Original Research Article

Spatial Variability of Soil Properties under Different Land Use Systems in Wokha District of Nagaland

ABSTRACT

A study was conducted in the Wokha district of Nagaland in 2015 to assess the variability of selected soil parameters of four different land use systems (wet terrace rice cultivation, shifting, cultivation, cultivated fallow and forest) and to map their spatial distribution. A total of 381 soil samples were collected and tested for six soil fertility parameters; clay, pH, soil organic carbon, available nitrogen (N), phosphorus (P) and potassium (K). The results showed that all of the soils were very acidic in nature; however the mean value of soil pH was substantially higher in the shifting cultivation system. Soil organic carbon concentrations ranged from high to very high across all land use systems. Average SOC concentration was highest in the forest, followed by cultivated fallow, shifting, and wet terrace rice cultivation (WTRC) systems, whereas available N content was very low to low. The P concentration of the soil was very low in the WTRC system and low in the other systems. Soil K concentration was high in shifting (361.95 kg/ha), cultivated fallow (312.4 kg/ha), forest (309.73 kg/ha), and low in WTRC (166.975 kg/ha) land use systems. Available N, P and K deficiency was found in 93.8%, 72.2%, and 32.9% of soil samples, respectively. Soil organic carbon correlated positively with K and significantly positively with N. Soil pH correlated negatively with clay content and positively but non-significantly with P. The generated maps might be used to assist farmers in identifying the expected nutrient levels in their areas and encourage them to change their crop management practices to improve crop yield and profitability.

Keywords: land use systems, soil mapping, acidic soil, nutrient variability, nutrient deficiency

1. INTRODUCTION

Geostatistical tools are important technique for estimating the spatial variability of soil parameters. In recent years GIS approaches have been increasingly popular in a various fields, including agricultural research and advisory systems. Effective soil management is critical for long-term sustainability in agricultural production system. The soil properties may largely influenced by various management and land use methods due to the cumulative effect of biological, physical, and chemical processes over time (Santra et al, 2008).

Nagaland, the 16^{th} State of the Indian Union with the geographical area of 16,579 Km^2, is bounded by Myanmar on the East, on the north by Arunachal Pradesh, on the west by Assam, and on the south by Manipur. More than 52% land of the state is under forest cover. Shifting cultivation is the state's main agricultural system, often known locally as jhum. Along with jhumming, wet terrace rice cultivation (WTRC) has been practiced. Despite various structural restrictions, the state's 19 million indigenous families continue to practice shifting cultivation over an area of 12.4 million ha. Wokha has the largest area (11,670 ha) among the shifting cultivation-dominated districts in the state. In this form of cultivation a new forest is selected and cleared for cultivation for one or two years and then an adjacent forest areas is selected for further cultivation, by keeping the land fallow where shifting cultivation was undertaken in the last season. It is the total devastation of forests caused by unintentional forest fires caused by uncontrolled burning during land clearance. The ever shortened shifting cycle in the region has impacted both the forest and environment negatively (Lele and Joshi 2009; Chatterjee et al. 2021). With the ever-increasing demand for food, it is becoming increasingly difficult to restore forest cover, safeguard the ecosystem, and preserve biodiversity in the region.

Soil fertility is controlled by land use history, cropping pattern and nutrient management, relief position and parent material under a specified climate. Soil property dynamics such as texture, pH, carbon (C), nitrogen (N), available phosphorus (P), and available potassium (K) are investigated at various land use scales and dimensions (Jafarian et al, 2014; Kharal et al, 2018). Because of soil acidity, P is the scarcest nutrient in the soils of Nagaland, and P deficiency has a significant impact on crop productivity. Estimating soil fertility levels is required for various land use systems in order to detect production-related restrictions and provide appropriate remedial activities for optimum crop productions (Panday et al, 2018). Furthermore, characterization and mapping of the soil attributes will provide essential information that will assist both farmers and local planners to adopt effective soil management strategies.

Therefore the study on “Spatial variability of soil properties under different land use systems in Wokha district of Nagaland” was undertaken with the following goals in mind: i) to investigate the variability in soil properties due to different land use and map their spatial distribution using GIS technique, ii) to determine the relationships of selected soil chemical properties under different land use, and iii) to recommend appropriate soil fertility management practices for the district.

2.MATERIALS AND METHODS

*2.*1Characteristics of the Study Area*:*

The present study was undertaken in Wokha district ($93^0$55’12”- $94^0$23’15” East longitude, $26^0$00’02”-$26^0$26’98” North latitude and elevation from 98-1503 m msl) of Nagaland (Fig. 1). The average annual rainfall (2014-15) 1996 mm, of which 1710 mm (85.6%) was received from June to September. June is the slightly hot and January is the coldest months. The mean maximum day temperature during the summer months (June, July, and August) ranged from 21.96 to 22.04^{o}C. The relative humidity ranged from 42.68 to 94.86% and temperature was varied 9.36 to 30.10^{o}C. Wind speed was recorded the lowest (2.72 km/h) in October and the highest (4.80 km/h) in March.

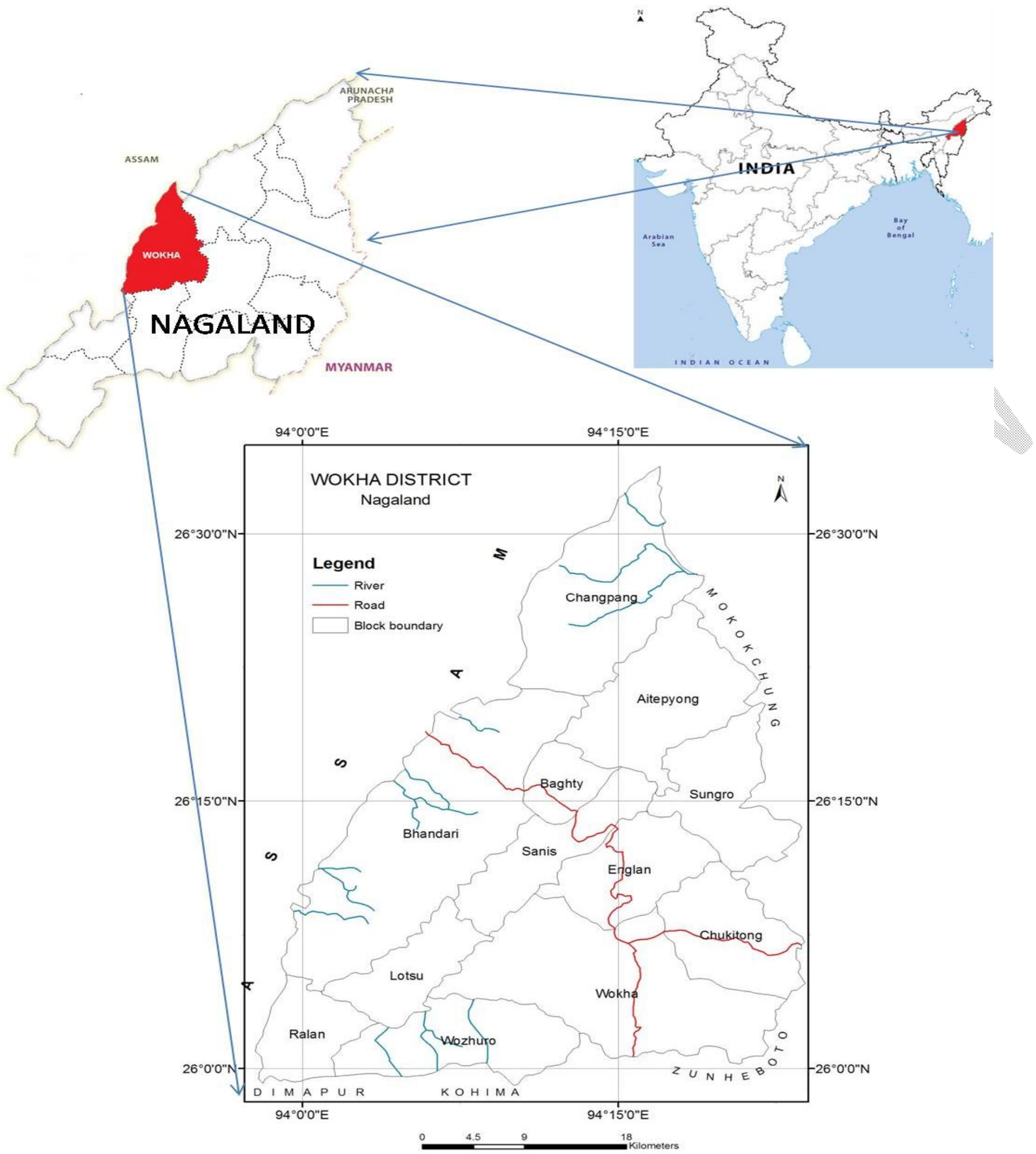


Fig. 1 Map showing study area and soil sampling locations of the Wokha district in Nagaland.

The district has a total area of 1,62,800 ha, with the majority of that being covered by forest (52%) and then shifting cultivation (*jhum*) and wet terrace rice cultivation (WTRC) system (Anonymous, 2014). Mixed cropping of short and long duration crop varieties are carried out in the shifting cultivation practice where the cropping intensity is 100%. The main crops that are grown during the pre-*kharif* and *kharif* seasons are paddy, maize, millets, ricebean, soybean, sesame, groundnut, colocasia, cassava, ginger, cucumber, etc. Double cropping practice is followed only in terraces, where puddle rice is taken up in *kharif* season and the crops like Mustard, French bean, Garden pea, Linseed, Knolkhol, Cabbage, *etc.* are taken during the *rabi* season.

2.2 Soil Sampling, Processing and Analysis:

A total of 381 surface (0-20 cm) soil samples were collected in between the months of September to October 2014, considering four land use pattern viz. WTRC (49 samples), shifting cultivation (165 samples), cultivated fallow (68) and forest (99 samples). Each soil sample was prepared by mixing five sub-samples. A global positioning system (GPS) was recorded to locate the sampling locations. The collected samples were air dried and passed through a 2 mm sieve for laboratory analysis and 0.5 mm sieve for soil organic carbon (SOC) analysis. The processed soil samples were analyzed for SOC concentration by Walkley and Black method. The soil pH was measured in 1: 2.5 soil water suspensions using a combine electrode in a digital pH meter. Available nitrogen (N) of soil was estimated by alkaline permanganate method. For soil available phosphorus (P_2O_5), soil samples were extracted with Bray-1 extractants, and the phosphorus content in the extracts was determined by ascorbic acid method. Available potassium (K) of soil was determined in flame photometer after extracting with neutral normal ammonium acetate (Page et al., 1982). Soil particle size distribution of sand, silt and clay was determined by following using a Bouyoucos hydrometer (Bouyoucos, 1927).

2.3 Statistical and Geostatistical Analysis:

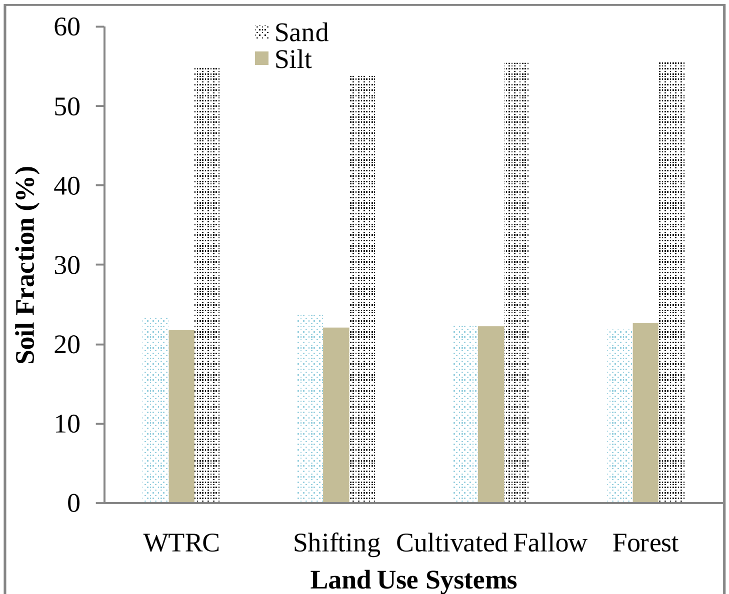
The pairwise Pearson's correlation of soil properties were analyzed by using SPSS software (version 16.0). The district, block, river, road, and railroad boundaries are all included in the base map. To store all of the primary data layers and establish relationships between them, a geo-database was developed. Using the ArcGIS application software, point, line, and polygon feature classes were digitalized. The latitude and longitude event and a point feature class were created using the input data in tabular form from an excel sheet. Coordinate system was specified by defining a projection as Geographic Coordinate Systems and datum as WGS 1984 for the study area. Sample data were then transformed into GIS maps by different geo-processing tools, such as projecting a dataset from one map projection to another, adding a field to a table, creating a buffer zone around the study area, spatial analyst techniques, *etc.* In order to estimate values for unmeasured places, the spatial analyst tool was used to interpolate the various soil nutrient characteristics throughout the Wokha district using the inverse distance weighting (IDW) method. Using this method, distinct thematic maps were created for each soil nutrient class, indicating different values for pH, SOC, available N, P_2O_5, and K_2O.

3.RESULTS AND DISCUSSION

3.1 Soil physical properties

3.1.1 Soil textural fraction

In all land use systems, sandy clay loam was the most prevalent soil texture class (Fig. 2), which highlights the homogeneity of soil formation processes and similarity in parent materials. In comparison to WTRC (23.53%), fallow (22.4%), and forestry (21.8%), shifting cultivation had a higher mean value of clay fraction (23.9%). Low clay content for all land use systems may be caused by a consistent quantity of fine particle loss from soil erosion on hilly slopes (Ray et al, 2021). However, soil erosions under sparser vegetation, clay fractions are likely to be lost due to selective water erosion processes in the forest land (Woldeamlak and Stroosnijder, 2003).



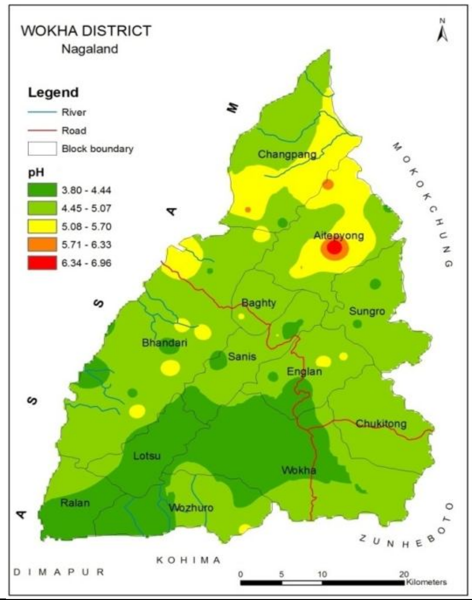


Fig. 2 Values of soil fractions based on land use systems in the Wokha district of Nagaland.

Fig. 3 Soil pH spatial variability map in the Wokha district of Nagaland.

3.2 Soil chemical properties

3.2.1 Soil pH

The soils of the study areas were highly acidic in nature. Extremely acidic soil reaction was noticed in WTRC (4.44 ± 0.037) soils (minimum 3.18 and maximum 5.85), cultivated fallow (4.38 ± 0.051) soils (minimum 3.48 and maximum 5.73) and forest (4.47 ± 0.053) soils (minimum 3.36 and maximum 5.79) (Tables 1). However, very strongly acidic (4.73 ± 0.065) soil pH reaction was found in shifting cultivating system with minimum and maximum value of 3.56 and 6.97 respectively. In WTRC system 42.9 % samples were very strongly acidic, 28.6% extremely acidic and 24.5% strongly acidic in reaction respectively, whereas, remaining land use systems were dominated by extremely acidic pH reaction by 72.1, 61.8 and 56.6% for cultivated fallow, shifting and forest land use systems respectively. Due to parent material (such as sandstone, siltstone, quartzite, and shale) and loss of significant cations during monsoon season as well as the atmospheric nature of aluminium in these soils, the majority of the soils were characterized by extremely acidic to very strongly acidic in reactivity. The addition of Ca, Mg, and K by conventional slash and burn operations may be the cause of the relatively higher soil pH in the shifting cultivated system (Moraes et al, 1996).

The pictorial presentation of soil pH of the district is shown in Fig. 3. It was also found that the study area were extremely acidic (57.8%) to very strongly acidic (28.8%) in nature followed by strongly acidic (9.8%) and medium acidic (3.4%) in reaction. A very little area (0.03%) with a soil pH class that is slightly acidic was present, but it cannot be seen on the variable map (Fig. 3).

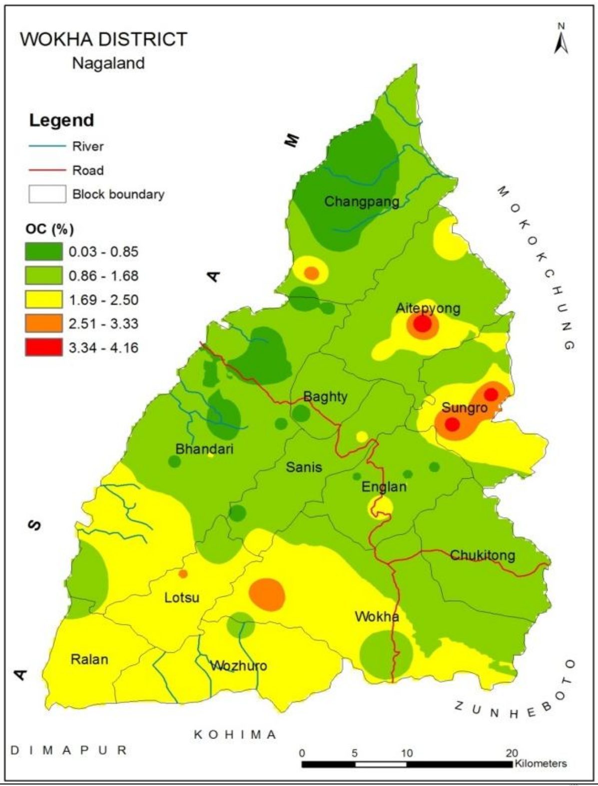


Fig. 4 Soil organic carbon spatial variability map in the Wokha district of Nagaland.

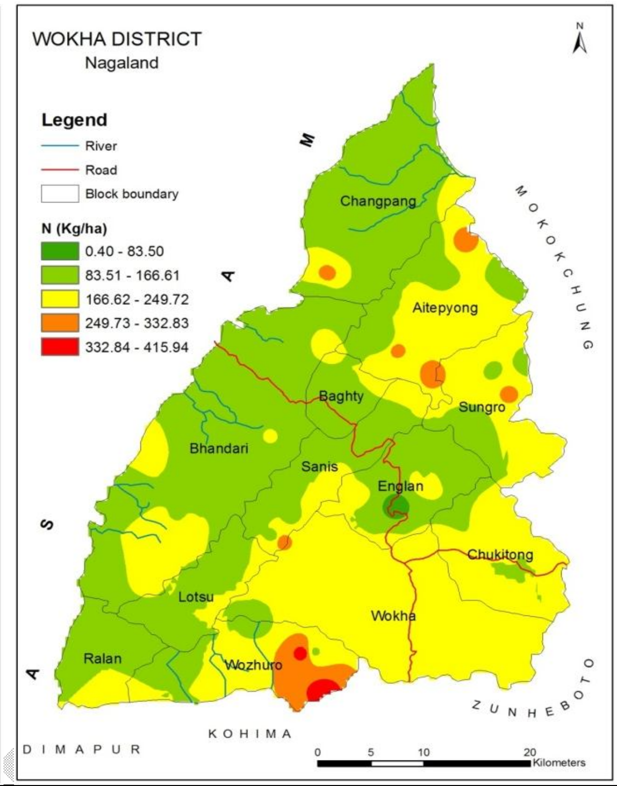


Fig. 5 Soil available N spatial variability map in the Wokha district of Nagaland.

3.2.2 Soil organic carbon:

Soils of the study area were rich in SOC. The highest SOC (2.202 ± 0.096) was recorded in forest land use system, however SOC content (Table 1) did not varied in between shifting (1.942 ± 0.069) and fallow (1.960 ± 0.105) cultivated system. The soils of WTRC systems had the lowest (1.175 ± 0.086) SOC. It was also found that the SOC content in 49.0% soil samples were very high, 26.5% high, 20.4% moderately high and 4.1% moderate respectively in WTRC land use system. However, the SOC was quite high in forest (88.5 %), cultivated fallow (87.9 %) and shifting (81.9 %) cultivated systems. Soil organic carbon of the study area was high in status (Fig. 4). Higher soil SOC in forest land use systems may be attributed to distribution of large root systems, plant litter, vegetation, and limited surface soil disturbance. Intensive tillage practices and crop residue clearance may be linked to a somewhat lower amount of soil organic carbon in WTRC systems. Overall the district was dominated by very high (82.9%), high (9.3%), moderately high (4.9%) and moderate (2.8 %) in soil organic carbon which is present in Fig. 4.

3.2.3 Available nitrogen:

According to the findings, forest soils had the maximum available nitrogen concentration (225.314 ± 8.136 kg/ha), followed by fallow (173.79 ± 6.918 kg/ha), shifting cultivation (162.06 ± 3.078 kg/ha) and WTRC lands (120.62 ± 9.043 kg/ha) (Table 1). In WTRC systems, low soil test results for available N showed increased leaching and volatilization losses of applied nitrogen, which may be caused by light soil texture, intense rainfall, and surface application of nitrogenous fertilizers during cropping times. According to the study, soil samples from WTRC, shifting, fallow, and forest land, respectively, were deficient in available nitrogen in 95.9%, 97.4%, 95.5%, and 80.8% of the cases. As N is usually considered as a mobile nutrient in the soil system, therefore, variation of SOC content altered N content within or in between the LUSs. Yimer et al, (2006) also found that the soil organic carbon and N contents to be significantly lower in the cultivated lands as compared to forest soil. Overall the district is very low (30.8) to low (63%) in soil N content. Only 5.4% of soil samples had a moderate N concentration, while only 0.8% had a relatively high level. A similar geographic graphical representation of the study area with N content is shown in Fig. 5.

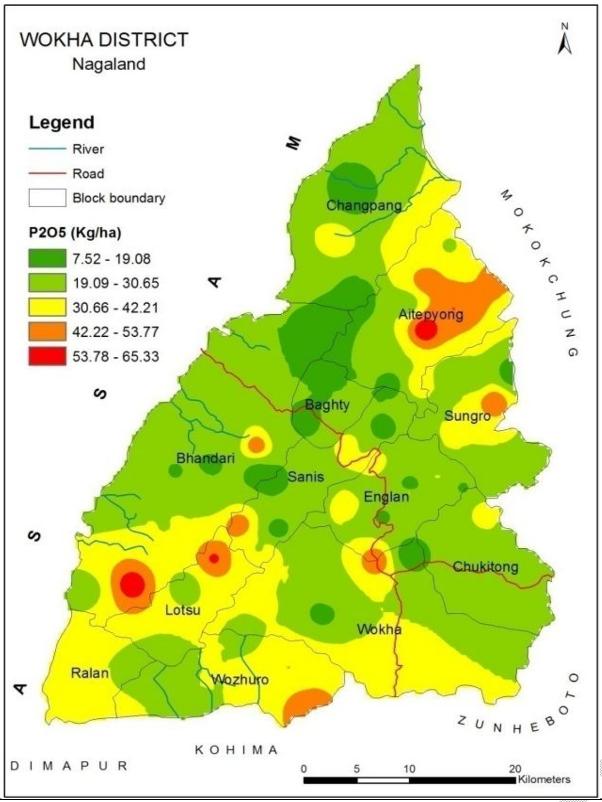
Table 1. Spatial variability of soil chemical properties among land use systems of Wokha district in Nagaland.

Soil Properties	Land Use Systems			
	WTRC (n=49)	Shifting (n=165)	Cultivated Fallow (n=68)	Forest (n=99)
Soil pH	4.44 ± 0.037	4.73 ± 0.065	4.38 ± 0.051	4.47 ± 0.053
Soil organic carbon (%)	1.175 ± 0.086	1.942 ± 0.069	1.960 ± 0.105	2.202 ± 0.096
Available N (kg/ha)	120.62 ± 9.043	162.06 ± 3.078	173.79 ± 6.918	225.314 ± 8.136
Available P_2O_5 (kg/ha)	16.565 ± 1.306	25.556 ± 1.051	25.496 ± 1.511	30.815 ± 1.088
Available K_2O (kg/ha)	166.975 ± 18.837	361.95 ± 17.869	312.4 ± 24.93	309.73 ± 22.913

3.2.4 Available phosphorus:

Forest soil had the highest available P of all the land use systems (30.815 ± 1.088 kg/ha) followed by shifting cultivated soil (25.556 ± 1.051 kg/ha), fallow (25.496 ± 1.511 kg/ha) soil and WTRC (16.565 ± 1.306 kg/ha) soil (Table 3). Increased phosphorus availability in the forest system may be caused by increased litter buildup (Zhang et al, 2017). However, P in shifting and fallow land use system did not differ considerably as compared to forest system. Lower P concentration in the WTRC areas may be caused by ongoing P removal from the soil and insufficient manure and fertilizer application.

Table 2 displays the percentage-wise distribution of classified soil available P. It was determined that the available phosphorus level of roughly 72.2% of the soil samples from the district was inadequate. When compared to the other LUSs, the WTRC system was shown to have the highest deficiency of P (93.8%) of the four land use systems. However, shifting, fallow, and forest systems, respectively, were substantially deficient in available P content by 76.3%, 80.9%, and 47.5%. In the soil system, phosphorus is typically regarded as an immobile nutrient, and its fixation is the primary process for converting the available form to the unavailable form for plants. Low availability of soil P in this region might be due to higher fixation of P in soils as majority of the soil samples are highly acidic in nature. The soil acidity of Wokha district may be responsible for the lower levels of phosphorus in the soil, as phosphorus availability is excellent between pH values of 6.5 and 7.5 (IPNI, 2010). Considering all the land use patterns, it was found that the available phosphorus level of 72.2% of the soil samples (Fig. 6) were very low to low, 21.2% was moderate, 5.2% was moderately high, and 1.3% was high.



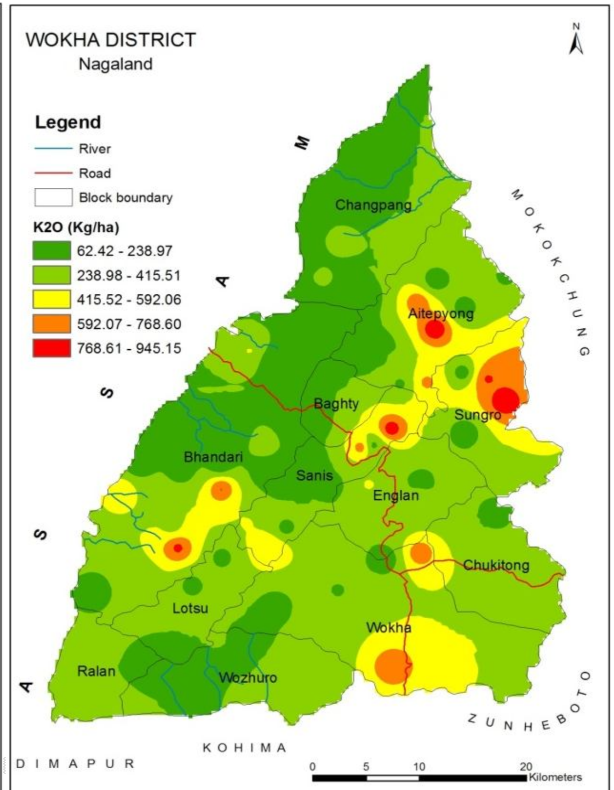


Fig. 6 Soil available P_2O_5 spatial variability map in the Wokha district of Nagaland.

Fig. 7 Soil available K_2O spatial variability map in the Wokha district of Nagaland.

3.2.5 Available potassium:

Considering mean values, shifting (361.95 ± 17.869 kg/ha), cultivated fallow (312.4 ± 24.93 kg/ha) and forest (309.73 ± 22.913 kg/ha) land use systems had the higher level of available potassium (K) content. The addition of ashes from the burning of forest litter during cultivation may be the cause of the highest potassium levels in shifting farming system. However, taking the average value into account, the WTRC system was low (120.95 kg/ha) in soil potassium availability.

The extent of soil potassium deficiency ranged from 22.5 to 81.7% among the LUSs (Table 2). Out of the four land use systems, WRTC system was found highly deficient (81.7%) in available K followed by forest (31.3%), cultivated fallow (26.5%) and shifting (22.5%) cultivation. Low levels of K in the WTRC system could be caused by the types of fertilizers applied their rates of leaching, and K removal from the soils through crop residue (Mbah, 2008; Uzoho & Ekeh, 2014). Additionally, light soil textures and prolonged deficit application of potassium fertilizer may exacerbate K deficiency. Fig. 7 presents a spatial pictorial look of the potassium availability at various LUSs. The category of potassium concentration that dominated the district overall was very high (28.2%), followed by low (20.7%), moderate (15.8%), moderately high (14.0%), very low (12.2%), and high (9.1%).

Table 2. Percentage wise area covered in different categories under different land use systems.

Soil Properties	Range	Class	Percentage distributed in different Land Use Systems			
			WTRC	Shifting	Cultivated Fallow	Fores t

Soil pH	<4.5	Extremely acidic	28.6	61.8	72.1	56.6
	4.5-5.0	Very strongly acidic	42.9	27.9	20.6	27.3
	5.1-5.5	Strongly acidic	24.5	6.7	4.4	11.1
	5.6-6.0	Medium acidic	4.1	3.0	2.9	5.1
	6.1-6.5	Slightly acidic		0.6		
SOC (%)	0.21-0.40	Low		1.8		1.0
	0.41-0.60	Moderate	4.1	1.8	4.2	1.0
	0.61-0.80	Moderately high	20.4	0.6	5.6	3.0
	0.81-1.00	High	26.5	7.3	2.8	7.1
	>1.00	Very high	49.0	88.5	81.9	87.9
Available N (kg ha^{-1})	<140	Very low	85.7	27.3	27.9	9.1
	141-280	Low	10.2	72.1	67.6	71.7
	281-420	Moderate	4.1	0.6	4.4	16.2
	421-560	Moderately high				3.0
Available P_2O_5 (kg ha^{-1})	<16.0	Very low	57.1	21.8	20.6	8.1
	16.0-32.0	Low	36.7	54.5	60.3	39.4
	32.0-48.0	Moderate	4.1	14.5	11.8	47.5
	48.0-64.0	Moderately high	2.0	7.3	5.9	5.1
	64.0-80.0	High		1.2	1.5	
	>80.0	Very high		0.6		
Available K_2O (kg ha^{-1})	<120	Very low	42.9	5.5	11.8	8.1
	121-180	Low	38.8	17.0	14.7	23.2
	181-240	Moderate	2.0	17.0	17.6	18.2
	241-300	Moderately high	4.1	12.7	16.2	18.2
	301-360	High	4.1	10.9	11.8	7.1
	>360	Very high	8.2	37.0	27.9	25.3

3.3 Correlation between soil chemical properties

In all of the land use systems, there was a negative but insignificant association between soil pH and clay concentration. Soil organic carbon had positive relationship with available N in all the LUSs but significant correlation had in shifting (r=0.511*), cultivated fallow (r=0.671*) and forest (r=0.590*) LUSs. Soil organic carbon also had a positive correlation with available K, but significant (r=0.536*) correlation was in WTRC land use system. The relationship between soil pH and available P concentration was found to be positive but not statistically significant. Likewise, available N and available K had positive non-significant correlation in all the LUSs.

Table 3 Correlation matrix based on Pearson's correlation coefficients between soil chemical properties under different LUS

	WTRC					Shifting				
	pH	SOC	N	P	K	pH	SOC	N	P	K
Clay	-0.045	0.047	-0.031	-0.116	-0.026	-0.285	0.089	0.048	-0.021	-0.154

pH		-0.187	0.056	0.139	-0.039		0.038	0.046	0.143	0.265
SOC			0.428	0.301	0.536*			0.511*	0.143	0.271
N				0.658*	0.336				0.199	0.288
P					0.292					0.099
	Cultivated fallow					Forest				
Clay	-0.056	-0.015	-0.261	0.006	-0.040	-0.003	0.041	-0.128	-0.071	-0.137
pH		-0.140	-0.015	0.213	0.010		-0.211	-0.020	0.070	0.243
SOC			0.671*	-0.160	0.257			0.590*	0.216	0.299
N				-0.078	0.280				0.225	0.341
P					0.023					0.361

4. CONCLUSION

According to the study, soils are very acidic in reaction, low to high levels of organic carbon, low levels of N and P, and medium to high levels of K. Therefore, slow release nitrogen fertilizers, larger dosages of phosphorus fertilization, and some commercially advantageous potassium responsive crops may be encouraged in farming practices. Preparation of soil nutrient map and their characterization using geostatistical methods is both the cost and time effective. The use of the maps of soil nutrients could help farmers in identifying the expected nutrient levels in their areas and motivate them to change their crop management for improving crop productivity and profitability. Additionally, it is essential to integrate the inventories of the soil resources through better planning and management in accordance with the socioeconomic conditions of the farmers in the district.

5. RECOMMENDATIONS

A balanced fertilizer recommendation can be made based on the available soil nutrient status. In the Wokha district; more than 86 % soil samples are extremely acidic to very strongly acidic in nature. Additionally, the availability of nitrogen and phosphorus in soil samples is inadequate in 93.8% and 72.2%, respectively. Though 81.7 % soil samples of WTRC system are deficient in soil K. Considering the nutrient status i.e. available nitrogen, phosphorus and potassium; 25% more than the recommended dose of fertilizer can be applied in the fields where the available soil nutrient was very low to low. In case of high status of a nutrient, 25% less than the recommended dose of fertilizer can be given. 100% recommended doses of fertilizer should be used when nutrient content of an area lies in medium range. Some acidity loving and acid tolerant crops, such as rice, groundnut, soybean, sesame, radish, sweet potato, potato, brinjal, chilli, coriander, cucumber, tomato, and colocasia, may be promoted, in view of extremely acidic to very strongly acidic soil pH reaction of the district. Application of lime may be recommended for cultivation of acid sensitive crops. Soil available N of the district was very low to low. Therefore, integrated application of organic and inorganic fertilizer along with introduction of legume in cropping sequence may be recommended. For WTRC systems in particular, the use of green manuring and split applications of low release nitrogenous fertilizer may be advised. Higher doses of P fertilization and the use of phosphate-solubilizing bacteria would be essential, especially for the cultivation of higher P responsive crops like maize, paddy, soybean, groundnut, mustard, rapeseed, tomato, cabbage, cauliflower, garden pea, and french beans, due to the high percentage of deficiency in soil available P. Some of the highly K responsive crops, such as maize, banana, pineapple, papaya, watermelon, potato, sweet potato, tomato, colocasia, sugarcane, etc., may be promoted because majority of the soils of the district is high in soil K status (except WTRC).

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