Portable sensor system for measuring

NPK nutrients in coffee crops, designed for precision agriculture in Loja, Ecuador

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Abstract

Timely monitoring of nutrients in agricultural soils is essential for optimizing fertilization and improving productivity in coffee crops under precision farming schemes. The aim of this study was to develop and preliminarily evaluate a portable monitoring system for nitrogen (N), phosphorus (P), and potassium (K) based on an Arduino microcontroller and a commercial sensor with RS-485 communication, applied to a coffee crop in Loja, Ecuador. Ten in situ measurements were taken on a plot of approximately three hectares, and the results were compared with a laboratory analysis obtained from a composite sample representative of the study area. The average values obtained by the system were 32.71 ppm for N, 32.92 ppm for P, and 0.216 meq/100 ml for K, while the laboratory reported 31.0 ppm, 34.0 ppm, and 0.21 meq/100 ml, respectively. The relative errors were 5.5% for N, −3.2% for P, and 2.9% for K. The results show a high average concordance between the proposed system and conventional analysis, demonstrating its potential as a preliminary monitoring tool for nutritional management in coffee.

Keywords:
agricultural sensors, macronutrients, soil monitoring, spatial variability, experimental validation.

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Introduction

The growing demand for food and the need to optimize the use of agricultural inputs have driven the development of precision agriculture strategies aimed at improving production efficiency and reducing environmental impact. This approach is based on the spatial and temporal characterization of variability within agricultural systems, enabling site-specific management of soil and crops (Nath, 2023). In this context, monitoring essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K) is critical for the sustainability and profitability of production systems.

Coffee production is one of the world's most important agricultural systems due to both its economic impact and its social importance in developing countries. It is estimated that more than 25 million families depend directly on coffee cultivation, particularly in tropical regions of Latin America, Africa, and Asia (International Coffee Organization [ICO], 2022). In this context, the sustainability of coffee production systems largely depends on the proper management of soil fertility, particularly the balance of the essential nutrients N, P, and K, whose availability directly influences vegetative growth, flowering, fruit filling, and bean quality (Eponon et al., 2023).

Nitrogen is a fundamental structural component of proteins and chlorophyll and plays a key role in leaf development and the photosynthetic capacity of the crop. Phosphorus is involved in energy-related processes and root development, whereas potassium regulates osmotic functions, stomatal opening, and resistance to water stress (Eponon et al., 2023). Deficiencies or excesses of these nutrients can significantly affect coffee yield and quality, as well as increase production costs and environmental risks associated with fertilizer leaching or runoff (Sadeghian, 2022).

Conventional soil fertility analysis is performed using standardized laboratory methods that provide high analytical reliability. However, these procedures often involve high costs, long processing times, and logistical constraints in rural areas. These limitations hinder the acquisition of timely information with sufficient spatial resolution for appropriate agronomic decision-making. Although soil sensors and in situ measurement technologies have emerged as promising alternatives, their implementation in real production systems, particularly in coffee crops in the Andean region, remains limited (Riaño & Barrero Sánchez, 2023).

In this context, although several studies have developed portable sensor-based devices for estimating soil properties, there is still a gap regarding the validation of these systems under specific field conditions and their ability to accurately estimate NPK concentrations in coffee crops. This limitation restricts their adoption as reliable tools for nutritional management in precision agriculture, particularly in environments with high soil variability such as those found in the province of Loja (Ecuador).

Therefore, the research problem lies in the lack of validated portable systems capable of rapidly, reliably, and in situ measuring N, P, and K levels in coffee-growing soils, thereby facilitating agronomic decision-making based on timely and spatially representative information. In this scenario, the development of accessible technological solutions becomes particularly relevant, as it can contribute to improving fertilizer use efficiency, reducing production costs, and minimizing environmental impacts associated with improper nutrient management. Within this framework, the present study proposes the development of a portable sensor-based system for measuring NPK nutrients using a microcontroller and RS-485 communication, applied to a coffee crop in Loja, Ecuador. Based on measurements collected at different points within a production plot and their comparison with laboratory results obtained using conventional methods, the performance of the device and its potential as a support tool for nutritional management in precision agriculture are evaluated.

Methods

Study type

The study focused exclusively on the initial validation of the portable NPK monitoring system, which was compared with a laboratory sample collected from a coffee-growing area to evaluate its accuracy and response through statistical analysis.

Study area

The study was conducted in a coffee plantation located in the city of Loja, Ecuador, at an approximate altitude of 2,100 m above sea level. The area is characterized by Andean agroecological conditions with topographic variability and volcanic soils, factors that influence nutrient availability and dynamics (Food and Agriculture Organization of the United Nations [FAO], 2015). The evaluated plot covers approximately three hectares, where ten sampling points were spatially distributed to capture the internal heterogeneity of the terrain.

Experimental design and study variables

The study was conducted under an applied experimental approach aimed at the preliminary validation of a portable nutrient (N, P, K) monitoring system under real field conditions. The experimental design consisted of a spatially distributed point sampling within a production plot to evaluate the sensor's performance and its ability to detect within-plot variability.

Study variables

The following variables were defined:

Dependent variables:

- CNitrogen (N) concentration in ppm
- Phosphorus (P) concentration in ppm
- Potassium (K) concentration in meq/100 ml

Independent variable:

- Measurement method (portable sensor vs. laboratory analysis)

Control variables (not manipulated):

- Measurement depth (0–20 cm)
- Soil type (Andean volcanic soil)
- Field conditions at the time of measurement (not experimentally controlled)
- Possible soil moisture (not quantified)

NPK Monitoring System

A portable data acquisition system based on an Arduino UNO microcontroller (ATmega328P, 16 MHz) was designed and implemented. The device was integrated with a commercial soil sensor

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capable of estimating nitrogen (N), phosphorus (P), and potassium (K) concentrations within a range of 0–1,999 mg/kg using RS-485 communication under the Modbus RTU protocol. The electrical interface was implemented through a MAX485 transceiver module configured in half-duplex mode, enabling the conversion of differential signals into TTL levels compatible with the microcontroller.

The embedded architecture also included an LCD display module for real-time visualization of measurements. Data acquisition was performed at 9,600 bps by averaging ten consecutive readings per sampling point to reduce electrical noise and instantaneous variability, a common practice in embedded sensing systems (Monk, 2016). The system was powered by a regulated 5 V DC supply and is shown in Figure 1.

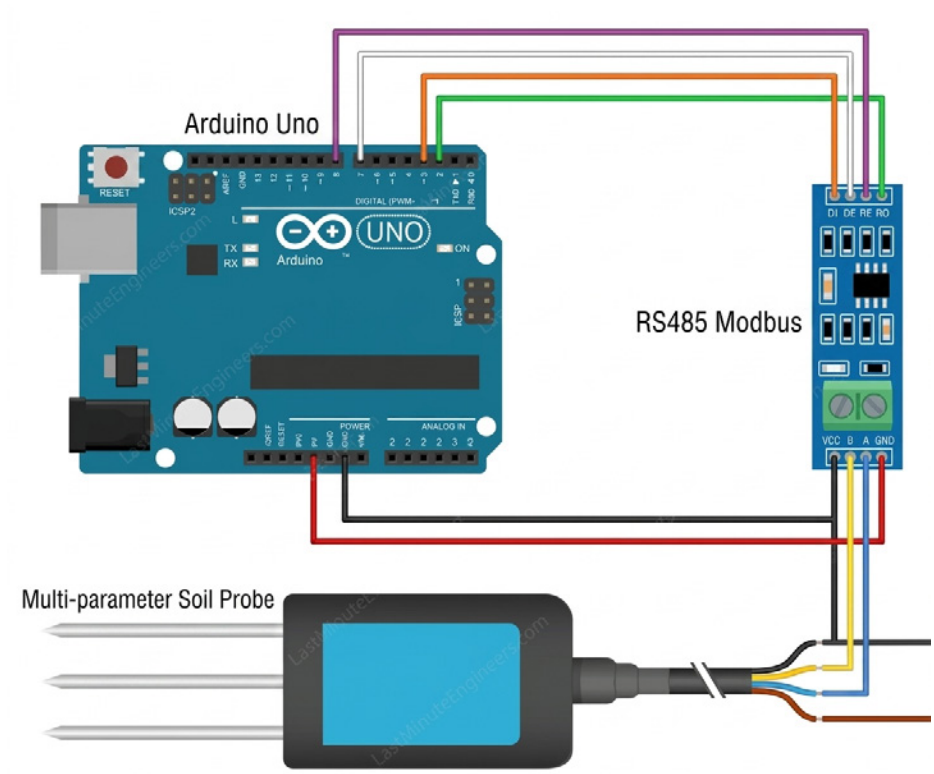

Figure 1

Diagram of the system

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The sensor estimates nutrient concentrations indirectly from soil electrical properties and the manufacturer's internal calibration models, making comparative evaluation against reference methods necessary (Viscarra Rossel et al., 2011).

Field sampling procedure

In situ measurements were performed by inserting the sensor probe to an approximate depth of 0–20 cm, corresponding to the active root uptake zone of coffee crops. N, P, and K values were recorded at each of the ten selected sampling points, generating a dataset representative of the plot's spatial variability. The measurement scheme is shown in Figure 2.

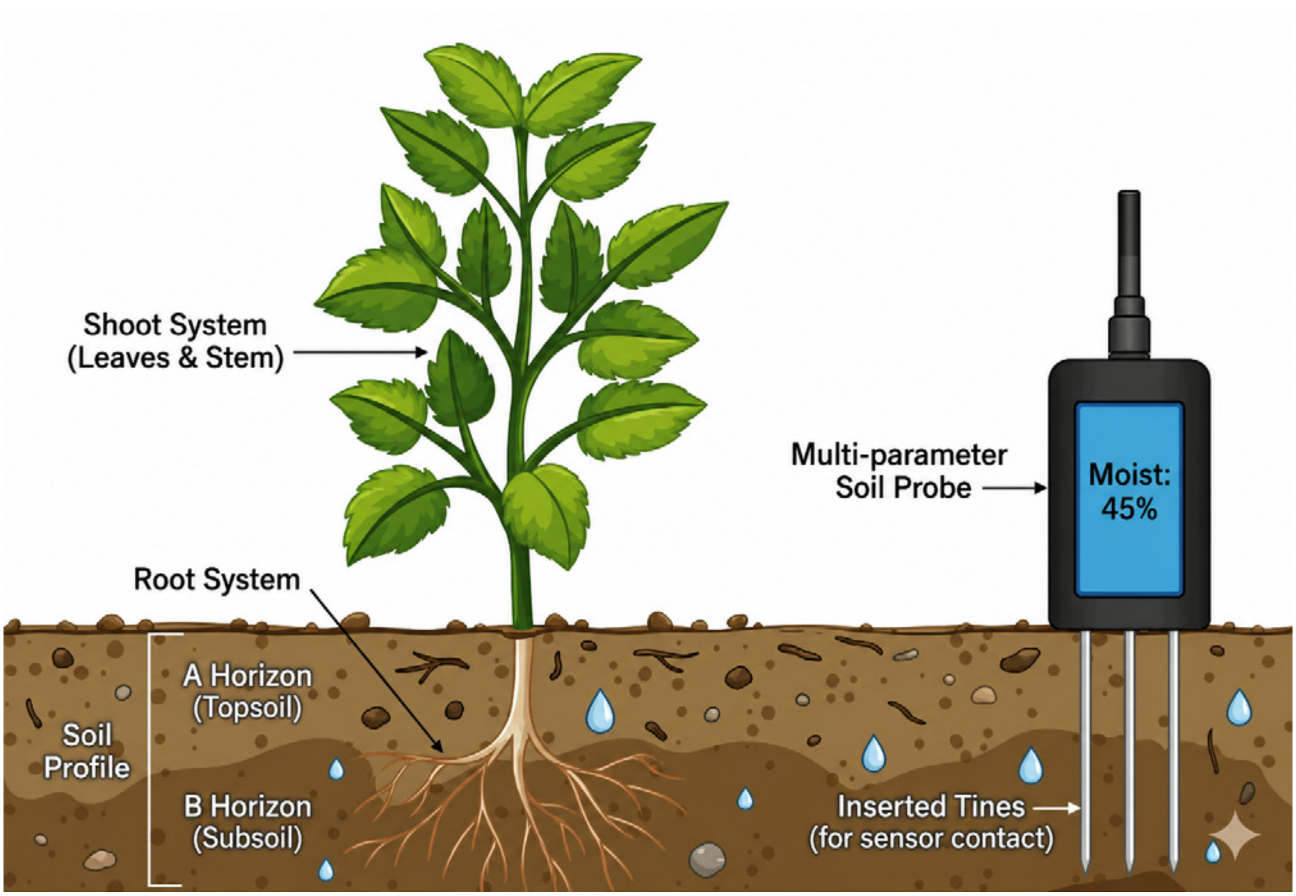

Figure 2

Measurement scheme

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Subsequently, soil subsamples were collected from the same sampling points and homogenized to produce a composite sample representative of the entire study area. This procedure is commonly used when the objective is to obtain an average characterization of the plot while reducing laboratory analysis costs (Havlin et al., 2014). Tables 1 and 2 present the data collected from the ten sensor sampling points and the laboratory analysis results, respectively.

Table 1
NPK sensor data

Sensor sample number	Nitrogen (N) (ppm)	Phosphorus (P) (ppm)	Potassium (K) (meq/100 ml)
1	38,4	19,0	0,33
2	30,7	33,6	0,30
3	28,9	39,1	0,28
4	35,4	21,8	0,21
5	27,0	23,3	0,15
6	25,2	33,6	0,22
7	31,8	45,0	0,20
8	40,7	31,1	0,11
9	36,7	44,4	0,18
10	32,3	38,3	0,18

Table 2
Laboratory analysis data

Laboratory Sample Number	Nitrogen (N) (ppm)	Phosphorus (P) (ppm)	Potassium (K) (meq/100 ml)
1	31,0	34,0	0,21

Laboratory analysis

The composite sample was subjected to soil fertility analysis using standardized methods. Nitrogen was determined by digestion and quantification according to the Kjeldahl method; phosphorus was determined through chemical extraction followed by spectrophotometric measurement; and potassium was quantified using flame photometry. Results were expressed in ppm for N and P and in meq/100 ml for K, following conventional agronomic procedures (Jones, 2001).

Comparative analysis

Since the laboratory provided a single value representative of the entire plot (composite sample), the comparison was performed between the mean value of the ten sensor measurements and the laboratory-reported value. The relative percentage error was calculated for each nutrient according to the following expression:

$$Error(\%) = \frac{Valor_{sensor} - Valor_{laboratory}}{Valor_{laboratory}} * 100$$

In addition, the internal variability of the sensor was evaluated using the range and descriptive analysis of the field data to examine its ability to detect spatial heterogeneity within the production plot. This methodological approach corresponds to a preliminary validation under real field conditions aimed at analyzing the average agreement between the embedded system and the conventional reference method (Bland & Altman, 1986).

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Results

Descriptive behavior of the portable system measurements

Measurements obtained with the portable NPK monitoring system at the ten sampling points distributed across the approximately three-hectare plot revealed appreciable spatial variability in nitrogen (N), phosphorus (P), and potassium (K) concentrations. These values are presented in Table 3.

Table 3
Descriptive Statistics of the Portable System Data

Variables	Range	Mean	Standard Deviation	Coefficient of Variation (CV%)	Variability Level
Nitrogen (N)	25,2 – 40,7 ppm	32,71	5,06	15,47	Moderate
Phosphorus (P)	19,0 – 45,0 ppm	32,92	8,69	26,41	High
Potassium (K)	0,11 – 0,33 meq/100 ml	0,22	0,07	31,94	High

These results confirm the presence of within-field heterogeneity, a common characteristic of Andean agricultural systems, where factors such as topography, agronomic management, and organic matter distribution significantly influence soil nutrient dynamics (Gebbers & Adamchuk, 2010).

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Comparison with laboratory analysis

Laboratory analysis of the composite sample reported concentrations of 31.0 ppm for N, 34.0 ppm for P, and 0.21 meq/100 ml for K. By comparing the average values obtained with the portable system against the laboratory results, the relative errors shown in Table 4 were calculated.

Table 4
Relative Error

Variables	Relative error (%)
Nitrogen (N)	5,5
Phosphorus (P)	-3,2
Potassium (K)	2,9

The observed differences were below 6% in all cases, indicating high average agreement between the proposed system and the conventional reference method. From a practical perspective, these levels of deviation can be considered acceptable for preliminary on-site nutritional diagnostic applications, particularly when the objective is to identify general trends or spatial variability rather than to completely replace laboratory analysis (Adamchuk et al., 2004).

Within-field variability

The descriptive analysis of the sensor measurements identified notable differences among sampling points within the same field. Phosphorus exhibited the greatest variation, with a 26 ppm difference between the minimum and maximum values, followed by nitrogen and potassium.

The system's ability to detect spatial differences is particularly relevant from the perspective of precision agriculture, where site-specific fertilizer management depends on identifying areas with different nutrient availability (Gebbers & Adamchuk, 2010). Real-time, in situ data acquisition facilitates the generation of variability maps and supports site-specific decision-making.

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Limitations

It is important to note that the analysis was based on a comparison between the average sensor measurements and a single laboratory reference value, limiting the application of inferential statistical methods such as correlation or regression analysis. Consequently, the findings should be interpreted as an initial or preliminary validation of the system.Future studies should include a larger number of laboratory samples and a greater number of field measurements, enabling regression analyses, root mean square error (RMSE) calculations, and agreement assessments using more robust methodologies.

The sample size of ten sampling points is justified because this study represents an initial system validation, whose primary objective was to evaluate functional performance under real field conditions. The selection of spatially distributed sampling points across a three-hectare field allowed the capture of within-field variability, while the use of average values reduced the need for large sample sizes. In addition, operational constraints associated with field sampling and laboratory analysis were taken into consideration.

The purpose of this preliminary validation study was to verify the operation of the portable system, identify trends, and estimate initial errors. Furthermore, the ten sampling points provided basic coverage of the field's spatial variability, which is sufficient for an exploratory characterization of sensor performance.

Summary of results

Overall, the results demonstrate that the portable NPK monitoring system exhibits good average agreement with conventional laboratory analysis, with relative errors below 6% for nitrogen, phosphorus, and potassium. This close correspondence suggests that the device can reliably estimate the average soil nutrient status under real field conditions, supporting its feasibility as a preliminary diagnostic tool.

From a practical standpoint, these findings indicate that the system can be used as an operational alternative for rapid soil nutritional assessment, particularly in situations where laboratory analyses are constrained by economic, logistical, or time-related factors. In this context, the device provides timely information that can support agronomic decision-making, including the identification of potential nutrient deficiencies or excesses, prioritization of intervention areas, and monitoring of nutritional trends over time.

A notable finding of this study is the system's ability to detect spatial variability within the evaluated field. The differences observed among sampling points, particularly for phosphorus and potassium, demonstrate the presence of within-field heterogeneity, a characteristic feature of agricultural systems in Andean environments. From an agronomic perspective, this variability implies that uniform fertilizer applications may be inefficient, leading to nutrient imbalances. In this context, the portable system offers a significant advantage by identifying areas with different nutritional behavior, thereby potentially supporting the implementation of site-specific fertilization strategies and more efficient input use.

Furthermore, the fact that the laboratory values fell within the range of variation measured by the sensor reinforces the system's ability to accurately represent the overall behavior of the soil. This finding suggests that the device not only provides consistent average estimates but also captures the spatial dynamics of soil nutrients, which is essential for precision agriculture applications.

Nevertheless, it is important to emphasize that these findings correspond to a preliminary validation of the system. The comparison between the average sensor measurements and a single laboratory reference value obtained from a composite sample limits the ability to evaluate the accuracy of individual measurements and to perform more robust inferential statistical analyses. Consequently, the results do not permit detailed quantitative relationships between the two methods nor the generalization of sensor performance to other soil or production conditions.

At this stage, the system should therefore be regarded as a complementary tool for in-field nutrient monitoring rather than a substitute for conventional chemical soil analysis. Its principal value lies in its ability to provide rapid, frequent, and low-cost measurements, facilitating the acquisition of preliminary information that can guide decision-making and optimize fertilizer management.

Finally, the findings highlight the system's potential for integration into precision agriculture frameworks, particularly when combined with georeferencing and spatial analysis tools. Future research incorporating a larger number of samples, point-by-point validation, and crop- or site-specific calibration models will broaden the applicability of the device and strengthen its use under real production conditions.

Discussion

The results obtained in this study demonstrate that the developed portable NPK monitoring system exhibits high average agreement with conventional laboratory analysis, with relative errors below 6% for nitrogen, phosphorus, and potassium. This level of deviation falls within the ranges considered acceptable for preliminary diagnostic tools in precision agriculture, particularly when the primary objective is the identification of spatial trends rather than the complete replacement of reference chemical analysis (McBratney et al., 2005; Naderi-Boldaji et al., 2013).

Comparison with previous studies

Several studies have reported that commercial nutrient sensors based on soil electrical properties may exhibit variable errors depending on soil and environmental conditions. The indirect estimation of NPK is generally influenced by electrical conductivity, soil moisture content, and soil mineralogical composition (Viscarra Rossel et al., 2011; Muñoz-Huerta et al., 2013). Studies conducted in temperate agricultural systems have reported errors exceeding 15% when site-specific calibrations are not applied (Shaviv, 2001).

Compared with these reports, the average errors obtained in the present study are relatively low. This agreement may be attributed to several factors:

- The relative homogeneity of the evaluated field.
- The use of averaged sensor readings to reduce measurement noise.
- Comparison against a composite soil sample, which smooths point-to-point variability.

However, it is important to acknowledge that average-based comparisons may underestimate local discrepancies that could only be identified through paired point-by-point analyses. The literature recommends that robust sensor validation should include point-by-point comparisons together with metrics such as root mean square error (RMSE), coefficient of determination (R^2), and Bland–Altman agreement analysis (Bland & Altman, 1986; Giavarina, 2015). In this regard, the present study provides the foundation for future investigations involving more comprehensive statistical validation.

Environmental conditions

An important aspect to consider when interpreting the results is the influence of environmental conditions on sensor performance. Previous studies have demonstrated that variables such as soil moisture, electrical conductivity, and temperature directly affect measurements obtained from sensors based on soil electrical properties (Viscarra Rossel et al., 2011; Muñoz-Huerta et al., 2013). In particular, soil moisture resulting from natural field conditions or recent rainfall events may alter electrical conductivity and consequently affect the indirect estimation of nutrient concentrations.

In the present study, these environmental variables were neither controlled nor systematically recorded, introducing a potential source of uncertainty. For example, increased soil moisture could lead to either overestimation or underestimation of nutrient concentrations depending on the specific field conditions, and this should be taken into account when interpreting the results.

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Furthermore, measurements were performed at a single point in time, limiting the ability to evaluate system stability under varying climatic conditions. Undocumented rainfall events occurring before sampling may have influenced both nutrient distribution and sensor response. Consequently, the lack of control over these environmental variables reduces the generalizability of the findings to other environmental conditions or seasons.

Sample size

Another important limitation is the sample size and the use of a single laboratory sample as the reference. Although this approach is acceptable for a preliminary validation study, it limits the application of inferential statistical analyses and point-by-point agreement assessment. Therefore, the results should be interpreted as an initial evaluation of system performance rather than a definitive validation. The literature recommends that sensor validation should include a larger number of independent samples and more robust statistical analyses to ensure reliable conclusions (Bland & Altman, 1986; Giavarina, 2015).

Spatial variability and its agronomic relevance

The within-field variability observed in this study is consistent with findings widely reported in precision agriculture, where significant differences in nutrient availability may exist even within moderately sized fields (McBratney et al., 2005; Gebbers & Adamchuk, 2010). In coffee plantations established on sloping Andean terrain, the natural redistribution of nutrients through runoff and erosion processes may generate heterogeneous fertility patterns.

Phosphorus exhibited the greatest variability among the evaluated nutrients. This behavior is consistent with its low mobility in soil and its tendency to form insoluble complexes in acidic environments or soils with high concentrations of iron and aluminum oxides, characteristics commonly found in Andean volcanic soils (Havlin et al., 2014). The detection of this variability using the portable system suggests that the device could be useful for identifying specific areas requiring site-specific phosphorus fertilization.

For nitrogen, the observed variability may be associated with differences in organic matter mineralization, fertilization history, or local variations in soil moisture. Potassium exhibited the smallest absolute range, although the observed differences remain agronomically meaningful.

Implications for sustainability and fertilizer use efficiency

The excessive or inefficient use of nitrogen and phosphorus fertilizers has been recognized as one of the major sources of environmental pollution in intensive agricultural systems because of nutrient leaching and runoff affecting both surface and groundwater resources (Tilman et al., 2002). In this context, implementing tools capable of providing more frequent and site-specific nutrient monitoring could contribute to reducing unnecessary fertilizer applications and improving input-use efficiency.

From an economic perspective, the ability to perform in situ measurements without relying continuously on distant, time-consuming, and costly laboratory analyses represents a significant advantage for small- and medium-scale producers. Although laboratory chemical analysis remains the reference standard, its cost may limit monitoring frequency. A low-cost portable system can complement laboratory analyses by providing intermediate assessments between laboratory campaigns.

Comparison with commercial sensors

Regarding commercially available sensors, several studies have reported that proximal sensing technologies provide rapid and non-destructive measurements, although their accuracy depends strongly on operating conditions (Riaño & Barrero Sánchez, 2023; Viscarra Rossel et al., 2011). Compared with these systems, the portable device proposed in this study offers several relevant advantages.

First, its low implementation cost, based on open-source hardware platforms such as Arduino, makes it an accessible alternative for small- and medium-scale producers compared with high-cost commercial sensors. Second, its capability to provide real-time measurements directly in the field represents a significant advantage over laboratory analyses, which require additional time and logistical resources. Finally, the observed error levels suggest that, under controlled conditions, the proposed system can achieve an average estimation accuracy comparable to that of mid-range commercial devices.

Nevertheless, it is important to recognize that advanced commercial sensors generally incorporate site-specific calibrations, environmental compensation mechanisms, and more sophisticated processing algorithms, which can improve performance under changing environmental conditions. Consequently, the proposed system still requires local calibration procedures and extended validation to achieve comparable levels of robustness.

Technological robustness of the embedded system

The stable performance of the system throughout the field measurements indicates that the Arduino-based architecture combined with RS-485 communication is well suited for agricultural environments. Differential RS-485 transmission offers advantages over simple analog interfaces by reducing susceptibility to electrical interference (Modbus Organization, 2012). The implementation of the Modbus RTU protocol enabled reliable sensor register acquisition without evidence of data loss or inconsistencies during data collection.

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The modular architecture also facilitates future enhancements, including:

- Integration of SD card data storage.
- Incorporation of wireless communication modules (LoRa, Wi-Fi).
- GPS-based georeferencing.
- Integration with cloud-based data analysis platforms.

These capabilities align the proposed system with current trends in digital agriculture and Agriculture 4.0, where connectivity and data analytics play central roles (Zhang et al., 2002).

Future perspectives and applicability

Expanding this study through more robust experimental designs would enable the development of calibration models specifically tailored to Andean soils in southern Ecuador. Likewise, integrating the system with spatial mapping tools could facilitate the generation of within-field fertility maps, supporting site-specific fertilization decisions. The continued development of locally adapted technological solutions has the potential to reduce technological gaps in regions where the adoption of precision agriculture remains limited.

In terms of practical applicability, the present findings agree with the literature in indicating that portable sensors should be regarded as complementary tools to laboratory analysis rather than direct replacements (Naderi-Boldaji et al., 2013). Their principal value lies in enabling frequent monitoring, identifying spatial trends, and supporting timely field-based decision-making. In coffee production systems such as those evaluated in this study, where spatial variability and limited access to laboratory services are important constraints, these technologies have the potential to improve nutrient management efficiency and reduce unnecessary fertilizer use.

Finally, this study should be regarded as a preliminary validation of the proposed system under real operating conditions. Future research should incorporate larger sample sizes, point-by-point validation, systematic recording of environmental variables, and site-specific calibration models for local soil conditions. Furthermore, integrating the system with georeferencing and spatial analysis tools will extend its applicability to more advanced precision agriculture applications, including fertility mapping and site-specific management strategies (McBratney et al., 2005; Zhang et al., 2002).

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Conclusions

The development and implementation of a portable NPK nutrient monitoring system based on an Arduino microcontroller and RS-485 communication demonstrated technical and operational feasibility under real field conditions in a coffee plantation located in Loja, Ecuador. The embedded architecture enabled stable data acquisition, processing through averaged sensor readings, and real-time visualization, demonstrating reliable performance of the integrated microcontroller–sensor system in agricultural environments.

The results showed high average agreement between the measurements obtained with the portable system and conventional laboratory analysis, with relative errors below 6% for nitrogen, phosphorus, and potassium. Although the comparison was performed against a composite soil sample representative of the study field, the close agreement between the values suggests that the device may serve as a reliable preliminary tool for in-field nutrient monitoring. This level of agreement is particularly noteworthy considering that the sensor provides indirect nutrient estimations based on the electrical properties of the soil.

The within-field variability detected by the measurements confirms the presence of nutritional heterogeneity across the evaluated plot, a characteristic feature of Andean agricultural systems with variable topography. The system's ability to identify spatial differences in nutrient availability reinforces its potential application in precision agriculture frameworks aimed at site-specific fertilizer management.

From a technological perspective, the modular design of the system enables future scalability and integration with georeferencing tools, data storage capabilities, and wireless communication technologies, facilitating its incorporation into digital agriculture platforms. Moreover, the use of low-cost components increases its potential adoption by small- and medium-scale producers, contributing to the reduction of technological gaps in coffee-producing regions.

Nevertheless, it is important to acknowledge that the preliminary nature of this study, the limited sample size, and the use of a composite laboratory sample restrict the statistical scope of the conclusions. Future research should include validation using paired individual soil samples, an increased number of sampling locations, and robust statistical metrics to assess point-by-point agreement and develop calibration models specifically adapted to local soil conditions.

In summary, the proposed portable system represents a promising technological alternative for preliminary nutrient monitoring in coffee crops, with the potential to support more efficient, sustainable, and spatially informed fertilization strategies.

Conflict of interest statement

The authors declare that they have no conflicts of interest.

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Declaration on the use of artificial intelligence

During the preparation of this manuscript, ChatGPT (OpenAI, GPT-5.3 model) was used to support improvements in writing quality, academic language clarity, and the structural organization of the manuscript. The use of this tool was limited exclusively to writing assistance and text editing tasks.

The authors critically reviewed all AI-generated content, made the necessary revisions, and assume full responsibility for the integrity, accuracy, and originality of the manuscript.

Author contributions (CRediT)

Franklin Gustavo Jiménez Peralta: Conceptualization; methodology; validation; formal analysis; investigation; data curation; project administration.

Marianela del Cisne Carrión González: Conceptualization; methodology; validation; investigation; writing – original draft; writing – review & editing; supervision.

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