Research article

The Spatial Variability of Soil Chemical Properties in a Selected Area of Myanmar

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Abstract Sustainable crop production requires detailed knowledge of the spatial variability of soil properties, such as soil nutrients. The primary purpose of this study was to assess the status of soil fertility by evaluating selected soil chemical properties, at Kyee Inn Village Tract, Pyinmana Township, Middle Myanmar using Geographic Information Systems (GIS). In this study soil samples were collected for the 80 grid references examined. Variables measured were soil pH, electrical conductivity (EC), cation exchange capacity (CEC), soil organic matter, and the total content of nitrogen and phosphorus. Grid size is 300 m × 300 m, covering an area of about 480 hectares, and samples were taken at a depth of 0-15cm using a Global Positioning System (GPS) to determine the coordinates of the sampling points. Soil fertility maps were generated using Inverse Distance Weighting (IDW) interpolation in ArcGIS software 10.5. Interviews were conducted with farmers to match results to soil management practices. The statistical analysis demonstrated a high variability of total nitrogen content with a coefficient of variation of 66.84%, while the soil pH and phosphorus levels showed the minimum variability in comparison to other soil properties. The pH values ranged from 5.48 to 7.58, while for phosphorus, minimum to maximum levels are 0.017% to 0.024%, respectively. Values for EC can be considered normal, with a mean value of 0.095 dS m^{-1} obtained. The CEC values ranged from 2.13 to 11.05 meq100 g^{-1}soil. The low level of organic matter (0.2% to 1.7%) indicated a need to increase the organic matter content to ensure sustainable crop production. This study provides farmers with an effective management and decision-making model that encourages sustainable crop production.

Keywords GIS, GPS, soil chemical properties, spatial variability

INTRODUCTION

Scientists face many challenges in developing strategies to develop sustainable crop production systems (Bakhsh et al., 2000). Assessing the spatial variability of soil chemical properties is crucial in the development of these cropping systems (Mamun et al., 2015). Agricultural sustainability requires that this evaluation of soil fertility should be undertaken periodically (Chimdi et al., 2012). The spatial variability of soil properties includes the variation of soil chemistry, physics, and biological properties in a given location. Even for the same soil type, soil characteristics may exhibit huge differences within short distances (Li et al., 2012).

A standard method for creating maps of topsoil properties is to sample an area using a grid sampling scheme. The density of sampling undertaken will depend on the heterogeneity of the area. With this information a 'prediction' map can be produced by interpolating the measured property values of the samples (Karydas et al. 2009). GISs are a powerful set of tools and useful for producing soil fertility maps for an area, which will help in formulating site-specific recommendations regarding fertilizer needs, as well as providing an understanding of the status of soil fertility both spatially and temporally (Thakor et al., 2014). Inverse Distance Weighting (IDW) was applied to the data as it is a good interpolator for phenomena whose distribution is strongly correlated with distance (Mustafa et al., 2011).

Soil fertility is one of the primary constraints to agricultural production in tropical countries, including Myanmar. Baroang (2013) reported that there is limited information on the dynamics of soil types and erosion patterns in Myanmar, and what does exist, is largely based on decades-old data. The establishment of monitoring stations and the determination of an appropriate monitoring design would be extremely valuable, as there is an obvious need to update the data concerning Myanmar soils.

OBJECTIVE

The main objective of this research is to generate accurate large-scale distribution maps of the selected soil properties by evaluating the current soil fertility status of the study area.

METHODOLOGY

Study Area and Soil Sampling

The study area was selected after conducting a pilot survey. The study area covers a total of 480 hectares, and is located at the Kyee Inn Village Tract, Pyinmana Township, in central Myanmar, and is situated between 19°42'30"-19°43'40"N and 96°13'30"-19°15'30"E (Fig. 1). Myanmar experiences three distinct seasons, hot, wet and cool, and the study area receives a mean annual rainfall of about 1420 mm and an average temperature of 26.8°C. Monsoon rice and pulses are the main crops, and within the area there is both rain-fed and irrigated farming. The required secondary data and hardcopy of the base-map of fields in this area are from Department of Agriculture and Department of Agricultural Land Management and Statistics. Sampling was done on a grid basis (300 m × 300 m), with samples taken at 0-15 cm depth using GPS to determine the coordinate of the sampling points. Where possible, three soil samples were taken from each grid to derive a representative sample. In total, 178 soil samples were collected from the 80 sampling plots (Fig. 2). All samples were taken after harvest, and before any land preparation for the next cropping season had been made. Interviews were conducted with farmers in order to identify variations in soil management practices in different locations in the sample area.

Laboratory Analysis

The collected soil samples were composited for each grid, then air-dried, pounded, and sieved in preparation for soil analysis. Soil pH and electrical conductivity were measured in the extract of soil: water (1:5) suspension using a digital pH-meter and EC meter (Hesse, 1971). Soil CEC was measured using Bascomb's method (Bascomb, 1964). Total nitrogen was determined by the Kjeldahl digestion, distillation and titration method (Bremmer and Mulvaney, 1982). The total phosphorus was analyzed using spectrophotometer as blue molybdate phosphate complexes under partial reduction with ascorbic acid (Jackson, 1958). The Walkley and Black (1934) wet digestion method was used to determine soil organic matter.

Statistical Analysis and Soil Fertility Mapping

The laboratory results of all parameters measured were subjected to descriptive statistic using Statistix (8th version). The low, medium and high levels of nutrients were determined according to standard ratings. The base-map preparation enabling use of GIS software was accomplished by data obtained from a DJI Phantom 4 drone, with this processed using Litchi software. The photos were combined and processed using pix 4D software for digitizing and incorporated onto the digital base map. A different thematic map for the spatial distribution of each parameter was generated using the Inverse Distance Weighted (IDW) interpolation by ArcGIS 10.5 software.

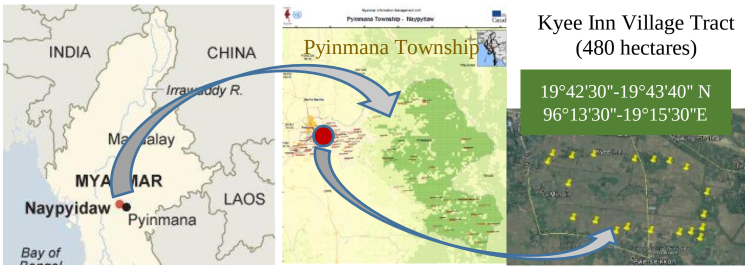

Fig. 1 Location of the study area

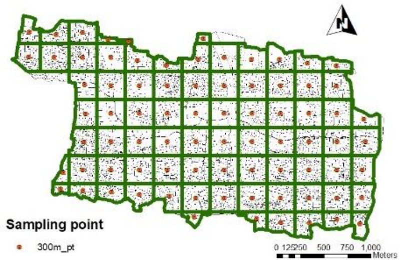

Fig. 2 Grid sampling points

RESULTS AND DISCUSSION

Spatial Variation in Soil Chemical Properties

The results for each soil parameter over the 80 soil sample sites are presented in Table 1. In the study area, there is a large variation in soil chemical properties. Total nitrogen showed the highest variability with 66.84% in its CV (Coefficient of Variation), followed by soil electrical conductivity, with a CV value of 54.36%. However, least variability across sample areas was found for soil pH and total phosphorus, with CV values of 5.08% and 6.68% respectively. Moderate variability occurred for soil CEC and organic matter, which have CV values of 28.02% and 35.93%, respectively.

Table 1 Descriptive statistics of soil chemical properties

Variables	Unit*	Minimum	Maximum	Mean	SE	SD	CV%
pH	$-\log[H^+]$	5.480	7.580	6.248	0.0355	0.317	5.08
Electrical conductivity	$dS\ m^{-1}$	0.051	0.506	0.095	0.0058	0.052	54.36
Cation exchange capacity	$meq100\ g^{-1}soil$	2.130	11.050	6.218	0.1948	1.742	28.02
Organic matter	%	0.200	1.700	0.874	0.0351	0.314	35.93
Total nitrogen	%	0.010	0.330	0.113	0.0085	0.076	66.84
Total phosphorus	%	0.017	0.024	0.019	0.0001	0.001	6.68

SE: Standard Error, SD: Standard Deviation, CV: Coefficient of Variation

** Units represent for the columns of minimum, maximum and mean in the table*

Soil pH and Electrical Conductivity

Soils in the study area were found to range from slightly acidic to moderately alkaline, with the mean pH value of the soil being 6.25, with a range from 5.48 to 7.58. The pH of the soil samples can be described as 21.25% moderately acidic, 58.75% slightly acidic, while 18.75% samples were neutral (pH 7) and only 1.25% samples were moderately alkaline (Fig. 3). The variation in levels of acidity could be due the topography of the study area, variations in moisture, or farmers' practice in the use of acid-forming nitrogenous fertilizers.

The values of EC range from 0.051 dS m^{-1} to 0.505 dS m^{-1} (Fig. 4). The observed mean EC value of 0.095 dS m^{-1} indicated that the study area does not have a salinity problem. According to Moore (2001), the observed EC values were only just above the low range of levels for EC values that is between 0.051 and 0.5 dS m^{-1}, a level expected to have a minimum effect on plant growth.

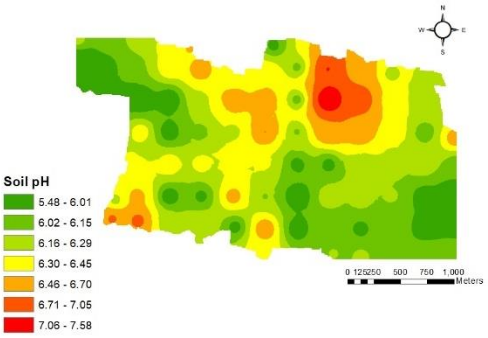

Fig. 3 Spatial distribution of soil pH

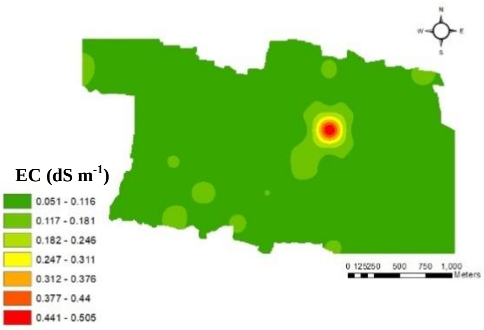

Fig. 4 Spatial distribution of EC

Cation Exchange Capacity and Soil Organic Matter

The observed CEC vary from a low to a medium level, ranging from 2.13 to 11.05 meq100 g^{-1} soil, with a mean value of 6.22 meq100 g^{-1} soil, for the study area (Fig. 5). Using Landon's (1991) classificatory system, 23.75% could be characterized as very low in CEC, while the remaining 76.25% has a low level of CEC. This would indicate that the study area has inadequate basic cations which would be detrimental to plant growth. Ahmed et al. (2015) stated that any CEC of <4 meq100g^{-1} soil indicates a high degree of soil infertility, making it unsuitable for agriculture.

Organic matter content ranges from 0.20% to 1.70%, with a mean value of 0.87%. Figure 6 displayed the spatial distribution of organic matter (in OM%) with lowest levels in the northeast and eastern portion, with content increasing towards the southwest. This may be the result of the slightly higher elevation of the northern portion, as organic matter accumulation is often favored in those areas at lower levels. Purdie (1998) states that soils with organic matter content greater than 2.6% provide good nutrient storage, so it can be seen that the level of organic matter content in all sampling grid plots was very low, affecting good nutrient storage and supply. Based on the survey of farmers' soil management practices, this lower organic matter content may be attributed to poor agricultural management practices, such as the complete removal of crop residues after harvest and the infrequent application of organic manures and organic materials (rice straw, pulses residues, cow dung, etc.) and the burning of crop residues after harvesting.

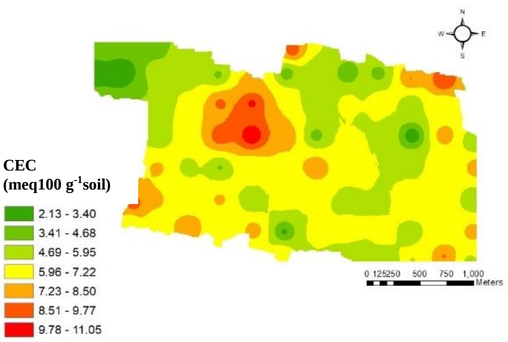

Fig. 5 Spatial distribution of CEC

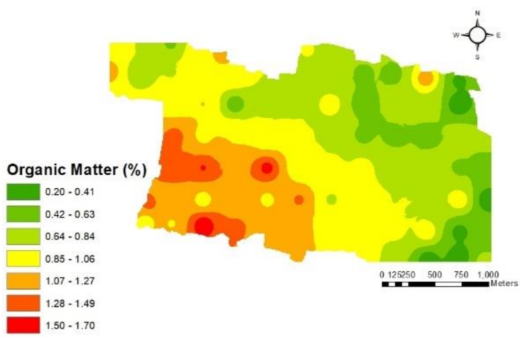

Fig. 6 Spatial distribution of OM

Total Nitrogen and Total Phosphorus

The total nitrogen content varied from 0.01% to 0.33% with a mean value of 0.11% overall. The study indicates that about 25% of the area sampled has 'very low' levels of nitrogen and a further 50% has 'low' levels, while 17.5% of the samples are in the medium range, and only 7.5% have a high range of total nitrogen content (Fig. 7). The low nitrogen content is probably due to the insufficient level of organic matter, which can be depleted by constant cropping and prevailing high temperatures, resulting in the faster degradation and removal of organic matter, with a corresponding drop in the soil's nitrogen reserves. On the other hand, the areas of medium to high level of total nitrogen appear to occur where organic materials have been added (mainly plant residues), and also as a result of nitrogen fixed through legume cultivation.

The spatial distribution of total phosphorus levels appears to be higher, with 43.75% of the sampling area being in the medium range, whereas 56.25% of the samples showed lower levels (Fig. 8). The values of total phosphorus ranged from 0.017% to 0.024% with a mean value of 0.019%. According to research, lower levels of phosphorus may be due to infrequent application of organic and inorganic phosphorus fertilizers. Another reason for these lower levels may be due to nutrient depletion by crops, since this area has a cropping pattern of monsoon rice and dry weather pulses.

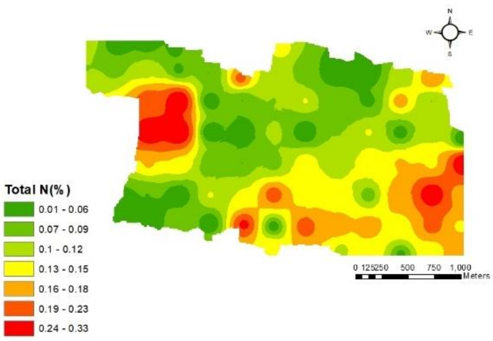

Fig. 7 Spatial distribution of total N

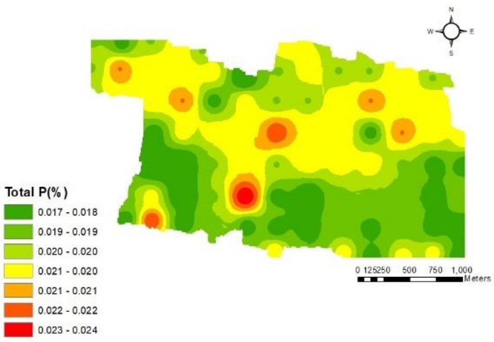

Fig. 8 Spatial distribution of total P

Survey Results for Soil Management Practices

Mostly preparation of land for cropping is mechanized, with only 21% of respondents using both machine and animal power. In this area, the dominant cropping pattern of monsoon rice and pulses is practiced under both rain-fed and irrigated farming. It was found that there is minimal application of organic fertilizers. After harvesting, farmers retain residues from the pulse crop on their fields, but this is done by a minority. About 23% of respondents use cow-dung manure and only 12% of respondents apply pulses residues. The most common types of inorganic fertilizers used by the respondents were urea and compound fertilizers for rice production. There is no evidence of the application of phosphorus and potash fertilizers for crop production. Application of fertilizers is mostly by the broadcast method and top dressing is applied two to three times, at the tillering and flowering stages. Fertilizers do not appear to be applied basally at planting time.

CONCLUSION

Results from the soil analysis show the following characteristics of the soil in the study area; it has low content of organic matter, it has (mostly) low to high levels of total nitrogen, low to medium ranges of total phosphorus, while the level of the CEC is very low to low. Although the measured ranges of soil pH and electrical conductivity ranges should not be detrimental to the crop cultivation, soil nutrient management for sustainable crop production should focus on addressing problems of acidity and alkalinity. As expected, the variability of each soil characteristic exists largely due to the differences in the management practices used by farmers. Therefore, farmers should be encouraged to return as much crop residue as possible to the soil, introducing systematic practices (sufficient and consistent) that provide for the addition of manure and fertilizers, in order to improve soil fertility levels which will lead to higher crop production. Further, a legume-based cropping pattern should also be introduced and consistently maintained to provide a long-term nutrient supply for better yields and diversify the economics of crop production. This study has shown that the use of new technologies such as GIS and GPS can provide important information for evaluating the current status of soil fertility, and for allowing better management of soil fertility at the farm level.

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