Case study on the soil physical parameters disparity and NPK concentrations in regions found in and around Pachapalayam, Coimbatore, Tamil Nadu.

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Abstract. Deficient soil fertility is a major constraint in crop productivity. Soil characteristics such as pH, bulk density, electrical conductivity, moisture content, etc. play a major role in the health and yield of crops. Major nutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K), are essential for the growth and yield of the crops as well. On account of the importance of soil physical properties and NPK concentration on the soil dynamics and plant development respectively, the study area was spatial distributed and geo-statistically analyzed to produce contour maps that can be used by decision makers in farm management for increased crop productivity.

1. Introduction

Soil is characterized by its physical properties which play a vital role in determining its suitability for environmental, agricultural and engineering uses. Penetration of roots; movement, retention of water and nutrients with its availability to plants; and flow of air and heat are directly related to the physical properties of the soil. Physical properties influence the chemical and biological properties as well. According to World Bank collection of development indicators, it was reported that India uses 60.45% of land area [1] for agriculture and its related activities. However, agriculture in India is highly conditioned by poor fertility of the soil.

Soil fertility refers to the soil’s ability to contribute essential plant nutrients and water in sufficient amounts for sustained plant growth and reproduction. In nature, the properties of soil are highly variable. Soils’ characteristics and parameters can significantly differentiate the character of the country’s soil structure and its utilization. Variability in soil physical properties is inherent in nature due to the geologic soil forming factors and the continuous changes on the earth’s surface. It may be induced by agricultural management practices as well. Also, soil susceptibility to erosion is influenced by the spatial variability of soil properties and is related to anthropogenic activities in cultivated lands. [2] The knowledge of the spatial variability of soil properties is important for decision making in farm management.

Soil reaction or soil pH is an indication of alkalinity or acidity of soil and is measured by pH units. Plants take up anions and cations, through their roots from the soil solution to meet their growth requirements. Specific plant requirements and fluid composition in soil determines the relative concentration of the ions. The addition of plant materials during decomposition increases the soil pH by ammonification and decarboxylation processes. [3] As soil nutrients’ solubility is different at
different pH, the properties of soil such as rate of nutrients leaching out of soil can be affected. Interactions between soil pH and nutrients are agronomically important as different decisions on the rate of fertilizer application must be made. The ideal soil pH is close to neutral and most nutrients are available optimally in 6.5 to 7.5 pH, which is generally compatible for plant root growth. [4] However for normal plant growth and development, moderately acidic to neutral soil pH (5.5 – 7.0) is required for most Indian vegetable crops [5]. Soil pH range for optimum growth of Indian vegetable crops is compiled by [5] and specificity will help farmers decide on the crops to be cultivated.

Soil salinity is defined to contain sufficient soluble salts to adversely affect the growth of a plant [6]. Saline soil is defined to contain sufficient soluble salts to adversely affect the growth of a plant [6]. Soil salinity reduces crop growth and affects the water uptake by the plant while causing specific ion toxicity and imbalance of nutrients [7]. It is measured by Electrical Conductivity (EC) and if the EC of the soil extract exceeds 4dS/m at 25oC, the soil is considered to be saline [6].

An indicator of soil health and compaction is bulk density (BD) which affects infiltration, water availability, soil porosity, plant rooting depth / restrictions [8], nutrient availability and microbial activity which influence significant processes productivity of soil [9]. BD depends on soil texture, organic matter, mineral density and their packing arrangement [10]. Also, available water capacity is influenced by the soil texture, depth and its restrictive layers. High bulk density affects available water capacity, movement of air and water through soil and root growth. In agricultural practices, unnecessary tillage destroys organic matter and the natural stability of soil aggregates declines, making them vulnerable to erosion. Water capacity of the soil is also affected by soil compaction and organic content [9].

Nitrogen is a key soil nutrient that is required by all plants in balanced amount for growth and development process. Nitrogen supplied by fertilizers can be lost in the soil system due to leaching, denitrification, volatilization, soil erosion and runoff, etc. [11], and the remaining is available for plant uptake as ammonium (NH$_4^+$) or nitrate (NO$_3^-$) form [12, 13] and is less influenced by soil pH [4]. At near neutral pH (pH 7), the microbial conversion of NH$_4^+$ to nitrate (nitrification) is rapid, and crops generally take up nitrate. In acid soils (pH < 6), nitrification is slow [14], and plants with the ability to take up NH$_4^+$ may have an advantage. Also, the incorporation of high N containing plant material during decomposition may modify the nitrogen cycle in the soil and thus produce soil pH variations.

Soil pH is also an important factor in the nitrogen (N) nutrition of legumes. Legumes live in symbiosis with Rhizobium which is the bacteria responsible for N fixation in legumes. [15] The survival and activity of Rhizobium declines as soil acidity increases. Soil pH affects the nodule numbers in legumes [16, 17, 18] and certain legume species such as Lupins spp. and Mimosa spp., etc., exhibit acid tolerant nodulation. [19, 20] Soil pH also plays an important critical role in ammonia volatilization losses [21] although soil temperature, soil water content, soil texture and cation exchange capacity and nitrification and hydrolysis inhibitors [22] can affect volatilization.

The form of phosphorus (P), the crucial factor for plant growth & grain production, and its availability in soil is also pH dependent [23]. Therefore, the modification of soil pH to soil type-specific optimal level is required to enhance the efficacy of P fertilizers [24]. As the P uptakes by the crops are from the soil solution, the rate of replenishment of P from other forms is crucial for P availability. Replenishment rate is dependent on soil pH, phosphorus levels in soil, its fixation by the soil, and placement of added phosphorus [25]. Phosphate ions tend to form less soluble compounds at alkaline pH (>7.5) by reacting rapidly with calcium (Ca) and magnesium (Mg) and at acidic pH by reacting with iron (Fe) and aluminum (Al) [4]. But phosphorus does not leach easily from soil as that of N, and removal of P from soil by plants is much less when compared to N or K [26].

Availability of potassium (K) in soil is influenced by the soil properties such as texture [27], pH [28, 29, 30], cation exchange capacity (CEC) [31, 32], moisture content [33] and concentrations of other ions [34] in soil. It plays an important role in improving crop quality and disease resistance [35]. Addition of lime increases K availability, possibly through the K displacement by Ca [36].

Changes in soil pH may affect the balance of the various forms of certain nutrients, as well as their availability to plants. [37] The availability of the micronutrients such as manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), and boron (B) tend to decrease as soil pH increases. The exact mechanisms
responsible for reducing availability differ for each nutrient, but can include formation of low solubility compounds, greater retention by soil colloids (clays and organic matter) and conversion of soluble forms to ions that plants cannot absorb. In order to identify nutrient deficiencies in the prevailing farmlands, large scale mapping of soil properties was recommended. Variation in soil parameters is a result of interactions of various ongoing soil processes and farm management practices [38]. Therefore, in this study, the spatial variability of soil physical properties and macro nutrients such as N, P and K, that promotes plant growth, was studied in Pachapalayam, Coimbatore, India, in order to identify areas of nutrient deficiency. The village of Pachapalayam, was chosen for study due to its avid farming practices and the people’s dependence on soil for their livelihood. An informed guidance is required for economic and strategic crop management.

2. Methodology

2.1. Study Area

Pachapalayam (Figure 1) is a village, between 10°58’06.9”N 76°53’56.1”E and 10°57’12.9”N 76°54’16.0”E located just outside Coimbatore town, Tamil Nadu, India, between Perur and Kovaipudur, at an elevation of 431m above mean sea level. It is a gram panchayat in a total geographical area of 731.97 hectares. This agricultural village has extensive cultivation of various varieties of banana (Musa sp.), brinjal (Solanum melongena), lady’s finger (Abelmoschus esculentus), tomato (Solanum lycopersicum), etc. and the people dependent on these cultivations for income for many generations. Soil in the study area is cohesive in nature.

![Location Map of the Study Area](image)

2.2. Soil sampling and pre-treatment

The study area was divided into 117 grids of 10,000 sq. m area. From each grid, three soil samples were taken as duplicates at 20 – 40m depths and the sampling points were established and maintained using a Global Positioning System (GPS) device. Samples were collected during January to March 2018 and were tested for soil physical properties such as soil pH, moisture content (MC), bulk density (BD) & electrical conductivity (EC) and for concentration of macro nutrients such as nitrogen, phosphorus and potassium. Soil pH and EC was measured in 2:1 water-to-soil (20cc, ~25g) mixture and using pH meter & conductivity meter respectively. BD was measured on duplicate undisturbed samples in 100 cm³ cylinders [39], after oven drying for 24 h at 105°C and soil MC was determined by gravimetric method [40]. Soil Measuring Kit was used to determine the concentration of N, P & K (turbidometric method).
2.3. Data Processing

The obtained physical properties and concentration of NPK in the soil was subjected to statistical analysis descriptively and geographically. The descriptive analysis of the data was obtained by Microsoft Excel software. The remarkable feature of Geographic Information System (GIS) is its ability to incorporate many forms of dataset with spatial reference (coordinates). The spatial reference (coordinates) of the acquired soil physical properties and NPK were converted to decimal degrees in Excel (CSV format) and imported to ArcMap 10.3 software for further processing for the soil properties conversion to raster format with World Geodetic Survey 1984 (WGS84) as the coordinate reference system.

2.4. Spatial Interpolation

Spatial interpolation is the process of using geographical points with known data values and coordinates to assess the values and coordinates of unknown points within the GIS environment [41]. Hence, it serves as a tool for creating data from sample point for geographical analysis. Many methods of interpolation are prevalent, but for this study, the inverse distance weighted (IDW) was used, which operates under the premise that the closest points has more influence on the unknown point than the points farthest away from it [42].

\[
Z(S_0) = \frac{\sum_{i=1}^{n} \frac{z(S_i)}{d_i^p}}{\sum_{i=1}^{n} \frac{1}{d_i^p}} \quad \text{……………………………………………….} (1)
\]

where \(Z(S_0)\) = value at the interpolated point
\(N\) = total number of samples in the dataset
\(S_i\) = \(i^{th}\) data value
\(d_i\) = distance between the known data value and the interpolated value
\(p\) = weighting power

The \(x\) and \(y\) coordinates of the acquired sample points are used to interpolate the unknown points and the soil properties are taken as \(z\) values for determination at the unknown points.

3. Results And Discussion

The descriptive analysis of the collected sample points for the soil properties (pH, EC, MC and BD) and the concentration of NPK was achieved. From the result of the statistical analysis (Table 1), the observations of pH, EC, BD, P and K are normally distributed whereas the distribution of MC and N indicated positively skewed.

| Description | pH | EC | MC (%) | BD (g/cm³) | N (Kg/ha) | P (Kg/ha) | K (Kg/ha) |
|-------------|----|----|--------|------------|-----------|-----------|-----------|
| Mean        | 7.24 | 0.66 | 2.56 | 1.11 | 41.71 | 9.90 | 54.74 |
| Standard Error | 0.08 | 0.04 | 0.62 | 0.05 | 5.02 | 1.12 | 6.66 |
| Median      | 7.22 | 0.53 | 0.11 | 1.39 | 16.40 | 3.55 | 17.00 |
| Mode        | 8.09 | 1.00 | 0.01 | 1.32 | 15.60 | 1.20 | 17.00 |
| Standard Deviation | 0.83 | 0.41 | 0.68 | 0.59 | 54.26 | 12.11 | 72.08 |
| Range       | 4.66 | 1.84 | 47.96 | 1.73 | 301.65 | 61.76 | 291.31 |
| Minimum     | 5.20 | 0.13 | 0 | 0.03 | 2.40 | 0.26 | 7.59 |
| Maximum     | 9.86 | 1.97 | 47.96 | 1.77 | 304.05 | 62.02 | 298.90 |
| Count       | 117 | 117 | 117 | 117 | 117 | 117 | 117 |

3.1. Spatial Analysis

All data were converted to raster format according to their geospatial reference and were subjected to spatial interpolation. IDW technique was used to analyze and study the spatial distribution across the area of study. The thematic interpolated layers of the soil physical parameters and concentration of NPK are illustrated in Figure 2 (a – g).
Figure 2. Thematic maps of soil (a) pH (b) Electrical Conductivity (c) Moisture Content (d) Bulk Density (e) Nitrogen (f) Phosphorus (g) Potassium
From classification of the interpolated data (Table 2), 57.2% of the area under study showed soil pH of 7.1 to 10 while most Indian vegetable crops require 5.5 – 7.0 soil pH for normal plant growth and development [5]. The EC of the soil extract is low and does not exceed 4dS/m at 25oC and therefore the soil in the study area is not saline. The study area has clayey to loamy soil with only 10.3% of the area having BD of < 2g/cm3. According to [8], BD < 1.1 – 1.9 g/cm3 is ideal for plant growth and BD > 1.47 – 1.8 g/cm3 restrict root growth. Since 89.7% of the study area has exceeding BD (Table 2), the agricultural practices have to be considered. The moisture content is also low in the study area for cultivation of crops which could be due to the time of sampling. During the sampling period the monsoon rain is low to moderate. Therefore, additional watering of the crops is required.

The tested soil samples were classified according to the soil rating chart of NPK [43] and it is found that a majority of the study area has low concentration of nitrogen available to plants (Table 3) which could be attributed to changes in cultivation [44]. Also, the study area does not contain high levels of N and K, however 36% of the study area shows high level of phosphorus which does not leach through the soil. As the study area contains more of vegetables and fruit plantations, it is recommended to cultivate pulses or oil seed crops which require higher P and to consider phytoremediation for P removal. Plant waste, vermicompost, yard manure, etc could be used to correct the NPK deficiency with the help of precision farming [45, 46, 47, 48]. Contour maps (Figure 2) generated in this study is GPS linked and hence the area to be managed accurately for the nutrient levels.

Table 2. Classification of Study Area according to the Interpolated Data (Soil Physical Parameters)

| pH Range | Percent Area | EC (dS/m) Range | Percent Area | Bulk Density (g/cm³) Range | Percent Area | Moisture Content Range | Percent Area |
|----------|--------------|-----------------|--------------|----------------------------|--------------|------------------------|--------------|
| 5.3 - 6  | 7.9%         | 0 - 0.5         | 36.0%        | 0 - 10                     | 51.5%        | 0 - 10                 | 50.2%        |
| 6.1 - 7  | 34.9%        | 0.6 - 1         | 39.0%        | 10.1 - 20                  | 15.2%        | 10.1 - 20              | 15.3%        |
| 7.1 - 8  | 44.8%        | 1.1 - 1.5       | 19.2%        | 20.1 - 30                  | 12.1%        | 20.1 - 30              | 13.0%        |
| 8.1 - 9  | 10.1%        | 1.6 - 2         | 5.8%         | 30.1 - 40                  | 12.1%        | 30.1 - 40              | 12.1%        |
| 9.1 - 10 | 2.3%         | 40.1 - 50       | 9.1%         |                            |              | 40.1 - 50              | 9.3%         |

Table 3. Classification of Study Area according to the Interpolated Data (NPK)

| Classification | Nitrogen (Kg/ha) | Phosphorus (Kg/ha) | Potassium (Kg/ha) |
|----------------|------------------|--------------------|-------------------|
| Low            | < 240            | < 11.0             | < 110             |
| Medium         | 240 - 480        | 11 – 22            | 110-280           |
| High           | > 480            | > 22               | > 280             |

4. Conclusion

The study area is an agricultural dependent village. Soil nutrients are important for the yield of crops cultivated here and the use of geostatistical tools has made it possible to generate contour maps by which decision makers and farmers can identify easily areas of low or high soil properties and NPK concentrations. Soil physical properties and macro-nutrients content influence greatly the plant growth and development. The results demonstrate the spatial variability of the study area with regard to pH, electrical conductivity, moisture content, bulk density and NPK. Considering the derived classification of the properties, eco-friendly, precise management of farms is required for improvement of the current soil condition and crop productivity. Spatial distribution of micro-nutrients such as Cu, Ni, Mn, Cr, Fe, etc could be studied for a holistic understanding of the soil dynamics in the cultivated area.
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References

[1] "Agricultural land (% of land area)," Food and Agriculture Organization, [Online]. Available: https://data.worldbank.org/indicator/AG.LND.AGRI.ZS. [Accessed 23 July 2018]

[2] Y. Q. Wang and M. A. Shao 2013, "Spatial variability of soil physical properties in a region of the loess plateau of PR China subject to wind and water erosion," Land Degrad. Dev., vol. 24, pp. 29 - 3

[3] F. Yan, B. Hütsch and S. Schubert 2006, "Soil-pH dynamics after incorporation of fresh and oven-dried plant shoot materials," J Plant Nutr Soil Sci, vol. 169, p. 506–508

[4] T. L. Jensen 2010, "Soil pH and the availability of Plant Nutrients," IPNI Plant Nutrition TODAY, no. 2, Fall

[5] A. N. Ganeshamurthy, D. Kalaivanan and G. C. Satisha 2016, "Management of Vegetable Crops in Acid Soils of India," Innovations in Horticultural Sciences, pp. 559 - 584

[6] S. S. o. A. 2001 "Glossary of Soil Science Terms," Soil Science Society of America, Madison, WI

[7] D. L. Corwin and S. M. Lesch 2003, "Application of soil electrical conductivity to precision agriculture: theory, principles and guidelines," Agron. J., vol. 95, pp. 455 - 471

[8] USDA 1987, Soil Mechanics Level I. Module 3 – USDA Textural Soil Classification. Study Guide., Stillwater, OK, USA: USDA, Soil Conservation Service

[9] A. Nyéki, G. Milics, A. J. Kovács and M. Neményi 2017, "Effects of Soil Compaction on Cereal Yield," Cereal Research Communications, vol. 45, no. 1, pp. 1 - 22

[10] N. C. Brady 1990, The nature and properties of soils, Macmillan Publishing Company Incorporated

[11] J. A. Lamb, F. G. Fernandez and D. E. Kaiser 2014, "Understanding Nitrogen in Soils," UMN Extension Specialists in Nutrient Management, Minnesota. AG-FO-3770-B

[12] S. A. Barber 1995, Soil Nutrient Bioavailability: A Mechanistic Approach, John Wiley & Sons

[13] C. Ste-Marie and D. Paré 1999, "Soil, pH and N availability effects on net nitrification in the forest floors of a range of boreal forest stands," Soil Biology and Biochemistry, vol. 31, no. 11, pp. 1579-1589

[14] D. M. Sylvia, J. J. Fuhrmann 2004, P. G. Hartel and D. A. Zuberer, Principles and Applications of Soil Microbiology, Second ed., Prentice Hall

[15] H. H. Zahran 1999, "Rhizobium-Legume Symbiosis and Nitrogen Fixation under Severe Conditions and in an Arid Climate," Microbiological and Molecular Biology Reviews, vol. 63, no. 4, pp. 968 - 989

[16] T. A. Lie 1969, "The effect of low pH on different phases of nodule formation in pea plants," Plant and Soil, vol. 31, no. 3, p. 391–406

[17] S. Mohebbi and R. L. Mahler 1989, "The effect of soil pH on wheat and lentils grown on an agriculturally acidified northern Idaho soil under greenhouse conditions," Communications in Soil Science and Plant Analysis, vol. 20, no. 3-4, pp. 359-381

[18] A. A. T. Vargas and P. H. Graham 1989, "Cultivar and pH effects on competition for nodule sites between isolates of Rhizobium in beans.," Plant and Soil, vol. 117, no. 2, p. 195–200

[19] F. B. J. dos Reis, M. F. Simon, E. Gross, R. M. Boddey, G. N. Elliott, N. E. Neto, M. F. Loureiro, L. P. de Queiroz, M. R. Scotti, W. M. Chen, A. Norén, M. C. Rubio, S. M. de Faria, C. Bontemps, S. R. Goi, J. P. Young, J. I. Sprent and E. K. James 2010, "Nodulation and nitrogen fixation by Mimosa spp. in the Cerrado and Caatinga biomes of Brazil.," The New Phytologist, vol. 186, no. 4, pp. 934-46

[20] J. I. Sprent 2009, Legume Nodulation: A Global Perspective., Chichester, UK: Wiley-Blackwell

[21] P. Rochette, D. A. Angers, M. H. Chantigny, M.-O. Gasser, J. D. MacDonald, D. E. Pelster and N. Bertrand 2013, "NH3 volatilization, soil NH4+ concentration and soil pH following subsurface banding of urea at
increasing rates," Canadian Journal of Soil Science, vol. 93, no. 2, pp. 261 - 268
[22] D. E. Clay, G. L. Malzer and J. L. Anderson 1989, "Ammonia Volatilization from Urea as Influenced by Soil Temperature, Soil Water Content, and Nitrification and Hydrolysis Inhibitors," Soil Science Society of America Journal, vol. 54, no. 1, pp. 263-266
[23] N. Devau, E. L. Cadre, P. Hinsinger, B. Jaillard and F. Gérard 2009, "Soil pH controls the environmental availability of phosphorus: Experimental and mechanistic modelling approaches," Applied Geochemistry, vol. 24, no. 11, pp. 2163-2174
[24] S. von Tucher, D. Hörndl and U. Schmidhalter 2018, "Interaction of soil pH and phosphorus efficacy: Long-term effects of P fertilizer and lime applications on wheat, barley, and sugar beet," Ambio, vol. 47, no. (Suppl. 1), pp. S41-S49
[25] D. B. Beegle and P. T. Durst, "Managing Phosphorus for Crop Production," [Online]. Available: https://extension.psu.edu/programs/nutrient-management/educational/soil-fertility/managing-phosphorus-for-crop-production. [Accessed 02 November 2018]
[26] M. Sillanpää 1982, "Micro nutrients and the nutrient status of soils: a global study," Food and Agriculture Organization of the United Nations, Rome
[27] Y. Pal, R. J. Gilkes and M. T. F. Wong 2001, "Mineralogy and potassium release from some Western Australian soils and their size fractions," Austr. J. Soil Res., vol. 39, pp. 813 - 822
[28] S. Sahu and S. K. Gupta 1987, "Fixation and release of potassium in some alluvial soils," J. Indian Soc. Soil Sci., vol. 35, pp. 35 - 40
[29] E. Uribe and F. R. Cox 1988, "Soil properties affecting the availability of potassium in highly weathered soils," Soil Sci.Soc. Am. J., vol. 52, pp. 148 -152
[30] J. Zhao, Y. Dong, X. Xie, X. Li, X. Zhang and X. Shen 2011, "Effect of annual variation in soil pH on available soil nutrients in pear orchards," Acta Ecologica Sinica, vol. 31, pp. 212 - 216
[31] A. N. Sharpley 1990, "Reaction of fertilizer potassium in soils of different mineralogy," Soil Sci., vol. 149, pp. 44 - 51
[32] K. Sardi and G. Csítsari 1998, "Potassium fixation of different soil types and nutrient levels," Commun. Soil Sci. Plant Anal., vol. 29, p. 1843 – 1850
[33] Q. Zeng and P. H. Brown 2000, "Soil potassium mobility and uptake by corn under differential soil moisture regimes," Plant and Soil, vol. 221, pp. 121 - 134
[34] L. Zawartka, G. Huszcza-Ciolkowska and E. Szumska 1999, "Effects of Poly and Orthophosphates on the Dynamics of some Macro and Micronutrient Elements in Soil Material of Varied pH III. Potassium Communications in Soil Science and Plant Analysis," Commun. Soil Sci. Plant Anal., vol. 30, pp. 655 - 661
[35] R. Mouhamad, A. Alsaeed and M. Iqbal 2016, "Behavior of Potassium in Soil: A mini review.," Chemistry International, vol. 2, no. 1, pp. 58 - 69
[36] F. R. Magdoff and R. J. Bartlett 1980, "Effect of Liming acid soils on Potassium availability," Soil Science, vol. 129, no. 1, pp. 12 - 14
[37] W. L. Lindsay 1979, Chemical equilibria in soils, New York (NY): Wiley, p. 449
[38] T. B. Parkin 1993, "Spatial variability of microbial processes in soil — a review," Journal of Environment Quality, vol. 22, p. 409 - 417
[39] N. J. McKenzie, D. J. Jacquier, R. F. Isbell and K. L. Brown 2004, Australian Soils and Landscapes An Illustrated Compendium., Collingwood, Victoria,: CSIRO Publishing
[40] I. S. McQueen and R. F. Miller 1968, "Calibration and Evaluation of a Wide-Range Gravimetric Method for measuring Water Stress," Soil Science, vol. 106, no. 3, pp. 225 - 231
[41] J. Li and A. D. Heap 2011, "A review of comparative studies of spatial interpolation methods in environmental sciences: Performance and impact factors," Ecol. Inform., vol. 6, no. 3 - 4, p. 228 – 241
[42] C. Childs 2011, "Interpolating Surfaces in ArcGIS Spatial Analyst," ArcGIS User, ESRI Educ. Serv., p. 32 – 35
[43] TNAU, "Resource Management :: Soil :: Soil Rating Chart," Tamil Nadu Agricultural University, 2016. [Online]. Available: http://agritech.tnau.ac.in/agriculture/agri_soil_soilratingchart.html. [Accessed 27 May 2019]
[44] W. M. Post and L. K. Mann, "Changes in Soil Organic Carbon and Nitrogen as a Result of Cultivation," 2005. [Online]. Available: https://doi.org/10.3334/CDIAC/TCM.006. [Accessed 27 May 2019]

[45] W. Whiteley 2002, “The Use of Precision Farming Technologies in Crop Decision Making,” in 7003, 13th Congress International Farm Management Association., Wageningen, The Netherlands

[46] M. Pandit, K. P. Paudel, A. K. Mishra and E. Segarra 2012, "Adoption and Nonadoption of Precision Farming Technologies by Cotton Farmers,” in Agricultural & Applied Economics Association’s 2012 AAEA Annual Meeting., Seattle, Washington

[47] D. R. Krindred and R. Sylvester - Bradley 2014, “Using Precision Farming technologies to improve nitrogen management and empower on-farm learning," Aspects of Applied Biology, vol. 127, pp. 1 - 8

[48] A. M. Blackmer and S. E. White 1998, "Using precision farming technologies to improve management of soil and fertiliser nitrogen,” Australian Journal of Agricultural Research, vol. 49, no. 3, pp. 555 - 564