Chemical Science Review and Letters ISSN 2278-6783
www.chesci.com Research Article

Smart Monitoring of Soil Chemical Properties in Coffee Plantation through IoT (Internet of Things) Sensor

Hareesh, S.B.*, Shivaprasad, P., Greeshma, G., Sushmitha, N., and J.S. Nagaraj

Central Coffee Research Institute, C.R.S, Chikkamagaluru – District, Karnataka

Abstract

Creating fertile land for coffee growing requires good soil health. Healthy soil leads to healthier coffee plants, which produce higher yields of superior quality coffee beans. However, soil health monitoring by traditional methods is laborious, time consuming and expensive. As an alternative, soil sensors can be used to perform analyses in economically. In this scenario, there is a significant need for compact, inexpensive, low-power, and rapid soil NPK sensors, anticipated to become more common in the near future, due to the demand for enhanced agriculture production and the future widespread usage of the Internet of Things (IoT). By utilization of soil sensors in coffee plantation, users can monitor real-time soil nutrients status to optimise soil management practices for sustainable coffee production. In view of above, a preliminary study was conducted at Arabica Coffee Plantation viz., M/s. Amyra Farms, Hospete Village, Chikkamagaluru District Karnataka to know accuracy and reliability of IoT soil sensor real time data (3 months, February to April 2024) with standard laboratory method. The analytical data from the laboratory (manual) testing method revealed that, soil reaction is optimum (6.2), medium organic carbon, medium N (280 – 560 kg/ha) and high P and K (>56 & >336 kg/ha) contents. All secondary and micronutrients were sufficient in the soil. When soil sensor data with manual soil testing results compared, it is found that average pH is 8.2, whereas the pH by laboratory (manual) testing method is 6.2 (variation of 2.0 pH compared with manual soil testing method). This assessment points out essentiality of calibration/configuration of soil pH sensor with manual soil testing data to overcome limitations of the soil sensor technology to get accurate and reliable data. Soil conductivity is also more detected by soil sensor (0.16 dSm^{-1}) compared with laboratory (manual) testing. More variability of nitrogen (N) & potassium (K_2O) results is found between sensor data and analytical results of laboratory (manual) testing. On average more N and K is estimated by laboratory (manual) testing method (265 kg/ha & 304 kg/ha) compared to sensor data. Only 2 kg/ha of variability in P is found between by laboratory (manual) testing method and sensor data. Hence, evaluation, calibration and precise configuration of soil IoT sensors is must before rendering any recommendations in coffee plantations underneath varied environments.

Keywords: Smart monitoring of soil, Internet of Things, soil sensor, available nutrients, coffee plantation & Karnataka

***Correspondence**
Author: Hareesh
Email: hareeshsb@gmail.com

Introduction

Creating fertile land for coffee growing requires good soil health. Healthy soil leads to healthier coffee plants, which produce higher yields of superior quality coffee beans. Coffee is the major plantation crop cultivated in the majority in sloppy hilly terrains of Chikkamagaluru and Kodagu districts of Karnataka [1]. Generally, manual soil testing is adopted to determine soil health, nutrient status and rendering lime and fertilizer recommendation. Coffee growing soils of India are deep, friable, high in organic matter, high in potassium, well-drained, and reacting slightly acidic in reaction. Iron oxides and aluminium oxides are present in high concentrations in these soils. High levels of organic matter give soils a good structure, which allows coffee soils to have good water-air relations. Crop productivity is influenced by the chemical environment and nutrient availability when the physical conditions of the soil are favourable to the plant. Soils provide the essential mineral nutrients that plants require for growth and development. The ability of different soils to supply all the necessary nutrients in sufficient amounts and in a balanced way varies. Again, interactions between nutrients in soil and plants can impede healthy nutrition [2].

To achieve sustainable coffee production and the health of the plants, deficiencies and excesses in nutrients must be assessed and supplemented through external inputs. In order to obtain economic yields external inputs of soil amendments and fertilizers were regularly applied in coffee plantations. Since, applied phosphorus is fixed by iron and aluminium oxides, the availability of phosphorus (P) in the soils used to grow coffee in India is thus limited. It has been estimated that a ton of clean coffee removes approximately 40, 7 and 45 kg of N, P_2O_5 and K_2O in the case of Arabica while 45, 9 and 58 kg of N, P_2O_5 and K_2O in the case of Robusta respectively from the soil [3]. They also concluded that, a positive relationship between coffee yield and soil potassium and phosphorus content. Hence, based on manual soil analysis, Coffee Board soil testing laboratories (STLs) provide growers with advisory services and categorise data into low, medium, and high categories [4].

However, soil health monitoring by traditional methods is laborious, time consuming and expensive. As an alternative, soil sensors can be used to perform analyses in a laboratory and lower the cost of soil sampling. Recently, several types of sensors are developed to measure the pH, moisture content, Nitrogen (N), Phosphorous (P), and Potassium (K) nutrients present in the soil, and they facilitate on-the-go detection. In this scenario, a significant need for compact, inexpensive, low power, and rapid soil NPK sensors anticipated in near future, due to the demand for enhanced agriculture production and the future widespread usage of the Internet of Things (IoT). IoT enabled technological approaches in agriculture also helps to assess soil health, soil erosion, need of fertilizer, status of soil fertility, and crop quality [5]. Meanwhile, assessment of ground water irrigation status, and soil health could have made easy by the cost-effective platforms employing IoT [6]. The IoT, smart sensors, and AI offer enormous potential for gathering and analyzing real-time data to track soil health and water contents in a specific region [7]. By utilization of soil sensors in coffee plantation, scientists/planters can monitor real-time soil nutrients status (intrinsic spatial and temporal variability), enabling them to optimise soil management practices such as fertilisation, irrigation, and other techniques for sustainable coffee production by optimizing soil nutrient levels to meet plant nutrient requirements. Using real-time data analysis, an integrated soil fertility monitoring system can turn less fertile land into more productive land by maximising efficiency, promoting sustainability and optimising soil health. It was found that the IoT's application to Agriculture is a great way to keep an eye on and manage environmental factors, which opens up new opportunities for technology to be used in coffee cultivation [8]. Meanwhile, it is well established that coffee cultivation management is quite complex, taking into account the variability of species, terrains, and specific environmental conditions that ultimately affect the production process and final grain quality [9].

Methods

To know accuracy and reliability of soil IoT sensor data with standard laboratory method, a preliminary study was conducted at Arabica Coffee Plantation (13°28'58.7"N and 75°46'21.8"E, 1210.4 m or 3971.0 feet MSL) viz., M/s. Amyra Farms, Hospete Village, Chikkamagaluru District Karnataka. In the current study, 3 IoT soil sensors (Viz., 1. Soil pH sensor, 2. Soil NPK sensor and 3. Soil Temperature, moisture & EC sensor of NioBoL make) were used. The measuring range of these sensors are -50 to 80°C for combined temperature sensor, 0-100% RH for combined moisture sensor, 0-10800µs/cm for combined EC sensor and 0 – 2000 mg/kg for NPK sensor. These soil IoT sensors were installed by Datakrew Pvt. Ltd., Bangalore and real time data captured by the soil sensors is utilized to determine soil chemical attributes of Arabica coffee plantation. The real time data of 3 months (February to April 2024) from the soil sensor is collected and compiled. Similarly, representative surface soil samples (0-9") were collected from sensor installed block and nearby locations (2-acre radius – left & right side) and these samples were processed and analysed in the laboratory by adopting standard methods. Further, data generated through IoT soil sensor (Source: https://studio.mads-iot.com/) and laboratory (manual) testing method were compared to know accuracy of data generated through both methods. The pH and Electrical Conductivity by 1:2.5 soil: water using pH and conductivity meters [10]; Soil organic carbon by Wet digestion method [11]; Available nitrogen by Alkaline $KMnO_4$ method [12]. The images of IoT sensors used in present study are depicted in **Figure 1**.

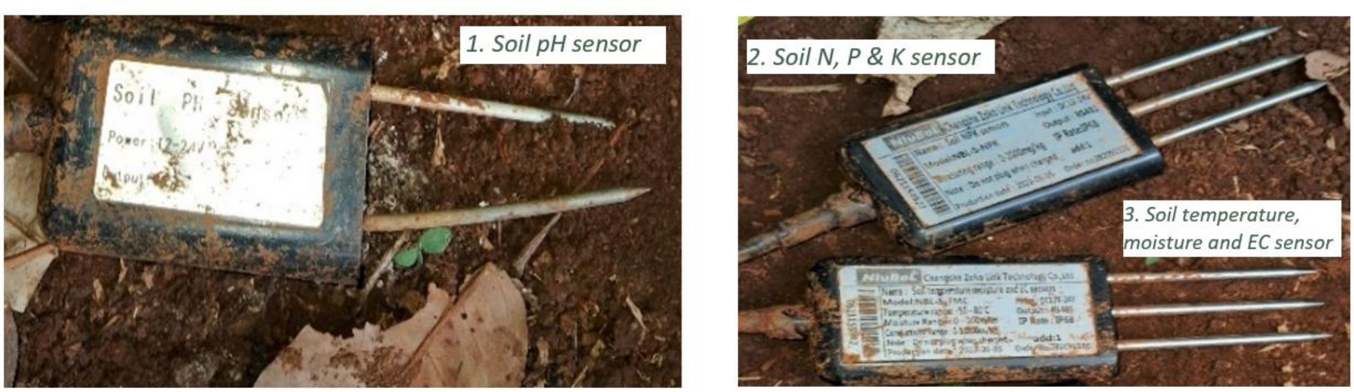

Figure 1 Soil pH, moisture, N, P & K sensors used for study

Results

The analytical data of sensor installed block by laboratory (manual) testing method have revealed that, the soil reaction is optimum (6.2), medium organic carbon, medium N (280 – 560 kg/ha) and high P and K (>56 & >336 kg/ha) contents in sensor installed block. All secondary and micronutrients were sufficient in the soil. The data generated from soil sensor over 3 months period (February to March 2024) had found that, soil pH ranged from 3.5 to 8.9 (Av.6.2), soil temperature ranged from 20.8 to 24.8 (Av.6.2), soil moisture ranged from 14.2 to 16.5 (Av.15.7), conductivity (dSm^{-1}) ranged from 0.4 to 0.5 (Av.0.5), nitrogen ranged from 15.7 to 17.9 (Av. 16.8) kg/ha, phosphorous ranged from 35.9 to 41.0 (Av. 38.5) kg/ha and potassium ranged from 167 to 186 (Av. 176.5) kg/ha. Over 3 months period rapid changes in pH are not observed, however other parameters such as soil temperature is found to be increased during February to April, conductivity is decreasing up to 15 April and then onwards followed increasing trend. Meanwhile, soil P & K suddenly decreased during end of February and gradual increased trend was recorded during end of April Month. Fluctuation of some nutrient properties may be due to intermittent power supply/ internet connectivity difficulties of soil sensors with server, since they are installed at remote location. This may also due to inherent physical, chemical and biological (dynamic) properties of soil and nutrient uptake by plants.

Table 1 Comparison of soil sensor data with manual soil analysis data

Block details/Months	pH	Soil conductivity (as dSm^{-1})	N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)
Soil sensor data from February to April 2024*					
Sensor Block (February – 2024)	8.5	0.50	18	41	182
Sensor Block (March – 2024)	8.5	0.47	16	36	176
Sensor Block (April – 2024)	7.6	0.46	16	36	170
Average	8.2	0.48	16	38	176
Analytical data of manual soil analysis method					
Sensor installed block	6.2	0.69	314	21	523
left side of sensor block 2 acre Radius	6.0	0.64	268	54	445
Right side of sensor block 2 acre Radius	5.8	0.58	262	44	473
Deviation from manual soil analysis method					
Sensor installed block (+)	2.0	-0.2	-298	17	-347
left side of sensor block 2 acre Radius (+)	2.2	-0.2	-252	-16	-269
Right side of sensor block 2 acre Radius (+)	2.4	-0.1	-246	-6	-297
Mean (+)	2.2	-0.16	-265	-2	-304
STDEV (P)	1.1	0.1	131.9	9.2	152.1
STDEV (S)	1.3	0.1	146.1	10.9	168.6
STD Error (SE)	0.5	0.0	59.6	4.5	68.8
T-test (p value)	0.009	0.017	0.004	0.87	0.005

* Monthly Average of sensor data

When manual soil test data compared with soil sensor data, it is found that variability in data captured by IoT soil sensor. The Average pH of 3 month of sensor installed block is 8.2, whereas the pH of same location by laboratory (manual) testing method is 6.2. Therefore, variation of 2.0 pH is observed when compared with manual soil testing method (MSTM). Similarly, soil sample collected from left side of sensor block (2-acre Radius) had pH of 6.0 by manual soil testing method (2.2 pH lower than sensor) and Right side of sensor block (2-acre Radius) had pH of 5.8 (2.4 pH lower than sensor). Similarly, soil conductivity as recorded by soil sensor is found to be more (0.16 dSm^{-1}) compared with manual soil testing method. More variability of nitrogen (N) & potassium (K_2O) results is found between soil sensor data and analytical results of laboratory (manual) testing. The nitrogen content captured by soil sensor is 16 kg/ha (3 months average), whereas soil test values by laboratory (manual) testing method is found to be 314 kg/ha in sensor block (298 kg/ha lower than sensor data), 268 kg/ha in left side of sensor block (252 kg/ha lower than sensor data), 262 kg/ha in left side of sensor block (246 kg/ha lower than sensor data). On average more N is estimated by manual method (265 kg/ha) compared to soil sensor data. Similarly, potassium content as detected by soil sensor at sensor installed block is 176 kg/ha, while K content by laboratory (manual) testing method is 523 kg/ha (347 kg/ha lower than sensor data), 445 kg/ha of K is recorded in left side of sensor block (269 kg/ha lower than sensor data), 473 kg/ha of K is recorded in right side of sensor block (297 kg/ha lower than sensor data). Hence, on average more K is estimated by laboratory (manual) testing method (304 kg/ha) compared to soil sensor data. However, minimum variation is recorded between soil phosphorous (P_2O_5) soil sensor data and laboratory (manual) testing results. The average of 3-month sensor data for soil phosphorous is 38 kg/ha, whereas analytical data of laboratory (manual) testing method of soil analysis of sensor block is 21 kg/ha (17 kg/ha lower than sensor data), 54 kg/ha in left side of sensor block (16 kg/ha more than sensor data) and 44 kg/ha in right side of sensor block (6 kg/ha more than sensor data). Therefore, on average only 2 kg/ha of variability is found between laboratory (manual) testing method of soil analysis and soil sensor data. Similarly, when this data was subjected to statistical analysis for standard deviation and Paired t-test (two tailed by MS excel). The statistical data of standard deviation has revealed variability between data points from their mean and standard error data has variability in the population parameter. Similarly, two tailed Paired t-test statistical analysis has significance difference between data acquired by two methods. The comparison data of soil sensor and manual soil analysis is presented in **Table 1**.

The analytical data soil samples by manual soil testing method have concluded that, organic carbon content, secondary and micronutrients were sufficient in the soil. The analytical data is presented in **Table 2**.

The soils of coffee plantations of India are heterogeneous in nature and these plantations are located at hilly terrains of Western Ghats. Hence, edaphic, cultural and nutrient management practices, environmental and microclimatic factors are playing a vital role in soil nutrient dynamics and availability of essential nutrients in coffee agroforestry systems. Hence, based on the soil sensor data generated by a single soil sensor may not be adequate to render fertilizer recommendations for wide areas in coffee plantations. Before rendering any irrigation or fertilizer recommendations based on soil sensors data, it is recommended to evaluate a greater number of different soil sensors in diverse locations under irrigated and rain fed conditions in coffee plantations.

Table 2 Soil analysis data (Manual method) at experimental location

Block details	**O.C. (%)**	**Ca (ppm)**	**Mg (ppm)**	**S (ppm)**	**Cu (ppm)**	**Zn (ppm)**	**Fe (ppm)**	**Mn (ppm)**
Sensor installed block	1.9	1997	185	63	14	3.0	23	46
left side of sensor block (2-acre Radius)	2.0	1494	180	44	15	4.0	28	51
Right side of sensor block (2-acre Radius)	2.1	1553	181	46	15	2.0	24	52
Average	**2.0**	**1681**	**182**	**51**	**15**	**3.0**	**25**	**50**

Conclusion

This assessment points out essentiality of calibration/configuration of soil pH sensor with manual soil testing data to overcome limitations of the soil sensor technology to get accurate and reliable data. Meanwhile, long-term replicated field trails at Arabica and Robusta coffee plantations underneath varied climatic environments will provide accuracy/precise reliability and data management when used in conjunction with standard laboratory (manual) testing methods. Further, there is a need to evaluate different sensors that can precisely quantify soil chemical attributes despite within field variability. Additionally, to enable on-the-go soil data analysis and quick distribution map compilation, sensor devices should ideally be integrated with a geo-location system.

References

[1] Anonymous. Coffee guide, Published by Coffee Board, India. 2023.

[2] Nair, K.M., Anil Kumar, K.S., Srinivas, S., Nagaraj, J.S., Violet D'Souza, M., Raghuramulu, Y., Rajendra Hegde, and Singh, S.K. Soil Quality Monitoring Sites (SQMS) for Traditional Coffee-Growing Areas of India NBSS Publ. No., National Bureau of Soil Survey and Land Use Planning, Nagpur, India. 2016.

[3] Jayarama, Krishnappa Naik, C.S., Shankar, B.N. and Reddy, H.T., Correlation between soil fertility parameters and coffee yield in small coffee holdings of Chikamagalur Zone. Journal of Coffee Research. 1993. 23(1): 25-31.

[4] Shiva Prasad, P., Nagaraja, J.S., Nadaf, S.A and Violet D' Souza, M. Build-up of soil phosphorus in coffee plantations of Karnataka over three decades. Journal of Plantation Crops, 2017, 45(1):66-71.

[5] Sishodia, R.P., Ray, R.L and Singh, S.K. Applications of remote sensing in precision agriculture: a review. Rem. Sens., 2020 (12), p. 3136

[6] Prem Rajak, Abhratanu Ganguly, Satadal Adhikary, Suchandra Bhattacharya. Internet of Things and smart sensors in agriculture: Scopes and challenges, Journal of Agriculture and Food Research, Volume 14, 2023, 100776, ISSN 2666-1543

[7] Ayaz, M., Ammad-Uddin, M., Sharif, Z., Mansour, A and Aggoune, E.-H.M. Internet-of-Things (IoT) - based smart agriculture: toward making the fields talk. IEEE Access, 7 (2019), pp. 129551-129583

[8] William Ruíz-Martínez, Díaz-Gutiérrez, Roberto, Luis Pallares. Application of the Internet of Things through a Network of Wireless Sensors in a Coffee Crop for Monitoring and Control its Environmental Variables. Artículos de investigación. TecnoLógicas, 2019 vol. 22 (46), pp. 155-170.
[9] Sase. Sase Simposio Argentino de Sistemas Embebidos. Disponibleen: 2011. http://www.sase.com.ar/#Que-son-los-sistemas-embebidos
[10] Jackson, M.L. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, 1973.106-203.
[11] Walkley, A.J. and Black, I.A. Estimation of soil organic carbon by the chromic acid titration method. Soil Sci. 1934. 37, 29-38.
[12] Subbiah BV, Asija GL. A rapid procedure for assessment of available nitrogen in soils. Current Science. 1956; 25:259-260.

Publication History

Received	06.10.2024
Revised	21.12.2024
Accepted	21.12.2024
Online	29.12.2024