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Instrumentation in Soil Science: *An advanced overview*

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ABSTRACT

This paper provides an overview of what soil science instruments entail in the global academic environment. This paper focused on developments in advanced soil science equipment with a specific compilation of forty (40) different instruments and their brief application. These sets of instruments are found to be applicable in soil science based on (a) optical methods, which focus on the measurement of the optical properties of substances; (b) chromatographic methods, which focus on the use of different substances for selective sorption; (c) electrochemical methods, which emphasize the measurement of the electrochemical properties of substances; (c) radiometric methods,which are built on the measurement of the radioactive properties of substances; (d) thermal methods, which are centred on the measurement of the heat effects of substancesand mass spectrometric methods, which are established for studying the ionized fragments ('splinters') of substances; and (w) kinetic methods, which focus on the measurement of the dependence of the reaction speed on the concentration of substances. The practical applications of these methods have provided significant contributions to the detailed understanding of primary and secondary soil properties, especially organic matter (or organic carbon), carbonate (or inorganic carbon), total nitrogen, clay minerals, iron content, particle size fractions of clay, silt and sand, and water content.

Introduction

Soils are multifarious environments with diverse mixtures of various physical, chemical, biological and ecological properties that interact with each other in dynamic and complex relationships (Usman, 2013). The interaction between these properties has been noted to involve multiple functional interactions between the atmosphere, hydrosphere, lithosphere, biosphere and pedosphere (Brady and Weil, 2021). In this regard, various instruments and modern equipment are needed for diverse analyses of soil (FAO, 2022). However, soil science is a field of study with various research interests and developments (Arnold, 1983). Instruments used in soil science have emerged and developed many years ago and appear to be important for various soil analyses (King *et al.*, 2003; Janvier *et al.*, 2021). Many soil science experts believe that the application of soil instruments in this field of study has contributed significantly to the expansion of soil science and its pertinence to agriculture, chemistry, biology, physics, and overall geography and environmental sciences (King *et al.*, 2003; Lindbo *et al.*, 2012; Singer, 2015). Various modern science applications require large amounts of high-resolution (both spatial and temporal) quantitative soil data (FAO, 2022). The use of modern soil science instruments, such as optical methods, particularly spectroscopy, plays a vital role in easing most of the difficulties and managing the limitations associated with conventional methods (Terhoeven-Urselmans *et al.*, 2010; Froba *et al.* 2014 Araújo *et al.*, 2014; Sharififar *et al.*, 2019). The current advancements in soil science research require the use of modern soil instruments, which are rapid, effective and low-cost methods for detecting and sensing primary and secondary soil properties under different soil objectives. Therefore, for these reasons, there is broad interest in providing an overview of soil science instruments, particularly the classification and principles behind the development of optical methods and their application in soil science. This short communication paper reviews some common and widely used instruments in the Soil Science Laboratory and provides a background definition regarding the existence of each of these instruments as well as their relevance to practical aspects of soil science.

Instruments in the Soil Science Laboratory

Instruments in the Soil Science Laboratory are used for a variety of purposes, and they serve as basic scientific methods for various soil analyses, which could lead to many advanced soil data records in the field of soil science. The authors thank Hoskin Scientific Ltd. (2013) and ICAR-DCR (2017) for the compilation of this equipment. According to these two publications, equipment in the Soil Science Laboratory is used for advanced soil and plant testing with careful application. The general features and descriptions of these instruments, which are provided below, are in accordance with vital information provided by Hoskin Scientific Ltd. (2013) and the ICAR-DCR (2017).

1. ***Microwave Plasma Atomic Emission Spectrometer (MP-AES, AGILENT 4210 MP-AES):*** This is a highly sensitive instrument for a wide range of elements down to the sub ppb level and is faster than conventional atomic absorption-based instruments. Instead of flammable gases, MP-AES uses microwave energy to produce plasma for the ionization of elements using nitrogen extracted from ambient air.
2. ***UV–Visible Spectrophotometer – Double beam (Shimadzu UV-1900):*** This instrument is used for the measurement of elements such as P, Mo, and B in soil, plants, water, manure, fertilizers, and pesticides. It is also used for qualitative and quantitative analyses of DNA, RNA and proteins. The instrument has third-dimensional spectrum utility for sample analysis and possesses various operational modes,such as standard, photometric, spectral, quantitative, kinetic, time scan, DNA and protein quantitation, in standalone and PC modes.
3. ***Microwave digestion system (Milestone Ethos-easy):*** This instrument is used for the digestion of various materials in soil, plant, manure, sediment, food, and rock samples. The microwave power rating was 1900 Watts, and the cavity size was 70 litres.
4. ***Refrigerated centrifuge (Remi CPR 30 Plus):*** This instrument is used for isolating and separating suspensions and immiscible liquids. It is also used for DNA preparation and macromolecular separation. It can be used at the same time for the removal of unwanted debris to make clear solutions that can be used analytically in spectrophotometers, HPLC and GLC.
5. ***Water distillation system:*** This instrument has two forms of application, namely,single and double. These two applications served the same purpose: the preparation of distilled water.
6. ***Top loading precision balance:*** This instrument is used for accurately weighing soil samples and chemicals.
7. ***pH meter:*** This instrument is used to measure soil pH and reagents.
8. ***Oakten waterproof PCS tester 35 Multiparameter pocket tester:*** This instrument served the same purpose as the pH meter but was specifically used for field estimation of soil pH.
9. ***An Elico CM180*** digital conductivity meter was used for measuring the electrical conductivity and salt concentration in the soil.
10. ***Water bath shaker:*** This was used for shaking and mixing the soil sample at the desired temperature.
11. ***A magnetic stirrer with a hot plate*** was used to mix reagents with the help of a stirring bar, and heating was used to increase the solubility.
12. ***Rectangular plate with a thermostat:*** This thermostat is used to heat chemicals, solution, and media.
13. ***Muffle furnace:*** This instrument is used for dry ashing of samplesand carbon estimation in soil and plants.
14. ***air oven:*** This instrument is used for drying plant samples, estimating soil moisture, and frying glassware and plastic waste.
15. ***A vortex mixer***was used to mix the samples quickly in the test tube.
16. ***Labline Centrifuge (Max speed: 4000):*** This instrument served the same purpose as a Hot plate rectangular with a thermostat,i.e., to heat chemicals, solution and media.
17. ***DK 20 Digestor (plant sample digestion system):*** This instrument is used for the digestion of plant samples for elemental analysis and the digestion of soil samples for total nutrient analysis.
18. ***A nitrogenanalyser (KEL PLUS)*** and a refrigerated water cooling circulation system were used to estimate the different forms of nitrogen in the soil and the nitrogen and protein contents in the plants.
19. ***Time TDR Soil moisture profiling system:*** This system is used for the estimation of soil moisture up to a depth of 1 meter.
20. ***Horizontal Rotary Shaker:*** This instrument is used for shaking soil, plant samples and chemicals. It is closely related to the use of a water bath shaker.
21. ***BOD Incubator:***This indicator is used for the estimation of biological oxygen demand.
22. ***Horizontal Autoclave:***This autoclave is used for autoclaving glassware, plasticware and media.
23. ***Microwave oven:***This oven is used for media preparation and reheating.
24. ***Laminar air flow chamber:*** This chamber is used for providing contamination-free areas for microbiological studies.

25. ***UV face shield:***This shield is used for eye protection and safe operation under radiation.
26. ***A colony counter (Digital)***was used for counting the colonies.
28. soil investigations and general soil sampling in the field. Various types of soil auger are used—Edelman auger, Riverside auger, Stone soil auger, Spiral auger, Soft soil auger, Gouge auger and Piston sampler. Hand augers are very useful for obtaining samples from depths of up to 8 – 10 cm in the field. There are various auger samplers that can serve this purpose. These auger samplers include a single gouge auger set, two-piece gouge auger set, liner sampler for sampling in soft and hard soils, soil column cylinder sampler, percussion drilling set for heterogeneous soils, soil sample ring kit, split-tube soil sampling kit, and soil coring kit for chemical research. The selection of these various auger samplers depends on the nature and condition of the study area, the type of study and the objectives outlined.
29. ***An Olympus*** microscope was used for normal visualization of the soil particles and soil organisms.
30. ***GPS (Garmin):***Garmin is used for navigation during field visits and field surveys and for generating geo-coordinates and altitude/latitude information.
31. ***Munsell Soil Color Chart*** (Munsell, 1975)***:*** This is a color chart book specifically for the assessment and classification of soil color in the field. This soil colour chart book is unique because of its application to various soil conditions. It can be used to classify soil under a broad range of environmental conditions and can be applied to rock identification, soil particle classification, and soil profile examination. The most permanent futures of this book are Hue, Chroma and Value. Other futures include 322 matte colour chips, which are permanently mounted; easy-to-view apertures between colour chips; charts for estimating the proportion of course and mottles fragments; and easy-to-view black and grey masks.
32. ***Soil Gas Lance:*** This instrument is used for extracting soil gas from unsaturated soils. It has a semipermeable hydrophobic membrane that is permeable only for gas and not for solution;thus, it has the functional power of not picking even moisture from the soil. Its bubble point is near 80 kPa. The total length is 200 mm,the diameter is 8 mm, and the pore length of the membrane reaches 100 mm.The soil gas lance has both single and dual capillary tubes. The single capillary tube has one capillary tube connected to its vacuum, which is applied to suck up the soil gas.However, the double capillary tube has two capillary tubes, with the air inside the sampler moving along the inside of the membrane and equalizing to the soil gas by diffusion through the membrane, which is then pulled out of one tube, leading through a gas analyser and back into the sampler through the other tube. It was constructed with a tube inside the sampler so that the air could enter at the upper end of it and be removed at the bottom end of it. This will allow the air to travel along the
27. ***Soil auger:***The soil auger is used for crying out,manual drilling and sampling of a great variety of different soils in an agronomically sound way. It is particularly suitable for general

full length of the membrane. This circulation is constant for online monitoring with a gas chromatography detector.

33. ***pH-Checker +:*** This instrument is an advanced device with multiple functional services. Its applications include atmosphere monitoring, soil and environmental clean-up, petrochemical analysis, industrial painting, soil contamination assessment, leak detection, indoor air quality assessment, pesticide residue analysis, etc.
34. ***Double-ring infiltrometer:*** This instrument is used for field measurement of the infiltration rate. It is ideal for direct measurement of infiltration water from the topsoil and is perfect for flood and irrigation advice. It is efficient for irrigation, drainage, and optimizing the availability of water for plant use and for soil erosion control for soil quality development.
35. ***Guelph Permeameter (E-127-2800K1):*** This instrument is easy to use for the insitu measurement of hydraulic conductivity, soil sorptivity, and matrix flux potential in all soil types under different environmental conditions. It is movable, and measurements can be made 15 to 75 cm below the soil surface.
36. ***Gee Passive Capillary Lysimeter (E-240-40340):*** This instrument is used for the determination of the volume of water and chemical from the vadose zone of groundwater. Thus, it can be used to monitor groundwater leaching, identify soil contaminants, and measure deep percolation. The instrument can be used for drainage identification, to monitor the efficacy of cover crops, to observe soil and water quality, and to control excess water application and fertilizer losses.
37. ***Mini-disk Infiltrometer (E240-40300):***This instrument is used for measuring soil water and water table levels at a length of 33 cm. It is ideal for irrigation system design, soil erosion risk and hazard evaluation, soil moisture potential and classroom demonstration purposes. It is 32.7 cm long and requires approximately 135 ml of water.
38. ***Tension Infiltrometer (E127-2826D):*** This instrument is used for the rapid, accurate and easy measurement of the unsaturated flow of water into soil. The applications of this instrument include the measurement of macropores and preferential flow, the estimation of soil structure, and the characterization of the soil hydraulic conductivity-water potential relationship.It is 20 cm in diameter and was designed to operate in two modes, namely,separated and attached. In the separate mode, the infiltration disc is separated from the water tower, whereas in the attached mode, the infiltration disc is attached to the bottom of the water tower using the supplied connector. However, operating the infiltrometer in separated mode is advantageous when taking measurements under windy conditions.Generally, in both separated and attached modes,

the water level in the water reservoir can be determined by reading the level on the attached centimeter scale or by measuring the pressure in the upper end of the water reservoir.

39. ***Column Transport System (E-127-1448):*** This instrument is used to study the movement of water and contaminants, tracers, nutrients, colloids, and pesticide residues through the soil. The test cells of this instrument have multiple testing functions, including the measurement of hydraulic properties under saturated and unsaturated hydraulic conductivity of porous matter, the assessment of contaminant and gas transport parameters, and the determination of moisture retention relationships on disturbed columns.
40. ***Soil Moisture Sensor (SM 300):*** This instrument is used for soil moisture and temperature detection. It offers outstanding performance under normal and saline soil conditions and is stable across wide ranges of temperatures and salinities. The SM 300 has the ability to minimize soil disturbance, preserves the original soil structure around the measurement rods, and is easy to insert and install, whether at the soil surface or at depth.It is provided with general calibrations for mineral and organic soils, and a two-point soil-specific calibration can be performed for greater accuracy if needed. It is generally applicable to soil science studies, agriculture and horticultural research, and irrigation examinations.
41. ***Delta-T WET Sensor:*** This instrument is designed for soil moisture and nutrients in the root zone of the soil. It has crucial applications in precision horticulture and soil science research and is usable in both soils and growing substrates. It is exceptional in its ability to measure pore water conductivity (ECp), the EC of the water that is available to the plant. The advantages of using these soil instruments include ease, accuracy, time and money, and the use of research-grade sensors.

According to the above-listed instruments of the Soil Science Laboratory, these equipment can generally be used based on the following methods(TDMUV, 2023): (a) optical methods, which are based on the measurement of the optical properties of substances; (b) chromatographic methods, which are based on the ability of different substances to selectively sorb; (c) electrochemical methods, which are based on the measurement of the electrochemical properties of substances; (c) radiometric methods,which are based on the measurement of the radioactive properties of substances; (d) thermal methods, which are based on the measurement of the heat effects of substances; mass spectrometric methods, which are based on the study of ionized fragments (‘splinters’) of substances; and (w) kinetic methods, which are based on the measurement of the dependence of the reaction speed on the concentration of substances. The main advantages of these light scattering techniques include measurements that can be performed in or close to thermodynamic equilibrium (almost without any input of energy), experiments that are conducted in noncontact mode by allowing access to regions of thermodynamic state that can hardly be probed by other techniques, and permission for the determination of a wide range of transport modes (Froba *et al.* 2014).

Optical methods of analysis and classification

Optical methods involve measuring the difference in optical response between blank portions of the sorbent and regions where a separated substance is located (Robards, and Ryan, 2022). Among sensor technologies, optical methods are among the earliest and most advanced technological studies of biological and chemical reactants, and different optical techniques have been used in the production of biosensors (Altuner *et al.*, 2022). The methods are based on how the sample acts toward electromagnetic radiation, where the absorption or emission of radiant energy, the bending of radiant energy, the scattering of radiant energy, and the delayed emission of radiant energy are typical optical properties that can be correlated with concentration; this construction of the instruments for these measurements generally involves the use of lenses, mirrors, prisms, and gratings (Donald and Clyde, 1979).Giuseppe (2011) noted that optical methods allow the detection of density variations that occur in a fluid due to changes in temperature and/or speed and/or composition. They are commonly employed to compare droplet size/velocity distributions between different nebulizers (Aguirre and Canals, 2023).Optical analysis techniques have proven to be useful for the characterization of different properties (López-Lorente and Valcárcel, 2014).

In an overview of what optical methods were employed and their classification concepts, the online survey by this short communication paper noted the works of Vejražka (2009) and TDMUV (2023), which provided vital information worthy of consideration. According to these two orientations, optical methods can be classified into four groups, and each group has other subgroups. These groups are based on (a) the investigated objects, (b)the nature of the interaction of electromagnetic radiation with substances, (c)the electromagnetic spectral range used in the analysis, and (d) the nature of the energy jump (TDMUV, 2023). However, the more important techniques of these groups are mass spectrometry analysis, nuclear magnetic resonance, and electron spin resonance (Donald and Clyde, 1979). These methods are typically summarized below based on the general perspectives outlined in Vejražka (2009), FAO (2022) and TDMUV (2023).

Optical methods based on investigated objects

1. Nuclear spectral analysis
2. Molecular spectral analysis

Optical methods based on the nature of the interaction between

electromagnetic radiation and substances

1.Absorption analysis: This analysis covered the atomic absorption, molecular absorption, and turbidimeril.

- **a.** *Atomic-absorption analysis* - Atomic absorption spectroscopy (AAS) is a spectroanalytical procedure for the quantitative determination of chemical elements employing the absorption of optical radiation (light) by free atoms in the gaseous state.
- **b.** *Molecular-absorption analysis* - Molecular absorption spectroscopy in the ultraviolet (UV) and visible (VIS)

- **c.** regions is concerned with the measured absorption of radiation in its passage through a gas, a liquid or a solid.
- **d.** *Turbidimetric analysis* - Turbidimetry (turbidity) is the process of measuring the loss of intensity of transmitted light due to the scattering effect of suspended particles. Light is passed through a filter, creating a light of known wavelength, which is then passed through a cuvette containing a solution.

3. Eemissive spectral analysis: This analysis included flame photometry and fluorescence.

- **a.** *Flame photometry* - Flame photometry, more properly called flame atomic emission spectrometry, is a fast, simple, and sensitive analytical method for the determination of trace metal ions in solution.
- **b.** *Fluorescence analysis* - Luminescence is the emission of light by a substance not resulting from heat; it is thus a form of cold body radiation.
- **c.** *Spectral analysis*of the effect of combinational dispersion of light.

3.Other methods: These methods include the nephelometric, refractometric, polarimetric and interferometric methods.

- **a.** *Nephelometric method* - Nephelometry is the measurement of scattered light. This technique requires a special measuring instrument, where the detector is set at an angle to the incident light beam.
- **b.** *Refractometric analysis* - Refractometry is the method of measuring a substance's refractive index (a fundamental physical property) to, for example, assess its composition or purity. A refractometer is the instrument used to measure the refractive index (RI).
- **c.** *Polarimetric analysis* - Polarimetry is the measurement and interpretation of the polarization of transverse waves, most notably electromagnetic waves, such as radio or light waves.
- **d.** *Interferometric analysis* - Interferometry is a family of techniques in which waves, usually electromagnetic, are superimposed to extract information about the waves.

Optical methods based on the electromagnetic spectral range used in the analysis:

1. Spectroscopy (spectrophotometry) in UV and visible spectra
2. IR - Spectroscopy - Infrared spectroscopy (IR spectroscopy) is a technique in which the infrared region of the electromagnetic spectrumis characterized by light with a longer wavelength and lower frequency than visible light.
3. X-ray spectroscopy - X-ray spectroscopy is a gathering name for several spectroscopic techniques for the characterization of materials by using X-ray excitation.
4. Microwave spectroscopy - The interaction of microwaves with matter can be detected by observing the attenuation or phase shift of a microwave field as it passes through matter.

Optical methods based on the nature of energy jumps

1. Electronic spectrum
2. Vibrational spectrum
3. Rotational spectrum

These different classes of optical methods have been used in many studies covering different components of environmental studies, such as soil science, chemistry, biochemistry, and physics. One of the possible reasons that these methods are receiving more attention in these fields of science is their advantages over conventional methods (Froba *et al.*, 2014). Many authors have discussed optical methods based on more advanced principles. For example, Altuner *et al.* (2022) noted that a unique optical biosensor is a group of optical components used to create a spectrum of light with certain properties from a light source and a factor that directs or displaces this light, a transformed sensing head (crystals covered with optical fibres or antibodies transformed with dyes and proteins and functional chemical groups), and a light detector. The optical method used for measuring the thickness D and refractive index n(D) of the medium separating two thin sheets of mica has been described by Terashima *et al.* (1983). The mica surfaces were immersed in a pure solvent (cyclohexane in these experiments), and n(D) was determined to be in the range of $0 < d \lesssim 300$ nm. The polymer was then introduced into the solvent to the required concentration, and the surfaces were incubated for 10 hours to allow adsorption from the solution to take place. After adsorption, n(D) is again determined, following which the solution is almost entirely replaced by pure solvent; this results in an approximately one hundredfold dilution of the original concentration. n(D) is then measured again over a period of up to 48 hours (Terashima *et al.*, 1983).

Similarly, the continuous variation method, also known as 'Job's plot method', is an optical method used by Anil and Hassan (2021) for thedetermination of host-guest stoichiometry. They described this method as Job's plot method, where different solutions are made with different compositions of host [H]0 and guest [G]0. The ratio of [H]0+[G0] is varied to ensure that the concentration of [H]0+[G0] remains constant. They recorded the optical responses of solutions with different ratios of [H]0 and guest [G]0, and then a graph of the optical responses on the Y-axis versus the [H]0/[H]0+[G]0 mole fractions on the X-axiswas plotted; in this regard, the maximum optical response obtained on the Y-axis and the corresponding mole fraction on the X-axis represented the stoichiometry of the host–guest ratio (Anil and Hassan, 2012). However, the principles of these optical methods have been investigated by Giuseppe (2011). These principles state that the variation in density, ρ, produces a variation in the refractive index, n, of the fluid, which in turn influences the trajectory (refraction) and the phase of the light rays that pass through the fluid. He further noted that the appropriate optical devices convert the resulting effect in changes in light intensity on a screen or on a photograph, and the index of refraction, n, of a transparent medium, which is the ratio between the speed of light in vacuum and the speed of light in the substance, is related to the density by the Lorenz–Lorentz equation,where R (λ) is, for each substance, a function of the wavelength, λ, of the light (Giuseppe, 2011).

Froba *et al.* (2014) noted that an approach to overcome the use of conventional methods is the application of light scattering techniques (optical methods), which make use of microscopic fluctuations, which are related to diffusive processes and to the transport properties to be measured.
Subjectively, these procedures are also used in soil science, as for examples, as covered in many studies, such as Surekha *et al.* (2020), who have worked on soil analysis for fertilizer prediction using IoT and machine learning. Machine learning has also been used for soil fertility prediction (Janvier, 2021). Real-time soil nutrient detection and analysis were studied by Pallevada *et al.* (2021). Krithiga and Sindhuja (2017) observed soil nutrients using Arduino, while N, P, and K were successfully detected using a fibre optic sensor and a PIC controller (Gavade, 2017). Chaudhari *et al.* (2023) described the use of a photodiode (LDR sensor module) for light detection purposes to evaluate the NPK concentration. They explained that the output obtained from the photodiode is handled using an Arduino UNO microcontroller, and based on the inputs received from the LDR module, the NPK concentration can be evaluated. This model can be trained with the crop prediction dataset to predict crops using the LightGBM algorithm, while the proportions of NPK nutrients and the predicted crop are sent to the user as text messages through the GSM module and Thing Speak cloud platform (Chaudhari *et al.*, 2023). There are also developments in soil spectral inference with R that have focused on analysingdigital soil spectra using the R programming environment (Wadoux *et al.*, 2021). These studies have shown that soil instrumentation is useful for addressing global soil issues and that the application of optical methods has a significant role and position in soil science.

In recent developments, taking an applied example from the work of the FAO on one of the optical methods of the time, soil properties have been reported to be estimated directly or indirectly by vis-NIR and MIR spectra (FAO, 2022). The primary soil properties under this estimation included organic matter (or organic carbon), carbonate (or inorganic carbon), total nitrogen, clay minerals, iron content, particle size fractions of clay, silt and sand, and water content. The general procedure (Figure 1) of these modern techniques was described as being distinguished from other conventional soil analysis techniques in such a way that vis-NIR or MIR instruments do not directly report the quantitative results of soil properties;rather, a training set (also known as a calibration set) is used to train (or calibrate) empirical models that relate the spectral data to the target soil properties; therefore, the soil samples in the training set need to be analysed by a reference (traditional wet-chemistry analysis) or laboratory-based analytical method (as an accepted standard) (FAO, 2022).
According to the FAO (2022), the empirical models need to be tested against an "independent" set of samples not used in calibrating the model (known as a test set, which is also measured by the same reference method) to assess the model performance. After full calibration and testing, the models can then be used for estimating the soil properties of new, unknown samples from their vis-NIR or MIR spectra.

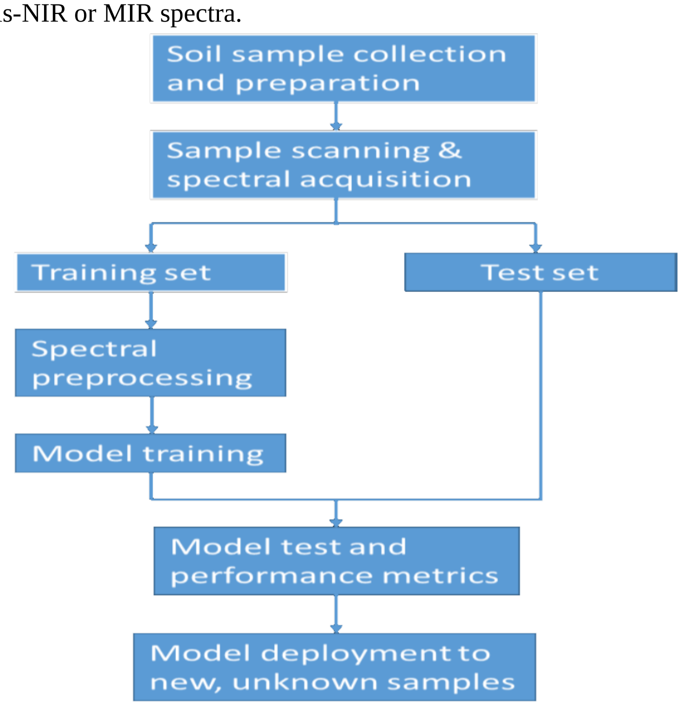

Figure 1: The workflow of vis-NIR and MIR spectroscopy for soil analysis (FAO, 2022)

The FAO (2022) noted that model training and testing are the core of vis-NIR and MIR analysis and require a different set of knowledge and skills (e.g., processing a large volume of spectral data, statistical modelling, programming in a computer language, and assessing model performance) compared to conventional lab-based soil analysis.

Revati *et al.* (2021) reviewed optical methods of soil nutrient detection suitable for building portable sensors because they can sense nutrients in dry soil samples directly without the need for complicated sample pretreatments. They have studied effective and utilitarian spectroscopic approaches and technologically advanced and recent methods, such as imaging systems, microfluidics, and microelectromechanical system (MEM)-based sensors. According to their observations, optical methods can be affected by environmental factors, which also affect the accuracy of sensor results; however, these methods are very useful for detecting NPK in the field (Chaudhari *et al.*, 2023). Trontelj ml and Chambers (2021) used artificial intelligence optical methods based on the hypothesis that a machine learning approach would improve the accuracy of soil property prediction. Using optical methods, they compared six commonly used techniques, namely, random forest, decision tree, naïve Bayes, support vector machine, least-square support vector machine and artificial neural network methods. They noted that the prediction of single-component soil properties was less accurate than that of compound soil nutrient characterization, which is more accurate.

Conclusion

Soil science instruments are important components of the significant advancements in soil science that have occurred throughout the history of its expansion and emergence. The development of optical methods has yielded many contributions to the detection of different soil properties in different studies. There is a need for detailed understanding through practical training for modified and recent modern soil science instruments. Modern soil science instruments, particularly optical methods, can be applied to all soil properties, although a vast understanding of the processes and principles involvedisneeded. Soil science laboratories should engage novel specialists in more detailed practical aspects of optical instruments and, where possible,organize workshops and training sessions for the benefit of students at all levels.

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