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Research Article

Soil Fertility Mapping of Different VDCs of Sunsari District, Nepal Using GIS

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Abstract

Soil fertility degradation has become a major problem for agricultural management in Nepal. A detailed soil fertility status of different VDCs of Sunsari district was investigated during 2015 and soil related crop production constraints were identified for proper utilization of agricultural land. Total 131 numbers of geo-referenced (GPS based) composite surface soil samples (0-15 cm) were collected from eleven Village Development Committees of Sunsari District. The sample points were recorded with a differential global position system and mapped using Geographic Information System (GIS). Soils were analyzed for mechanical composition, pH, organic matter, total nitrogen, available phosphorus, potassium and micronutrients like Boron, Zinc, Copper and Iron. About 38.9% soils were found to be silty clay loam, 20.6% were silty clay, 19.1% were clay loam and 21.4% were of other textural classes. Most of the soils were acidic and only few were neutral and slightly alkaline in nature. Soil Organic matter varies from 3.57% to 0.28% with a mean value of 1.53 %. The mean total nitrogen, available phosphorus, potassium was found to be 0.08%, 44.37 kg/ha and 128.04 kg/ha respectively. The mean hot water extractable Boron, DTPA extractable Copper, Zinc and Iron was found to be 0.14, 0.06, 0.15 and 10.71 mg/kg respectively. Thematic maps were prepared for each soil parameters using ArcGis10.1 software and ordinary Kriging interpolation was used in order to predict values for not sampled locations. The fertility maps provide the readymade source of information about soil fertility status and serve as the decision making tool for successful raising and development of crops. It can be concluded from the above study that GPS and GIS based soil fertility maps helps farmers, scientists, planners and students in providing soil test based fertilizer recommendation for intensive and sustainable site specific crop production.

Keywords: Geographic Information System; Global Positioning System (GPS); Kriging; Soil fertility mapping; Soil NPK

Introduction

Soil fertility mapping is the way of assessing soil nutrients on the basis of soil sample test results and preparation of soil fertility maps at the required scale. Global Positioning System (GPS) has been widely adopted in the area of agriculture in preparation of thematic maps like land use, land cover, soil fertility maps, etc. Determination of available soil nutrients status of the area using GPS helps to formulate site specific nutrient management practice of the location, understand the soil fertility spatially and

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temporally for better production of the crops and also helps to determine the crop suitability in that specific area.GPS provides valuable support to handle voluminous data which were generated through conventional and spatial format. A Geographic Information System (GIS) is a system designed to capture, store, manipulate, analyze, manage and present spatial or geographic data. GIS based soil fertility maps can be used to develop solutions of natural resources management issues such as urban planning, soil erosion, soil degradation, desertification and water quality assessment (Tomlinson, 1987). Soil test based fertility management is an effective tool for of agricultural soils that have high degree of spatial variability which find out the soil fertility related production constraints of the study area and suggest the remedial measures for optimum production of the crops.

GIS based soil fertility maps outline a cost effective option for implementing improved nutrient management in large tracts. With the incorpation of this method, agricultural areas with very high or low nutrient loading can be easily determined to enable the development of appropriated and economically sound management recommendations. Moreover, soil characterization in relation to evaluation of the fertility of the soil of an area is an important aspect in the basis of sustainable agriculture (Singh, 2012). To have suitable soil management practice, the farmers should know what amendments are required to optimize the productivity of the soil for specific crops (Kavitha and Sujatha, 2015).

Fertilizer is one of the costliest inputs in agriculture and the use of right amount of fertilizer is fundamental for farm profitability and environment protection (Mahendra, 2010). Farmers apply heavy or very low fertilizer doses without considering the current nutrient status of their soils due to lack of knowledge and institutional incapability to implement the developed norms. Therefore, farmers need to be aware of the nature and severity of the nutrient problems in order to arrive at a prudent decision regarding the kind and dose of fertilizer to be applied (Rashid and Ryan, 2004). In agricultural, global positioning system (GPS) and geographical information system (GIS) technologies have been adopted for better management of land and other resources for sustainable crop production (Palaniswami *et al*., 2011).

Prepared soil fertility maps available for farmers and extension workers is useful in making informed decisions on soil and nutrient management to improve selection and crop production. Field surveys have consistently indicated that low soil fertility is a limiting factor for crop production. A survey of soil fertility status which includes soil sampling, analysis and preparation of soil fertility maps would provide valuable information for diagnosis and predication of fertilization needs. Indicators of soil quality and soil fertility are useful for variety of users including farmers, researchers, extension agents and policy makers (Doran and Safley, 1997; Beare *et al*., 1997). GIS generated soil fertility maps may serve as a decision support tool for nutrient management (Iftikar *et al*., 2010) and it also helps to determine plant nutrient availability and distribution and the pattern of nutrient depletion in the project area.

GIS and GPS based soil fertility maps have been prepared by different government and private sectors for different areas of the country. The soil fertility maps can be used in the study site by development agents in order to guide farmers as fertilizer application with some more validation test of soil parameters at laboratories. The soil map prepared in the present study can be used by agriculturist as well as land use planners to implement appropriate land use strategy in the VDC for achieving maximum benefit from the land through its sustainable use. Therefore, an attempt has been made to prepare GPS and GIS based soil fertility maps of different VDCs of Sunsari district in order to identify and classify soil nutrients status of the study area. The main objective of the study was to prepare a scientific and comprehensive soil map showing the occurrence and extent of different types of soil in the studied Village Development Committees and characterize them that will help develop a sound land use plan based on the characteristic features of soils.

Materials and Methods

Location of the Study Area

Sunsari District lies in the eastern part of Terai plain of Nepal which is located at 26°36'N, 87º8'E. The soil association to these micro-topography developed by changing river morphology and predominantly the soils have evolved from alluvial deposits. Climate in the study area is subtropical monsoon type. Summers are hot and wet, which favors chemical weathering. Winters are mild and dry. Average air temperature ranges from a minimum of about 9°C in winter to the maximum of about 40ºC in summer. Since rainfall is not uniform throughout the year, more than 85% occurs during four months (June–September). However, the stability of landscape for the development of soil is affected by the variability and intensity of rainfall.

Soil Survey Methods

The soil survey was carried out systematically and scientifically using field sampling. The Global Positioning System (GPS) instrument was widely used to locate the location of soil sampling pits. In addition, the location was also marked on the base map (printed satellite image). The soil survey comprised of identification, examination, classification and mapping of the soil and land units and characterization of both the physical and chemical properties of the soil units. All findings of both the field and laboratory investigations have been recorded in the standard format and then the various soil units identified have been mapped as they occur in the different land types prevailing in the study area.

A detailed soil survey of the study area was carried out on grid map prepared using Arc GIS software. The soil sampling locations were decided based on the land system units, morphology, land use condition, geology etc. The soils were sampled from the places that best represent the various units of the morphology, land system, land use and geology. Soil sampling was carried out in such a way that each of the land types was equally represented. A total of 131 soil samples were collected from eleven VDCs; Chadbela, Madheli, Sonapur, Aurabani, Simaria, Duhavi, Tanmuna, Bhaluwa, Chhitaha, Purbakusaha, and Chimdi Sunsari district. The samples from A Horizon (0-20 cm) was collected for laboratory analysis of soil parameters that include particle size distribution, soil pH, total nitrogen, organic matter, available phosphorus, available potassium, Boron, Zinc, Copper and Iron. The exact sample location (latitude and longitude) were recorded with the help of a hand held GPS device for preparation of thematic soil fertility maps (Mishra *et al.*, 2013) and imported to Arc GIS software. The location of the sampling pits is given in the Fig. 1.

Laboratory Soil Analysis

Soil samples collected from field were air dried in shade and crushed and sieved for physico-chemical laboratory analysis. The parameters tested and methods used are given in the Table 1.

The level of soil nutrients in the order of rank is summarized in Table 2.

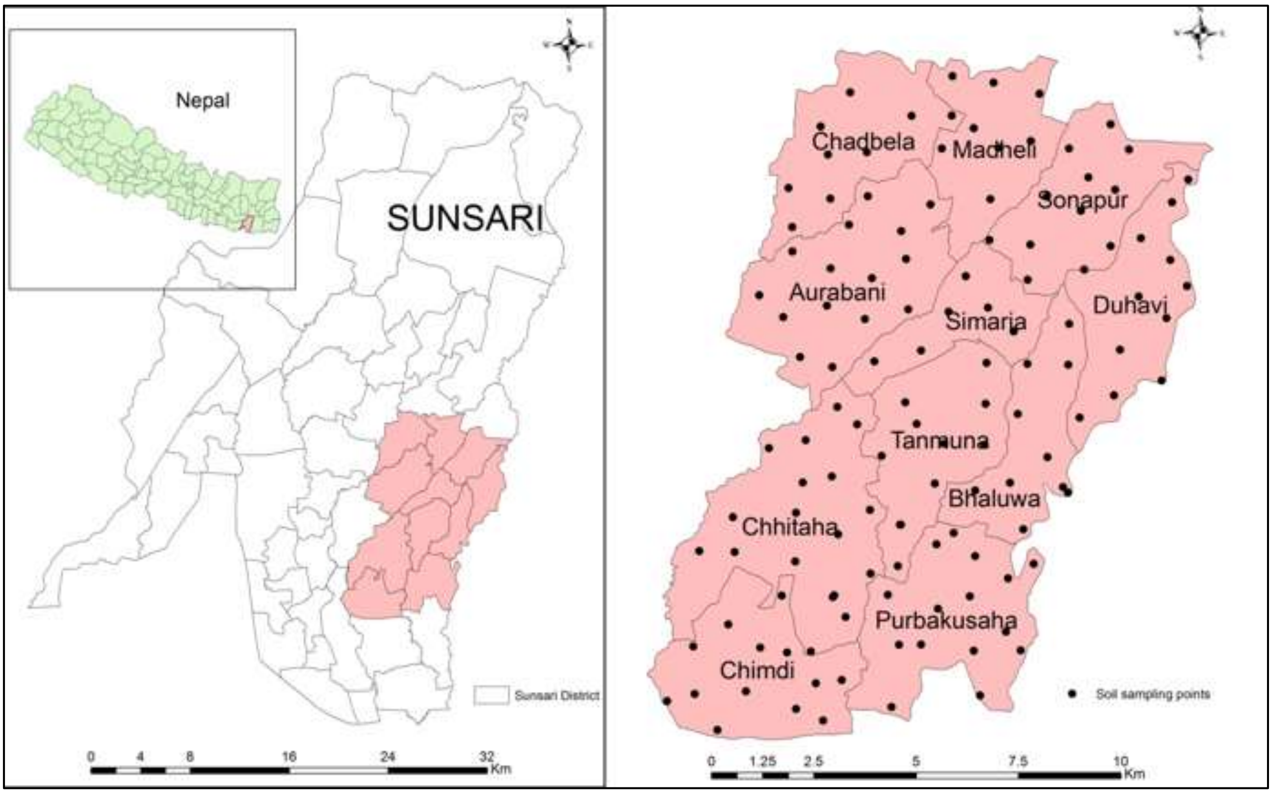

Fig. 1: Location map and Soil Sampling Pits of Study VDCs of Sunsari District

Table 1: Soil Parameters and laboratory soil test methods

S.N.	Test Parameters	Methods
1	Particle size fraction and texture	Hydrometer (Bouyoucos, 1962) and Texture classification (USDA Texture triangle)
2	Soil pH	1:2.5 soil water suspension (Jackson, 1967)
3	Soil Organic Matter Content (%)	Walkely and Black (Walkely and Black, 1934)
4	Total Nitrogen content (Total N %)	Micro-Kjeldahl (Bremner and Mulvaney, 1982)
5	Available Phosphorus (P_2O_5 kg/ha)	Olsen (Olsen *et al*., 1954)
6	Available Potassium (K_2O kg/ha)	Ammonium acetate (Jackson, 1967)
7	Available Boron	Hot water method (Berger and Truog, 1939)
8	Available Zinc	DTPA (Lindsay and Norvell, 1978)
9	Available Iron	DTPA (Lindsay and Norvell, 1978)
10	Available Copper	DTPA (Lindsay and Norvell, 1978)

Table 2: Rating Chart of Soil Test Data for Terai Region of Nepal

S.N.	Soil parameters	Unit	Very Low	Low	Medium	High	Very High
1	SOM	%	<0.75	0.75-1.5	1.5-3.0	3.0-5.0	>5
2	Total N	%	<0.03	0.03-0.07	0.07-0.15	0.15-0.25	>0.25
3	Available P_2O_5	kg/ha	<11	11-28	28-56	56-112	>112
4	Available K_2O	kg/ha	<55	55-110	110-280	280-500	>500
5	Available B	ppm	<0.4	0.4-0.7	0.7-1.2	1.2-2.0	>2
6	Available Zn	ppm	<0.5	0.5-1.0	1.0-3.0	3.0-6.0	>6
7	Available Fe	ppm	<5	5-10	10-16	16-25	>25
8	Available Cu	ppm	<0.3	0.3-0.8	0.8-1.2	1.2-2.5	>2.5
			Moderately Acidic	Slightly Acidic	Nearly Neutral	Slightly Alkaline	Moderately Alkaline
9	Soil pH	pH scale	5.2-6.0	6.0-6.5	6.5-7.0	7.0-7.5	7.5-8.3

Statistical Analysis and Soil Fertility Mapping

Latitude, longitude and the data resulted from the soil analysis were entered into attributed table in MS-Excel and processed in Arc GIS10.1 software thematic soil fertility maps and Geospatial tool i.e. ordinary Kriging (OK) interpolation (Cressie, 1992) was preferred for predicting values for not sampled locations. Ordinary Kriging is one of the advanced geo-statistical tools that creates surface by using spatial correlation from a scattered set of points by incorporating their properties (Economic and Social Research Institute, 2001). Descriptive statistic (mean, range, standard deviation, standard error) of soil parameters were computed in the MS Excel and SPSS 16.0 package.

Results and Discussions

Soils were analyzed for mechanical composition, pH, organic matter, total nitrogen, available phosphorus, potassium and micronutrients like Boron, Zinc, Copper and Iron and results obtained from laboratory analysis are presented in Figures 2-6 and Table 3.

Soil Texture

Soil texture refers to proportion of clay, silt and sand. The soil texture of the first horizon (0-20cm) was determined from the laboratory test using textural model. Eight types of soil textural classes were found in the study area dominated by silty clay loam (38.9%), silty loam (20.6%) and clay loam (19.1%). Other classes were silty loam (7.6%), sandy loam (5.3%), clay (5.3%), sandy clay loam (2.3%) and loam (0.8%) (Fig. 2).

Soil pH

The pH is an indicator of the acidity or alkality of soil which controls the mobility and hence the availability of soil nutrients (Amacher *et al*., 2007). The soil of the study area was found to be moderately acidic to moderately alkaline. Most of the soils were acidic and only few were neutral and slightly alkaline in nature (Fig. 2). The sample pits in the VDCs have pH value in the range of 5.0 to 8.4. Most of the soils were found to be acidic in nature which may be due to natural systems like mineralogy (soil containing Fe, Al, etc.), climate (excessive rainfall) and weathering, use of acid-forming nitrogen fertilizers, or removal of bases (potassium, calcium, and magnesium). It also affects the activity of microorganisms responsible for breaking down organic matter and most chemical transformations in the soil. Soil pH influences the solubility and availability of plant nutrients. Low pH causes deficiency and unavailability of plant nutrients like P, Ca, K, Mg and Mo (Wang *et al*., 2006). In general, soils with near neutral reaction (pH 6.0-7.0) are the most fertile (LRMP, 1986). Soil nutrient management for sustained crop growth and yield should be directed at strategies to address acidity problem through liming and organic matter management.

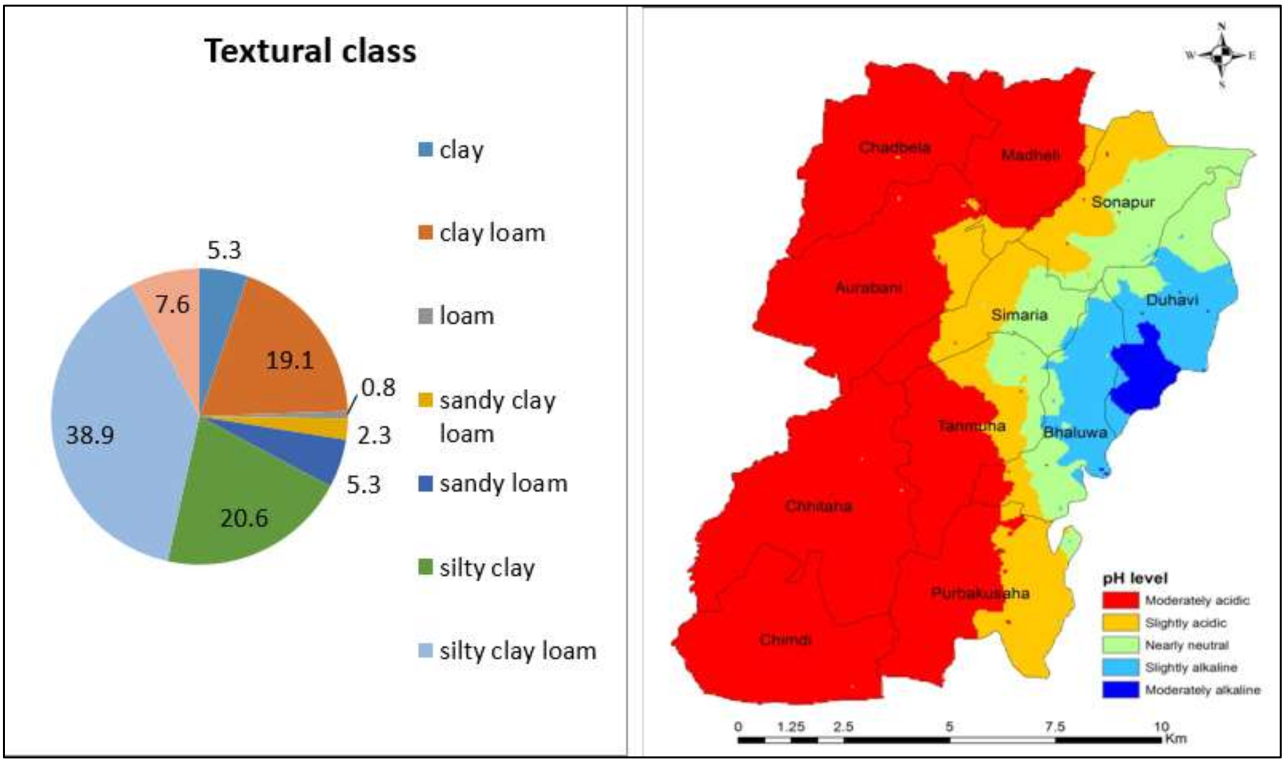

Fig. 1: Soil textural classes and soil pH found in the study area

Table 3: Soil fertility status of different VDCs of Sunsari district, Nepal, 2015

S.N.	Soil parameters	Unit	Mean	Range	Standard Deviation	Standard Error
1	Soil pH	pH scale	6.0	5.0-8.4	0.969	0.084
2	SOM	%	1.53	0.28-3.6	0.570	0.049
3	Total N	%	0.08	0.01-0.18	0.027	0.003
4	Available P_2O_5	kg/ha	44.37	5.1-199.1	50.22	4.39
5	Available K_2O	kg/ha	128.04	80.6-537.6	60.91	532
6	Available B	ppm	0.14	0-0.53	0.101	0.009
7	Available Zn	ppm	0.15	0.12-0.19	0.012	0.001
8	Available Fe	ppm	10.71	0.04-91.4	11.97	1.045
9	Available Cu	ppm	0.06	0.01-0.4	0.058	0.005

Soil Organic Matter

In broad sense, soil organic matter comprises all living soil organisms and all the remains of previous living organisms in their various degrees of decomposition. The range of organic matter ranges from 0.28 to 3.6% with mean value of 1.5% (table 3) which varies from very low to medium. Organic matter can be considered a pivotal component of the soil because of its role in physical, chemical and biological processes.

Comparatively lower organic carbon is may be due to high decomposition of organic matter in Terai region of Nepal as the temperature in the summer season rises up to 40 °C and less applicationof organic residues. The amount of organic matter in a soil is highly dependent on a range of ecological factors (climate, soil type, vegetative growth, topography) in which it occurs as well as land use and management and tillage of the soil, intensive cropping.. Organic matter is the main source of N, P and S for plant growth in now fertilizer smallholder agriculture (Acquaye, 1990). Maurice *et al.* (1998) used SOM as an indicator of soil fertility, aggregate stability and erosion. In addition, SOM contributes to enhanced soil water storage and maintenance of pH. Farmers should therefore be encouraged to return as much as residue as possible to soil in addition to application of manure and compost.

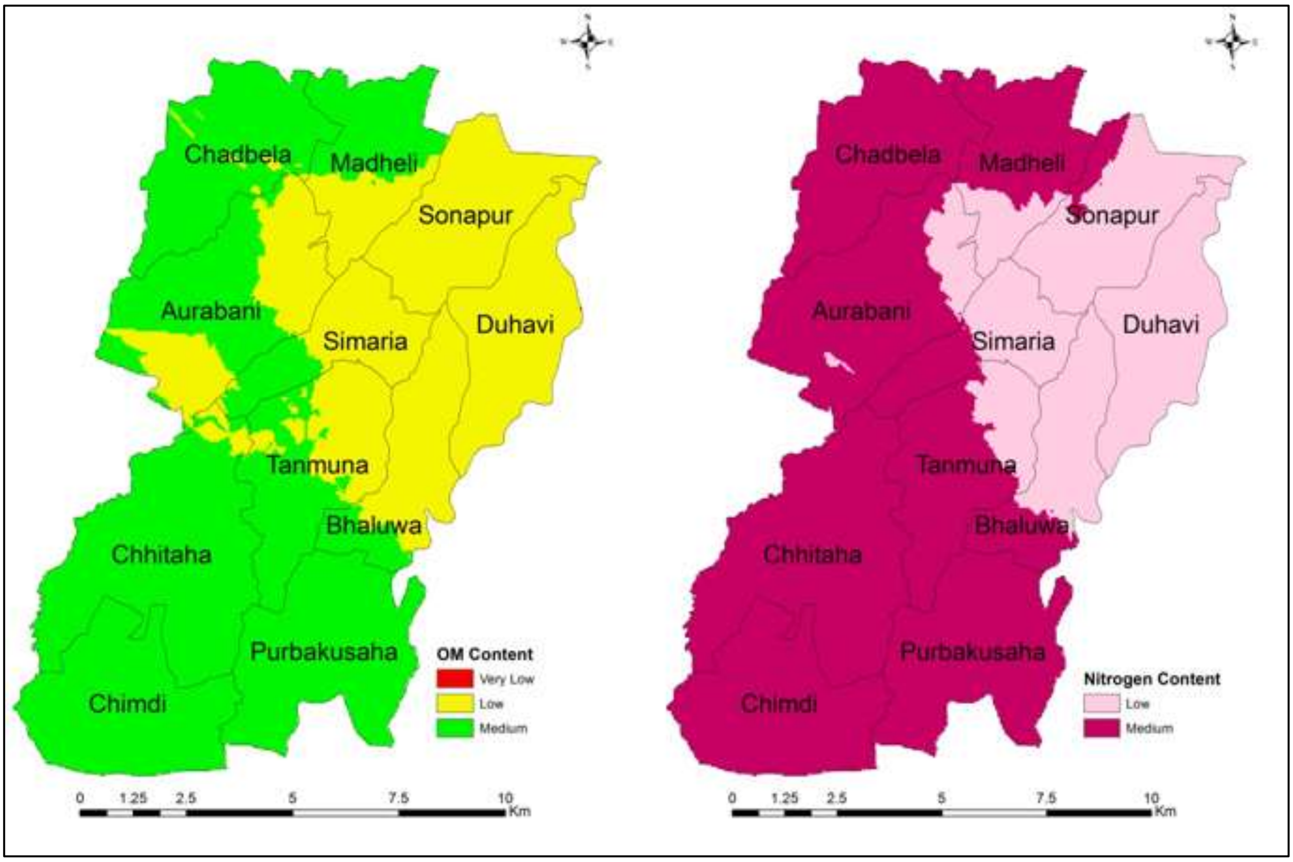

Fig. 3: Soil Organic matter and Total Nitrogen Content of Different VDCs of Sunsari District

Total Nitrogen

Nitrogen is the basic nutrient that helps in seed formation and increases the food and feed value of crops. It usually has greater effect on crop growth, crop quality and yield. The total nitrogen content varies from 0.01% to 0.18% with the mean value of 0.08%. Overall results showed that the nitrogen content was low to medium in range. Nitrogen content of Sonapur, Duhavi, Simaria and Bhaluwa was low whereas Chadbela, Madheli, Aurabani, Tanmuna,, Chhitaha, Purbakusaha and Chimdi VDCs had medium nitrogen content which justify that recommended dose of nitrogen is required to apply in the field for increasing production of crops (Fig. 3). The low nitrogen content in the study area may be possibly due to low organic matter content in soils, crop removal and due to high temperature which facilitate faster degradation and removable of organic matter leading nitrogen deficiency. As SOM increases, available N, P K as well as some micronutrients also increase (Oates, 1998).

Available Phosphorus

Phosphorus is one of the important primary elements essential for plant growth and development. It is particularly helpful in the production of legumes, as it increase the activity of nodule bacteria, which fix nitrogen in the soil. The available phosphorus content in the study area varies from 5.1 to 199.1 kg/ha with the mean value of 44.37 kg/ha (Table 3).

Phosphorus content of most of the areas was medium in range, some of the areas of Aurabani Tanmuna, Simaria and Purbakusaha had lower phosphorus content whereas some areas of Bhaluwa, Chhitaha, Duhavi and Madheli had higher amount of phosphorus (Fig. 4). Generally, phosphorus deficiency causes the plant in dark-green but the lower leaves may turn yellow and dry up. Soils of the study site containing medium level of phosphorus may be possibly due to application of phosphotic fertilizer to crops by farmers.

Available Potassium

Potassium is the element which is involved in physiological processes of plants with the activation of large number of enzymes. It plays a vital role in the formation or synthesis of amino acids and proteins from ammonium ions which are absorbed from the soil. The available potassium ranged from 80.6 to 537.6 kg/ha with mean value of 128.4 kg/ha (table 3). In about 70% of the study area, potassium content was medium whereas in other areas potassium was low indicating that the amount of potassium is decreasing in Terai soils, which justify that recommended dose of potassium should be reviewed for increasing production of crops (Fig. 4). Deficiency of potassium causes the margins of leaves turn brownish and dry up. The stem remains slender. Low available potassium signifies higher leaching as evidenced by low base saturation in these soils which may be due to high rainfall in those areas (Patil and Dasog, 1999).

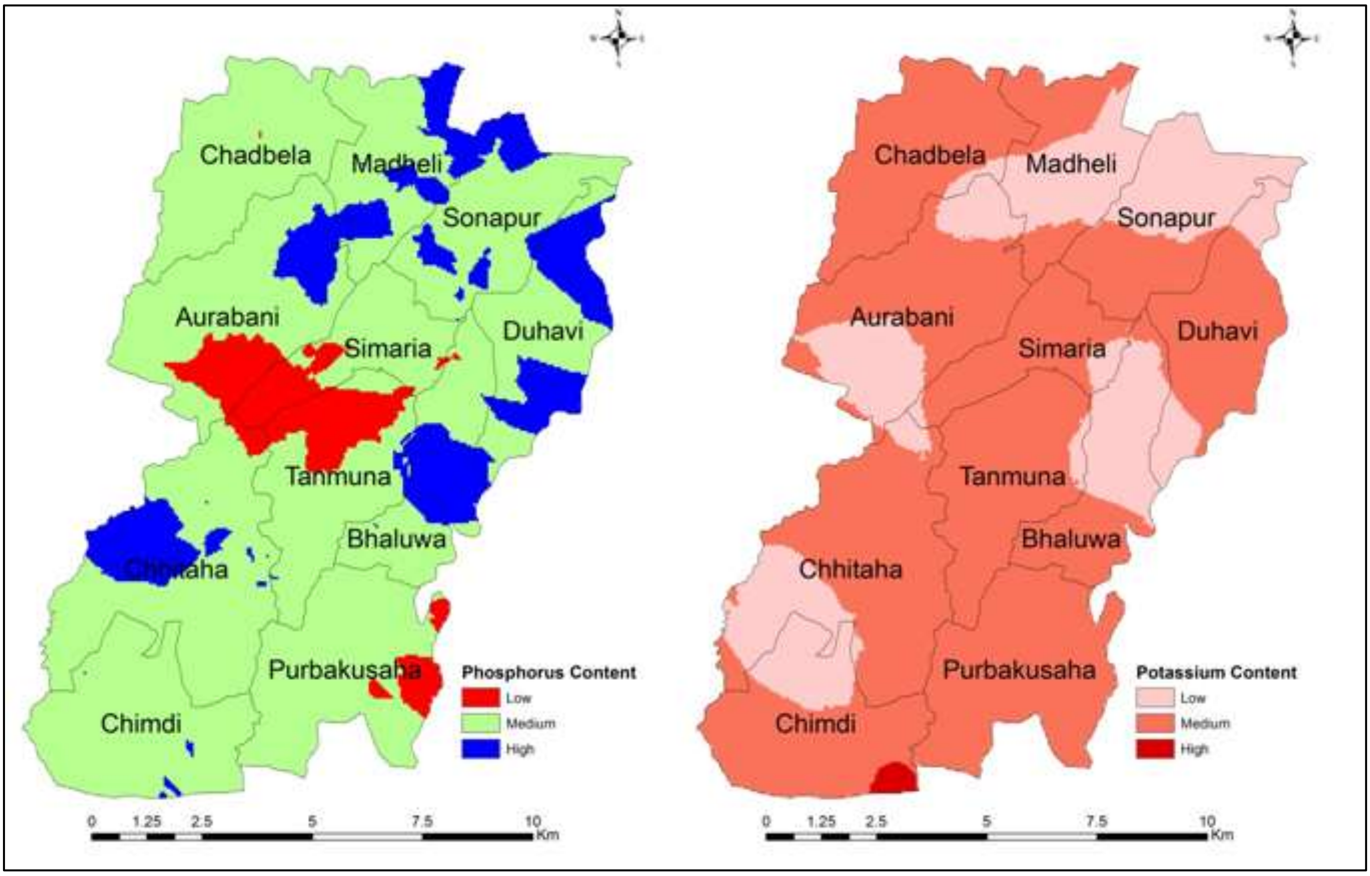

Fig. 4: Available phosphorus and potassium Content of Different VDCs of Sunsari District

Available Boron

Boron is the trace element which is required for normal growth and development of crops especially for proper development of reproductive parts and carbohydrate metabolism. It is required by plants for their cell wall structural integrity (Havlin *et al*., 2010). Boron content of the study areas ranged from 0 to 0.53 ppm with mean value of only 0.14 ppm. Almost all VDCs of Sunsari was very low in boron content i.e. <0.4 ppm indicating that the soil is deficient in boron content due to lower content of organic matter (Fig. 5). Soil organic matter greatly affects the availability of boron and absorption of boron in mineral soil decreases if the organic matter is lower in the soil (Niaz *et al*., 2007); razan *et al*., 2002 and Shafiq *et al*., 2008).

Available Iron

Although iron does not enter into the composition of chlorophyll, its deficiency manifests itself in chlorosis, yellowing or whitening of leaves. Iron content in the sites varied from 0.04 to 91.4 ppm with the average value of 10.71 ppm. It ranged from very low to very high. The concentration of iron plays important part in the oxidation process in leaf cells. Severe deficiency results in loss of leaf and plant growth is very much restricted.

Available Zinc

Zinc is another trace element essential for plants for the normal healthy growth of plants. It is associated with the development of chlorophyll in leaves. The available zinc content ranged from 0.12 to 0.19 with the mean value of 0.15. Almost all VDCs of Sunsari was very low in zinc content i.e. <0.5 ppm indicating that the terai soil is deficient in boron content due to lower content of organic matter (Fig. 6). The maps suggested that there are overall multi-nutrient deficiencies in the different VDCs of Sunsari district. The reason for low fertility may be the intensive cropping system, imbalanced use of fertilizer and thus nutrient mining, possibly of potassium, boron, zinc and copper. Balanced fertilizer use and complementary use of organic matter inputs with chemical fertilizers are the possible agro-techniques to sustain yield, increase fertilizer use efficiency and to restore soil fertility under intensive cropping (Dwivedi *et al*., 2003; Timsina and Conner, 2001; Yadav *et al*., 1998). Extreme deficiency of zinc causes chlorotic conditions and dark colored veins in leaves and disease like khira in rice, white bud in maize, etc. Application of different sources of zinc is applicable to reduce the stress in the plants and its parts.

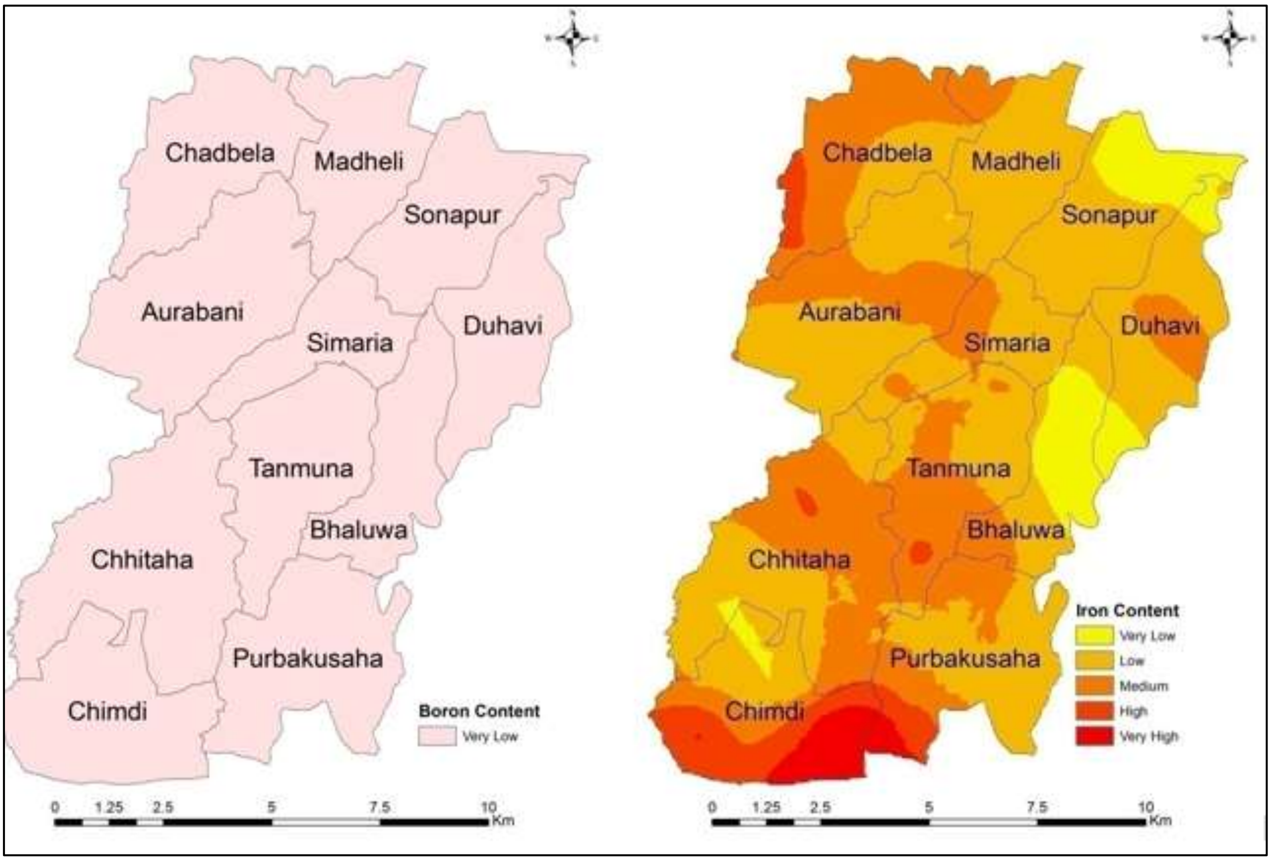

Fig. 5: Available Boron and Iron Content of Different VDCs of Sunsari District

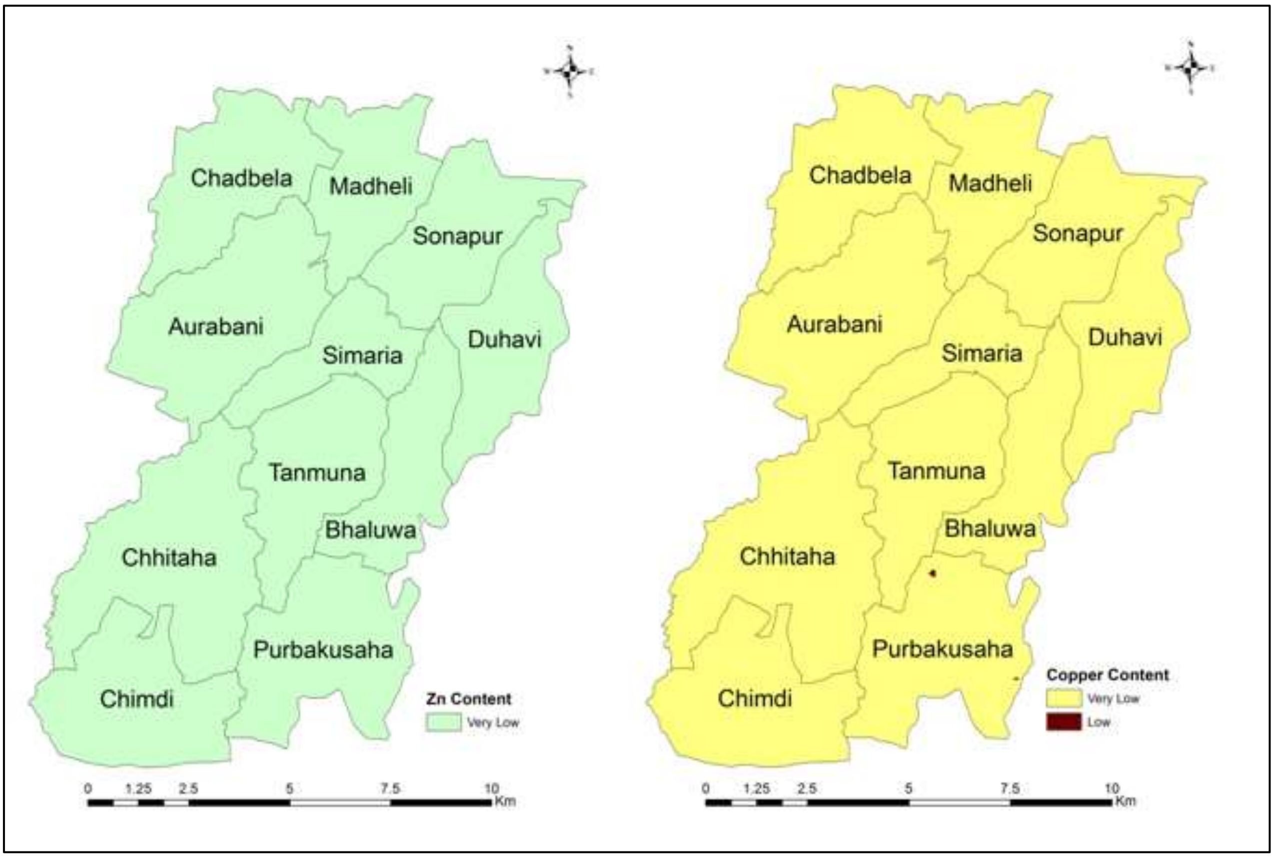

Fig. 6: Available Zinc and Copper Content of Different VDCs of Sunsari District

Available Copper

Copper is another micronutrient which is essential for plant growth and development as an enzyme activator. In the chloroplasts of leaves, there is a enzyme which is concerned with the oxidation-reduction processes. The presence of copper is essential for this enzyme to function. The available copper content in the soils of study areas ranged from 0.01-0.4 ppm with average value of 0.06 ppm. Almost all VDCs of Sunsari was very low in copper content i.e. <0.3 ppm indicating that the soil of research sites is deficient in copper content (Fig. 6). Copper plays important role in the process of photosynthesis. In extreme deficiency, there may occur excessive leaf shedding.

Conclusion

Results of soils tests clearly show that most of the cultivated areas are poor in organic matter contents and available nitrogen, phosphorus and potash is also below desired level. Due to continuous tillage and absence of organic matter without compensating nutrient supply from natural and artificial sources has led to low level of soil micronutrient content like zinc, boron, copper, etc. Majority soils sample have pH value within the acidic range. Analysis of soils characteristics shows that most of land in the VDC is suitable for production cereals and vegetables crops throughout the year under irrigation conditions and appropriate land/soil management practice. It can be concluded that from the above study that GPS and GIS based soil fertility maps helps farmers, scientists, planners and students in providing soil test based fertilizer recommendation for intensive and sustainable crop production. In order to achieve this goal, the land use plan should be implemented through interaction at various levels with the consent of the local people. Sound soil fertility management should be applied which includes use of available livestock, poultry and other crop residues and organic manures wherever practical taking appropriate nutrient credit of these materials and using mineral fertilizers to balance the crops nutritional requirements for realistic yield goals (Quansah, 2000). It also found to be useful in site specific nutrient management and for thorough monitoring of the soil health for present and future agriculture.

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