Soukoukro is a village in the Sikensi sub-prefecture, 8 km from the town. Soukoukro's latitude is 5.730 and its longitude is -4.621. Agriculture is the main source of income for the villagers of this village, due to the interesting conditions for crop development. In addition, the Sikensi area boasts soils with interesting chemical and mineralogical properties, as well as solar potential, providing the heat flux needed by plant roots, and high annual rainfall.

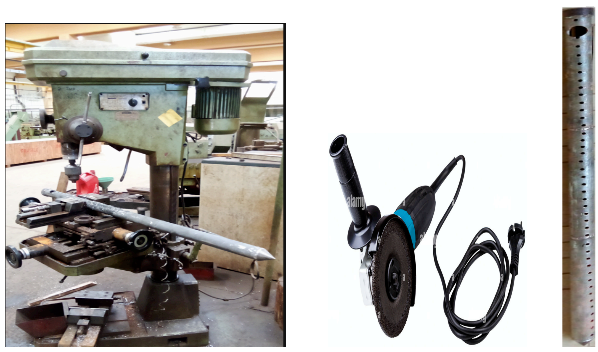
B. *Design of a system for acquiring soil and ambient air temperature and humidity, and the chemical and mineralogical properties of soils*

The data acquisition system consists of three parts:

- A metal tube is thermally insulated with thin polystyrene to avoid the effect of the metal material's resistance on heat transfer in the soil. The sensors are inserted into this rod, and their tips are pulled out of the rod and inserted directly into the soil at the meshed depth.
- The combination of electronic components using the sensors forms the acquisition system.
- Three firmware packages provide the means of communication between the sensors and the computer.

1. Metal tube

A metal tube was manufactured to serve as a means of protecting and inserting the sensors, at the desired depth and in real-life situations, into the earth (Figure 37). The metal tube, 1.5 m long and 5 cm in diameter, was designed in the Mechanical and Energy Engineering workshop at the Institut National Polytechnique Félix Houphouët-Boigny, using two machines. A milling machine was used to create the sensor ports, and a grinding wheel was used to create a slot on the opposite side of the ports along the length of the tube to facilitate sensor insertion. Using a metal welding machine, the end of the tube was welded together, with the holes equidistant by 2.5 cm.



(a) (b) (c)

Figure 1: Design of a metal tube using two machines: (a) a milling machine, (b) a grinding wheel and (c) a metal tube

2. Electronic components of the Arduino Uno acquisition system

There are two main parts to the acquisition system: hardware and firmware [21].

Electronic materials

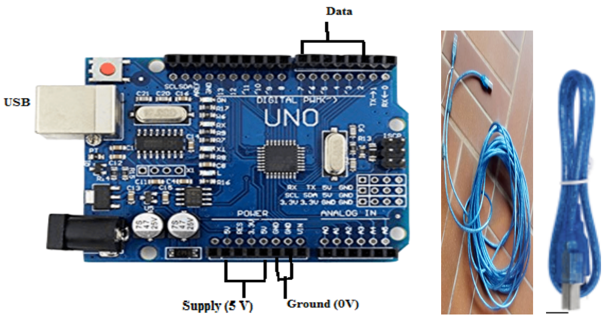
The main hardware for the data acquisition system consists of an Arduino Uno board and accessories (PCB and soldering components, printer cable), DHT 11 sensors and JXBS-3001-SCY-PT soil tester sensors.

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (6 of which can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power socket, an ICSP header and a reset button [22].

The Arduino Uno board pins used are:

- two 5 V pins to supply the board with power, one for the soil sensors and the other for the DHT11 sensors measuring air temperature and relative humidity.
- two 0 V pins for ground, one for soil sensors and the other for ambient air sensors.
- Pins 7 and 2 of the board were used to acquire soil and ambient air data, respectively.

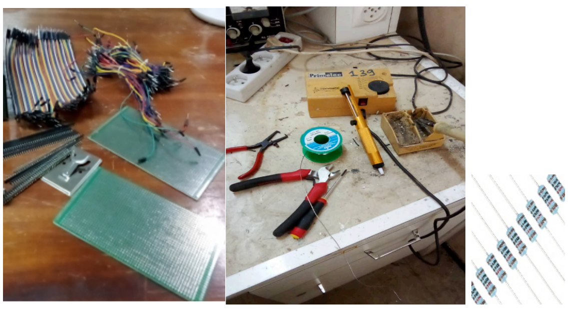
The USB port on the Arduino Uno board connects the computer to the sensor network, enabling them to communicate with each other via a printer cable.



a) c)

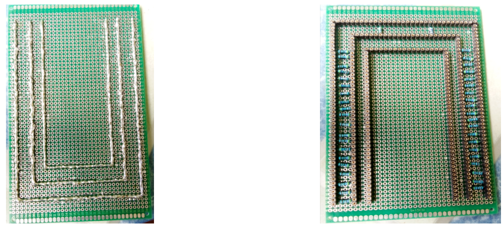
Figure 2 : Arduino Uno board and ports used: a) Arduino Uno board; b) printer cable

Accessories for the Arduino Uno module include a printed circuit board, female soldering rods, 40 CM female-to-male jumper wire, tin and a tin soldering station, electrical dominoes (to extend the sensors and connect them with Jumper cables, 47 Ohm resistors with 0.5 W power and $\pm1\%$ tolerance), a millimeter for monitoring voltage and current intensity, and continuity of measurement sensors.



a)

b) c)



d) e)

Figure 3 : Printed circuit board and its components: a) electronic components; b) 10 mm ^{2} 10 Amp electrical dominos; c) multimeter; d) and e) printed circuit board after soldering of female leads and resistors.

Two types of sensors, including 40 JXBS-3001-SCY-PT soil tester sensors and 1 DHT II air temperature and relative humidity sensor, were used to measure the properties of cultivated land and ambient air, respectively. The sensors were used to collect information [208] from the soil and ambient air. In addition, DHT II sensors are suitable for temperature readings ranging from 0 to 50°C with an accuracy of 2°C and for relative humidity readings in the 20-80% range with an accuracy of 5% [224]. The specifications of the JXBS-3001-SCY-PT soil tester sensors are summarized in the table below.

Tableau I : Spécifications des capteurs JXBS-3001-SCY-PT

Soils parameters	**Beaches**	**Specifications**
Temperatures	-45°C to - 115°C	±0,5°C
Humidity	0-100 %	±3 % in the range 0 to 53%; ±5% in the range 53 to 100%.
Electrical Conductivity (EC)	0-10000 us/cm	10 us/cm
Potential Hydronium (pH)	3-9	± 0,3 pH
Nitrogen (N) Phosphorus (P) Potassium (K)	0-2000 mg/kg	2 % FS Resolution 1 mg/kg (mg/l)

Figure 4 illustrates the various sensors, and the data verification tester used.

a) b) c) d)

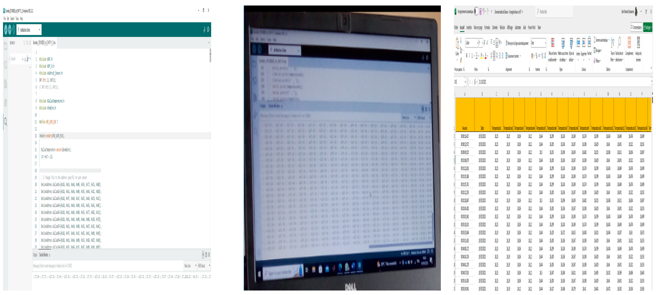
Figure 4 : Ground and air sensors: a) DHT11; b) 2×0.22 mm microphone cable; c) soil tester model JXBS-3001-SCY-PT; d) soil tester sensor JXBS-3001-SCY-PT

Microsoftwares

Arduino data acquisition is used to collect raw data [11]. Three (3) freeware programs were used to display, record and process the data. These software packages were interconnected to facilitate data acquisition:

- Arduino IDE software was used to program the sensors and display the information received.
- Tera Term software was used to convert the raw data displayed above and transfer it to Microsoft Excel, saving it in CSV format.
- Microsoft Excel was used to process the recorded data.

The software interfaces are shown in the figure below.



(a) (b) (c)

Figure 5 : Data acquisition software: a) Arduino IDE 2.3.2; b) Tera Term; c) Microsoft Excel

C. Measuring soil and air temperature and humidity, and the chemical and mineralogical properties of cultivated land

A metal tube with integrated soil sensors was inserted into the soil to measure its properties. The sensor tips are inserted horizontally into the soil and perpendicular to its sidewall at a spatial pitch of 2.5 cm. Data is measured from the soil surface down to a depth of 100 cm. The DHT11 sensor, integrated into the system, was positioned at a height of 2 meters above the soil surface. Data was recorded automatically on a computer connected to the data acquisition system via a printer cable. Disruptions to the Wi-Fi or Bluetooth network in the wireless communication mode largely resulted in data loss [15]. The use of a cable printer therefore met the challenge. Measurements were taken over a one-week period during the rainy season (August 15–August 21, 2023). The choice of this season was based on the fact that mineral salts, which can be assimilated by plant roots, are soluble, released and easily quantified in real-life situations. Data for the first three days was not recorded to ensure that thermal and water balance between soil constituents and sensors was achieved. Recording was carried out using interconnected software for 24 hours a day.

III. Results and Discussion

A. Results

1. Description of the Cropland and ambient air data acquisition system

Figure 6 shows the system for acquiring the physical, chemical and mineralogical properties of soil, useful for crop development, as well as air temperature and humidity. The programming considered a transmission speed of 9600 bits per second. This speed allowed a recording rate of 4 data per minute.

(a) (b)

Figure 6 : Data acquisition system designed: a) inside the case; b) complete system

Figure 7 shows a schematic diagram of the above-mentioned data acquisition system. In this diagram, each sensor consists of three lines represented by the ground line (0 Volt), the data line and the power supply line (5 Volt). These lines are distinguished by the colors green, yellow and red, respectively. All the sensors are grouped together on a printed circuit board to form a sensor network. For each JXBS-3001-SCY-PT sensor, the power supply line is connected to the data line via a 4.7 kOhms resistor. Each of the sensor network lines is connected to its corresponding pin on the Arduino board via a wire. The three wires of the DHT11 sensor are connected directly to the Arduino board.

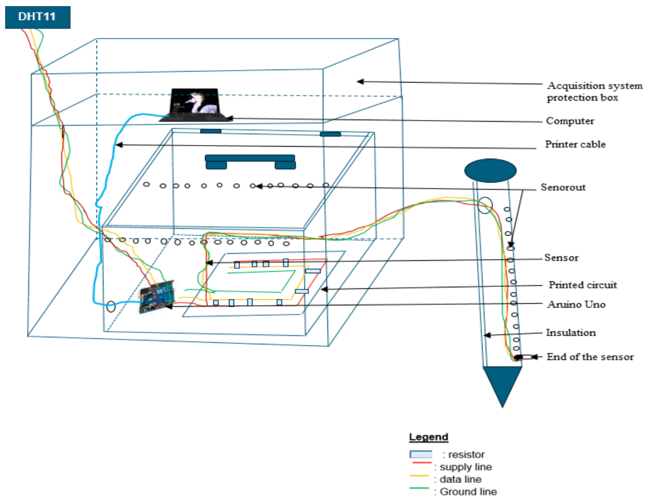


Figure 7 : Schematic diagram of the data acquisition system operating principle

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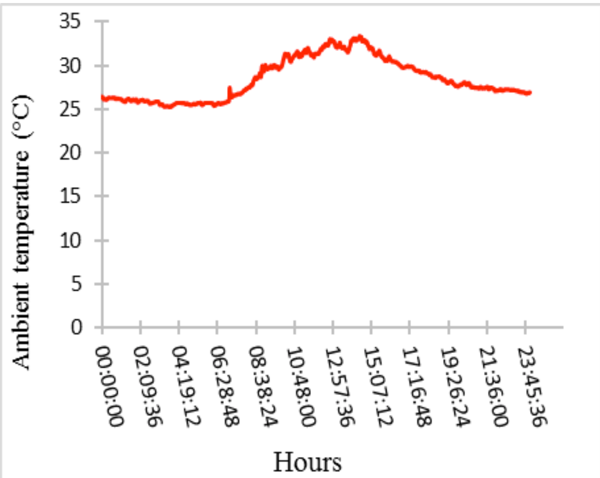
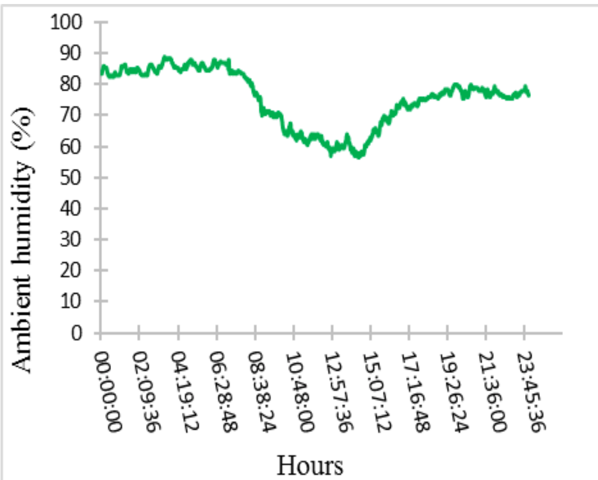
2. **Instantaneous variations in soil and air temperatures and humidities, and in the chemical and mineralogical properties of cultivated land from August 15 to August 21, 2023**

Instantaneous variations in average ambient temperature and relative humidity

Figures 8a) and b) show, respectively, instantaneous variations in ambient temperature and relative air humidity as a function of time. Analysis of figure 9a) shows that room temperature varies from 25°C to 35°C, with an average of 28.40°C. Moreover, this temperature has low values (between 25°C and 26°C) before 08 o'clock, then gradually increases to reach high values around 13 o'clock. After 13 o'clock, the temperature gradually decreases, returning to the starting range at 18 o'clock. As for the analysis of figure 8b), relative humidity varies between 50% and 90%, with an average of 75.63%. Before 07 o'clock, humidity reached high levels, tending towards 90%, then decreased from 08 o'clock, reaching low levels (close to 50%) around 13 o'clock. This humidity climbs again to a second range of high values, but these new values are lower than those before 07 o'clock. The second range remains almost constant until midnight, when the cycle starts again.



(a)

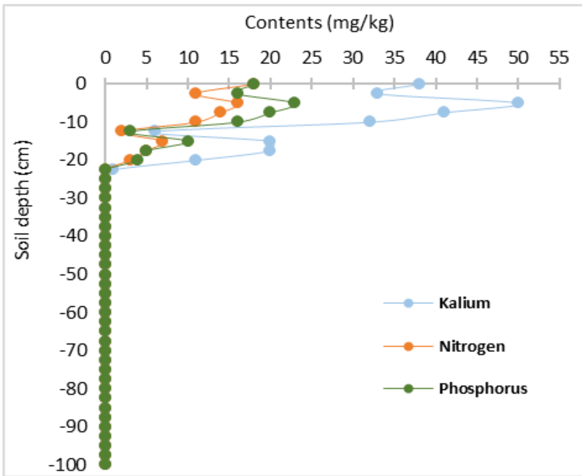


(b)

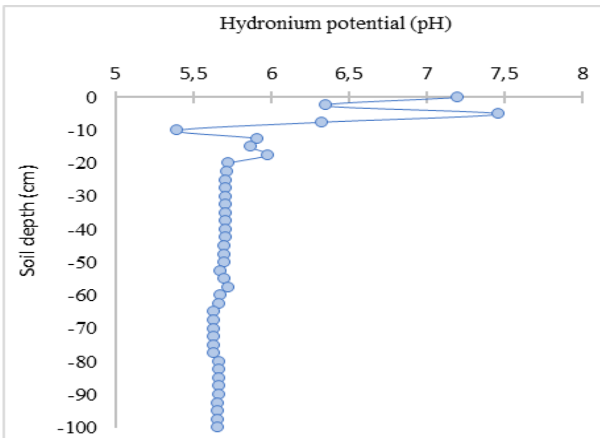
Figure 8 : Instantaneous variations in average ambient air temperature and relative humidity

Measured physical, chemical and mineralogical soil properties

Figures 9a), b), c), d) and e) illustrate, respectively, variations in calcium, nitrogen and phosphorus content, hydronium potential, electrical conductivity, temperature and average soil moisture as a function of depth. Analysis of figures 9a), b), c) and e) shows that high values for mineral content, pH, electrical conductivity and soil moisture content are observed in the first 20 cm of soil depth. Below this 20 cm depth, pH and soil moisture are almost constant, at 5.7 (Figs. 9b and e) and 6%, respectively, while calcium, potassium, nitrogen content, and soil electrical conductivity have almost zero values (Figs. a and c). Specifically, in the top 20 cm, calcium content ranged from 6 to 56 mg/kg with an average of 27.89 mg/kg; nitrogen content ranged from 2 to 18 mg/kg with an average of 9.67 mg/kg; phosphorus content ranged from 3 mg/kg to 23 mg/kg with an average of 12.78 mg/kg; pH ranged from 5.40 to 7.46 with an average of 6.25 mg/kg; and electrical conductivity ranged from 9 to 253 with an average of 157.67. Soil moisture content (Figure 9e) is high on the surface and decreases from 48.2% to 11.7% in this 20 cm depth, with an average of 20.2%. On the other hand, Figure 9d) shows that soil temperature is low at the surface, with a value of 23.84°C, and increases progressively with depth, reaching high values at around 20 cm depth, rising from 23.84°C to 29.1°C. Below a depth of 20 cm, soil temperature remains almost constant, with a high value (28.7°C on average).



(a)



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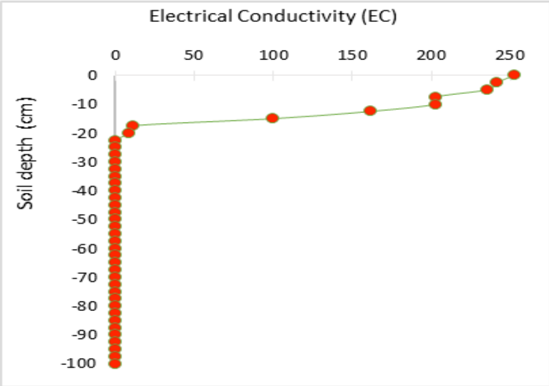

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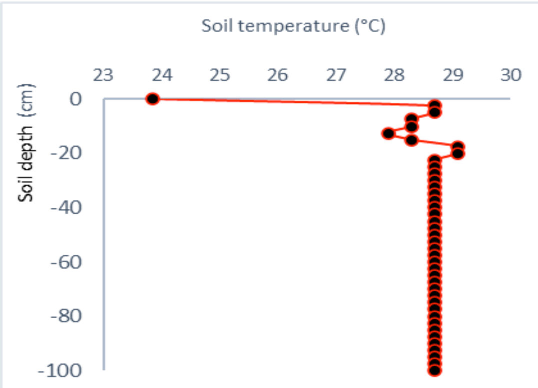
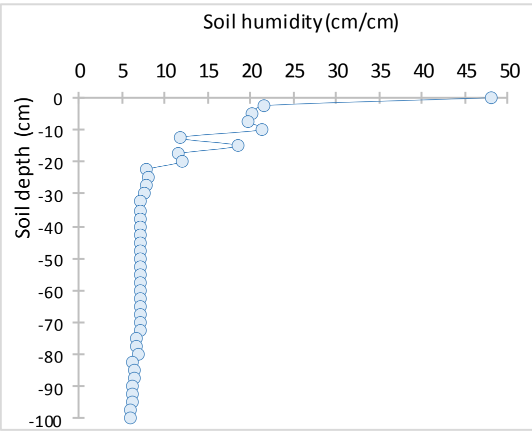


(d)



(e)

Figure 9 : Daily variations in the average physical, chemical and mineralogical properties of cultivated land in the Sikensi zone

B. Discussion

The data recorded by our acquisition system were compared with those of systems used in previous work [17, 18, 25] ; giving a sensor accuracy of 98.89%. In addition, the JXBS-3001-SCY-PT sensors showed high sensitivity to soil temperature and humidity, resulting in variations from the DS18B20 temperature sensors widely used in the literature. These observations suggest that farmers should use specific JXBS-3001-SCY-PT sensors to obtain accurate data. Finally, the sensors frequently used to measure temperature and humidity are only 1 meter long, so the contribution of experimental work under in-situ conditions at significant soil depths is limited. The present study has found techniques for extending the sensors using microphone cables without impacting data accuracy. The soil moisture and temperature acquisition system developed by Kojima et al. (2016) [15] worked down to a soil depth of less than 30 cm. However, measurements beyond a depth of 30 cm were unsuccessful due to the short length of the sensors, which failed to detect changes in humidity and temperature. Their sensor design technique did not prove successful, resulting in an incomplete database governing leakage current in the electrical circuit. The results of previous studies have shown that data acquisition using Arduino boards is one of the most advanced and simplest technologies available. The simplicity of our Arduino-based data acquisition system has been confirmed by the work of [5, 19]. A comparison of their results with those obtained in our work suggests that the acquisition system we have developed is improved by its ability to measure a number of soil properties at significant depths in real-life conditions.

The increase in ambient temperature from 6 a.m. to 4 p.m. is due to the power of solar radiation emitted during the day. During this period, the intensity of the sun's rays gradually increases, reaching its maximum from 13 o'clock onwards, when it peaks and remains constant until 15:30. After 4 p.m., solar power gradually diminishes until sunset, at 6:30 p.m. The manifestation of this solar power is seen in the variation of ambient heat in the form of temperature. Similar profiles have been obtained in previous work [26, 27, 28]. However, contradictory trends are observed with the relative humidity of the air, as the heat transforms the water droplets in the air into vapor by evaporation. This quantity of water in the air is then absorbed by the increase in heat [27]. In addition, during the night, evapotranspiration from plants, water surfaces and the ground causes large quantities of water droplets to be released into the air, creating relative humidity. This high humidity, marked by the absence of sunlight, absorbs the sun's thermal effect. As a result, a drop in ambient temperature is observed during the night[30, 31].

Cultivated land receives plant and animal debris on its surface. When soil temperature and humidity conditions are favorable (below 28.7°C and above 5% humidity, respectively, in our study) for earthworms and microorganisms, they multiply, increasing in density and biomass. Because of the low temperature in the sub-surface layers of the soil during the rainy season compared with the deep layers, the activities of earthworms and microorganisms are high, which implies a high level of moisture. This accelerates the mineralization of plant and animal debris by these living creatures. According to Chaudhuri et al., (2016) [30], earthworms decompose plant and animal debris, helping to improve soil fertility. According to the work of Bhadauria and Saxena (2010) [31], the biomass of soil macrofauna is dominated by earthworms, which rapidly incorporate detritus into soil mineral salts. Mucus production associated with water excretion in earthworm intestines enhances the activity of other soil-beneficial microorganisms, providing organic matter (nitrogen, phosphorus, potassium and calcium). The organic matter thus released is easily assimilated by plants in fresh clay deposits.

The subsurface layers of the soil studied had a high proportion of clay, while the deeper layers were rich in hydromorphic elements, with red coloration caused by the presence of ferrous minerals. The decomposition of debris by earthworms and microorganisms' releases humus, or mineral salts, reducing the loss of nutrients through leaching. This mineralization improves the physicochemical and biological characteristics of the soil. Most humus is retained in the subsurface layers of the soil and gradually diminishes with increasing depth and decreasing soil moisture. When the soil's available water content (soil moisture content) is high, the solubilization of mineral salts is accelerated, providing the soil with the various ions required for crop development. Mineral salts act as nutrients for crop roots, and their solubilization is slowed down when water content is low. The accessibility of these ions to plant roots can be cancelled out in dry soil conditions.

Moreover, the Sikensi area boasts high rainfall and significant solar potential, providing the soil with the conductive energy required for crop development. In addition, rainwater increases soil pH, promoting the growth of microbial activity and earthworms. Our results corroborate those obtained in the work of [32, 33]. In addition, soil pH increases with electrical conductivity [32, 33, 34], phosphorus, nitrogen [30], and potassium levels. Fortunately, phosphorus, nitrogen [30], and potassium are readily absorbed by plants to improve crop growth and yield [35, 36]. According to the findings of Placidi et al., [14], the decrease in soil electrical conductivity is mainly due to water salinity and ionic content. The results of [31] showed that the mineralization process is cyclical, such that the renewal of soil organic matter is carried out by earthworms. The spatial evolution of soil nutrients is highly dependent on agricultural practices [35], of which tuberous crops and cereals are beneficial to soils because of their secreted rhizotomes [36]. According to the results of studies by Su et al., (2021) [37], red soils are sometimes low in phosphorus. According to Heiniger et al., (2003) [38], the levels of change in soil layers rich in mineral salts, are achieved by differences in electrical conductivity.

Mazur *et al.,* (2022) [39] established the relationships between soil and crop attributes (potassium and phosphorus, magnesium), soil electrical conductivity and vegetation cover index. The results showed that soil potassium and phosphorus contents were strongly related to soil electrical conductivity and vegetation cover index. Their results gave a pH ranging from 5.1 to 7.6, a phosphorus content ranging from 0.82 mg/kg to 1.63 mg/kg, and a potassium content that varied from 1.57 mg/kg to 2.40 mg/kg. A comparison of these authors' results with our own suggests that soil in the Sikensi area is more suitable for agriculture. Electrical conductivity, pH, nutrient content (particularly N, P and K), soil organic matter and vegetation indices are all factors that improve crop productivity. These results are confirmed by the work of Eric *et al.* (2006) [32].

In the work of Kojima et al., (2016) [15], soil moisture content varied from 0.03 to 0.35 cm^3/cm^3 and was not horizontally identical. Soil moisture decreased with depth and decreased average relative humidity; this confirms the results of our work. Soil moisture is higher in loose soil layers due to high hydraulic conductivity than in compact soil layers. According to the work of Lekshmi et al., (2014)[16], soil moisture content decreases with soil depth. This decrease is related to the concentration of organic matter. Yang et al., (2024) [40] studied the distribution of the physical, chemical and mineralogical properties of soils using chemical and soil analyses in the laboratory in Pará (Brazil). The results showed low concentrations in the surface layer of the soil of phosphorus (2 to 16 mg/kg), calcium, magnesium, pH (3 to 5), and bio-available potassium, compared with high concentrations of silicon and aluminum. Finally, a parity was observed between the organic carbon content and the mineral content, proving that a high mineral content in a soil reveals its richness for plant root development. The pH values above 5 indicate the predominance of basic rocks (basalt and diabase) with a clay texture, while low pH values indicate the acidic nature of the rocks present. These acid rocks may be sedimentary, sandstone or mudstone with a quartz-rich texture [41]. The decrease in phosphorus content is also linked to high levels of iron and aluminium oxides, due to their strong capacity to immobilize phosphorus [42]. Despite the alkaline soils studied in the studies by Su et al., (2021) [37], the results showed a low phosphorus content because of the high aluminium convention, which inhibited the soluble effect of phosphorus. This made it difficult to release phosphorus and iron minerals. Tufa et al., (2019) [43] studied the effects of the distribution of physical and chemical properties of croplands on soil types in Kuyu district, Ethiopia. The soils studied had high proportions of sand and clay, with pH values between 7.68 and 8.00. Despite the basic nature of these soils, they unfortunately had a low average available phosphorus content, ranging from 1.26 to 5.37 mg/kg. A comparison of their results with ours shows that the soil at Sikensi is rich in phosphate. According to the results of a study by Su et al. (2021) [37], a soil phosphate content of less than 6.6 mg/kg defines soil deficiency. Soil phosphorus deficiency therefore limits crop development by reducing root sponges, which has a negative impact on agricultural productivity. According to Lambers (2022)[44], plant roots are the main organs for absorbing nutrients. In response to phosphorus deficiency, plants modify their root morphology, in particular by reducing the elongation of primary roots. High soil phosphorus levels suppress the release of muginic acids. Phosphorus deficiency seriously impairs photosynthesis [45].

IV. Conclusion

Our system for acquiring the physical, chemical and mineralogical properties of the soil, and the temperature and relative humidity of the air, enabled us to carry out the measurements successfully. The Arduino Uno technology used two types of sensors: the JXBS-3001-SCY-PT soil tester and the DHT11 sensor. The design of this system for acquiring soil and ambient air properties is a simplified version and requires no advanced knowledge of electronics for its realization; this will now enable every grower to realize at a lower purchase cost, the properties of his plots in real condition and in real time. This system measures several land properties, unlike the data acquisition systems used in previous studies. This strategy will help our growers improve their agricultural productivity and land management.

Experimental results have shown that soil content, pH and moisture are higher in the subsurface than in the deep layer (top 20 cm). In this subsurface layer, calcium content averaged 27.89 mg/kg; nitrogen content averaged 9.67 mg/kg; phosphorus content averaged 12.78 mg/kg; pH averaged 6.25 mg/kg; and electrical conductivity averaged 157.67. On the other hand, soil temperature increased in the deeper layers of the soil, with an average of 27.8°C. The ambient temperature varied from 25°C to 35°C, and the relative humidity ranged from 50% to 90%.

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