JOURNAL OF AGRICULTURE AND ENVIRONMENTAL SCIENCE
ISSN 2788-7723
DEC. 2021 VOL. 1, NO. 2

Study on Spatial Variability of Soil Properties to Guide the Efficient Use of Resources

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ABSTRACT

Soil fertility and nutrient management influence agricultural productivity and hence food security and livelihood. The results reflect that inherent fertility status of the study area was low overall. Rawal et al. [27] noted similar findings in their study of Sunsari district of Nepal. Nutrient mining (extracting more nutrients than are returned) is a key factor in impoverishing the soil. The deteriorating soil fertility cannot be ameliorated only by green manuring and use of legumes. Using them in conjunction with mineral fertilizers can have a greater sustainable impact. Soils and their management options are site and situation-specific. The prepared spatial distribution and fertility maps will aid farmers and planners in understanding the existing soil conditions and making judicious decisions to better manage the soil for sustainability and productivity.

KEYWORDS

GIS; GPS; Ordinary kriging; Soil fertility maps; Sarlahi District.

1. Introduction

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. The use of GIS and GPS for soil fertility mapping is popular and gaining acceptance worldwide. The collection of soil samples using GPS for the preparation of thematic soil fertility maps is very important [1]. It helps to formulate site-specific nutrient management for the location. In agriculture, GPS and GIS technologies have been adopted for better management of land and other resources for sustainable crop production [2]. Based on the geostatistical analysis, several studies have been conducted to characterize the spatial variability of different soil properties [3]. GIS-based soil fertility maps are useful for developing solutions to resource management issues such as land management, soil erosion, soil degradation, water quality and urban planning [4]. GIS generated soil fertility maps may serve as a decision support tool for nutrient management [5] and it also helps to determine plant nutrient availability and distribution and the pattern of nutrient depletion in the project area. Among the different geostatistical methods, ordinary kriging is widely used to map the spatial variation of soil fertility because it provides a higher level of prediction accuracy [6].

Soil testing is the most popular everywhere, as well as more appropriate also. Soil testing provides information regarding nutrient availability in soils which forms the basis for the fertilizer recommendations for economic production of crops. Soil test based fertility management is an effective tool for of agricultural soils that have a high degree of spatial variability which finds out the soil fertility related production constraints of the study area and suggests the remedial measures for optimum production of the crops. Moreover, soil characterization in relation to the evaluation of the fertility of the soil of an area is an important aspect on the basis of sustainable agriculture [7]. To have suitable soil management practice, the farmers should know what amendments are required to optimize the productivity of the soil for specific crops [8]. The main objective of the study was to prepare a scientific and comprehensive soil fertility map of the studied Village Development Committees and characterize the spatial distribution of soil properties.

2. Material and Methods

2.1 Study Area

Sarlahi District lies in the eastern part of Terai plain of Nepal which extends from 26°45′-27°10′N and 85°20′E85°50′E. The soil association to micro-topography developed by changing river morphology and predominantly the soils have evolved from alluvial deposits.

Table 1. Soil parameters and methods adopted for laboratory analysis.

Parameters	Unit	Methods
Soil Texture		Hydrometer [5]
Soil pH		Potentiometric 1:2 [14]
Organic Matter	%	Walkey and Black [32]
Total Nitrogen	%	Kjeldahl [6]
Available Phosphorous	Kg ha-1	Olsen's [24]
Available Potassium	Kg ha^{-1}	Ammonium acetate [13]
Available Boron	mg kg^{-1}	Hot water [3]
Available Zinc	mg kg^{-1}	DTPA [20]

The climate in the study area is subtropical monsoon type. Summers are hot and wet, which favors chemical weathering. Winters are mild and dry. The average air temperature ranges from a minimum of about 9°C in winter to a maximum of about 40°C in summer. The onset of southwest monsoon takes place generally by the third week of June. Around 85% of the rainfall occurs during four months (June– September), July and August being the wettest months. Rice, wheat, maize, pulses, oilseeds, and vegetables are the major crops of this region.

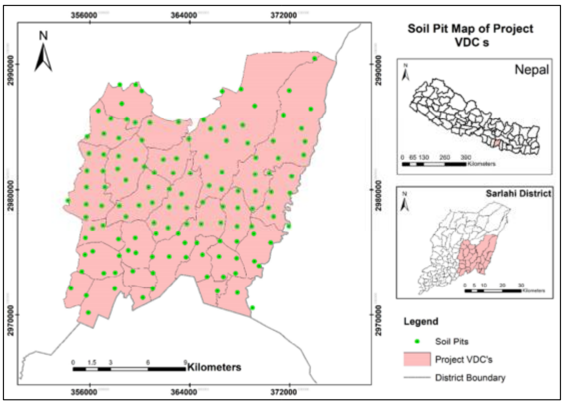

Figure 1. Soil pit map of the project VDCs of Sarlahi District, Nepal.

2.1.1 Soil sampling

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. Soil samples were analyzed for different parameters such as soil pH, Total soil nitrogen, soil available phosphorus, soil available potassium, soil organic matter, soil particles, soil texture, available zinc, and available Boron. A total of 131 surface soil samples (0-20 cm depth) were collected.

2.1.2 Laboratory analysis

Table 2. Soil rating chart for the Terai Region of Nepal.

Soil Parameters	Unit	Low	Medium	High
Organic Matter	%	0.75-1.5	1.5-3.0	3.0-5.0
Total Nitrogen	%	0.03-0.07	0.07-0.15	0.15-0.25
Available Phosphorous	Kg ha^{-1}	11-28	28-56	56-112
Available Potassium	Kg ha^{-1}	55-110	110-280	280-500
Available Boron	mg kg $^{-1}$	0.4-0.7	0.7-1.2	1.2-2.0
Available Zinc	mg kg $^{-1}$	0.5-1.0	1.0-3.0	3.0-6.0
		Slightly Acidic	Nearly Neutral	Slightly Alkaline
Soil pH	pH Scale	6.0-6.5	6.5-7.0	7.0-7.5

The collected soil samples were air-dried in shade and crushed and sieved for physicochemical laboratory analysis. The different soil parameters tested as well as methods adopted to analyze are shown in Table 1.

2.1.3 Statistical analysis

Descriptive statistics (mean, range, standard deviation, standard error, coefficient of variation) of soil parameters were computed using the Minitab 17 package. Rating (very low, low, medium, high and very high) of determined values was based on Soil Science Division, Khumaltar (Table 2). The coefficient of variation was also ranked for determination of nutrient variability according to the procedure of Aweto [2]; where CV <25% =low variation, CV >25<50%= moderate variation and CV>50%= high variation. The level of soil nutrients in the order of rank is given in Table 2. Arc Map was used to prepare spatial distribution maps of soil parameters, while the interpolation method employed was ordinary kriging. Kriging is an optimal interpolation method among various methods for spatial interpolation of soil properties [12].

3. Results and Discussions

3.1 Soil Texture

Soil texture plays an important role in drainage, water holding capacity, aeration, organic matter content, erosion susceptibility, cation exchange capacity, pH buffering capacity and soil tilth [4].

Four different types of soil textural classes were identified in the study area. Sandy loam (75%) soils were found to be the most dominant in the study area followed by Loamy sand (12%) and Sandy clay loam (11%).

3.2 Soil Reaction (pH)

Soil pH is a measure of soil acidity or alkalinity. It is a vital fertility parameter as it governs the availability of nutrients in the soil. Most crops grow best with a soil pH between 6 (somewhat acidic) and 7.5 (slightly alkaline) [22]. When soil pH is maintained at the proper level, plant nutrient availability is optimized, the solubility of toxic elements is minimized, and beneficial soil organisms are most active.

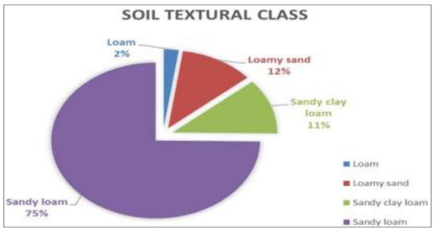

Figure 2. Soil textural classes in the project VDCs, Sarlahi.

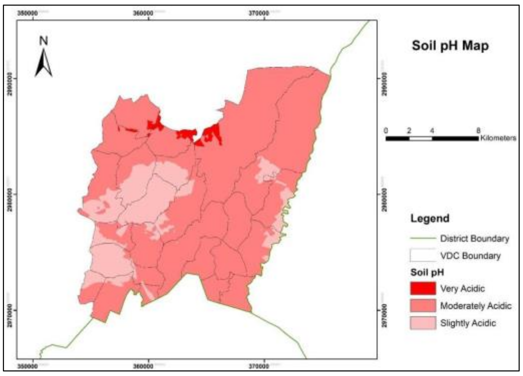

Figure 3. Soil Organic Matter Content map of the project VDCs of Sarlahi district, Nepal.

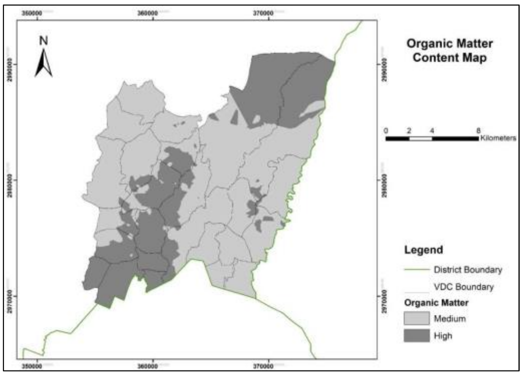

Figure 4. Soil Organic Matter Content map of the project VDCs of Sarlahi district, Nepal.

The soil reaction of the study area varied from very acidic to moderately alkaline in nature. Most of the soils were moderately acidic with a mean pH of 5.771 (Table 3) which may be caused by the nature of soil mineralogy, the use of acidic fertilizers, low input of organic materials and removal of basic nutrients. Inherent factors affecting soil pH like climate, mineral content and soil texture cannot be changed. In warm humid environments, soil pH decreases over time due to leaching. Sandy soils with low soil organic matter content have a low buffering capacity which makes them more vulnerable to soil acidification. High acidity in the soil reduces most of the nutrient availability, as well as directly affects root structure also [9]. Soil pH is affected by land use and management. The addition of Nitrogen and Sulphur fertilizers can lower soil pH over time. The use of diversified crop rotations, minimum tillage and cover crops that help build soil organic matter can increase soil buffering capacity to limit changes in soil pH. The most effective strategy to manage soil acidity is to apply agricultural limestone in conjunction with organic matter management. The quantity of lime required is determined by the target pH (based on crops to be grown) and the soils buffering capacity. Soil pH showed low variability (12.36%) among samples of the project VDCs.

3.3 Organic Matter

Organic matter is the heart of the soil and it plays a vital role in crop performance and maintaining soil health. OM supplies nutrients through the process of mineralization, which is the decomposition of organic compounds by microbial action into carbon dioxide and mineral constituents. SOM has a direct influence on water holding capacity due to its ability to absorb large amounts of water, and indirectly by improving soil structure, which creates more pore space for water storage. Soil structure is enhanced by SOM because in the process of decomposition sticky compounds are produced by microorganisms. The distribution of organic matter ranged from medium to high. The optimum range for SOM for soil health varies across soil types. Generally, lower levels of SOM are sufficient, and practical to achieve, in coarse-textured, sandy soils as compared to finer soils with more clay content.

The organic matter content varied from 0.48% to 5.73% with a mean of 2.85% (Table 3). The distribution of organic matter ranged from medium to high, but mostly medium was prevalent (Figure 4). A comparatively medium level of organic matter may be due to the regular incorporation of residues in combination application of manure and compost. Organic matter showed moderate variability (38.08%) among the samples.

3.4 Total Nitrogen

Nitrogen is usually the most limiting crop nutrient. It is essential to nearly every aspect of plant growth. It is a great role in crop growth and yield. Nitrogen is added to the soil naturally from N-fixation by soil bacteria and soil legumes and through atmospheric deposition in rainfall. Nitrogen is absorbed by plants as nitrate (NO3-) and ammonium (NH4+). Soil NO3- and NH4+ levels can fluctuate widely with soil and weather conditions over very short periods of time.

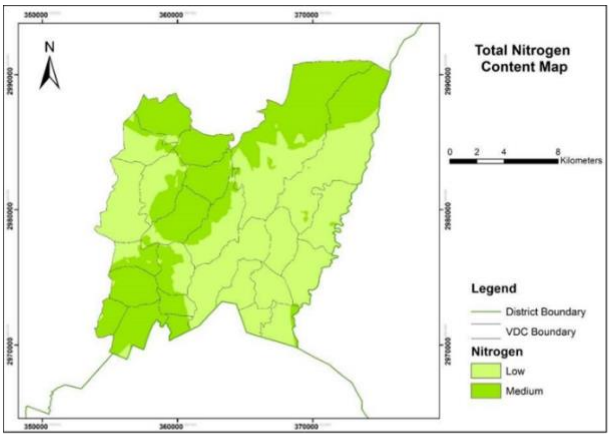

Figure 5. Total Nitrogen Content map of the project VDCs of Sarlahi district, Nepal.

The total Nitrogen content varied from 0.007% to 0.147% with a mean of 0.066% (Table 3). The distribution ranged from low to medium for the study area. (Figure 5). Low Nitrogen levels were found for the majority of the area. Lower Nitrogen levels may be due to low pH levels, coarse texture, a high temperature that facilitates faster degradation, well-aerated conditions and crop removal. Nitrogen can readily leach out from sandy soils. With the majority of the study area acidic in nature, the availability of Nitrogen is limited. Total Nitrogen was moderately variability (47.67%) in the study area. Applying recommended dose and timing the N application with peak crop demand is key to N management. Also, optimum irrigation should be provided so as to optimize yield while avoiding excess irrigation which can leach N below root zone.

3.5 Available Phosphorous

Phosphorous, next to Nitrogen, is often the most limiting nutrient for crop production (Sharma et. al., 2017). Phosphorus provides plants with a means of using the energy harnessed by photosynthesis to drive its metabolism. A growth, weak root systems, poor fruit and seed quality, and low yield. Plants require fairly large quantities of phosphorus, but the levels of phosphorus available to plant roots at any given time are usually quite low. When a soil test indicates that phosphorus is low and fertilizer is needed, the rate recommended is intended to satisfy immediate crop needs and begin to build soil phosphorus levels to the optimum range (i.e., build and maintain). Phosphorous is highly immobile in the soil, making it less plant-available.

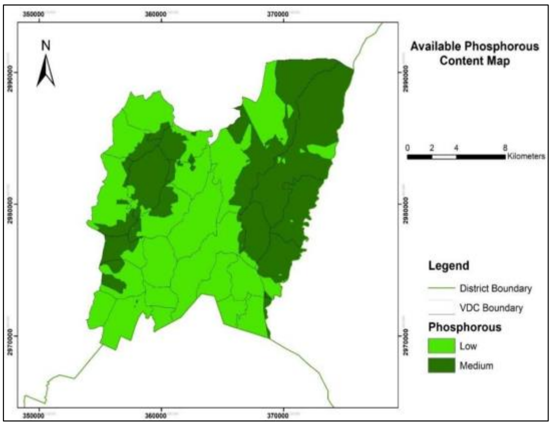

Figure 6. Available Phosphorous Content map of the project VDCs of Sarlahi district, Nepal.

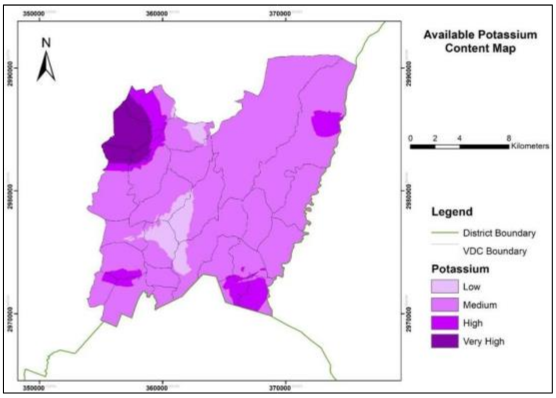

Figure 7. Available Potassium Content map of the project VDCs of Sarlahi district, Nepal.

The available Phosphorous content varied from 1.09 kg/ha to 69.09 kg/ha with a mean of 27.66 kg/ha (Table 3). The distribution ranged from low to medium for the study area. (Figure 6). Low phosphorus levels were dominant for the study area. Phosphorous is highly limiting in acidic soils like that of the project VDCs where it can get easily fixed with Al, Fe to non-labile forms. Available Phosphorous had high variability (61.07%) in the study area.

3.6 Available Potassium

Potassium is the third major nutrient required by the plant for proper growth and development. Like nitrogen, crops take up a relatively large proportion of plant-available potassium each growing season. Plants deficient in potassium are unable to utilize nitrogen and water efficiently and are more susceptible to disease. Most available potassium exists as an exchangeable cation. The slow release of potassium from native soil minerals and from fixed forms in clays can replenish some of the potassium lost by crop removal and leaching. This ability, however, is limited and variable. Fertilization is often necessary to maintain optimum yields.

The majority of the soils were found to be medium in potassium content. 37% of the soil i.e. 352 ha were rated low. Plants can continuously absorb K beyond yield requirements, so it is important to test soil for nutrient availability to reduce profit loss from over-fertilization. Available Potassium had high variability (86.19%) in the study area. The available Potassium content varied from 30.1 kg/ha to 789.6 kg/ha with a mean of 192.6 kg/ha (Table 3). The distribution ranged from low to very high for the study area. (Figure 7). Medium potassium levels were dominant for the study area, with very little of low, high and very high areas. The use of potassium fertilizers is very low among Nepalese farmers. The use of a recommended dose of fertilizer is required for tackling the deficiency.

3.7 Available Zinc

Micronutrients are elements essential to plants that are required in very small amounts. Micronutrient deficiencies are most likely to occur in sandy, low organic matter soils. High soil pH may also bring about micronutrient deficiencies, especially in sandy soils.

Zinc is a trace element that is needed in small but critical concentrations to the plants. In the absence of it, plants will suffer from physiological stress brought about by the dysfunction of enzyme systems and other metabolic functions in which zinc plays a part. Many of the new crop varieties are much more susceptible to deficiency than traditional ones.

The available Zinc content varied from 0.09 mg/kg to 0.27 mg/kg with a mean of 0.15 mg/kg (Table 3). The whole of the study area was deficient with a very low rating for available Zinc content (Figure 8). The reason for low fertility may be the intensive cropping system practiced in the terai which causes nutrient mining along with imbalanced use of fertilizer [26]. Balanced use of fertilizers in conjunction with organic inputs and chemical fertilizers is key to sustainable agriculture and restoring soil fertility under intensive cropping [8, 30]. Available Zinc content showed low variability (20.15%) among the samples.

3.8 Available Boron

Boron is a trace element required for normal growth and development of crops especially for proper development of reproductive parts and carbohydrate metabolism. It is the second most important micronutrient constraints after Zinc in the world [1].

The available Boron content varied from 0.008 mg/kg to 0.340 mg/kg with a mean of 0.142 mg/kg (Table 3). The whole of the study area was deficient with a very low rating for available Boron content (Figure 9). The very deficient status of available boron was also reported by Khadka et al. [16-18]. The intensive cropping system with no use of boron boron deficiency stress in crops [19]. Available Boron fertilizers may be the reason for low levels in the study area. content showed moderate variability (50.40%) among the Application of 2-3 kg boron per ha is advisable for reducing samples.

4. Conclusion and Recommendations

Soil fertility and nutrient management influence agricultural productivity and hence food security and livelihood. The results reflect that inherent fertility status of the study area was low overall. Rawal et al. [27] noted similar findings in their study of Sunsari district of Nepal. Nutrient mining (extracting more nutrients than are returned) is a key factor in impoverishing the soil. The deteriorating soil fertility cannot be ameliorated only by green manuring and use of legumes. Using them in conjunction with mineral fertilizers can have a greater sustainable impact. Soils and their management options are site and situation-specific. The prepared spatial distribution and fertility maps will aid farmers and planners in understanding the existing soil conditions and making judicious decisions to better manage the soil for sustainability and productivity.

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