Original Research Article

Assessment of Soil Fertility Status in Paroo and Saraiyan Blocks of Muzaffarpur district of Bihar using GPS and GIS

Abstract

The experiment was conducted during 2019–21 at Paroo and Saraiya blocks of Muzaffarpur district of Bihar, India to identify the nutrients status for crop management. Soil fertility inventory research was carried out in these two identified blocks (Paroo and Saraiyan) for generation of thematic soil fertility map. For nutrient assessment altogether 40 (forty) geo-referenced composite soil samples were collected from the various locations of the studied area using a hand-held GARMIN GPS device. The processed soil samples were used for analysis of various soil fertility parameters by using prescribed standard methods. Soil nutrient status and fertility maps were created by using ArcGIS 10.4.1 software employing Inverse Distance Weighted (IDW) interpolation techniques. The results clearly indicated that the soils pH was alkaline in nature ranges from 7.4–9.5. The mean value of Soil organic matter (0.55%) and potassium (150 to 250 kg ha^{-1}) was found to be low to medium whereas, available nitrogen (119.9 to 319.1 kg ha^{-1}) found 90% deficient, however, phosphorus (4.34 to 18.4 kg ha^{-1}), and sulphur were recorded low in the blocks. However, most of the sample of micronutrients like copper (0.23 to 1.07 mg kg^{-1}) and Iron (1.64 to 13.2 ppm) showed above critical limits while manganese, zinc deficiency were occurred in wide area. The intensive cropping system and imbalanced use of chemical fertilizer is degrading the soil quality in study area.

Keywords: GIS, GPS, Muzaffarpur, Soil Fertility

1. Introduction

Land use and soil management strategies have an impact on soil fertility, which varies spatially from field to field (Sun et al., 2003). Soil test-based fertility management is an effective tool for increasing productivity of agricultural soils that have high degree of spatial variability resulting from the combined effects of physical, chemical or biological processes. The soil fertility indicators are primarily based on the physico-chemical attributes of soil including macro and micronutrients. These properties vary spatially from a field to a larger regional scale is affected by soil forming factors and soil management. Understanding the state of the soil's fertility is essential for creating effective soil management plans that support crop cultivation design (Ramadan et al., 2023, Kashiwar et al., 2022, Schröder et al., 2018, Upadhyay et al., 2020). Identify and describing the spatial variability of soil fertility across a field has been difficult until new technologies such as Global Positioning Systems (GPS) and Geographic Information Systems (GIS) were introduced. Collection of soil samples by using GPS is very important for preparing thematic soil fertility maps (Thakur et al,. 2021, Kundu et al., 2021, Mishra et al., 2013). GIS is a potential tool used for easy access, retrieval and manipulation of voluminous data of natural resources often difficult to handle manually.

GIS has emerged as a powerful tool for handling spatial and non-spatial geo-referenced data for preparation and visualization of input and output, and for interaction with models. There is considerable potential for the use of GIS technology as an aid to the soil erosion inventory with reference to soil erosion modelling and erosion risk assessment. A GIS can be used to scale up to regional levels and to quantify the differences in soil loss estimates produced by different scales of soil mapping used as a data layer in the model (Sannidi et al., 2022, Neissian et al., 2023, Beltran et al., 2022, .

The integrated use of remote sensing and GIS could help to assess quantitative soil loss at various scales and also to identify areas that are at potential risk of soil erosion (Nal et al., 2022, Fan et al., 2021). Several studies showed the potential utility of GIS technique for quantitatively assessing soil erosion hazard based on various models (Thilagam et al., 2022, Navidi and Mohammad, 2022, Coulibaly et al., 2021, Qiu et al., 2021). Considering the inaccessibility of the hilly terrain if it is extensive area, RS is essential to accommodate spatial variability and information. Spatial modelling involves the use of GIS for representation of the conceptual model and performance of simple mathematical computations on the stored GIS object attributes for displaying the results spatially (Aggag and Alharbi, 2022, Shaloo et al., 2022, Zakarya et al., 2021).

GPS based evaluation also helps in monitoring the soil health from time to time (Al-Soghir et al., 2022). In order to that, rare study was done to identify the nutrient status block-wise in the study area using data base for preparation of thematic soil preparation map. Agriculture-related thematic maps (Soil fertility, land usage, land cover, soil erosion etc.) generated through GPS tool aids immensely in developing site-specific nutrient management strategies (Hemalatha et al., 2020). Moreover, GIS based soil fertility maps for precision agriculture also serves as a decision support tool for solving resource management issues like land management, soil erosion, soil degradation, water quality, and urban planning (Elsharkawy et al., 2022, Habibie et al., 2021). Keeping all the facts, a study was undertaken to assess the soil fertility level to generate soil fertility maps using remote sensing and GIS for Paroo and Saraiyan blocks of Muzaffarpur district of Bihar.

2. Materials and Methods

2.1. Location of the Study area

The investigation was done during *kharif* and *rabi* season of 2019 to 2021 covering the blocks of Paroo and Saraiyan is situated in the Southern part of Muzaffarpur district of Bihar, India consisting of a geographical area of 437.85 km^2. The study area lies between 25.9692° to 26.2231° North Latitude and 84.9133° to 85.2881° East Longitude. The main rivers blown across the district are Burhi Gandak, Baghmati, and Baya. The mean annual rainfall of the study area received on the year 2021 was around 1640.2 mm in which about 85% of its rainfall is received during south-west monsoon and a small quantity from the north east monsoon during winter. The fluctuations occur in climatic throughout the year, where in the summer season lasts from April to June and is extremely hot and humid, with temperatures reaching up to 40°C, however, from mid-November to March temperatures ranging from 6°C to 20°C. The location of the study area is depicted in Figure 1.

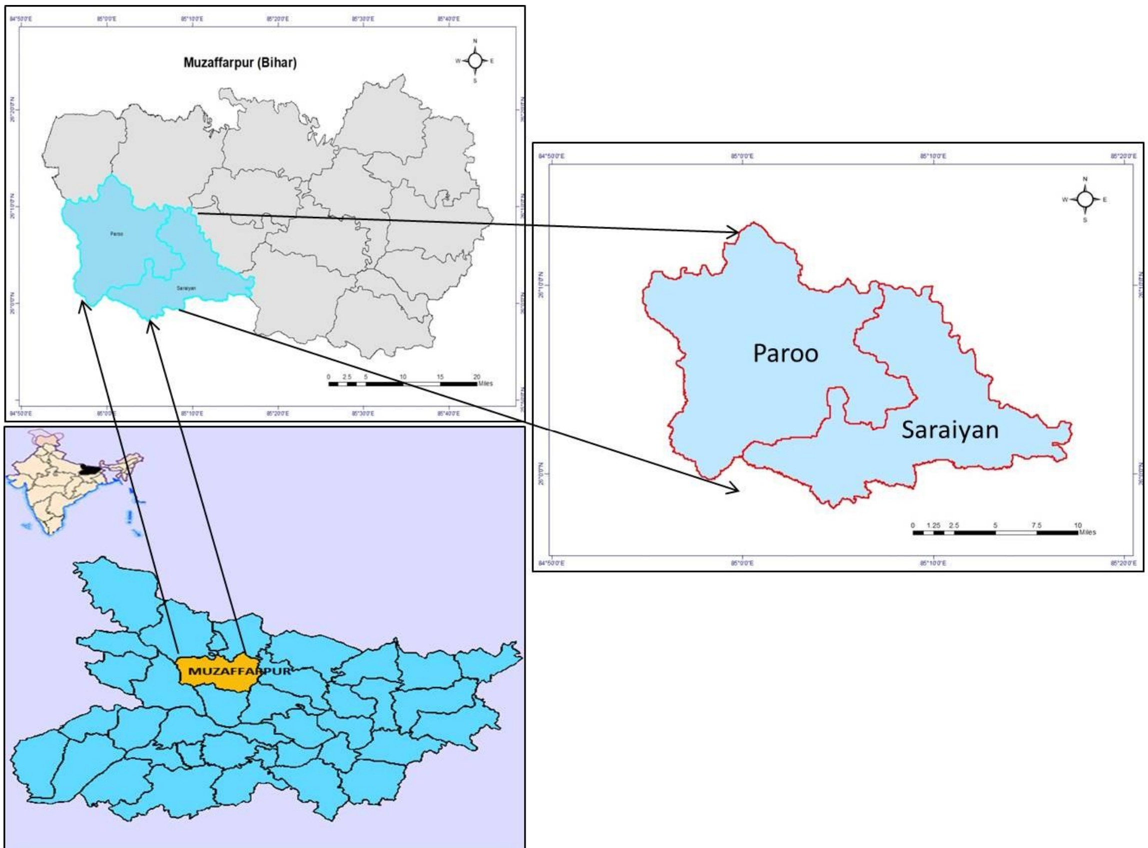

Figure 1: Location map of the study area (Paroo and Saraiyan) in Muzaffarpur district of Bihar

2.2. Soil Sampling

The soil samples were collected from entire study area and exact location was earmarked and geo-coordinates of site were also recorded using GPS device. Soil sampling was carried out in such a way that each of the land types was equally represented. A total of 40 soil samples (0 to 20 cm depth) were collected from two blocks (Paroo and Saraiyan) of Muzaffarpur district of Bihar for the assessment of various soil parameters. The recorded geo-coordinates of the sampling points were imported to the GIS environment for the preparation of thematic soil fertility maps. Locations of the sampling points are represented in Figure 2.

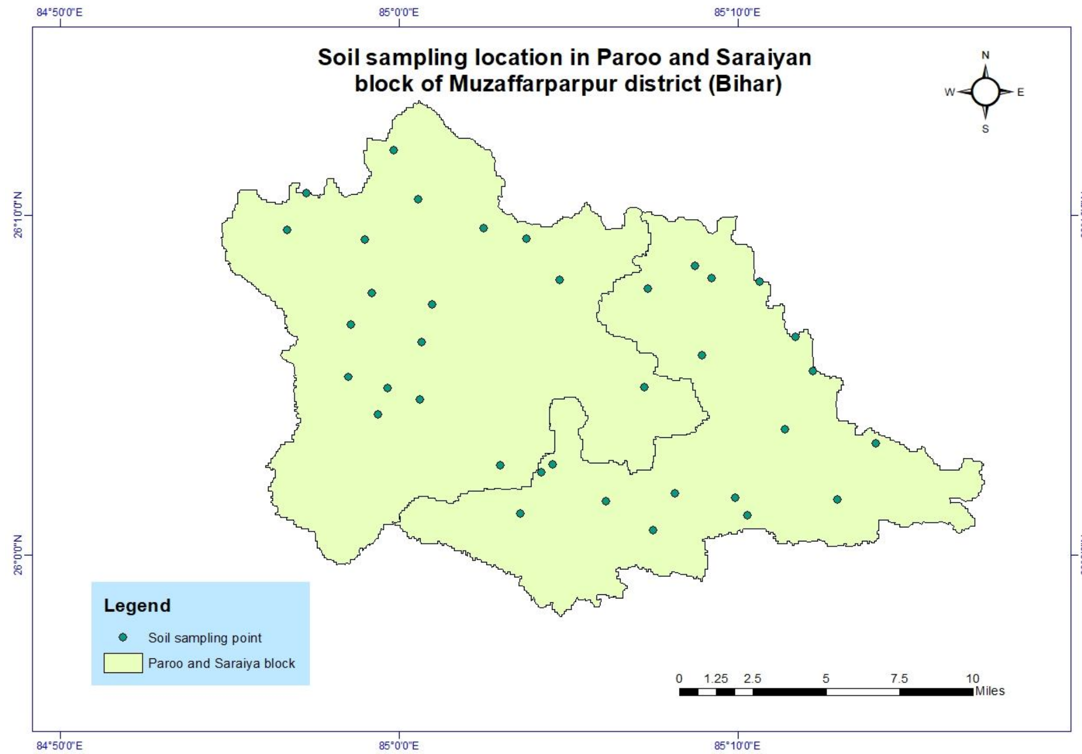

Figure 2: Location of soil sampling points in Paroo and Saraiyan block of Muzaffarpur district (Bihar)

2.3. Laboratory Soil Analysis

The prescribed standard methods were followed for assessment of soil parameters viz. soil pH was determined using a glass electrode pH meter (Model-Systronics-36) keeping up the soil-water suspension ratio 1: 2.5 as recommended by (Jackson, 1973). The electrical conductivity of the soil was measured with soil-to-water ratio of 1: 2.5 by EC meter (HANNA-HI2300). Available nitrogen of the soils was determined by alkaline potassium permagnate method (Subbiah and Asija, 1954). Available phosphorus was extracted from the soil with the help of 0.5 M $NaHCO_3$ at pH 8.5 and the molybdophosphoric blue colour method determined by using spectrophotometer (Elico SL-177). The available potassium was determined using extractant 1 N NH_4OAc at pH 7.0 (Jackson, 1973) and analyzed by a flame analyzer (Elico CL-378) at 589 nm for determination. Organic carbon content of samples was determined by Walkley and Black's (1934) wet oxidation method. Available Sulphur determined using calcium chloride method. Available micronutrients assessed using DTPA extractant (Lindsay and Norvell, 1978).

2.4. Soil fertility mapping

The coordinates of each sampling locations were recorded in a Garmin GPS device and the geo-coordinates were imported to the base map in ArcGIS software. The reference coordinate system utilized was the World Geodetic System 1984 (WGS84) for locating and geo-referencing the sampling points in GIS software. Arc toolbox, used for the interpolation of data and the kriging interpolation technique is based on regression of observed Z-value of point data and weighted mean as per spatial covariance. The interpolation observes the values of unsampled variables from sampled variables. The thematic soil fertility maps were categorized as per soil variability in the results. Descriptive statistical analysis was done using MS Excel and SPSS packages.

3. Results and Discussion

Sampled soils were taken for analysis of various soil parameters viz. pH, electrical conductivity, organic matter, available nitrogen, available phosphorus, available potassium, available sulphur, and micronutrients. The status of soil fertility and percent distribution were obtained from laboratory analysis are summarised in Table 1 and 2.

Table 1: Soil fertility status of Paroo and Saraiyan Block in Muzaffarpur district of Bihar

Sl. No.	Soil parameters	Minimum	Maximum	Mean	Standard Deviation
1	pH	7.40	9.58	7.92	0.25
2	Soil Organic Carbon (%)	0.17	0.98	0.51	0.09
3	Available Nitrogen (kg ha^{-1})	119.9	319.1	228.1	23.1
4	Available Phosphorus (kg ha^{-1})	4.34	18.4	12.1	1.82
5	Available Potassium (kg ha^{-1})	68.8	377.4	186.2	36.8
6	Available Sulphur (kg ha^{-1})	6.78	19.1	11.3	1.43
7	DTPA-Zinc (mg kg^{-1})	0.29	1.10	0.70	0.16
8	DTPA-Copper (mg kg^{-1})	0.23	1.07	0.73	0.16
9	DTPA-Iron (mg kg^{-1})	1.64	13.2	7.17	2.12
10	DTPA-Manganese (mg kg^{-1})	1.18	6.12	3.51	0.65

Table 2: Distribution of soil fertility in Paroo and Saraiyan Block of Muzaffarpur district, Bihar

Soil parameters	Class	Limit	Number of sample	Distribution (%)
pH	Acidic	<6.5	0	0%
	Neutral	6.5–7.5	1	2.5%
	Alkaline	>7.5	39	97.5%
Soil Organic Carbon	Low	<0.5	18	45.0%

(%)	Medium	0.5–0.75	17	42.5%
	High	>0.75	5	12.5%
Available Nitrogen (kg ha^{-1})	Low	<280	36	90.00%
	Medium	280–560	4	10.00%
	High	>560	0	0.00%
Available Phosphorus (kg ha^{-1})	Low	<14	30	75.0%
	Medium	14–28	10	25.0%
	High	>28	0	0.0%
Available Potassium (kg ha^{-1})	Low	<150	31	77.5%
	Medium	150–250	9	22.5%
	High	>250	0	0.0%
Available Sulphur (kg ha^{-1})	Low	<10	14	35.0%
	Medium	10–20.0	26	65.0%
	High	>20	0	0.0%
DTPA-Zinc (mg kg^{-1})	Low	<0.6	15	37.5%
	Medium	0.6–1.8	25	62.5%
	High	>1.8	0	0.0%
DTPA-Iron (mg kg^{-1})	Low	<4.5	10	25.0%
	Medium	4.5–9	7	17.5%
	High	> 9	23	57.5%
DTPA-Copper (mg kg^{-1})	Low	<0.2	0	0.0%
	Medium	0.2–0.8	18	45.0%
	High	>0.8	22	55.0%
DTPA-Manganese (mg kg^{-1})	Low	<3.5	21	52.5%
	Medium	3.5–5.0	15	37.5%
	High	>4	4	10.0%

The soil reaction indicates the degree of acidity or alkalinity and it also regulates the availability of its nutrients. In the present study the data obtained on soil pH of the study area was found slightly alkaline in nature ranged from 7.40–9.5 (Table 2). Similar results were also reported by Singh et al. (2012) & Singh et al. (2022). The variability in soil pH in the study area showed in soil fertility map is depicted in Figure 3. The soil map clearly showed the pH value greater than 8.0 in North Western part of the study area however, the remaining area falls under soil pH value 7.5–8.0 (Figure 3.).

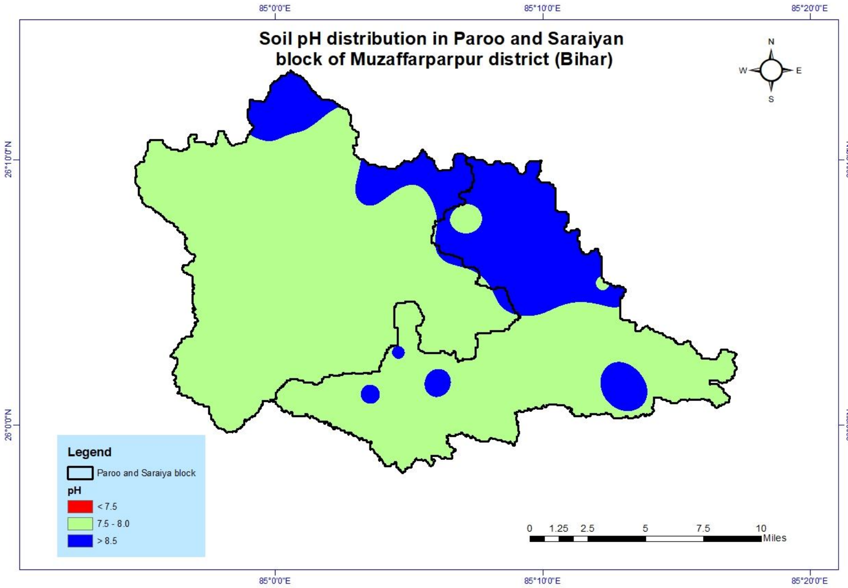

Figure 3: Soil pH distribution in Paroo and Saraiyan Block of Muzaffarpur district, Bihar

The analysed samples contain range of soil organic matter from 0.17 to 0.98% with a mean value of 0.51%. The data obtained from the results showed where, maximum samples falls under less than 0.5% and soil fertility map covered most of the area under low status of organic carbon. The organic carbon categorization as low, medium and high which contains around 45%, 42.5%, and 12.5% respectively shown in table Table 2. The variability in organic carbon showing in the study area is depicted in Figure 4.

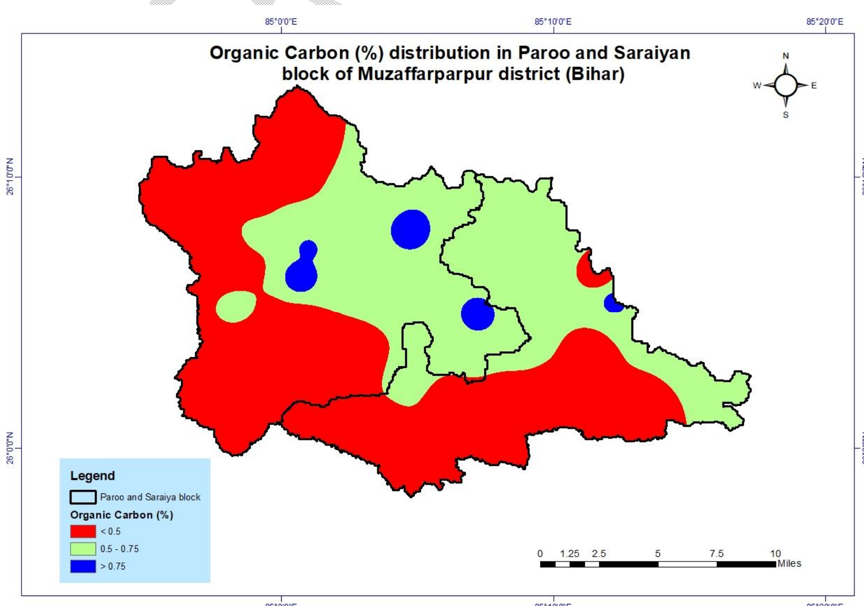

Figure 4: Soil organic carbon (%) distribution in Paroo and Saraiyan block of Muzaffarpur district, Bihar

The map clearly depicts that low OC is widely distributed in the eastern and southern region while, the central part of the study area covered by medium OC. The appearance of reduced content of organic carbon in the area may be due to the high decomposition of organic matter at high temperature which rises to 40°C in summer season and scanty application of organic residues.

Available nitrogen content in soil varied from 119.9 to 319.1 kg ha^{-1} with a mean value of 228.1 kg ha^{-1} (Table 1). The study area showed around 90% samples found to be deficit in nitrogen content (Table 2). The variability and distribution of soil available nitrogen in the study area was generated and presented in soil fertility map (Figure 5).

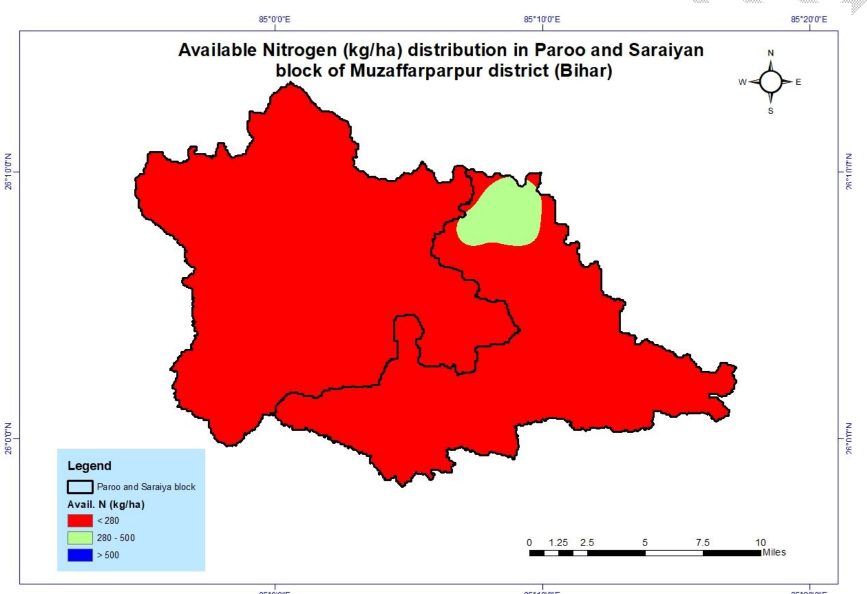

Figure 5: Distribution of available Nitrogen (kg ha^{-1}) in Paroo and Saraiyan Block of Muzaffarpur district, Bihar.

The deficient availability of nitrogen that may be possibly due to low organic matter content in soils as evident from low OC content (Table 2). Tagung et al. (2022a) and Santhi et al. (2018) also reported similar kind of results, where, rice–wheat cropping system followed.

The data on available phosphorus content in the study area ranged from 4.34 to 18.4 (kg ha^{-1}) with a mean value of 12.1 kg ha^{-1} (Table 1). The distribution accounted around 75% and 25% of the study area falls under low and medium phosphorus content respectively (Table 2). However, the medium phosphorus content was observed in the northern, eastern and western region however, the remaining area found deficient Phosphorus showed in soil fertility generated map depicted in Figure 6. Similar results are also reported by Tagung et al. (2022b).

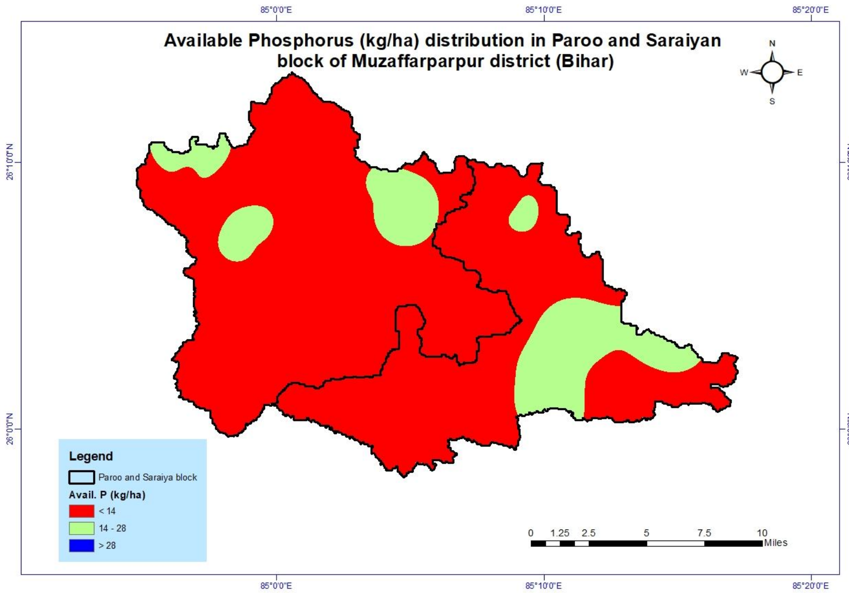

Figure 6: Distribution of available Phosphorus (kg ha^{-1}) in Paroo and Saraiyan Block of Muzaffarpur district, Bihar

Potassium plays an important role in physiological processes of plants which involved in the activation of several enzymes. The available potassium content in the study area ranged from 68.8 to 377.4 (kg ha^{-1}) with a mean value of 186.2 kg ha^{-1} (Table 1). The generated soil fertility map showing the distribution of soil available potassium in the study area is depicted in Figure 7.

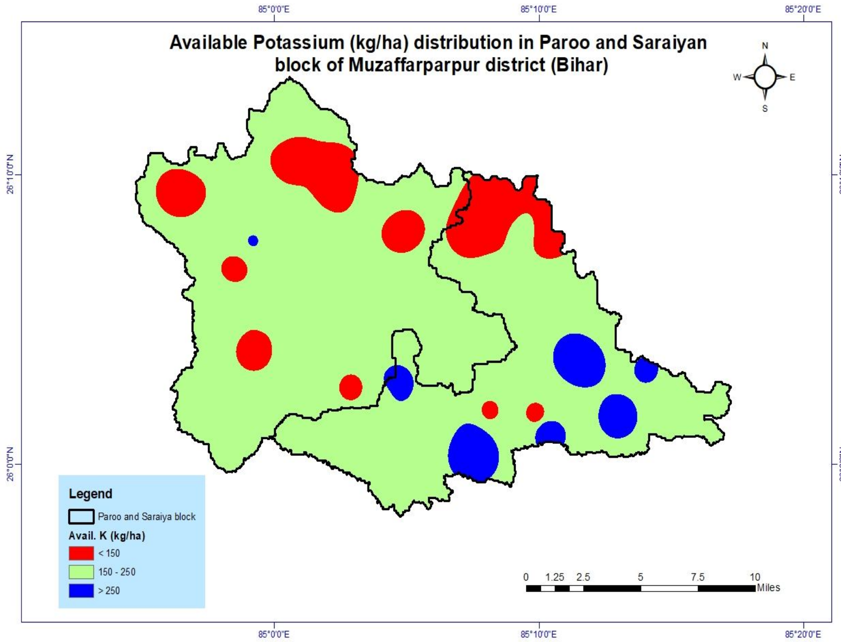

Figure 7: Distribution of available Potassium (kg ha^{-1}) in Paroo and Saraiyan Block of Muzaffarpur district, Bihar

Available K value of 150 to 250 kg ha^{-1}, covered maximum area presented in the thematic map. The Northern region is distributed sparsely in patches with K content lower than 150 kg ha^{-1}. The available K content more than 250 kg ha^{-1} is observed in patches in the south eastern region of the study area. Low K content in the region may be influenced by the presence of lower amount of clay and soil organic matter in the region which in turn strongly influences the degree of K leaching in soil. Similar result as also observed by Prabhavati et al. (2015).

The status of available sulphur content is presented in Table 1. The finding of the study reveals that around 35% and 65.0% of the study area falls under low and medium sulphur content respectively (Table 2). Distribution of sulphur in soils covered most of the area under medium sulphur content which is shown in Figure 8.

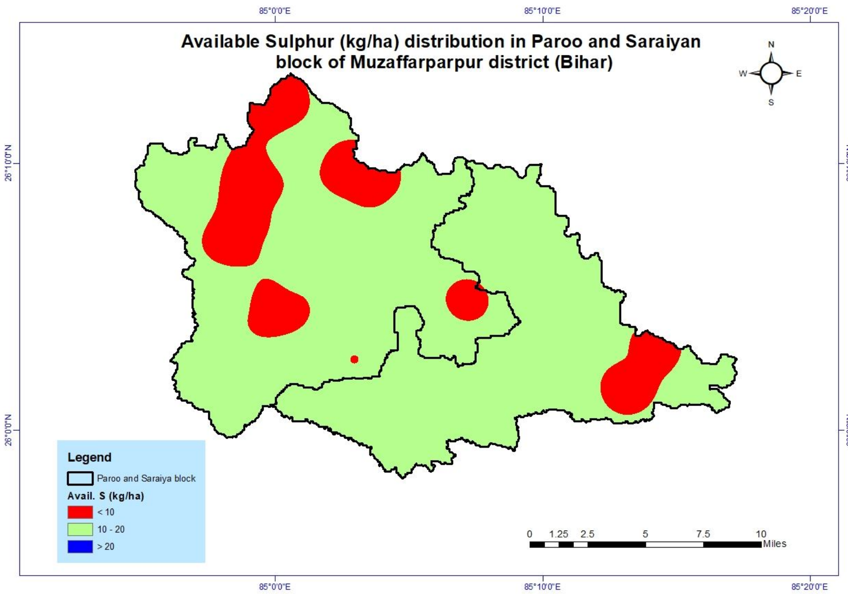

Figure 8: Distribution of available Sulphur (kg ha^{-1}) in Paroo and Saraiyan Block of Muzaffarpur district, Bihar.

Zinc (Zn) is an important micronutrient required to plants in trace quantity and plays a crucial role for plant growth and development. The availability of zinc content in the study area ranged from 0.29 to 1.10 mg kg^{-1} with the mean value of 0.70 mg kg^{-1} given in the Table 1. The level of zinc in soils reveals nearly 37.5% and 62.5% of the study area falls under low to medium Zn content (Table 2). The reason may be due to the intensive cropping system and imbalanced use of fertilizer. The variability in zinc content showed in fertility map in the study area is depicted in Figure 9.

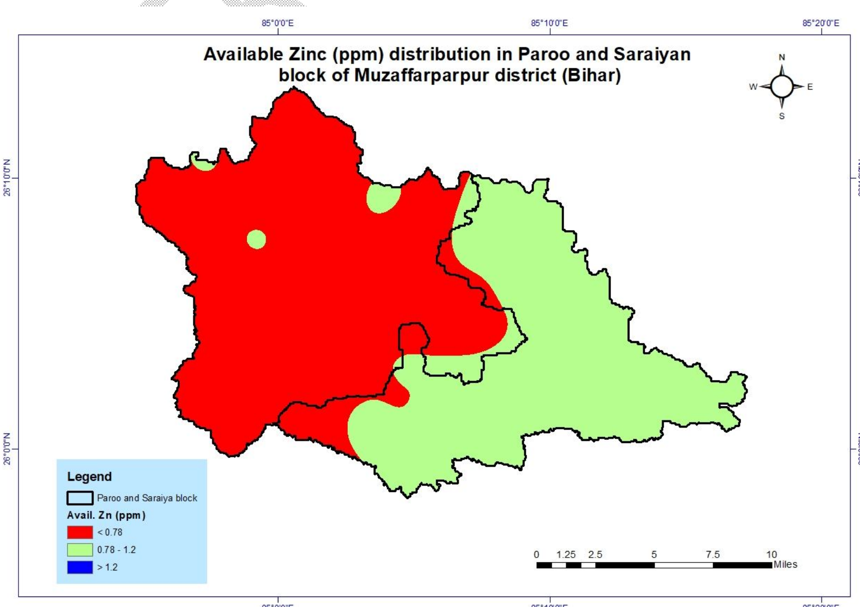

Figure 9: Distribution of DTPA-Zinc (mg kg^{-1}) in Paroo and Saraiyan Block of Muzaffarpur district, Bihar.

The analysed data regarding the iron content in the study area varied from 1.64 to 13.2 ppm with a mean value of 7.17 mg kg^{-1} depicted in the Table 1. Out of total soil sample, about 25% found deficient, however, 17.5 observed medium in concentration and remaining samples contain high iron concentration. The generated soil fertility map showing the distribution of DTPA-Fe content in the study area is depicted in Figure 10. The map clearly indicates that higher Fe content in the eastern part and low to medium content in the western and central region of the study area (Figure 10).

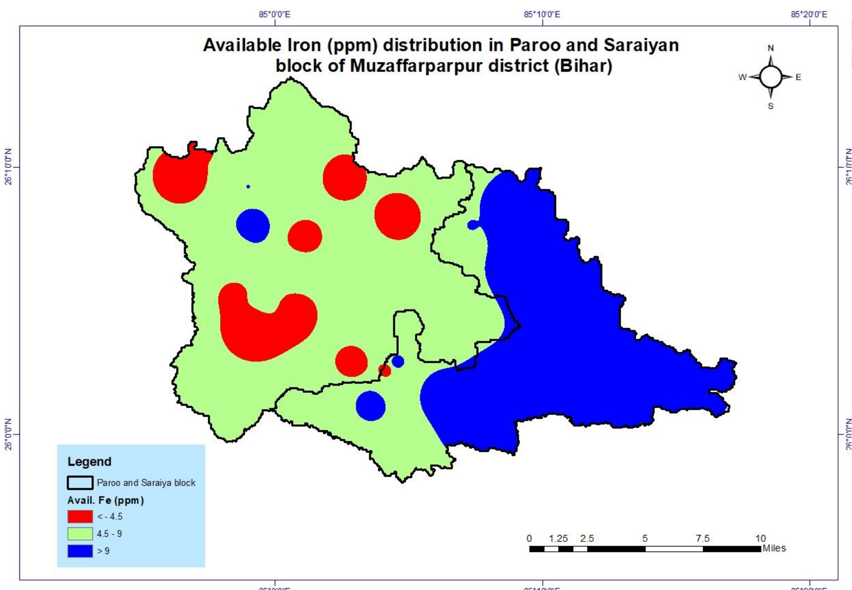

Figure 10: Distribution of DTPA-Fe (mg kg^{-1}) in Paroo and Saraiyan Block of Muzaffarpur district, Bihar.

The high proportion of available iron may be due to the presence of numerous primary and secondary iron minerals, including olivine, siderite, goethite, and magnetite. Proper care must be taken for antagonistic elements of the iron like K, Zn etc. as high iron availability may end up iron toxicity symptoms in crops.

The status of manganese (Mn) in study area is presented in Table 1 ranged from 1.18 to 6.12 (ppm) with a mean value of 3.51 mg kg^{-1}. The manganese detected samples reveals 52.5% and 37.5% of the study area falls under low and medium while, 10% observed under high manganese content (Table 2). The generated soil fertility map showing the distribution of DTPA-Mn content in the study area is depicted in Figure 11.

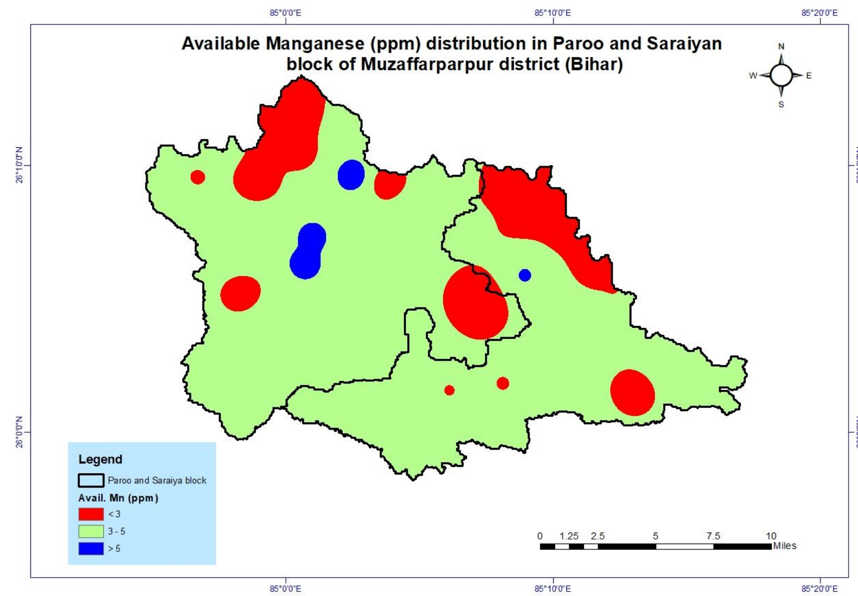

Figure 11: Distribution of DTPA-Mn (mg kg^{-1}) in Paroo and Saraiyan Block of Muzaffarpur district, Bihar.

The deficiency of micronutrients in the region may be due calcareous soils bearing high pH. Copper is also an important micronutrient that is crucial for plant growth and development, which acts as an enzyme activator and involved in the oxidation-reduction processes is found in the chloroplasts of leaves.

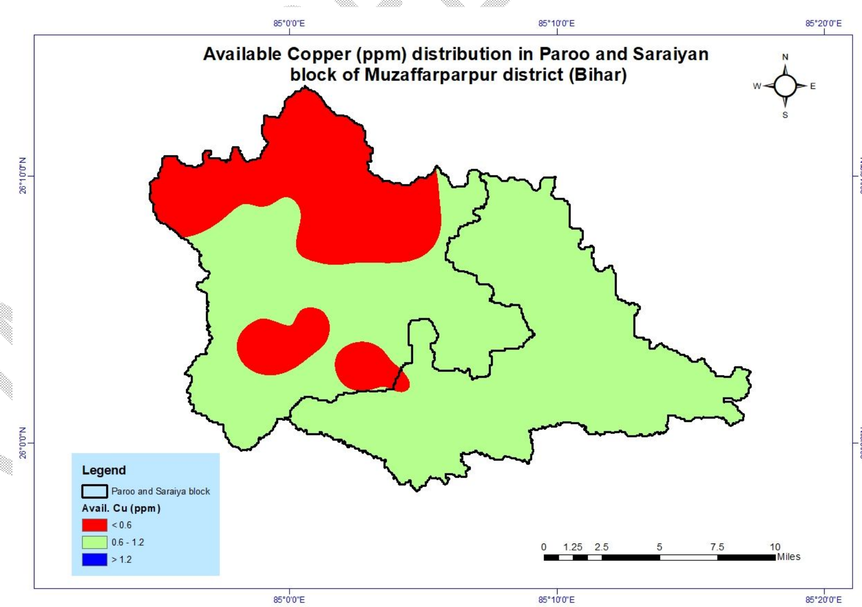

Figure 12: Distribution of DTPA-Cu (mg kg^{-1}) in Paroo and Saraiyan Block of Muzaffarpur district, Bihar.

The availability of in the soil varied from 0.23 to 1.07 mg kg^{-1} presented in the Table 1. The finding of the study reveals that the majority of the study area falls under medium to high copper content (Table 2).

4. Conclusion

The results obtained from Paroo and Saraiyan Block of Muzaffarpur district, Bihar had observed the status of organic carbon low to medium category, however, most of the area have low available nitrogen. Soil pH was found to be under slightly alkaline in nature across the study area. Similarly, phosphorus and potassium were found mostly at low level. In case of micronutrient status, iron and copper content was noticed at higher, while zinc and iron deficiency were occurred in wide area.

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