Journal of Physics:
Conference Series

PURPOSE-LED PUBLISHING™

PAPER • OPEN ACCESS

A Review on Estimation of soil Macronutrients using Satellite Image Processing

To cite this article: Swagota Bera *et al* 2023 *J. Phys.: Conf. Ser.* **2576** 012003

View the article online for updates and enhancements.

You may also like

- Applied Research on Agricultural Big Data
  Feng Wang
- Digitalization and automation of the agricultural sector
  Y Evdokimova
- An Econometric Study of the Factors Affecting the Value of Agricultural Output in Iraq for the Period 2000-2022
  Saif Al-Din Muhammad Shihab and Firas Ibrahim Rahim

This content was downloaded from IP address 189.203.192.106 on 30/12/2024 at 01:01

A Review on Estimation of soil Macronutrients using Satellite Image Processing

Swagota Bera[1*], Arti Shrivastava[2], Himani Agrawal[3], Sunandal Mandal[4]
[1]SSTC, SSGI, Bhilai
[2]Govt. Engineering College, Raipur
[3]Govt. Polytechnique College, Durg
[4]SOS in Electronics and Photonics, Pt. R. S. University, Raipur
*Corresponding Author Email ID- swagotaberasarkar@gmail.com

Abstract. Major portion of Indian economy depends on agriculture. More than 40 % of the Indian land is used for agriculture which contributes to Gross Domestic Product (GDP) of the country and also provides employ to the population of the country. Increment in the population day by day increases the requirement for the increment in the yield of the agricultural products. There are several factors which is responsible to control the agricultural product yield. Among them Nitrogen, Phosphorus and Potassium are the macronutrients are the vital elements of the soil . Due to the instability in the climatic condition of India and also due to other biotic and abiotic factors macronutrients get varies. To increase the crop yield, the perfect handling of macronutrients i.e., nitrogen, phosphorus and potassium are required. As the technology is developing day by day, the application of remote sensing in agriculture is becoming promising. The satellite images of agricultural land can be processed and analysed to provide vital information for efficient agricultural practices. This paper is the review of the present state of art in the field of satellite image processing techniques for the estimation of the macronutrients of the agricultural land. This review will promote the acceptance of hyperspectral image technology for the investigation of soil NPK.

Keywords: Hyperspectral Imaging, Macronutrients, Machine Learning, Remote Sensing

1. Introduction

According to the document IISS Vision 2030, under Dr. S. Ayyappan, Director General, Indian Institute of Soil Science, Bhopal has come up with great work in the basic and planned soil research in India. The Indian population had increased from 683 million to 1210 million in the time span from 1981 to 2010. It is estimated to that population will reached to 1412 million in 2025 and to 1475 million in 2030. For feeding 1.48 billion in India by 2030, it is required to yield 350 million tons of food grains. The production of per unit of productive land is decreased from 0.34 ha to 0.15 ha from 1950-51 to 2000-01 and is expected to reduce more to 0.08 ha in 2025 and to 0.07 ha in 2030. The productivity of the soils differs and need different management practices. The physical, chemical and biological properties of soil are different for different soils and also the rainfall/availability of water also varies. So, the cropping system and irrigation system are different for different soils. Due to degradation in chemical, biological and physical health of the soils, the efficiency of the nutrient becomes less. The degradation in Phosphorous is 15-20 %, Nitrogen is 30-50 %, Sulphur is 8-12 %,

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

Zinc is 2-5 %, Iron is 1-2 % and Copper is 1-2 %. Due to climate and precipitation, organic C levels get reduce by 50- 70%.

There are many reasons for the deterioration in the soil health. Major reasons are nutrient gap between nutrient demand and supply, imbalanced fertilization, deficiencies of secondary and micronutrients in soils, nutrient fixation in red, laterite and clayey soils, nutrient leaching in sandy soils, soil salinization soil acidity and sodification etc. So, to maintain the better quality of the soil regular monitoring of the soil is to be done through soil quality indicators and methods to assess and monitor soil quality, assessment of soil quality under different land use management systems. Soil organic matter in the soil can be maintained in various forms. Each year organic manures, organic waste and residue in soil can maintain Soil organic matter [12].

Our goal is to produce quality products by enhancing and sustaining soil properties. Nitrogen, Phosphorous and Potassium are the macronutrients of the soil which decides the soil fertility. To assess soil quality, it is needed for the development of soil quality indicators and methodology. So, soil NPK estimation is required time to time.

1.1. Factors affecting the NPK Content in Soil

There are several factors affecting the NPK Content in Soil. They can be climatic factor such as rainfall, temperature, agricultural operations and other local factors. In climatic factor, rainfall (i.e. precipitation) and temperature influence the nitrogen amount in the soil. The nitrogen content of soil increases with water supply.

$$N = K\,(1 - e^{-K2H}) \tag{1}$$

Where, N = Nitrogen Percentage, H = Humidity factor and also known as Mayer factor measures the ratio of annual precipitation in milli-meter to the absolute saturation deficiency of the air in milli-meter of mercury. It measures the effective precipitation. Increase in rainfall is causes increase in vegetative growth and thus increases the Nitrogen in the soil. The increase of nitrogen is only due to vegetative growth of the plants. Nitrogen increases with the decrease of microbial activity when land is under water logged condition. Above factures also depends on the soil texture also. The amount of nitrogen in soil decreases with the increase of temperature. Mathematical equation explanation represents the relationship between temperature and nitrogen content of soil as follows

$$N = Ke^{-K1T} \tag{2}$$

Where, N = Percentage of nitrogen of surface soil, e = base of natural logarithm, K = Constant, T = Temperature, K_1 = Another constant.

This relationship holds good in virgin soil. Other local factors are type of vegetation, slope of the land, direction of slope, water logging condition, soil texture. The amount of nitrogen in the soil at a some temperature and climatic condition is greater in soils developed under grass land than under forest vegetation. The plant nutrient particularly nitrogen remains on the surface of the soil. The soil erosion causes the depletion of nitrogen from surface soil due to run-off. So the soil of steep slope region contains less nitrogen due to run-off of surface soil with most of nitrogen. The nitrogen content of a soil is indirectly related with the direction of slope. Influence of the direction of slope is based upon the variation of temperature. The slope facing south to north hemisphere contains less nitrogen due to direct sunrays. The supply and availability of nitrogen is more in water logged soils due to reduced microbial activity. Under water logged condition, the decomposition of organic matter takes place by the organisms which requires less nitrogen. The clay soil contains more nitrogen than sandy soil. If the soil texture is finer, the nitrogen content is better. The dependency of the quantity of nitrogen in the soil on soil texture are caused due to differences in water holding characteristics, aeration, productivity and tendency of mineral portion of soil to combine with organic matter.

The virgin soil gives more nitrogen after it has been cultivated. If a virgin soil is brought under cultivation and laps some year, there will be increase of nitrogen in the soil. The reduction of nitrogen content can be maintained by addition of organic matter or other land management practices.
Cultivation Index (C.I.): Cultivation index is the measure of the quality of management practices with respect to nitrogen.

$$C.I = NC/NV \tag{3}$$

where, NV = Nitrogen content in virgin soil, NC = Nitrogen content in soil after cultivation for some years. Few factors that may affect the potassium content in soil are soil type, temperature, lack of moisture and aeration. The availability of the Phosphorus is supposed to be controlled by three basic factors. They are soil pH, organic matter content and proper implementation of fertilizer phosphorus [10].

1.2. Satellite Image Analysis for Soil Macronutrient Estimation

The distribution of nutrients in soil such as soil phosphorus and nitrogen in tissues highly depends on topography and zones of potential accumulation of water in the soil. This fact comes when satellite imagery is analysed. The different colours in the Digital Elevation Model (DEM) image represents different aspects such red represents higher elevations, blue represents lower elevation.

Landscape topography explains the distributions of soil properties and processes in land. The detailed topographic information is provided by large scale DEM images due to development in aerial, space, and geographic technologies. Light detection and ranging (LiDAR) generates high resolution topographic variables derived DEMs. 3-D images are created using LiDAR for the recommendation of soil and water conservation structures. Shuttle Radar Topography Mission (SRTM) uses radar observations to construct DEM while Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) use stereo imagery and photogrammetric techniques to extract DEM. In Google Earth Engine, orthorectification i.e. terrain correction converts data from ground range geometry to σ° using the SRTM. In 1999, NASA's launched SRTM 30 meter DEM.s ASTER DEM measures high latitudes may be greater than 60° or less than -60°. SRTM is open source and is better than ASTER. The spatial resolution of DEM images is increased by sub-pixel/pixel attraction. In table 1details of various bands are represented [13].

Table 1: List of spectral band and resolution

Bands	Resolution	Intermediate Wavelength	Specification
B 1	60m	443nm	Ultra-Blue
B 2	10m	490nm	Blue
B 3	10m	560nm	Green
B 4	10m	665nm	Red
B 5	20m	705nm	V N I I R
B 6	20m	740nm	V N I I R
B 7	20m	783nm	V N I I R
B 8	10m	842nm	V N I I R
B 8a	20m	865nm	V N I I R
B 9	60m	940nm	S W I R
B 10	60m	1375nm	S W I R
B 11	20m	1610nm	S W I R
B 12	20m	2190nm	S W I R

VNIIR - Visible and Near Infrared
SWIR – Short Wave Infrared

NDVI (Normalized Difference Vegetation Index):

$$NDVI = (NIR - red) / (NIR + red) \quad (4)$$

If the NDVI value is close to 0 means the vegetation of that area is very little which represents early stages of cultivation or bare soil or non-productive land. If the NDVI value is negative means the area may be associated with water, snow or clouds. Recommended in early stage of agriculture to identify the cultivation land.

NDVI variants are NDRE, MSAVI2

MSAVI2 or Modified Soil Adjusted Vegetation Index:

$$\boldsymbol{MSAVI2 = \frac{(2 * NIR_1 + 1 - 1\sqrt{(2 * NIR + 1) - 8 * (NIR - RED)}}{2}} \quad (5)$$

When the indices such as NDVI or NDRE are not correct then MSAVI2 is used. This index is used in the area where bare soils exist because of deficiency in chlorophyll. It will allow us to observe the first seedlings emerging or for woody plants.

NDRE (Normalized Differences Red Edge):

$$NDRE = (NIR - RED\ EDGE) / (NIR + RED\ EDGE) \quad (6)$$

If NDRE value is 1 to 0.2 then it represents the area is bare soil or a developing crop, if NDRE value is 0.2 to 0.6 then it represents the area either an unhealthy plant or a crop that is not mature yet, if NDRE value is 0.6 to 1 then it represents the area is healthy, mature, ripening crops. This index is advisable where the canopy is dense and the crop is in the later stage. If the owner's decision of fertilizing a field is solely on NDVI measurements, they might go wrong which and will be a very expensive mistake.

GNDVI - (Green Normalized Difference Vegetation):

$$GNDVI = (NIR-GREEN) / (NDVI+GREEN) \quad (7)$$

If GNDVI value is between -1 and 0 then it represents the presence of water or bare soil. This index is advisable in the middle and final stages of the crop cycle. In the crop canopy, these vegetation indices determine water and nitrogen uptake [11].

1.3. Literature Survey

There are many publications on the soil macronutrients estimation using satellite spectral bands. Among them few of them is explained here which provides promising result.

Doses of potassium fertilizer on tea plant can be determined using laboratory analysis but cost is very high and is challenge for many farmers. In this paper, the nutrient content of potassium in tea plants is estimated using sentinel-2 satellite imagery. In this paper, Potassium content in tea can be estimated using sentinel-2 satellite imagery. The final multiple linear regressions is $K\% = 0.619 + 0.001876\ x\ b3 - 0.001264\ x\ b4 - 0.000201\ x\ b8$ Backward regression method is used on Image. The model was validated and correctness of 84.82% is obtained [1].

In this paper, the relationship is established between Normalized Difference Water Index, Normalized Difference Vegetation Index and apparent soil Electrical Conductivity for the prediction of soil macro nutrient and pH. Positive correlations were observed between the NDVI and pH for the bare soil and also for all nutrient contents in the soil. Very strong relationship is observed between the soil EC and the potassium shows moderate correlation with the magnesium content. A multiple-regression analysis relationship is depicted in equation (8)[2].

$$\begin{gathered} P2O5 = -10.04 + 211.90xNDVI - 0.49xEC \\ K2O = 8.46 + 44.97xNDVI + 1.13xEC \\ Mg = 0.57 + 9.50xNDVI + 0.07xEC \\ pH = 4.48 + 15.26xNDVI - 0.06xEC \end{gathered} \tag{8}$$

In this paper, Soil Organic Matter , Potassium , Phosphorus and Nitrogen contents in top soil are estimated using topographic attributes in Nigeria. The three topographic attributes i.e. elevation, slope and curvature, Land surface temperature , Normalized difference vegetation index and four soil attributes i.e. Water holding capacity, and bulk density were used to predict the spatial distribution of soil macro nutrient. 66 samples are used. Soil attributes were derived DEM images. For the prediction of Nitrogen, Potassium, Phosphorous and Soil Organic Matter, Multiple Linear Regression Analysis is implemented. The regression formulae are represented in equation (9) [3].

$$\begin{gathered} N(\%) = 0.219 - 0.388\,X\,BD + 0.01313\,X\,WHC + 0.0167\,X\,Slope \\ P(mg/kg) = -10.4 + 0.1178\,X\,WHC(\%) - 8.3\,X\,NDVI + 0.522\,X\,LST(°C) \\ K(cmol/kg) = 2.065 - 0.236\,X\,BD - 0.02382\,X\,Slope - 0.000731\,X\,DEM - 0.0305\,X\,LST \end{gathered} \tag{9}$$

In this study, classification of potassium treatments (low, medium, and high) and estimation of transpiration rate is done for using hyperspectral–physiological plant database. The average accuracy is 80% for potassium estimation. Extreme Gradient Boosting Algorithm is implemented for plant classification. Estimation of transpiration rates is used for the purpose of irrigation management and crop yield optimization for different potassium applications [4].

In this paper, remote sensing index crop nitrogen is estimated using a new advanced Nitrogen Nutrition Index. Field data is collected at Beijing in China. This model shows good stability with reduced RMSE values [5].

In this paper, Visible Near Infrared and Shortwave Infrared VNIR-SWIR spectroscopy is implemented to estimate soil macronutrients i.e. Nitrogen, Phosphorous, Potassium, pH, and Soil Organic Matter from Landsat-8 Operational Land Imagery. Soil samples are collected from depth of 25 cm in the northwest coast of Egypt. The prediction shows high performance. The relationship is represented in the equation (10) [6].

$$\begin{aligned} Ava.N &= -31.661 + 186.022\text{x}Blue - 364.274\text{xGreen} + 421.943\text{xRed} - 308.068\text{xNIR} \\ &\quad + 207.957\text{xSWIR1} - 12.762\text{xSWIR2} \\ Ava.P &= 0.404 - 2.702\text{x}Blue + 22.5404\text{xGreen} - 14.1563\text{xRed} + 3.613\text{xNIR} - 2.648\text{xSWIR1} \\ &\quad + 2.304\text{xSWIR2} \\ Ava.K &= -610.060 - 1733.486\text{x}Blue + 4103.577\text{xGreen} - 1424.543\text{xRed} + 933.043\text{xSWIR2} \\ pH &= 3.983 - 0.544\text{x}Blue - 1.112\text{xGreen} + 6.131\text{xRed} + 2.193\text{xNIR} - 1.647\text{xSWIR1} \\ &\quad + 2.739\text{xSWIR2} \\ SOM &= -1.421 - 8.083\text{x}Blue + 17.355\text{xGreen} - 5.135\text{xRed} + 2.473\text{xNIR} - 3.275\text{xSWIR1} \\ &\quad + 2.134\text{xSWIR2} \end{aligned} \tag{10}$$

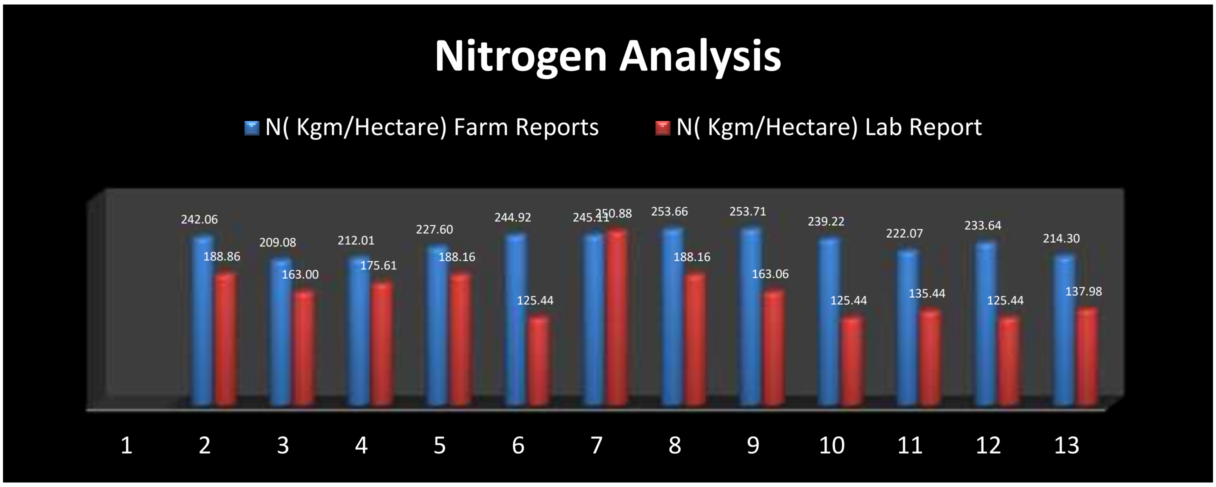
In this paper, Nitrogen, Phosphorous, Potassium and Organic Carbon areestimated using optical Landsat8 and Sentinel-2 and terrain/climate data such as precipitation, radiation, slope etc. for two districts of Maharashtra, India. Multiple linear regression (MLR), random forest regression (RFR), support vector machine for regression (SVR) and gradient boosting (GB) are implemented for generarting linear and non-linear regression models for macronutrients estimation.[7].

In this paper, available Nitogen, Phosphorous, Potassium, pH and Soil Organic Matter in soils is estimated using VNIR-SWIR spectroscopy in the Wadi El-Garawla area in Egypt. About 100 surface soil samples are collected from depth of 25 cm and accuracy is 89 %. To model the relationship between the averaged values from the ASD spectro-radiometer and the available Nitogen, Phosphorous, Potassium, pH and Soil Organic Matter in soils contents, Partial Least Squares regression was used. [8].

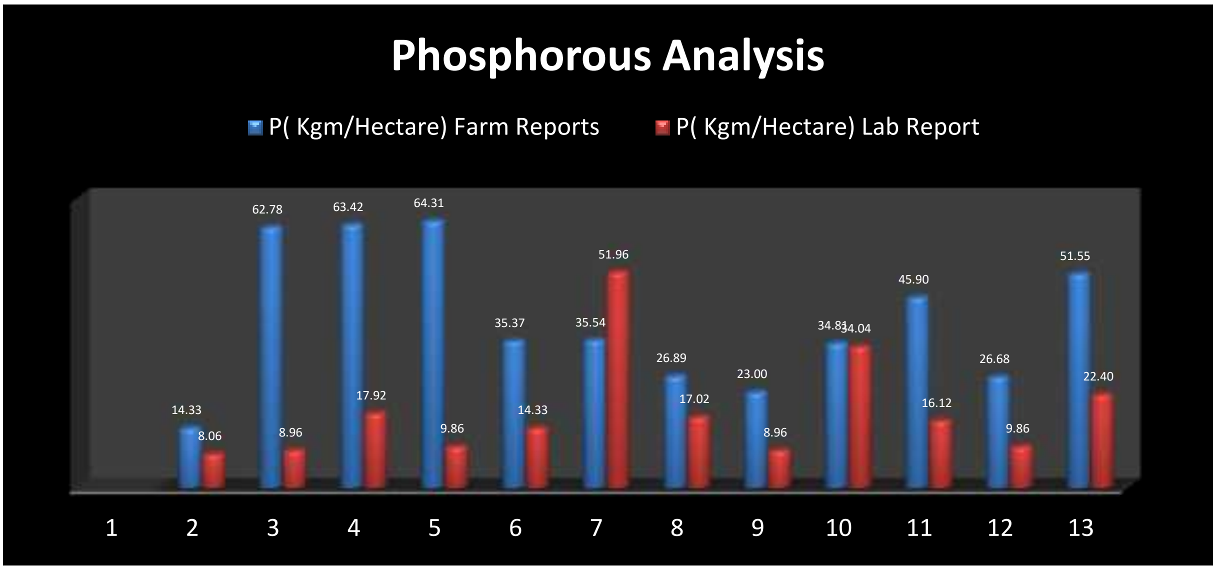
In this paper, nitrogen, phosphorus and potassium are estimated for wheat crop using linear correlation analysis. Soil macronutrients are estimated using eight traditional vegetation indices. When biomass-based nutrient contents were considered rather than concentrations, the prediction accuracy of linear regressive models is improved. The Nitrogrn, Phosphorous, Sulphur and Potassium in plants can be monitored with the help of reflectance in the SWIR region and reflectance at either visible or near infrared NIR region[9].

2. Implementation and Results

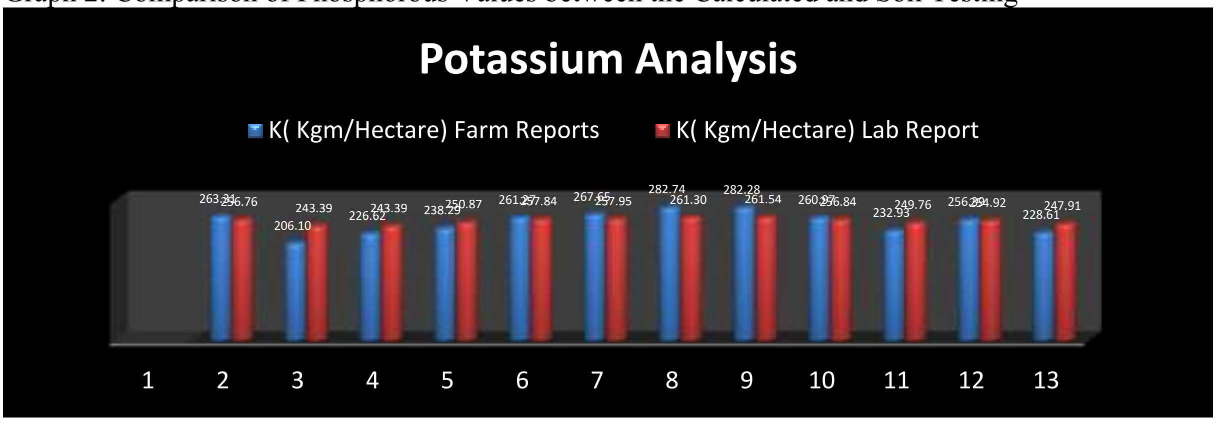
The nitrogen, phosphorous, potassium and soil organic carbon values ranges providing by the soil testing lab report is compared with the calculated values using formulae suggested by E S Mohamed and his research partners in the paper for 12 different farms[6]. The value ranges for all macro-nutrients consider here are low, medium and high. Graph 1 representing the comparison of nitrogen value ranges between the calculated and soil testing lab, Graph 2 representing the comparison of phosphorous value ranges between the calculated and soil testing lab, Graph 3 representing the comparison of potassium value ranges between the calculated and soil testing lab and Graph 4 representing the comparison of SOC value ranges between the calculated and soil testing lab.



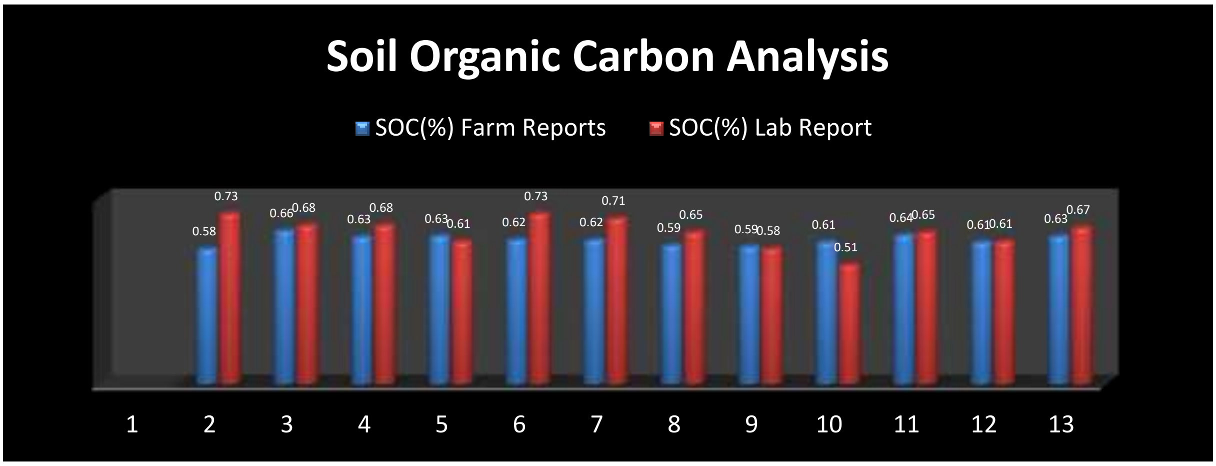
Graph 1: Comparison of Nitrogen Values between the Calculated and Soil Testing Lab



Graph 2: Comparison of Phosphorous Values between the Calculated and Soil Testing



Graph 3: Comparison of Potassium Values between the Calculated and Soil Testing



Graph 4: Comparison of SOC Values between the Calculated and Soil Testing

The regression formulae suggested in paper [6] is implemented on our data sets collected from the Rajnandgaon district of Chhattishgarh (i.e. 21.16365, 81.25316, 21.12625, 81.15360 etc.) and got a promising results. The prediction accuracy of nitrogen, Potassium and SOC is 100 % and for Phosphorus is 58%.

3. Conclusion

After the discussion about the remote sensing technology and its utilization in agriculture one can conclude that this technique can prove to be an efficient and novel practice to collect soil related information for improving the soil productivity. Further the efficiency is justified by the implementation result discussed in the above section through graphs. This research paper will promote the implementation of hyperspectral image technology for the investigation of soil NPK. Soil testing Lab report which is done physically in the lab contains many macronutrients and micronutrients in the soil. Nitrogen, Phosphorus, Potassium, Calcium, Magnesium and Sulphur are the macronutrients found in larger quantity. Micronutrients are Iron, Manganese, Boron, Molybdenum, Copper, Zinc, Chlorine and Cobalt which are found in very small quantity in the soil. Literature review states that many promising work had been done for the estimation of macronutrients in soil using remote sensing techniques but no promising work had been reported for the estimation of all micronutrients in soil. This work can be taken as a challenge in future.

References

[1] Dwiputra A, and Seminar K B 2022 *In IOP Conference Series: Earth and Environmental Science*, vol **1038**.1 p. 012047.
[2] Mazur P, Gozdowski D, and Wójcik-Gront E 2022 *Agriculture*, vol **12**.6 p. 883.
[3] Komolafe A A, Olorunfemi I E, Oloruntoba C, Akinluyi F O 2021 *Remote Sens. Appl. Soc. Environ.* Vol **2021** p. 21.
[4] Weksler S, Rozenstein O, Haish N, Moshelion M, Wallach R, and Ben-Dor E 2021 *Sensors* vol **21**.3 p. 958.
[5] Yu Z H A O, Wang J W, Chen L P, Fu Y Y, Zhu H C, Feng H K, ... and Li, Z. H 2021 *Journal of Integrative Agriculture*, vol **20**.9 p. 2535-2551.
[6] Mohamed E S, Baroudy A A E, El-Beshbeshy T, Emam M, Belal A A, Elfadaly A, and Lasaponara R 2020 *Remote Sensing* vol **12**.22 p. 3716.
[7] Kaur G, Das K, and Hazra J 2020 In *IEEE International Geoscience and Remote Sensing Symposium* p. 4677-4680.
[8] Kawamura K, Tsujimoto Y, Rabenarivo M, Asai H, Andriamananjara A, and Rakotoson T 2017 *Remote Sensing* vol **9**.10 p. 1081.
[9] Mahajan G R, Sahoo R N, Pandey R N, Gupta V K, and Kumar D 2014 *Precision agriculture* vol **15** p. 499-522.
[10] Yu Z H A O, Wang J W, Chen L P, Fu Y Y, Zhu H C, Feng H K, ... & Li Z H 2021 *Journal of Integrative Agriculture* vol **20**.9 p. 499-522.
[11] Cammarano D, Fitzgerald G J, Casa R, and Basso B 2014 *Remote Sensing* vol **6**.4 p. 2827-2844.
[12] Ray S K, and Banik G C 2016 *Journal of the Indian Society of Soil Science* vol **64**.2 p. 169-175.
[13] Weintraub S R, Townsend A R, and Cleveland C C 2011 In *AGU Fall Meeting Abstracts* vol **2011** p. B31L-05.

Acknowledgments

Colleagues, special work and technical team from iAvenue Labs Pvt., Mumbai support the present work by providing their assistances regarding the soil sample collection to testing, solving technical issues and validation of the work.