Spatial Variability of Soil Properties under Different Land Use in the Dang District of Nepal

Dinesh Panday¹*, Roshan Babu Ojha², Devraj Chalise³, Saurav Das¹, Bikesh Twanabasu³

¹Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln, NE 68583 United States; saurav12das@gmail.com (S.D.)
²Nepal Agricultural Research Council, Khumaltar, Lalitpur 44700 Nepal; roshanbachhan@gmail.com (R.B.O.); chalisedevraj@gmail.com (D.C.)
³Shree R. S. Engineering Solution, Bhatbhateni, Kathmandu 44600 Nepal; bkesh14@gmail.com

*Correspondence: dinesh.panday@unl.edu | agriculturenepal@gmail.com

Abstract: A study was carried out in the eastern part of Dang district in Nepal to assess the variability of selected soil properties due to different land use and map their spatial distribution. Considering three land use types (agriculture, agroforestry, and grassland), a total of 120 samples were collected from surface soil (0 to 15 cm depth) in May 2015 and analyzed for soil fertility parameters: pH, organic matter (OM), nitrogen (N), phosphorus (P), potassium (K), boron (B), and zinc (Zn). Results revealed that the average value of soil pH significantly (P<0.05) varied from 7.05 in agroforestry to 7.53 in agriculture land use. Soil OM and N contents were medium in range in all land use with slight variation, the highest average OM and N found in grassland (2.87% and 0.14% respectively), followed by agriculture (2.64% and 0.13% respectively), and agroforestry (2.45% and 0.12% respectively). Further, the results showed significant variation for P among agroforestry (18.99 kg ha⁻¹) and grassland (8.49 kg ha⁻¹) while the K content was the highest for grassland (144 mg kg⁻¹) and lowest for agriculture (120 mg kg⁻¹). Micronutrients- B was low (0.28 to 0.35 mg kg⁻¹) and Zn was very low (0.14 mg kg⁻¹) in all land use. There is a need to add appropriate fertilizer N, P, B, and Zn to the soil in order to increase
the fertility status under different land use. Spatial variability maps for soil chemical properties can be used by farmers and local planners to make effective soil management strategies.

**Keywords:** agriculture; kriging; land use; Nepal; soil nutrient variability

### 1. Introduction

Soil properties vary in different spatial extent due to the combined effect of biological, physical or chemical processes over time [1]. It varies within a farmland [2] to the landscape scale [3-4]. Land management and land use pattern greatly influence the variation in soil properties [5]. Knowledge of the spatial variation of soil properties within land use is important to find out the soil nutrients related production constraints, suggest the remedial measures for optimum production of the crops, and execute efficient management decisions based on their proper understanding of the conditions of existing farm soils [6].

Dynamics of soil properties like texture, pH, electrical conductivity, organic carbon, total nitrogen (N), available potassium (K), available phosphorus (P), and micronutrients are studied in different land use scale and dimensions [7-10]. Conversion of pasture land to cultivated land brings negative change in soil organic carbon (SOC), N, and P concentration [11-13]. The higher concentration of plant nutrients is found in forest and pasture land compared to the cultivated land [8]. In cultivated land, tillage systems also affect the soil properties vary spatially [14].

The spatial variability of soil properties can be mapped using an interpolation technique [15]. Among different methods of spatial interpolation, inverse distance weighing and ordinary kriging are the most common. There are many reasons to choose either of these, but the inverse
distance-weighted method does not provide an assessment of errors. However, kriging provides prediction error assessment and from a theoretical standpoint, it is the optimal interpolation method [1,6,16]. Kriging has the power of interpolating the non-sampled locations based on sample locations by estimating the values between the samples [17]. Study of spatially variable soil properties in macro-scale and micro-scale is helpful to generate the information in landscape level to farm-level. This information is helpful to plan effective soil management strategies from regional scale i.e. landscape management to the farm scale level i.e. precision farming [18-19].

Dang is a valley of alluvial deposit in Nepal where the soil from sandy loam to clayey texture occurred. It is unique in terms of its soil class and thus required a special attention for soil management. Many of the smallholder farmers reside in this valley and have poor access to the agricultural inputs such as quality of organic and inorganic fertilizers. The objectives of the study were to; a) explore the variability in soil chemical properties due to different land use; b) map the spatial distribution of soil chemical properties with the help of spatial statistical technique (kriging); c) evaluate relationships of some selected soil chemical properties under different land use; and d) provide soil fertility management practices under different land use systems in the Dang districts of Nepal. This study will be helpful for the farmers and local planner to make effective soil management strategies.

2. Materials and Methods

2.1 Study Area

Dang district is in Province number 5 in the Mid-Western region of Nepal. It is in between the Churiya range on the south and the Mahabharat range on the north in inner Terai.
Dang valley is the largest valley of Asia. It is about 180 km far from Butwal, the capital city of Province 5 and 450 km from Kathmandu, the capital city of Nepal.

This study was carried out in the eastern part of Dang district and includes Lamahi Municipality (old name: Chaulahi and Sonpur Village Development Committees) and Rapti Rural Metropolitan (old name: Sisahaniya and Lalmatiya Village Development Committees) and covers 22461.60 ha of land as shown in Figure 1. The topographic variation of the study area ranges from 235 to 885 m.

![Soil Sample Locations in Study Area](image)

**Figure 1.** Map of the study area and locations of soil sampling from the eastern part of Dang district of Nepal. A total of soil samples was taken, from the depth of 0-15 cm, by representing three different land use system: agriculture, agroforestry, and grassland for the determination of pH, OM, N, P, K, B, and Zn status on it.
2.2 Climate and Soil

The climate of study area is tropical to sub-tropical, characterized by monsoon rainfalls from June to September, which on average account for 85% of the total annual rainfall (of 1500 mm) with an average temperature of 27 °C [20]. The details of year-round air temperature, rainfall, minimum, and maximum temperature of 2015 are presented in Figure 2 [21].

![Year-round air temperature, rainfall, minimum, and maximum temperature in 2015 from study area (eastern part of Dang district of Nepal).](image)

Figure 2. Year-round air temperature, rainfall, minimum, and maximum temperature in 2015 from study area (eastern part of Dang district of Nepal).

Physically, the district has undulating terrain sloping toward the south. Most part of the plain is made by the fertile alluvial deposit from different small and large rivers in the different geological time [22-23]. The study area is classified as Ustorthents (46.07%), Dystrudepts (21.41%) and Haplustolls (21.43%) soil followed by others (11.09%) according to the United States Department of Agriculture (USDA) Soil Taxonomy [24]. Loam and clayey soils dominate the study area.
2.3 Farming System and Land Use

In the study area, agriculture is the main income source for most of the households and is characterized by subsistence mixed crop-livestock farming where forest covers maximum area (64.62%) followed by agriculture (32.72%), and grassland (2.76%) systems.

Agriculture: Major crops of the study area are rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), lentil (*Lens culinaris*), maize (*Zea mays* L.) oilseeds, vegetable, and potatoes (*Solanum tuberosum* L.). Rice–wheat (35.25%) is the dominant cropping pattern, followed by rice–pulses (21.81%). Livestock is closely integrated into the farming system and is used mainly for plowing, threshing, and transport purpose. Livestock also provides food and household income. After main crop harvesting from the field, farmers follow the removal of crop residues either for fuelwood or animal feed purpose. Thus, no crop residue remains in the field each season for organic amendment to their soil. These farmers use different sources of organic manure (mainly farmyard manure) and chemical fertilizers (mainly urea and di-ammonium phosphate) to maintain soil fertility [25].

Agroforestry: Nepal’s agroforestry can be broadly categorized into two headings: (i) farm-based and (ii) forest-based agroforestry system [26]. Farmers from Lamahi Municipality mainly follow farm-based agroforestry whereas forest-based agroforestry is dominant in Rapti Rural Municipality. Sal (*Shorea robusta*) forest is the dominant vegetation, along with khair (*Acacia catechu*), sissoo (*Dalbergia sissoo*), and silk cotton tree (*Bombax ceiba*) occur in the stream and riversides.
Grassland: The grassland use system is without tree cover, permanent grass and relatively flat or rolling, and available throughout the year for animal grazing [27]. Common vegetation for grassland includes siru (*Imperata cylindrical*), worela (*Saccharum bengalensis*), kans (*Saccharum spontaneum*), kharahi (*Narenga porphyrocoma*), and kush (*Desmostachya bipinata*).

2.4 Soil Sampling and Analysis

From the study area, surface soil samples (0 to 15 cm depth) were collected in May 2015 using a soil auger considering three land use types (agriculture, agroforestry, and grassland). By following one soil sample per location, a total of 120 soil samples were collected including agriculture (94 samples: representing 73.40 km² area), agroforestry (22 samples: representing 144.91 km² area), and grassland (4 samples: representing 6.20 km² area). Selection of soil sampling location was based on the best representation of land use condition with consideration for terrain attributes and drainage facilities. Sample intensity is higher in agriculture land compared to agroforestry and grassland because more numbers of land units were presented in agricultural land. In agroforestry and grassland similar terrain resulted less land unit. Based upon these land units sampling points were decided. A global positioning system (GPS) was used to locate each sample location. The details of soil sampling locations are given in Figure 1.

All soil samples were bagged, labeled, and transported to the laboratory for preparation and analysis of soil texture, pH, organic matter (OM), N, P, K, boron (B), and zinc (Zn). Methods used for testing of soil chemical parameters at the Regional Soil Testing Laboratory, Kaski district of Nepal are described in Panday et al. [6]. Limited number of soil samples (three representative samples from each land use) were collected for bulk density determination using
soil core method [28]. Soil results obtained from the laboratory were ranked based on the standard recommendation given by Nepal Agricultural Research Council, and used by Soil Management Directorate, Department of Agriculture, Nepal which is given in Table 1.

**Table 1.** Rating for different soil chemical parameters given by the Soil Management Directorate, Department of Agriculture for Terai region of Nepal (adapted from Panday et al. 2018).

<table>
<thead>
<tr>
<th>Rating</th>
<th>OM (%)</th>
<th>N (%)</th>
<th>P (kg ha⁻¹)</th>
<th>K (kg ha⁻¹)</th>
<th>B (mg kg⁻¹)</th>
<th>Zn (mg kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>&lt;1.00</td>
<td>&lt;0.05</td>
<td>&lt;5.00</td>
<td>&lt;40.00</td>
<td>&lt;0.20</td>
<td>&lt;0.25</td>
</tr>
<tr>
<td>Low</td>
<td>1.10-2.50</td>
<td>0.05-0.100</td>
<td>5.00-12.00</td>
<td>40.00-80.00</td>
<td>0.20-0.50</td>
<td>0.25-0.50</td>
</tr>
<tr>
<td>Medium</td>
<td>2.51-5.00</td>
<td>0.11-0.200</td>
<td>13.00-25.00</td>
<td>81.00-120.00</td>
<td>0.51-1.20</td>
<td>0.51-0.75</td>
</tr>
<tr>
<td>High</td>
<td>5.00-10.00</td>
<td>0.210-0.40</td>
<td>26.00-50.00</td>
<td>121.00-200.00</td>
<td>1.21-2.00</td>
<td>0.76-1.00</td>
</tr>
<tr>
<td>Very high</td>
<td>&gt;10</td>
<td>&gt;0.400</td>
<td>&gt;51.00</td>
<td>&gt;200.00</td>
<td>&gt;2.00</td>
<td>&gt;1.01</td>
</tr>
</tbody>
</table>

Range for pH: strongly acidic= <5.5; moderately acidic= 5.5-6.2; neutral= 6.2-7.0; moderately alkaline= 7.0-7.8; strongly alkaline= <7.8.

2.5 **Statistical analysis**

Descriptive statistics and geostatistics were used to analyze and interpret soil related datasets. Descriptive statistics was run in Statistix 10. Differences among the land use types were evaluated by Tukey-Kramer test. If a significant effect was found, pairwise comparisons were conducted using the least significant differences test to determine means of soil chemical properties among the land use types. All maps were produced using GIS software- ArcMap v. 10.2 and its spatial distribution was analyzed through kriging interpolation. Pairwise Pearson’s correlation between the soil chemical properties was analyzed in RStudio v1.1.463 and
correlation plot was generated using R package “corrplot”. Significant differences were stated at the level of $P<0.05$.

3. Results and Discussion

3.1. Soil Physical Properties

3.1.1. Soil textural fraction and bulk density

Soil texture of the study area was not influenced by land use. The textural class across all the land use types of the study area is clay loam (Figure 3), indicating the homogeneity of forming processes and similarity of parent materials. The overall mean of clay fraction was found to be higher in agricultural land (34.43%) compared to agroforestry (30.00%) and grassland (28.33%). Intensive soil management that promotes further weathering processes could be the possible reason for higher clay content [29] whereas under sparser vegetation, clay fractions are likely to be lost due to process of selective erosion in grassland [30]. The sum of mean of silt and clay fractions were high in grassland (73.33%) and agriculture (71.91%) compared to agroforestry (66.77%). A recent finding of Whisler et al. [31] suggests that silt and clay contents were the strongest predictor of soil carbon and nitrogen.
Figure 3. Mean soil separates (left) and bulk densities (right) based on land use type in Dang district of Nepal. Solid capped lines in the bar chart represent standard error bar.

When the dry bulk density values under different land use were compared, the lowest value (1.04 g cm\(^{-3}\)) was measured in agroforestry soils and the highest value (1.5 g cm\(^{-3}\)) was measured in agricultural lands (Figure 3). Bulk density was significantly affected by land use (\(p < 0.05\)). It is important to highlight that bulk density strongly correlates with SOM and organic carbon content [32]. The lower bulk density of agroforestry could be due to continuous addition of higher soil organic residues from agroforestry components on the surface layer [33]. On the other hand, higher bulk density of agricultural land is due to continuous tillage operation, which in turn lower SOC (from the process of rapid mineralization of SOM), thereby exposing OM for decomposing agent [34]. Grassland has intermediate bulk density. Farmers often use to graze their animals on the existing small or bare plots of land and this has significant contribution for the increment of bulk density in grassland [6]. Our results indicated that a change in bulk density is associated with changes in SOM and textural fractions.

3.2. Soil Chemical Properties

3.2.1. Soil pH

Assessment of pH of soils related to different land use is presented in Table 2. The average value of soil pH found significantly (\(P<0.05\)) varies from 7.05 in agroforestry (minimum: 5.8 and maximum: 8.20) to 7.53 in agriculture (minimum: 6.10 and maximum: 8.40) land use. However, soil pH of grassland (average: 7.47, minimum: 6.60, and maximum: 8.10) does not significantly differed to either agriculture or agroforestry land use. According to the rating given by Soil Management Directorate, Department of Agriculture in Nepal [25], the overall pH of the studied soil was dominated by moderately alkaline, followed by neutral and...
strongly alkaline (details is given in Figure 4). Furthermore, area covered by land use under different pH classes based on the range representing their magnitude in the soil is presented in Table 3.

Literature supports that soils in Nepal is dominated with moderately acidic in nature because of parent material (such as sandstone, siltstone, quartzite, and shale), loss of major cations during monsoon season, and atmospheric nature of aluminum in those soils [35,25]. However, soils in western part of Nepal is dominated by alkaline nature parent material, the presence of base-forming cations associated with carbonates and bicarbonates found naturally in soils and irrigation waters. However, when forest land use is converted in to cropland and grazing land use types, significant changes occurs in soil properties. In our study, for higher soil pH in agriculture land use might be related to the addition of potash through the traditional slash and burn practices. Moraes et al. [36] reported that burning releases nutrients in the ash, which increases soil pH. Another reason could be the provision of irrigation water which can have Ca content on it [37].

**Table 2.** Spatial variability of soil chemical properties among land uses in eastern part of Dang district of Nepal.

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Agriculture</th>
<th>Agroforestry</th>
<th>Grassland</th>
<th>F-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.53 ± 0.05 a</td>
<td>7.05 ± 0.14 b</td>
<td>7.47 ± 0.44 ab</td>
<td>6.85*</td>
</tr>
<tr>
<td>OM, %</td>
<td>2.64 ± 0.13</td>
<td>2.47 ± 0.24</td>
<td>2.78 ± 0.99</td>
<td>0.22NS</td>
</tr>
</tbody>
</table>
### Table 3. Area covered by land use under different soil categories based on soil fertility parameters in the eastern part of Dang district of Nepal.

<table>
<thead>
<tr>
<th>Soil properties</th>
<th>Range</th>
<th>Class</th>
<th>Area covered by land use, ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Agriculture</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>&lt; 5.5</td>
<td>strongly acidic</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>5.5 – 6.2</td>
<td>moderately acidic</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6.21 – 7.0</td>
<td>neutral</td>
<td>833.90</td>
</tr>
<tr>
<td></td>
<td>7.1 – 7.8</td>
<td>moderately alkaline</td>
<td>4349.07</td>
</tr>
<tr>
<td></td>
<td>&gt; 7.8</td>
<td>strongly alkaline</td>
<td>2166.03</td>
</tr>
<tr>
<td><strong>OM, %</strong></td>
<td>&lt; 1.00</td>
<td>very low</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1.10 - 2.50</td>
<td>low</td>
<td>4375.81</td>
</tr>
<tr>
<td></td>
<td>2.51 - 5.00</td>
<td>medium</td>
<td>2973.19</td>
</tr>
<tr>
<td></td>
<td>5.01 - 10</td>
<td>high</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>&gt; 10</td>
<td>very high</td>
<td>-</td>
</tr>
<tr>
<td><strong>N, %</strong></td>
<td>&lt; 0.05</td>
<td>very low</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.05 - 0.10</td>
<td>low</td>
<td>824.30</td>
</tr>
<tr>
<td></td>
<td>0.11 - 0.20</td>
<td>medium</td>
<td>6189.81</td>
</tr>
</tbody>
</table>

Values (mean ± standard error) in each row with the same letter are not significantly (P<0.05, LSD) different among land uses, *Significant at 0.05, NS: Not Significant.
<table>
<thead>
<tr>
<th>Soil Nutrient</th>
<th>Category</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Very High</th>
</tr>
</thead>
<tbody>
<tr>
<td>P, kg ha$^{-1}$</td>
<td>0.21 - 0.40</td>
<td>high</td>
<td>334.89</td>
<td>0.98</td>
<td>22.14</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.40</td>
<td>very high</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>&lt; 5.00</td>
<td>very low</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>5.00 - 12.00</td>
<td>low</td>
<td>3935.40</td>
<td>8984.48</td>
<td>404.18</td>
</tr>
<tr>
<td></td>
<td>13.00 - 25.00</td>
<td>medium</td>
<td>3187.01</td>
<td>5210.86</td>
<td>209.60</td>
</tr>
<tr>
<td></td>
<td>26.00 - 50.00</td>
<td>high</td>
<td>226.58</td>
<td>296.57</td>
<td>6.92</td>
</tr>
<tr>
<td></td>
<td>&gt; 51.00</td>
<td>very high</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>&lt; 4.00</td>
<td>very low</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4.00 - 8.00</td>
<td>low</td>
<td>170.14</td>
<td>61.66</td>
<td>1.52</td>
</tr>
<tr>
<td>K, kg ha$^{-1}$</td>
<td>81.00 - 120.00</td>
<td>medium</td>
<td>4638.32</td>
<td>4262.78</td>
<td>420.75</td>
</tr>
<tr>
<td></td>
<td>121.00 - 200.00</td>
<td>high</td>
<td>2286.39</td>
<td>9588.29</td>
<td>184.01</td>
</tr>
<tr>
<td></td>
<td>&gt; 200.00</td>
<td>very high</td>
<td>254.15</td>
<td>579.17</td>
<td>14.41</td>
</tr>
<tr>
<td></td>
<td>&lt; 0.20</td>
<td>very low</td>
<td>3191.82</td>
<td>8608.16</td>
<td>280.42</td>
</tr>
<tr>
<td></td>
<td>0.20 - 0.50</td>
<td>low</td>
<td>3969.73</td>
<td>5883.35</td>
<td>332.86</td>
</tr>
<tr>
<td>B, kg ha$^{-1}$</td>
<td>0.51 - 1.20</td>
<td>medium</td>
<td>187.45</td>
<td>0.39</td>
<td>7.43</td>
</tr>
<tr>
<td></td>
<td>1.21 - 2.00</td>
<td>high</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>&gt; 2.00</td>
<td>very high</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>&lt; 0.25</td>
<td>Very Low</td>
<td>7349.00</td>
<td>14491.90</td>
<td>620.70</td>
</tr>
<tr>
<td></td>
<td>0.25 - 0.50</td>
<td>Low</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zn, kg ha$^{-1}$</td>
<td>0.51 - 0.75</td>
<td>Medium</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.76 - 1.00</td>
<td>High</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>&gt; 1.00</td>
<td>Very High</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

| Total area | 7349.00 | 14491.90 | 620.70 |
Figure 4. Soil pH spatial variability map in eastern part of Dang district, Nepal. Most of the study area was with moderately alkaline (57.50%) followed by neutral (27.81%) and strongly alkaline (14.68%) pH. Moderately acidic soil pH was present in very small area (0.01%) which could not see in the variable map.

3.2.2. Soil organic matter

Soil organic matter (OM) content varied slightly with land use, the highest average soil OM found in grassland (2.87%), followed by agriculture (2.64%), and agroforestry (2.45%) as presented in Table 2. Most of the study area were occupied by low and medium soil OM, according to a range given by the Soil Management Directorate, Department of Agriculture in Nepal (details are given in Figure 5). In addition, area covered by land use under different OM classes based on the range representing their magnitude in the soil is presented in Table 3. A study conducted by Wei et al. [38] in northern Loess Plateau, China revealed that distribution of
extensive root system may contribute in higher SOC and N under the natural grasslands. Additionally, the vegetation and plant litter, combined with minimal disturbance, form an almost covering layer in grassland that protects the soil from erosion [36].

A relative lower amount of SOC in the agriculture soils can be generally accounted through the competing use of crop residues as animal feed which then constrains their return to the soil [40]. A recent study by Pandey et al. [25] reported that due to the intensive cropping system and tillage operation in some parts of Nepal, it has removed essential plant nutrients from the soil including OM, thereby exerting pressure on soil fertility.

**Figure 5.** Soil OM spatial variability map in eastern part of Dang district, Nepal. The study area was dominated with low (69.40%) and followed by medium (30.60%) soil OM content.
3.2.3. Total nitrogen

Results show that grassland (0.14%) had a highest total nitrogen (N), followed by agriculture (0.13%) and agroforestry (0.12%) land use as presented in Table 2. The values of N for all land use were dominated by medium, followed by low and high, a range given by the Soil Management Directorate, Department of Agriculture in Nepal (details are given in Figure 6). Furthermore, area covered by land use under different N classes based on the range representing their magnitude in the soil is presented in Table 3. These results are in line with the findings of Duguma et al. [41] who found higher N in woodlot and pasture land compared to agriculture land. In a similar study conducted by Yimer et al. [42] found the SOC and N contents to be significantly lower in agriculture land compared to grazing and forest lands.

Variation in N within agriculture land use of the study area may be related to soil management, application of farm yard manure, and applied fertilizer to previous crops, etc. [43]. In addition, a combination of lower carbon inputs because of less biomass carbon return on harvested land, increased aeration by tillage and crop residue collecting partly causes the reduction of OM and N in agriculture soils [44]. In general, N has a greater effect on crop growth, crop quality, and yield.
Figure 6. Soil N spatial variability map in eastern part of Dang district, Nepal. Most of the study area was with medium (77.16%) for soil N content. High soil N was present in less than 2% of total study area.

3.2.4. Available phosphorus

Results show that a significant variation among agroforestry (18.99 kg ha\(^{-1}\)) and grassland (8.49 kg ha\(^{-1}\)) for available phosphorus (P) as presented in Table 2. However, agriculture (11.89 kg ha\(^{-1}\)) had a non-significant relation to agroforestry or grassland. Figure 7 shows that soil P spatial variability map was dominated by low and medium classes according to the range given by the Soil Management Directorate, Department of Agriculture in Nepal. In addition, area covered by land use under different soil P classes is presented in Table 3.

Table 2 shows that amounts of available P were slightly higher in the agroforestry in comparison to agricultural land and grassland. It could be due to higher litter accumulation and
higher availability of materials such as lignin. Higher P content in soils of agricultural land could possibly be explained by application of P-containing fertilizer (such as di-ammonium phosphate which contains 18% N and 46% P) [25] and somehow from the application of animal manure for soil fertility improvement in farmers’ field [45]. Soils with inherent pH values between 6 and 7.5 are also ideal for P availability; higher the pH, the phosphate (HPO$_4^{2-}$) ions tend to react quickly with calcium (Ca) and magnesium (Mg) to form less soluble compounds [46].

![Available Phosphorus](image)

**Figure 7.** Soil P spatial variability map in eastern part of Dang district, Nepal. Most of the study area was with low (60.18%) and followed by medium (37.32%) for soil P content. Only 2.20% of the study area was with high P content in the soil.
3.2.5. Available potassium

Our analysis shows that soil concentration of available potassium (K) was at a medium to high levels in the study area (Table 2), which covers about 98% of the total study area (Figure 8). The average value of K for agriculture was 120 mg kg⁻¹, whereas 130 and 144 mg kg⁻¹ for agroforestry and grassland, respectively. However, the effect of K for different land use was insignificant. The details of area covered by land use under different K classes based on the range representing their magnitude in the soil is presented in Table 3. Many studies support parent materials and degree of weathering along with K fertilizer applied, varying land use systems, crop removal, erosion, and leaching alter the distribution and availability of K content in soils [47-49].

In general, the concentration of exchangeable cation tends to increase from cultivated land into forest land. The increased addition of organic manures yielded a corresponding increase in exchangeable K content [47]. However, leaching due to the high amount of rainfall or irrigation facilities, limited recycling of dung and crop residue in the soil, declining fallow periods, or continuous cropping and soil erosion have contributed to the depletion of basic cations on the cultivated land as compared to the adjacent agroforestry and grassland [50-52]. In our study, we observed a low value of K in some part of those soils with high OM in lowland agriculture dominated by silt clay and clay which could be due to mainly from leaching effect.
Figure 8. Soil K spatial variability map in eastern part of Dang district, Nepal. Study area was dominated by medium (50.51%), followed by high (44.26%) and very high (3.99%) for K content in soil. Only 1.25% of the study area was with high K content in the soil.

3.2.6. Available boron and zinc

Results show that the between two micronutrients measured, B was low, and Zn was very low in the study area (Table 2). Relatively, B content was higher in grassland (0.35 mg kg\(^{-1}\)) compared to agriculture (0.3 mg kg\(^{-1}\)) and agroforestry (0.28 mg kg\(^{-1}\)), respectively. Available Zn content was indifferent to land use (0.14 mg kg\(^{-1}\)) though the highest value of Zn content was 0.17 mg kg\(^{-1}\). still, all the results from soil concentration of Zn were very low. Figure 7 shows that soil B spatial variability map was dominated by low and medium classes and Figure 8 shows that soil Zn variability map was solely dominated by very low class according to the range
given by the Soil Management Directorate, Department of Agriculture in Nepal. In addition, area covered by land use under different soil B and Zn classes is presented in Table 3.

The possible reasons for low micronutrients could be due to unfavorable soil pH, intensive cropping, the use of high yielding varieties, and different fertilizer application strategies practiced by smallholder farmers [6]. The Khaira disease (leaf bronzing) in rice due to Zn deficiency and sterility in wheat induced by an inadequate B supply are major concerns [Panday]. Many findings alarmed that Zn deficiency should be expected at many locations in Nepal [6,53]. The B deficiency severely restricted the growth of plant [54], was also more important in grain legumes of the study area.

Figure 9. Soil B spatial variability map in eastern part of Dang district, Nepal. Most of the study area was with very low (52.70%) and low (46.44%) for B content. Soil B at medium level was present in less than 1% of total area.
Figure 10. Soil Zn spatial variability map in eastern part of Dang district, Nepal. All the study area was with very low level of Zn content.

3.2.8. Correlation between soil chemical properties

The significant correlations between different soil chemical properties are presented in Figure 11. The OM with N ($r^2 = 0.98$, $p<0.01$), OM with B ($r^2 = 0.92$, $p<0.01$), and N with B ($r^2 = 0.94$, $p<0.01$) had a strong correlation. Available K with Zn ($r^2 = 0.56$, $p<0.01$) had a moderate correlation. However, pH with Zn ($r^2 = 0.21$, $p<0.01$), N with K ($r^2 = 0.21$, $p<0.01$), OM with K ($r^2 = 0.04$, $p<0.01$), and K with B ($r^2 = 0.04$, $p<0.01$) had least correlation. The pH of the soil was found to be responsible for distribution of different soil minerals and it was found, Zn, B, P, N, and OM were negatively correlated with pH with $r^2 = 0.20$, $0.02$, $0.03$, $0.001$, and $0.007$, respectively. In general, there was a strong association between the different soil chemical properties.
Figure 11. Correlation matrix based on Pearson’s correlation coefficients between soil chemical properties in eastern part of Dang district, Nepal.

3.3 Soil fertility management

Status of different soil chemical parameters such as soil pH, OM, N, P, K, B, and Zn in different land use of the Dang valley demand the necessity of soil management options to upscale the productivity. Managing the condition of these nutrients is helpful to address the nutrient mining problem of the studied area. In addition to that, it is also helpful to replenish the mined soil nutrients with appropriate soil management strategies.
The major limitation of the study is the small size of samples under some land use like agroforestry and grassland relatively with agriculture land use. There seems a significant difference in the soil pH and P. The slight increase in the alkalinity of the soil of cropland can be managed through crop rotation with legume integration in the long run. Organic matter is present in low and medium amount in most of the study area which can be increased and could be helpful to manage the soil pH too. Higher soil pH in crop land due to the presence of alkaline parent materials is hard to manage with soil amendments. Continuous weathering from carbonates replace H$^+$ ions making soil alkaline. In such case, it would be better to use elemental sulphur for S and ammonium sulphate for N and S as soil amendment for acidification or grow alkali loving plant like cauliflower (Brassica oleracea var. botrytis), lettuce (Lactuca sativa), spinach (Spinach oleracea), carrot (Daucus carota subsp. sativus), asparagus (Asparagus officinalis), cabbage (Brassica oleracea var. capitata), beet (Beet vulgaris), celery (Apium graveolens), etc. Leaching of Ca salts could be a better option for large farm with non-saline irrigation water.

For medium level of OM, N should be increased. In agroforestry and grassland, the continuous deposition of leaf litter and root decomposition will be helpful to manage OM. The challenge of managing OM is greater in agriculture land use. The continuous exhaustion of N due to crop harvest and OM due to oxidation can be maintained with the use of local OM resources. The incorporation OM resources like dhaincha (Sesbania bispinosa), barseem (Trifolium alexandrinum), asuro (Adhatoda vesica L.), banmara (Eupatorium spp.), soybean (Glycine max L.) etc. is one of the sustainable ways to increase soil OM and N along with balancing soil pH. In addition to that, manage crop residues, protecting fire (modify slash and burn to slash and residue retention), optimal use of organic inputs for example, organic manures and processed human
wastes, adoption of conservation tillage are other ways to manage soil OM and N in the soil. The high degree of correlation of soil OM with N will be helpful to manage N jointly with soil OM.

Phosphorous level in grassland is relatively lower than agriculture and agroforestry land use. The availability of P highly depends on soil pH but the soil pH in the study area is in the favorable range. So, lower P level might be due to depletion of P in grassland and cropland due to harvest/grazing. The replenishment of P either from chemical source or from organic source could be the option. Various inorganic sources of P such as super phosphates, compound phosphates are available and organic sources like bone phosphate, rock phosphate, soft phosphate can be used. Potassium level is moderate to high in all land use. So, management of potassium to its current level through continuous replenishment through K sources is necessary to avoid future K mining problems.

Boron and zinc are present lower amount in all land uses. It affects the crop productivity and pasture productivity in cropland and grassland, respectively. In cropland lower level of B affects root crops, wheat, and maize and lower level of Zn affect rice production significantly. Addition of B and Zn through inorganic and organic sources in both cropland and grassland is very necessary to boost their respective productivity. In summary, following specific soil management options are recommended for eastern part of Dang district of Nepal.

- Maintain soil pH in agriculture land use with the use of legume incorporated crop rotation along with the use of acidifying inputs like elemental S and ammonium sulphate,
- Incorporation of locally available organic matter resources with organic inputs to increase OM and N,
- Addition of organic and inorganic sources of P, B, and Zn to increase P, B, and Zn levels in agriculture and grassland,

- Apply 1/4th of recommended fertilizer dose to maintain K levels,

- Modify slash and burn system to slash and residue retention system.

4. Conclusion

A major limitation of our study is the small number of samples from grassland while comparing soil properties under different land use system. However, the results reflect the soil properties of this study area is not so high with majority of the nutrients having low (even completely very low for Zn) to medium amounts. There is a need to add appropriate fertilizer (from organic and/ or inorganic sources) N, P, B, and Zn to the soil in order to increase the fertility status. The production of soil nutrients maps to measure the spatial variability of the non-sampled locations based on sampled data provides the basis for controlling it. These maps aid farmers into making efficient management decisions based on their proper understanding of the conditions of existing soils under different land use. These results can be used to make recommendations of the best management practices within the locality and to improve the livelihood of smallholder farmers.

Author Contributions: Conceptualization, D.P.; Methodology, D.P. and B.T.; Software, D.P., B.T. and S.D.; Validation, D.P., B.T. and R.B.O.; Formal Analysis, D.P.; Data Curation, B.T. and D.C.; Writing-Original Draft Preparation, D.P.; Writing-Review & Editing, D.P., B.T., R.B.O., S.D. and D.C.

Funding: The authors received no specific funding for this work.
Acknowledgments: The authors would like to thank Cube Info Company Pvt. Ltd., Kathmandu and Esteem Info Company Pvt. Ltd., Kathmandu, Nepal for providing access and assistant with the datasets. Also thanks to the National Land Use Project, Ministry of Land Reform and Management, Government of Nepal for their supports. The residents of the study area who supported and provided valuable information are deeply acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

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