Detection of Macronutrients (NPK) using LED Based Spectroscopy Method

1Nishad Kumbhare, 2S. R. Kumbhar
1Assistant Professor, 2Professor
1Shikshanmaharshi Dr. Bapuji Salunkhe College, Miraj, India,
2Willingdon College, Sangli, India

Abstract - **The soil is a dominant medium to grow the plants in which the soil nutrients especially macronutrients play a major role to improve the fertility and hence growth of seeds and crops. The traditional geochemical analytical methods to explore macronutrients used in agricultural laboratories give accurate results, but it is more time consuming, so the need for different chemicals and highly skilled workers are required at prior. Instead, the modern methods are beneficial to explore major macronutrients i.e. Nitrogen, Phosphorus and Potassium (Kalium – Latin name) with the help of electronic sensors that give accurate results without the need of chemicals and highly skilled staff. Hence, the farmer himself can explore the macronutrients NPK concentration and deficiencies and then use proper fertilizers to improve the soil fertility with the reference of an ideal ratio for NPK i.e. 4:2:1. This paper reviews the different modern electronic analytical methods to determine NPK concentrations without going into the agriculture laboratory. LED based spectroscopy focused in this research paper is an emerging technology without destruction of target soil matters or particles. It's timely, reliable and less expensive compared to the other methods explained.**

keywords - **Macronutrients, NPK, LED Spectroscopy, Soil**

I. Introduction

Many farming communities such as Indians are still using mundane ways of farming with an increase in demand for food. The customized sensor based analysis may provide precise data quickly rather than the traditional method, which is generalized and not to the targeted area or not to the specific area [1], [2]. That is, quickly and accurately soil data can be analyzed by the precise agriculture practice through electronic systems rather than traditional geochemical analysis. Also, the manual method of measuring the soil nutrients is less accurate because of the time difference of soil samples collected at the field and measured in a laboratory that is not real time. The smarter agriculture practice can be made by the measurement of major macronutrients such as Nitrogen (N), Phosphorous (P) and Potassium (K) through electronic sensors. Also, the unsystematic use of fertilizers may lead to groundwater pollution, hence nutrient management, balanced plant nutrition of crops is necessary [3]. This research work will focus the exploration of major macronutrients – Nitrogen (N), Phosphorous (P) and Potassium (K) by the method of LED spectroscopy. Precision Agriculture (PA) and soil testing are essential to determine nutrients availability in soil before applying any fertilizers nowadays. The conventional soil testing in the laboratory is a time consuming method and requires more cost, highly skilled operators and can't be real time. Since, spectroscopy is an emerging technology which is rapid, simple and can be used in agriculture to explore major macronutrients content.

II. Other Different Macronutrients Exploration Methods

Soil is the most important medium for plant growth. The nutrients in soil improvise the fertility and hence the growth of seeds and crops. In agriculture as well as electronics, several researches have been undertaken to improvise the practice in the agricultural field, but due to increase in population, a major disadvantage requires new methods which will grow the crop plantation management methods in dominant ways without expense [4]. Table 1 illustrates various sensors used in agriculture such as electrical, electromagnetic, optical, radiometric, mechanical, acoustic, pneumatic and electrochemical for PA. Meanwhile electric and electromagnetic sensors are widely used today, but other types may be suitable to improve the soil relevant information in future very soon. The food yield globally is based on the presence of nutrients. The Phosphorus (P) is an important nutrient due to its low recovery and finite availability. To obtain the good and healthy growth of a crop, the average sum of macronutrients N+P+K=2 (N=0.5, P=1.0, K=0.5). However, The NPK Ratio of 4:2:1 is considered as an ideal and accepted as a macronutrients level of the soil [5], [6], [7].

Table 1 Sensors Used for Precision Agriculture Practice

Sr. No.	Sensor Type	Measurement Principle
1	Electrical / Electromagnetic	Resistivity, conductivity, capacitance, inductance
2	Optical and Radiometric	Level of energy absorbed / reflected from target
3	Mechanical	Resulting force from object
4	Acoustic	Sound produced / reflected from object
5	Pneumatic	Ability to inject air into object
6	Electrochemical	Ion-selective membrane that produce voltage output by chemical reaction

Following techniques are being used to explore the major soil macronutrients that is NPK by the method of –

Sensing ferromagnetic properties, 1997

In this technique, detection is carried out by the observations of granular soil particles relationally together by sensing the ferromagnetic property of welsh soil granular by Secondary Ferromagnetic Mineral (SFM) method with dependent premature mechanism to explain the observed link between soil magnetism and climate by lowering the temperature below 20 Kelvin. Hence, the effect of depressing values of low field susceptibility in percentage is noticed [8].

By portable Raman sensor, 2004

The portable Raman sensor for soil nutrient detection was provided to obtain a significant phosphorus absorption band in soils and thus determines the phosphorus concentration with the use of bulky components – Laser source, Spectrometer, Computer and File storage. In Raman Spectroscopy emission technique, the spectral peaks that are frequency shifted from the incident optical energy by the scattering are processed to know Algal Bloom because of phosphorus present in the soil sample. Algal Bloom is nothing but pollution because of excess phosphorus nutrients [9].

By image spectral measurement, 2011

The macronutrients N, P and K can be analyzed by the ground method spectrum data in the laboratory by exploration on spectral measurements, interior diameters and surface treatment of soil roughness and Signal to Noise Ratio (SNR) / Spectra, these compared with standard spectrum. But there was no image data in this method. The second is multispectral remote sensing allows capture of hyper spectral images, not possible in the first method, but poor resolution of images prone to difficulties in extraction of soil information and spectral reflectance relation, so the method is not suitable for quantitative estimation of nutrients in soil. Also a lot of statistical data logging is required [10].

By Wireless Sensor Network (WSN) and cloud monitoring, 2014

Real time monitoring of macronutrients NPK by the use of Wireless Sensor Network (WSN) and android phone facilitates the user to view soil fertility at the convenience of his phone through mobile application. Overall system helps farmers to get real time information. The data from sensors is sent to the Cloud. These values are stored in cloud databases [11], [12].

By electrical conductivity measurement, 2014

The soil salinity is an important issue, sustaining the productivity and irrigation of agriculture around the world. The salinity analysis gives rise to determination of nutrients present in soil by the use of conductivity sensors. The co-relationship between Electrical Conductivity (EC) and amount of fertilizers required shows that EC is directly related to nutrients concentration but inverted with depth of soil. The overuse of fertilizers can lead to more soil salinity (Salts), hence conductivity is more [13].

By optical fiber sensor, 2015

Detection of soil NPK nutrients using fiber optic sensor includes multimode plastic fiber optic sensor. Aqueous solution of the soil under test is illuminated by different light colors. Light gets reflected from solution depending upon its absorbent coefficient of soil. Reflected light is received by another optical fiber which then converts into electrical signals. Then using signal conditioning and microcontroller (MCU), different components of NPK are determined. In this method, NPK deficiencies can be analyzed in terms of ratio based on the principle of absorption of light [14], [15].

By UV-visible spectroscopy, 2016

The spectrum analysis can be carried out by characterization of nutrients using Deuterium Halogen Light (DHL) source and Ocean Optic Spectrometer (OOS) to measure the absorbance of macronutrients at 450 nm for N, 750 nm for P and 500 nm for K, in which Deuterium covers UV and Halogen covers visible light spectrum [16].

By multispectral hyperspectral cameras, 2017

Ranging and imaging techniques in precision agriculture includes the state of art in optical visible and near visible spectrum sensors and techniques to estimate phenotyping variables from intensity, spectral and volumetric experiments. Hence, these techniques were distributed for plant structural characterization, plant detection and plant physiology assessment that delivers the future innovating sensor methodologies to provide proper fertilizers and pesticides [17].

By electrochemical sensors with ion selective transistors, 2017

A system consists of an ion selective membrane and a transducer, which transforms chemical reaction into detectable electrical signals. Two types of sensors – Ion Selective Electrode (ISE) in which the voltage of the second electrode is compared or measured with the reference (first) electrode. Ion Selective Field Effect Transistor (ISFET) chemically modulates the threshold voltage and is measured with the related concentration of a targeted ion. But due to ion selective membrane, measurement of one target ion by electrochemical measurement is possible. However, electrochemical sensors may be integrated onto chips to provide a feasible approach of multi target simultaneous detection of nutrients in soil [18].

By electrophoresis of anions, 2017

Electrophoresis based micro fluidic ion nutrients sensor for detection of anions in soil solution samples, in which the sensor is capable to analyses various anions in extracted soil nutrition with high sensitivity as well as high specificity with the conductivity measurement using pair of microelectrodes (that is electrophoresis chip).Because of arrival of different separated anions of electrophoresis chip at various time, different time peaks represent concentrations of anion [19].

By integrated optical sensor, 2018

In this, soil macronutrients are detected by using optical sensors containing transmitter and receiver. The soil sample is taken on a flat glass plate and transmitters, receivers are placed at opposite ends. The photodiodes at the receiver system with signal conditioner responses to remaining passed light through the glass plate. Hence detection of nutrients in terms of individual potential differences for NPK. This system requires more space as the transmitter and receiver are bulky hence it is not a portable system. Also the readings / detections may be improved by optical fiber instead of Light Emitting Diode (LED) and photodiode [20].

By Ultra Violet- Infra Red (UV-IR) Light Emitting Diode (LED) spectroscopy, 2019

Through this spectroscopy, chemical bonds present in molecular substances absorb specific wavelengths and give important information related to physical properties. However, such analysis equipment is quite expensive and difficult to access. With optoelectronic components, the cost as well as difficulties can be reduced. The emission of 1400 – 2250 nm (near Infra-Red - IR) light is illuminated on a Gallium Indium Arsenide based photodiode used to detect the signals reflected from non-homogeneous chemical substances [21], [22].

By an integrated color sensor, 2020

The exploration of macronutrients can also be carried out by interfacing color sensors with Microcontroller (MCU) along with LCD. The sensor data is collected and processed by MCU. The data sensed by TCS3200 Integrated Color Sensor (ICS) after reflecting spectra from soil sample (since light fall on targeted soil sample by LED source) and red, green, blue (RGB) colored spectrum analyzed and proportional to standard K, N and P concentrations respectively which have been programmed in microcontroller. [23], [24], [25]. While soil analysis is also carried out by the global positioning system by image processing [26].

III. LED BASED SPECTROSCOPY METHOD

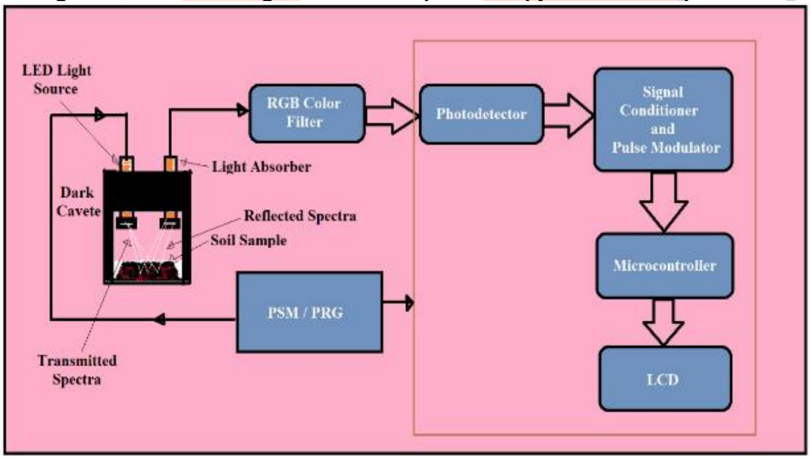
Testing the nutrient contents by the sensors, we can help to select the fertilizers to improvise crop growth without going into soil test laboratories, it would take a lot of time to analyse instead electronic analysis. It will also help to prevent the overfeeding of fertilizers [27]. By the year 2017, LED based spectroscopy is a rapid, less expensive and non-destructive analytical technique. It's widely preferred in optical methods to explore macronutrients NPK without the need of chemicals. LED based Spectroscopy uses LED as a light source and spectrometer / spectrophotometer to measure the light spectrum after passing into soil samples. A bright LED source is preferred because wide wavelengths range from Ultra Violet (UV) and Infra-Red (IR) and long durability [28].

Why LED spectroscopy

With reference to mentioned above, there are different methods to find the nutrients and their analysis through chemical, optical, electronic cordial. In developing countries like India, farmers still do not have an awareness of advanced things like networking, cloud and web. Hence, within, it's possible to do the In-Situ or spot analysis of soil macronutrients and deficiencies by LED based Spectroscopy since it is rapid, timely, reliable, and less expensive. The LED Spectroscopy is a destructive analytic method without the need of chemicals. The traditional methods to explore soil macronutrients in laboratories provide accurate results, but drawbacks are a time consuming process and cannot be real time and also a lot of different soil samples testing and their chemical analysis take a lot of time, perhaps a number of days to estimate the finalized results in Agricultural Laboratories. As the population is increasing at a high rate, it will increase the demand for food. So sophisticated techniques like stated above should be taken under investigation.

System block diagram

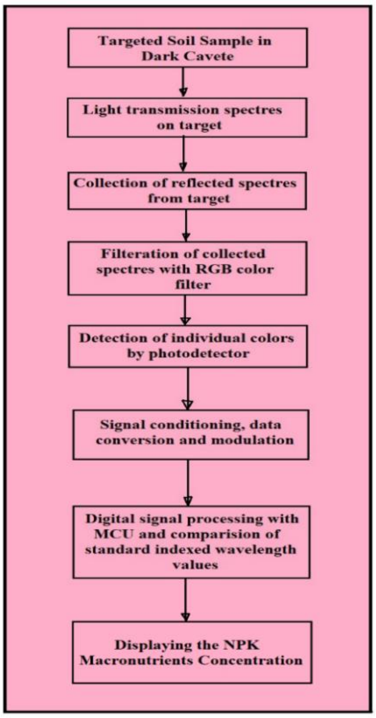
Figure 1 A Block Diagram of LED Spectroscopy for NPK Exploration



Method in brief

The In-Situ analysis includes LED Spectroscopy Method to explore the macronutrients Nitrogen (N), Phosphorous (P) and Kalium / Potassium (K) in the targeted soil. The bright light (especially white) emitted from source is illuminated on soil sample (refer Figure 1). Soil sample should be kept in dark cavete to avoid interference of unwanted spectra from transmittance and reflectance spectra over the targeted sample. Some part of light energy gets absorbed by soil (target) and emitted spectra from soil then filtered by passing through RGB color filters. These three color spectra i.e. Red, Green and Blue are then collectively converted into electrical signals by means of photo detectors. Converted electrical signals are passed through signal conditioner, data converters and pulsed generator circuits. Hence, the wavelengths from reflected spectra (should be around the mean wavelengths) as given in Table 2 by soil sample and the wavelengths corresponding to base colors Blue, Green and Red which are programmed within Microcontroller Microchip PIC18F4550 are compared collectively, proportional to the concentration of macronutrients Nitrogen, Phosphorus and Potassium respectively. Finally, NPK concentrations are displayed on LCD interfaced to the MCU. By this method it is possible to determine macronutrients NPK concentration within just a minute or two.PIC 18F4550 (8-bit RISC Architecture) MCU from Microchip technology has been selected because it facilitates at most features those modern embedded systems deserves. The Power Supply Module and Power Regulator (PSM / PRG) provides constant +5V to the system as well as LED light source. In short, this method is summarized in Figure 2.

Figure 2 Analysis Steps in In-Situ Portable Electronic System to detect NPK Macronutrients with LED Spectroscopy



IV. Results And Discussion

The concentration is more near the mean wavelengths as mentioned in Table 2. Here, the LED based spectroscopy method is compared with standard method using TCS3200 color sensor (amalgamation of LED source and array of photodiodes) to detect NPK content with the absorbed spectra for the base colors Red, Green and Blue.

The absorption wavelengths (transmitted spectra) are sampled accordingly the Beer-Lambert's Law [29], given by –

$$Ab = -\frac{It}{Io} = -\frac{1}{T} = K.D.C$$

Where, Ab = absorbance of the target soil,
T = transmittance (Io/It),
Io = light intensity incident on target,
It = light intensity transmitted from target,
K = proportionality known for attenuation constant,
D = optical depth and
C = concentration of macronutrients.

Three different target soil samples are taken under investigation both by LED spectroscopy and TCS3200 integrated color sensor (ICS). Analytics noticed from Figure 3, method of TCS3200 ICS for Target 1 show that 464 nm of Nitrogen, it is so near the mean 462 nm (Table 2) but distorted absorbed spectra of Phosphorus and Potassium with means. Analytics from Figure 4 shows that 459 nm is well comparable with the mean. Hence, results of both analyses are rendering the high concentration of Nitrogen. For Target 2, observed spectra show high concentration of Phosphorus, i.e. 539 nm and 521 nm by ICS and LED Spectroscopy methods respectively. Transmitted wavelengths are comparable with the mean 527 nm. Target 3 contains high concentration of Potassium since, transmitted spectral wavelengths observed are fairly high but comparable with the mean 667 nm. Herewith results are summarized in Table 3.

Figure 3 Analysis with TCS3200 Color Sensor – NPK Exploration in 3 different Target Soil Samples by Absorbed Wavelengths

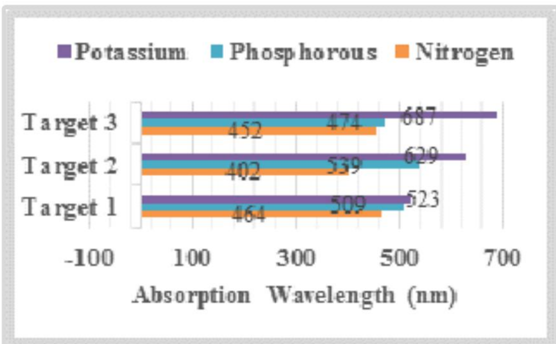


Figure 4 Analysis with LED based Spectroscopy – NPK Exploration in 3 different Target Soil Samples by Absorbed Wavelengths

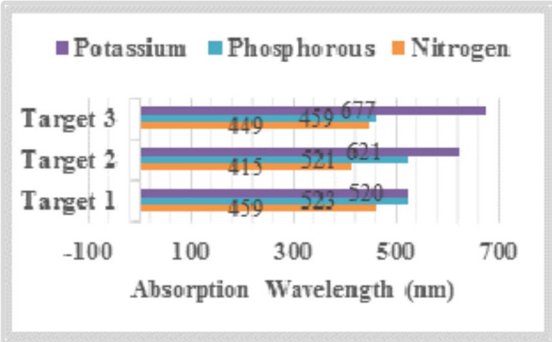


Table 2 Color Extraction and Corresponding Macronutrient

Macronutrient	Extraction Color	Standard Wavelength Range	Mean Wavelength Identification
Potassium (K)	Red	635 nm to 700 nm	667 nm
Phosphorous (P)	Green	495 nm to 570 nm	527 nm
Nitrogen (N)	Blue	450 nm to 495 nm	462 nm

Table 3 Analytics and Comparison of TCS3200 ICS and LED based Spectroscopy Methods

Macronutrient	Absorbance Color	Mean Wavelengths (nm)	Observed Transmitted Wavelengths (nm)						Resulted Concentrations					
			TCS3200 ICS			*LED Spectroscopy*			*TCS3200 ICS*			*LED Spectroscopy*		
			T1	*T2*	*T3*	*T1*	*T2*	*T3*	*T1*	*T2*	*T3*	*T1*	*T2*	*T3*
Nitrogen (N)	Blue	462	464	402	452	459	415	449	H	N	L	H	N	L
Phosphorous (P)	Green	527	509	539	474	523	521	459	L	H	N	L	H	N
Potassium (K)	Red	667	523	629	687	520	621	677	N	L	H	N	L	H

(T1 – Target 1, T2 – Target 2, T3 – target 3; H – High, L – Low, N – Normal).

V. Conclusion

The LED based spectroscopy is well suitable for portable In-Situ or spot analysis to explore major macronutrient contents like Nitrogen (N), Phosphorous (P) and Potassium (K) without need of different chemicals and skilled workers. This is an emerging technique to maintain the ideal macronutrient concentrations and hence soil fertility for better crop yield. The advantages of LED spectroscopy are it is rapid, lower cost, having almost maintenance free and although gives comparable results. However, results may be faulty if photo sensors, signal conditioning and microcontroller are not well calibrated without the correction factor applied at the time of programming and customization.

VI. References

[1] Nishad Kumbhare and S. R. Kumbhar, "Instant Detection of Macronutrients Nitrogen, Phosphorous and Potassium using Analog pH Sensor," International Journal of Engineering Development and Research (IJEDR), vol. 10, no. 1, 32-38.

[2] Pandey G., Kumar R., and Weber R. J. (2014). A Low RF-Band Impedance Spectroscopy Based Sensor for In Situ, Wireless Soil Sensing. IEEE Sensors Journal, 14(6), 1997–2005.

[3] A. D. Shaligram and Nishant Singh (2014). NPK Measurement in Soil and Automatic Soil Fertilizer Dispensing Robot, International Journal of Engineering Research and Technology (IJERT) Vol. 3, Issue 7, July. 2014, 635-637.

[4] Lavanaya M. and Parameswari R. (2018). Soil Nutrients Monitoring for Greenhouse Yield Enhancement Using pH Value with IoT and Wireless Sensor Network. Second International Conference on Green Computing and Internet of Things (ICGCIoT), 547-554.

[5] Adamchuk V., Hummel J., Morgan M., and Upadhyaya S. (2004). On-the-go soil sensors for precision agriculture. Computers and Electronics in Agriculture, 44(1), ELSEVIER, 71–91.

[6] Sattari S. Z., Van Ittersum M. K., Bouwman A. F., Smit A. L., and Janssen B. H. (2014). Crop yield response to soil fertility and NPK inputs in different environments: Testing and improving the QUEFTS model. Field Crops Research, 157, ELSEVIER, 35–46.

[7] NAAS (2009). Crop Response and Nutrient Ratio, Policy Paper No. 42, National Academy of Agricultural Sciences, New Delhi, India, 1-18.

[8] Dearing J. A., Bird P. M., Dann R. J. L. and Benjamin S. F. (1997). Secondary ferromagnetic minerals in Welsh soils: a comparison of mineral magnetic detection methods and implications for mineral formation. Geophysical Journal International, 130(3), 727–736.

[9] Lee Won Suk (Gainesville, FL, US) and Bogrekci Ismail (Gainesville, FL, US) (2007). Portable Raman Sensor for Soil Nutrient Detection, United States Patent Application 20070013908, Kind Code: A1

[10] Hongyan Chen, Gengxing Zhao, Yinjuan Wang, Long Sui and Hu Meng (2011). Discussion on remote sensing estimation of soil nutrient contents. International Conference on Remote Sensing, Environment and Transportation Engineering, 3072-3075.

[11] Shylaja S. N. and Veena M. B. (2017). Real-time monitoring of soil nutrient analysis using WSN, International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS), 3059-3062.
[12] Estrada-Lopez J. J., Castillo-Atoche A. A., Vazquez-Castillo J. and Sanchez-Sinencio E. (2018). Smart Soil Parameters Estimation System Using an Autonomous Wireless Sensor Network with Dynamic Power Management Strategy, IEEE Sensors Journal, 1–11.
[13] Miss Yogita Kulkarni, Krishna K. Warhade and Susheel Kumar Bahekar (2014). International Journal of Emerging Engineering Research and Technology, Vol. 2, Issue 2, 198-204.
[14] Visconti F., and de Paz J. M. (2016). Electrical Conductivity Measurements in Agriculture: The Assessment of Soil Salinity. New Trends and Developments in Metrology, Intech Open Access Book, 100-126.
[15] Ramane Deepa, Patil Supriya and Shaligram A. D. (2015). Detection of NPK nutrients of soil using fiber Optic Sensor. International Journal of Research in Advent Technology, Special Issue National Conference ACGT, 66-70.
[16] Khairunnisa MohdYusof, Suhaila Isaak, Nurfatihah CheAbd Rashid and Nor Hafizah Ngajikin (2016). NPK DETECTION SPECTROSCOPY ON NON-AGRICULTURE SOIL, Jurnal Teknologi (Sciences and Engineering) 78:11, 227–231.
[17] F. Yandun Narvaez, G. Reina, M. Torres-Torriti, G. Kantor and F. A. Cheein (2017). A Survey of Ranging and Imaging Techniques for Precision Agriculture Phenotyping, IEEE/ASME Transactions on Mechatronics, Vol. 22, no. 6, 2428-2439.
[18] Lin J., Wang M., Zhang M., Zhang Y., and Chen L. (2017). Electrochemical Sensors for Soil Nutrient Detection: Opportunity and Challenge. The International Federation for Information Processing, 1349–1353.
[19] Xu Z., Wang X., Weber R. J., Kumar R., and Dong L. (2017). Nutrient Sensing Using Chip Scale Electrophoresis and In Situ Soil Solution Extraction. IEEE Sensors Journal, 17(14), 4330–4339.
[20] Masrie M., Rosli A. Z. M., Sam R., Janin Z., and Nordin M. K. (2018). Integrated optical sensor for NPK Nutrient of Soil detection. IEEE 5th International Conference on Smart Instrumentation, Measurement and Application (ICSIMA), 1-4.
[21] P. P. Pinheiro, J. C. F. Dos Santos and M. B. De Morais França (2019). Development, Testing, and Validation of a Prototype for Qualification of Substances Based on Near-Infrared Spectroscopy, IEEE Access, Vol. 7, 25650-25659.
[22] Sheikhi M., Guo W., Dai Y., Cui M., Hoo J., Guo S. and Ye J. (2019). Mechanism of improved luminescence intensity of Ultraviolet Light Emitting Diodes (UV-LEDs) under thermal and chemical treatments, IEEE Photonics Journal, 1–10.
[23] Akriti Jain, AbizerSaify and Vandana Kate (2020). Prediction of Nutrients (NPK) in soil using Color Sensor (TCS3200), International Journal of Innovative Technology and Exploring Engineering (IJITEE), Vol. 9 Issue-3, 1768-1771.
[24] Suhaila Isaak, YusmeerazYusof, NorHafizah Ngajikin, Norhafizah Ramli and Chuan Mu Wen (2019). A low cost spectroscopy with Raspberry Pi for soil macronutrient monitoring, TELKOMNIKA, Vol.17, No.4, 1867-1873.
[25] Isaac W. and Na A. (2016). On-the-go soil nitrogen sensor based on near infrared spectroscopy. International Conference on Information Technology (InCITe) - The Next Generation IT Summit on the Theme - Internet of Things: Connect Your Worlds, 312-315.
[26] Vaishali Patil, S. R. Kumbhar and N. M. Dhawale (2019). Soil Analysis Technique Based on Global Positioning Enabled Mobile Image Processing, International Journal of Research and Analytical Reviews (IJRAR), Vol. 6, Issue-1, 322-326.
[27] H. Varma, C. Mulla, R. Raut and V. R. Pawar (2017). Fertigation and Irrigation System for Agricultural Application along with Soil Monitoring using IoT, VJER-Vishwakarma Journal of Engineering Research, Vol. 1 Issue 2, 241-245.
[28] Khairunnisabinti Mohd Yusof, Suhailabinti Isaak, Nor Hafizahbinti Ngajikin and Nurfatihahbinti Che Abd Rashid (2016) LED based soil spectroscopy. Buletin Optik, 3 (1), 1-7.
[29] Liu R. T., Tao L. Q., Liu B., Tian X. G., Mohammad M., Yang Y., and Ren T. L. (2016). A Miniaturized On-Chip Colorimeter for Detecting NPK Elements. Sensors, 16(8), 1234, 1 – 9.