

Original Research

Effects of Land Cover/Use Change and Altitude on Soil NPK Nutrients in Selected areas in the North West Region of Cameroon

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Abstract

Land-use change is one of the main indicators of soil quality. Soil physical and chemical properties vary with land use change and altitude as inferred from transect surveys and toposequences. Soil nitrogen, phosphorus, and potassium (NPK) are essential macronutrients for plant growth and soil nutrient balance. Their presence in the soil in appropriate quantities is important for maintaining crop yields and farmers income, particularly in developing countries where resources of soil chemical additives may be limited. This paper assesses the effects of land cover/use change and altitude on soil NPK nutrients in plots of 30 m² in the North West Region of Cameroon for maintaining soil NPK levels and boosting crop yields. A total of 60 soil samples were collected at the 0-20 cm depth from the plots with various land cover/use types (eucalyptus plantation, farmland, grazing land, and natural forest). Soil samples were analyzed for nitrogen (N), phosphorus (P), and potassium (K) contents based on standard procedures. The concentrations of soil NPK nutrients were below the critical values for different land use types and the studied sites. The decline in soil NPK nutrient contents is partly linked to land use change, long-term nutrient mining through crop harvest, and rainfall-induced leaching of N and K nutrients. To increase food crop yields and sustain the livelihood of farmers, appropriate nature-based solutions of manure application, mulching, the



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intercropping of legumes, and sustainable use of appropriate chemical NPK fertilizers will help restore the soils and increase crop yields.

Keywords

Crop yield gaps; food security; land use change; NPK; soil fertility decline; topographic variations

1. Introduction

Globally, the land becomes an integral part of human survival and development [1], as soils have played pivotal roles in the Earth's ecosystem for decades [2]. Population growth and demand pressures alongside human activities have progressively threatened this renewable resource [3], upon which humans rely to meet their spiritual, social, material, environmental, and cultural needs [1]. Land use and soil management practices, climatic conditions, the degree of soil development, cultivation intensity, and the parent materials from which the soil is formed, among others, have caused environmental degradation, inhibiting sustainable agricultural production to the extent that urgent remedial actions are required to minimize the decline in soil quality and subsequently in the fertility which is a major development challenge [4]. Characterizing spatial variability of soil nutrients in relation to site properties, including climate, land use, landscape position, etc., is important for understanding how ecosystems work and also assessing the effects of future land use changes on soil nutrients [5]. Agricultural land use and management practices may affect soil properties, which play critical roles in sustaining crop production [6]. Altitude is a determining factor of ecosystem services and processes in mountains [7]. Knowledge of soil resources and their agricultural potentials as important factors for sustainable agricultural land use planning and management are required [8, 9].

Soil fertility in Africa is under pressure, as an increasing number of farmers attempt to make a living based on what the land can offer to grow plants [10]. Soil fertility challenges in Sub-Saharan Africa can be very serious, as large areas in Africa are characterized by strongly acid soils with aluminum toxicity [2] which are limiting to crop growth. Deteriorating soil fertility, associated with nutrient depletion and unsustainable cropping practices, has been widely reported across Tropical Africa. Improving food security in Africa would require a good understanding of the yields of farming systems as well as reducing yield gaps [11]. In Cameroon, soil fertility status is the backbone on which all input-based high agricultural production systems can be built [12]. Soil quality highly estimates crop yields since plants, like other living organisms, require nutrients for their growth, development, and reproduction [13]. However, soil fertility has declined as a result of poor and unimproved farming practices, such as excessive use of agrochemicals, intensive shifting cultivation, slash-and-burn cultivation practices, induced leaching, and soil erosion. Therefore, crops grown with an inadequate supply of nutrients cause soil fertility deterioration and the emergence of multi-nutrient deficiencies under intensive farming systems in this area [14]. Continuous cropping under such systems has led to nutrient mining, further soil fertility decline, and keeping farmers in a poverty trap via crop yield decline.

In the North West Region of Cameroon, increased intensive cropping without sufficient organic and mineral inputs is commonplace. This deteriorates the functional or productive capacity of the soil as a result of negative changes in its physical, chemical, biological, and hydrological properties. Thus, it is necessary to adopt soil fertility management practices to remove constraints associated with soil fertility through intensification of campaigns for green manures, organic manures, and composts, and judicious use of chemical fertilizers [14]. Nevertheless, soil fertility management practices in this region cannot be promoted without an appropriate and rapid assessment of soil nutrient status so that decision-makers and farmers can be careful about the soil fertility problems and thus accordingly make rational decisions to improve crop yields and better manage soil nutrients. According to [15], soils are exposed to six types of land uses in the North West Region of Cameroon, and the constant loss and conversion of forest to farmland critically influence human vulnerability, landscape design, biodiversity, and atmospheric environment, as well as the sustainability of resources. [16] reported that altitudinal gradients directly affected soil characteristics which in turn had an impact on the soil-water-plant relationships. Therefore, it is vital to assess the spatial variability of soil properties to arrive at the best management decisions, such as the selection of appropriate fertilizer doses, as well as the methods and frequency of its application [17]. Few studies [15, 18] have evaluated the variability of soil essential nutrients with land use change and altitude in the Western Highlands of Cameroon. The knowledge about the nutrient requirements of crops and soil nutrient status is vital for improving yields. This study looked into the effects of land cover/use change and altitude on soil NPK nutrients in selected sites of the North West Region of Cameroon. Soil NPK are essential macronutrients required for plant growth, and therefore a clear understanding of their appropriate quantities present is important for increasing yields in both subsistence and commercial farming systems alongside the farmers income. NPK are the three most indispensable and usually deficient elements for crop production in the tropics [19]. These soil properties vary widely with soil types, which in turn control water and nutrient uptake by plants [16]. We thus assessed the variability of soil NPK macronutrients across four land use types, namely eucalyptus plantation, farmland, grazing land, and forest in selected sites in the North West Region of Cameroon.

1.1 Study Area

The North West Region of Cameroon is surrounded by the Republic of Nigeria in the north and west, by the West and South West Regions in the south, and by the Adamawa Region in the east, covering a surface area of about 17,400 km² and extending between latitudes 5.45°N-9.9°N and longitudes 9.13°E-11.13°E [20]. The study areas are located in three altitudinal zones (Table 1, Figure 1).

Table 1 Location and topographic factors of the study sites in the North West Region of Cameroon.

Study sites	Latitude	Longitude	Altitude m (asl)	Elevation class
Baba II (Santa)	05°51' N	010°12' E	>1450	High
Bafut	05°58' N	010°09' E	850-1450	Mid
Babungo	06°03' N	010°28' E	<850	Low

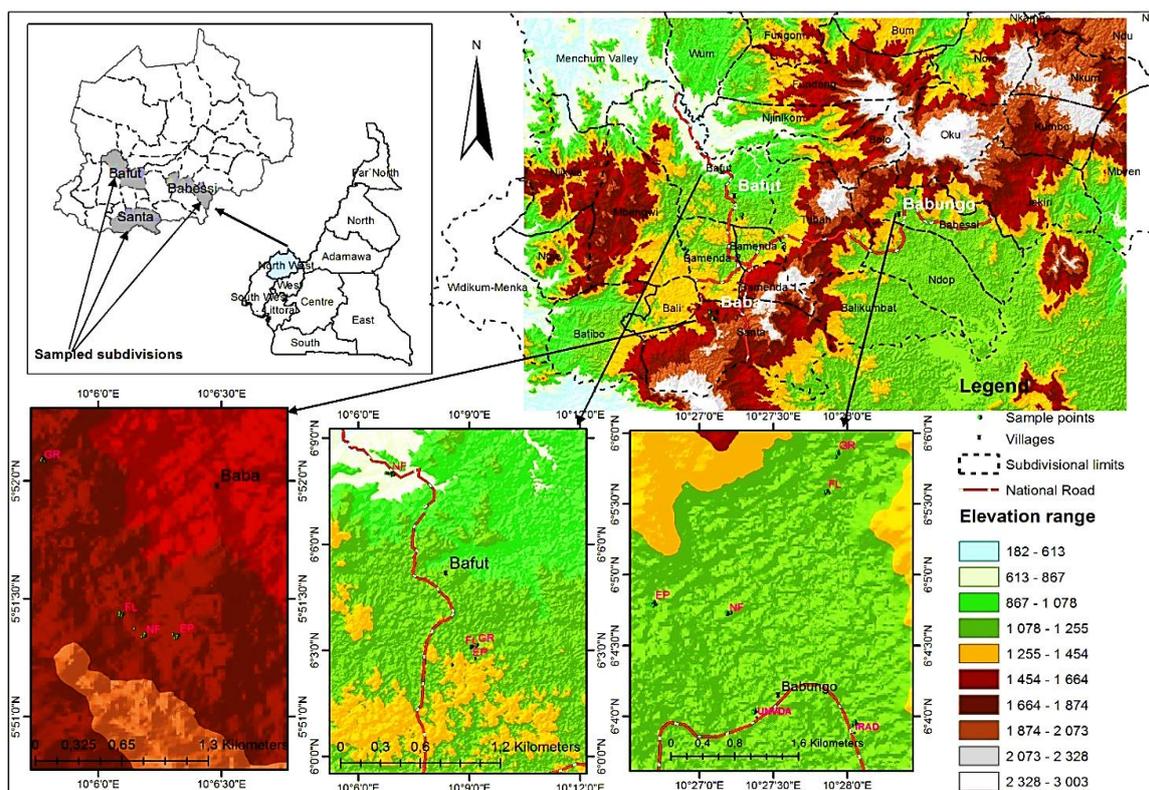


Figure 1 The location of selected sites and soil sampling points. **Note:** GR (Grassland or grazing land), NF (Natural Forest), EP (Eucalyptus plantation), FL (Farmland).

The three sampled communities represented specific altitudes in the North West Region, including the low altitude (< 850 m a.s.l.), the mid-altitude (850-1450 m a.s.l.), and the high altitude (> 1450 m a.s.l.) (Figure 1).

In Baba II (high altitude), there are young soils with some color changes that have rocks at very shallow depths and, thus, are Inceptisols [15]. These soils are highly weathered, red and yellowish-red, and with high content of iron and aluminum oxide. The clayey soil has a sandy loam texture and is acidic and generally deep without much horizon differentiation [15]. In this area, the soil is used for the cultivation of crops such as maize (*Zea mays* ssp.), beans (legumes), carrot (*Daucus carota* subsp. *Sativus*), green beans (*phaseolus vulgaris*), huckleberry (*Solanum* sp.), and a wide variety of garden crops.

In Bafut (mid-altitude), the distribution of soils is chiefly conditioned by topography and climate. The soil types range from Endisols, those that lack pedogenic horizons and occur on slopes, to Oxisols, which have deep dark red color, are clayey with sandy loam texture, well-structured, slightly acidic, and rich in organic matter, and contain little or no weathered minerals, with a fair to good fertility status [21]. In Babungo (low altitude), soils are alluvial and primarily formed through erosion due to the detachment, transport, and deposition of materials from surrounding hills. The high lava plateaux are covered by humid volcanic soils overlain by the basement complex.

The study sites have different climatic characteristics. In Bafut, the mean annual precipitation is 2657.2 mm, while the mean annual temperature is 22.3 °C, with a long rainy season from March to November and a dry season from December to February [22]. The ecology in this area varies from grasses mixed with deciduous shrubs and stunted trees to swampy valleys dominated by raffia bushes and palm trees [23], which are highly modified by human activities. Bafut is located within

the Bamenda Mountains along the Cameroon Volcanic Line, particularly along with the Wum-Tungoh sector, and comprises three main geological formations, including volcanic rocks, metamorphic rocks, and alluvial deposits [24]. The metamorphic rocks, mainly gneiss and schist, outcrop principally in the north, especially on slopes with high plateaux, and constitute the basement complex [9]. The relief is a rolling topography of hills and valleys extending to the flood plains of the River Mezam. Thus, red ferrallitic soils occur in the southern high plateau [9]. In the north, the majority of the hill slopes are covered by brunified soils, while alluvial soils are abundant in the Mezam River Valley [9]. Hydromorphic soils are common in swampy valleys [25-27]. Soils from recent lava flows, carrying andosol and laterite, occur in Babungo [28]. Guedjeo et al. [29] reported that Babungo is covered by plutonic rocks (granite and gneiss) and volcanic rocks (basalt, trachyte, and ignimbrite), while flooded plains are covered by alluvium. Santa (Baba) is characterized by three soil types, including the penevoluted ferrallitic soils in low-lying parts of Baligham, Santa, and Ndzong, modified orthic soils in highland areas of Akum, Baba, Mbu, and Awing, and the alitic and penevoluted ferrallitic red soils in the intermediate relief areas of Mbei and Pinyin [30]. The topography generally includes mountains extending to Mount Bamboutos in the southwest. Santa Highlands on the North West of the Bamboutos Range reaches its peak in Mount Lefo in Awing (2209 m), presenting an area of irregular relief configuration of highlands and valleys typical of a volcanic terrain [30]. The hydrogeological setting provides a configuration of river valleys that promotes market gardening.

2. Materials and Methods

2.1 Soil Sampling, Processing, and Chemical Analysis

This study was carried out in three phases, including fieldwork, laboratory, and data analysis (Figure 2).

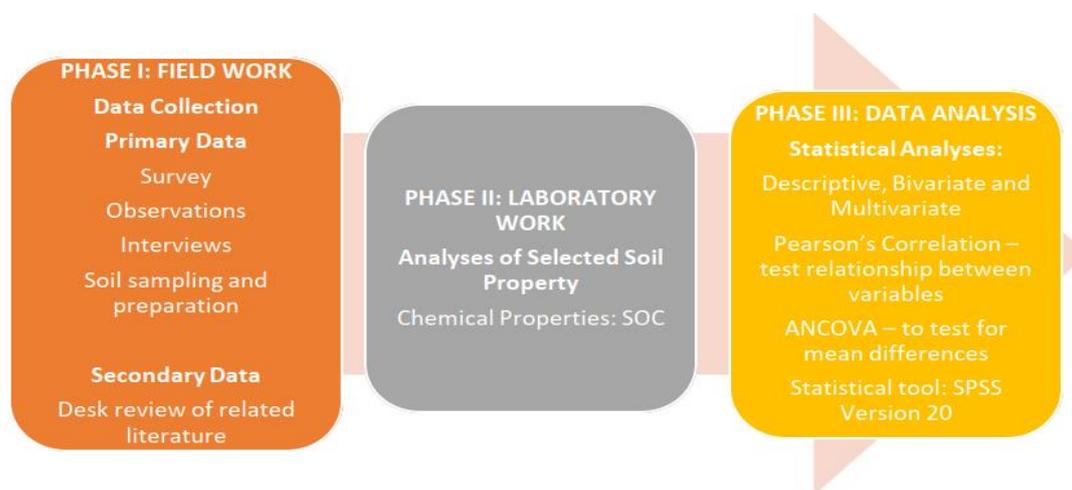


Figure 2 Schematic representation of materials and methods used in the study.

Materials used during the collection included zip-lock plastic bags, tape, metal, trowel, scale, and cups. Both the quantitative and qualitative models were employed to compare the differences in soil quality parameters under four different land use systems using the selected soil quality indicators (NPK) at three topographic locations for proxy assessment of land degradation. In the

selected study sites, 60 composite soil samples were collected at 0-20 cm depth from plots of 30 m² in Baba II, Bafut, and Babungo. These sites were chosen because they are agricultural lands with small-scale agriculture and varied land use practices, including limited control of plant diseases/pests, the use of basic tools and low fertilizer inputs, and low yields. Approximately 1 kg of the composite soil samples collected using the “Z” design, as described by Carter and Gregorich [31], was transferred to the Laboratory of Soil Analysis and Chemistry of the Environment (LABASCE), Dschang School of Agronomy and Agricultural Sciences. In the laboratory, soil samples were placed on plastic trays, air-dried at room temperature, crushed with a mortar, and passed through a 2-mm sieve before laboratory analysis. The Kjeldahl method was used to determine soil total nitrogen (TN), as described by Bashour and Sayegh [32]. For the extraction of available phosphorus from the soil solutions of 0.1 N HCl and 0.03 N NH₄F, the molybdenum blue method was used to determine phosphorus colorimetrically with ammonium molybdate solution, while potassium was determined on the Sherwood 410 Flame Photometer after preparing the standard solutions. To ensure future soil nutrient monitoring, we used the Garmin GPSmap 65s to collect the geographic coordinates (XYZ) of each sample point from the selected sites.

2.2 Data Analysis

The data were subjected to statistical analysis using Microsoft Excel 2007 and SPSS statistical package 20, while maps showing the areas where soil samples were collected were drawn using QGIS 3.14.1-1. Descriptive statistics, including bivariate and multivariate analyses (mean, frequency, percentage, standard error mean, and standard deviation), were used to analyze soil nutrients. The Pearson product-moment correlation was used to test the linear relationships between soil quality indicators. Analysis of covariance (ANCOVA) was employed to test the significant differences between the means of values obtained under different land use types and elevations.

3. Results and Discussion

3.1 Variations of Soil NPK Nutrients under Land Use Change and Altitude in Selected Sites

3.1.1 Variations of Total Nitrogen (TN) with Land Use Change and Altitude

Total nitrogen exhibited no statistically significant difference with elevation ($p > 0.01$) but was significantly different between various land use types ($p < 0.01$) and also for the between-subjects interaction effect ($p < 0.01$) (Table 2).

Table 2 Correlation matrix (r values) for the selected chemical soil properties in the study areas.

Soil trio	N (%)	P (ppm)	K ⁺ (cmol+)/kg
TN (%)	-		
P (ppm)	0.185	-	
K ⁺ (cmol+)/kg	0.233	0.276*	-

* Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

With regard to the mean values of soil NPK, we observed variations with different land use types (Table 3).

Table 3 Means of the estimated soil NPK nutrients at 0-20 cm soil depth.

Soil nutrients	Land use types					P-value
	Eucalyptus	Farmland	Grazing land	Natural forest	Total	
	Mean/SD	Mean/SD	Mean/SD	Mean/SD	Mean/SD	
TN (%)	0.248 ±0.110	0.260 ±0.109	0.243 ±0.074	0.298 ±0.078	0.262 ±0.096	0.393
P (ppm)	15.186 ±14.013	21.001 ±8.099	21.432 ±1.232	13.851 ±6.952	18.315 ±10.452	0.660
K ⁺ (cmol (+)/kg)	0.615 ±0.199	1.074 ±1.370	0.503 ±0.389	1.099 ±1.028	0.586 ±0.988	0.177

SD is the standard deviation, * represents the statistical significance at p < 0.05

At mid-altitude, soils had the highest fractions of TN under natural forest land cover (0.21%), followed by eucalyptus plantation (0.18%), while those under farmland had the lowest TN content (0.10%). No significant differences were found at this altitude and under LULC systems (Table 4).

Table 4 The variation of soil NPK nutrients at 0-20 cm depth across different LULC systems and altitudes.

Soil properties	Altitude (m)	Land-use types				ANOVA
		Under eucalyptus	Farmland	Grazing land	Natural forest	
TN (%)	High (>1500 m)	0.314 ±0.172	0.352 ±0.026	0.316 ±0.052	0.320 ±0.024	NS
	Mid (900-1500 m)	0.180 ±0.028	0.104 ±0.011	0.168 ±0.049	0.208 ±0.044	*
	Low (<900 m)	0.250 ±0.187	0.281 ±0.088	0.244 ±0.011	0.366 ±0.047	NS
Phosphorus (ppm)	High (>1500 m)	29.826 ±13.560	24.438 ±2.966	23.152 ±1.478	17.938 ±2.782	NS
	Mid (900-1500 m)	14.174 ±10.450	12.062 ±0.461	27.998 ±15.287	14.622 ±0.644	*
	Low (<900 m)	1.558 ±0.126	22.835 ±8.573	13.146 ±7.890	8.994 ±10.483	*
Ex.K ⁺ (cmol(+)/kg)	High (>1500 m)	0.736 ±0.150	1.038 ±0.075	0.914 ±0.445	2.260 ±1.010	NS
	Mid (900-1500 m)	0.560 ±0.236	0.262 ±0.059	0.338 ±0.095	0.304 ±0.114	NS
	Low (<900 m)	0.548 ±0.180	1.357 ±1.700	0.258 ±0.058	0.732 ±0.152	NS

Means within the same row followed by the same letters are not significantly different at 0.01 level. * Significant at P<0.01

Ns non-significant; TN total nitrogen; (Ex.) Exchangeable K⁺ Potassium

At high altitudes, the mean percentage of TN was high in soils under farmland (0.35%) but low in soils under eucalyptus plantation (0.31%). Altitude exhibited no statistical significance (P > 0.001) under LULC systems (Table 5). As expected, the mean values of TN were high in soils of forest land at all topographic classes because these soils had higher organic matter (OM) contents than soils under other land use types; this is in agreement with the findings of [33].

Table 5 The summary of ANOVA for Total Nitrogen, Phosphorous, and Potassium across different land cover/use types and altitudes.

Sources of variations	TN (%)		Phosphorous (ppm)			Ex.K ⁺ (cmol(+)/kg)	
	df	MS	P	MS	P	MS	P
Land use (LU)	3	0.011	0.093	203.070	0.024	1.099	0.257
Elevation (E)	2	0.141	0.000	812.550	0.000	3.839	0.011
LU * E	6	0.008	0.123	357.811	0.000	1.473	0.104
Error	58	0.005	-	59.888	-	0.793	-

MS is the mean square; P is the p-value; df is the degree of freedom

The relatively high TN content in farmland is linked to a high application rate of nitrogen fertilizer, while grazing land exhibited low TN content because the soils were sandy, thereby having limited nitrogen retention capacity, which is in line with the results reported by [34]. In accordance with the results of the study conducted by [35], the low TN content in farmland is due to the continuous decline in the soil OM content; thus, indicating the deficiencies of N, S, and P in low-input farming systems. In conformity with the results obtained by [36], TN content of the soils were high in natural forest but low in farmland at mid-altitude. Furthermore, the burning of grasslands resulted in the production of ashes rich in K, N, and other key nutrients in grazing lands. This could explain the presence of higher amounts of nitrogen in soils under grazing land use compared to those under farmland and eucalyptus plantation. Moreover, [15] confirmed that the high OM content in grazing lands from cow dung are strongly associated with high nitrogen content. At low altitudes, natural forestland had a very high TN content (0.37%), followed by farmland (0.28%), while grazing land showed the lowest TN value (0.24%), close to that found under eucalyptus plantation (0.25) (Figure 3).

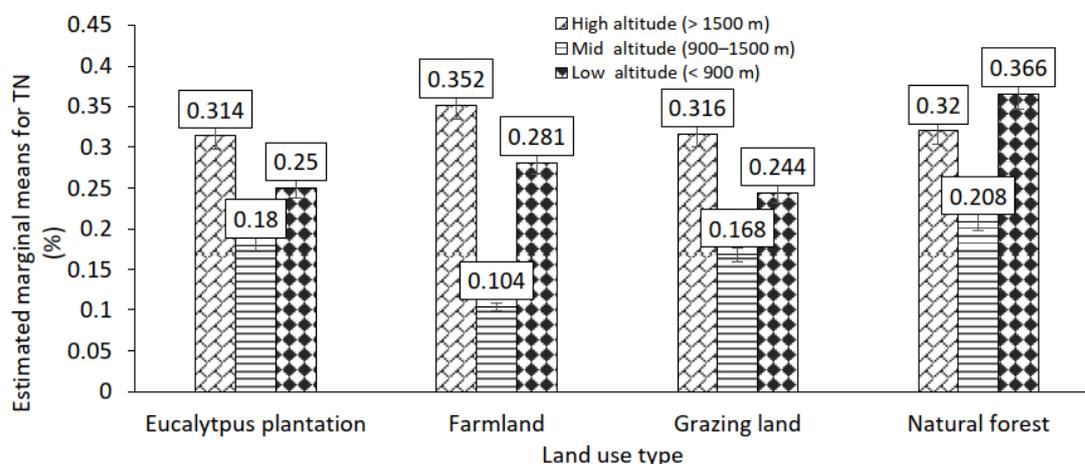


Figure 3 The estimated marginal means of Total Nitrogen (%) across different land cover/use types and altitudes.

The soil surface (0-20 cm) showed no significant difference ($P > 0.01$) among the soils under all LULC systems. Based on the value suggested by [37], the TN contents of soils under eucalyptus plantation, farmland, grazing land, and natural forestland were high at all elevations.

3.1.2 Phosphorous (P)

Soil available phosphorus showed statistically significant differences at different altitudes ($P < 0.001$) and also significant between-subjects interaction effect ($P < 0.001$) but no statistically significant difference between land use types ($P > 0.001$) (Table 2). The p-values for soils under eucalyptus plantation ranged from 1.56 ppm at low altitude to 29.83 ppm at high altitude. P contents decreased with decreasing elevation under eucalyptus plantation, farmland, and natural forestland, while they fluctuated for grazing land.

The results revealed variations at high altitudes where soils under eucalyptus plantation had the highest P content (29.83 ppm), followed by farmland (24.44 ppm), whereas grazing land and natural forestland had relatively lower P (23.15 ppm and 17.94 ppm, respectively) (Figure 4). There was no statistically significant difference between P content in all land use types ($P > 0.01$) at this altitude. The significant reduction in P contents in soils under natural forestland could be attributed to the transport of particulate P by erosion and runoff into streams and rivers, as well as the low-P status of the parent material [19].

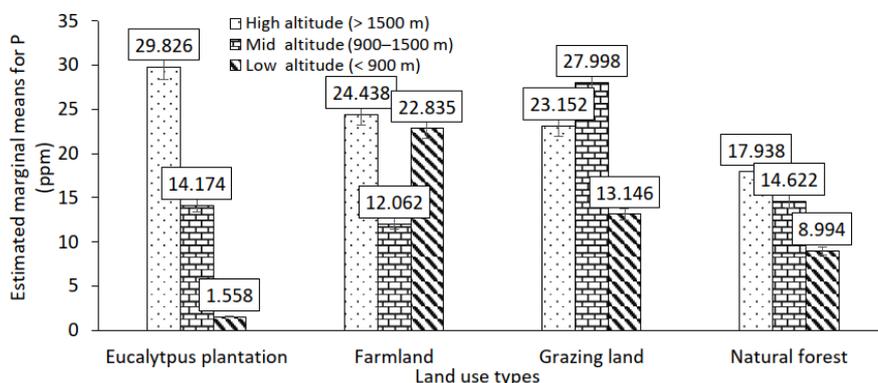


Figure 4 The estimated marginal means of phosphorus (ppm) across different land cover/use types and altitudes.

The results indicated that at the mid-altitude, soils under grazing land had the highest P content (28.00 ppm), followed by natural forestland (14.62 ppm), while eucalyptus plantation and farmland had relatively lower P content (14.17 ppm and 12.06 ppm, respectively). There was also no statistically significant difference between P content for all land cover/use types ($P > 0.01$) at this altitude, which indicates the inadequacy of available P in the soils under farmland, thereby limiting plant growth in both cultivated and uncultivated lands [38]. The frequent burning of grazing fields by cattle herdsman along with cow dung may account for the high P content in grazing lands. These findings correspond to those of the study carried out by Tellen and Yerima [15], who reported that burning resulted in the formation of ash deposits, which enhanced P concentration with an increased application rate of organic manure and P fertilizers.

At the low altitude, the highest P content was obtained under farmland (22.84 ppm), followed by grazing land (13.15 ppm). Soils under natural forestland and eucalyptus plantation had relatively lower P content (8.99 ppm and 1.56 ppm, respectively) (Figure 4). No statistically significant difference was observed between land use types ($P > 0.01$) at this altitude. The high P content in farmland may be due to the continuous application of P fertilizers in the soil by farmers. These

findings correlate with those obtained by [39]; [40, 41], who stated that P availability characterized in soils under farmland resulted from the high concentration of available P with the application of P fertilizers.

Furthermore, Voundi et al. [42] asserted that the burning of household and floral wastes and crop residues which produce wood ashes in soils under farmland, is a good source of P, K⁺, Ca²⁺, and Mg²⁺; thus, explaining the high P content in soils under farming systems where ‘Ankara’ (burning of grass within the soil) was practiced. Based on the rates obtained by Landon [43], available soil P in the study area ranged from low to high (1.56 ppm at high altitude to 29.86 ppm at low altitude) for eucalyptus plantation. This is in line with the results reported by many authors, including [44, 45], who stated that the availability of P in most soils of the North West Region of Cameroon was very low for all land use types due to the impacts of erosion, P-fixation, crop harvest, and inherently low-P status of the parent material.

3.1.3 Exchangeable Potassium (K⁺)

Exchangeable potassium (K⁺) varied but showed no statistically significant differences between different land use types ($P > 0.001$) and elevations ($P > 0.001$) and also for between-subjects interaction effect ($P > 0.001$) (Table 2). This variation occurred between 0.26 cmol (+)/kg to 2.20 cmol (+)/kg. The highest exchangeable K⁺ (2.20 cmol (+)/kg) was recorded under natural forestland use type at the high altitude, whereas the lowest (0.26 cmol (+)/kg) was obtained under farmland (2.20 cmol (+)/kg) at the mid-altitude (Figure 5). The exchangeable K⁺ of soils in the study area was within the range of very low to very high, according to the rates achieved by FAO [46]. At the high altitude, natural forestland and farmland had higher K⁺ values (2.20 cmol (+)/kg and 1.04 cmol (+)/kg, respectively) than eucalyptus plantation (0.91 cmol (+)/kg) and grazing land (0.74 cmol (+)/kg).

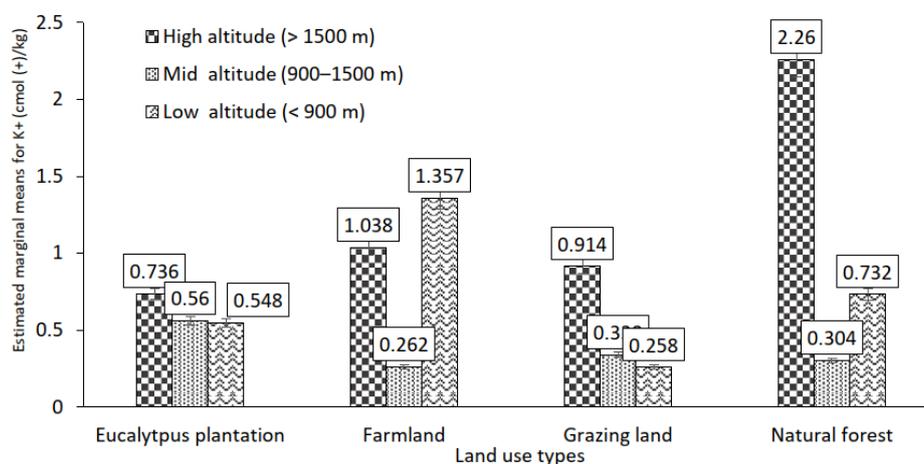


Figure 5 The estimated marginal means of potassium (cmol (+)/kg) across different land cover/use types and altitudes.

There was no significant difference ($P > 0.001$) between different land use types. This finding agrees with those obtained by [47], who stated that the relative pumping of K⁺ from the subsoil to topsoil by vegetation might account for the relatively high exchangeable K⁺ in soils in the natural forest system.

At the mid-altitude, eucalyptus plantation and grazing land had higher exchangeable K⁺ values (0.56 cmol (+)/kg and 0.34 cmol (+)/kg, respectively) than natural forestland (0.30 cmol (+)/kg) and farmland (0.26 cmol (+)/kg) (Figure 5). There was no significant difference (P > 0.001) in exchangeable K⁺ between different land use types (Table 3). The high clay content in soils under eucalyptus plantation explains the greater availability of K⁺ in soils, which is in line with the results published by [21], who stated that generally, soils with high activity of clay experience less severe K⁺ losses, and K⁺ from fertilizer application move into the deeper soil profile. [48, 49] also reported low exchangeable K⁺ in acidic soils under intensive cultivation.

At the low altitude, farmland and natural forestland had higher K⁺ values (1.36 cmol (+)/kg and 0.73 cmol (+)/kg, respectively) than eucalyptus plantation (0.55 cmol (+)/kg), and grazing land (0.26 cmol (+)/kg). There was no significant difference (P > 0.001) in K⁺ between different land use types. As a result of common burning practices of household wastes and farm residues, wood ash increased K⁺ contents in farmland; this corroborates with the results reported earlier [47].

Generally, the variations of K⁺ were consistent; K⁺ value decreased with decreasing altitude, except for farmland where irregularities, resulting from intensive cultivation, weathering, the use of acid-forming inorganic fertilizers such as nitric and sulfuric acid, and also from decaying organic matter and oxidation of ammonium and sulfur fertilizers, were observed. Strongly acidic soils are usually formed as a result of the activity of these strong organic and inorganic acids. This finding agrees with the study of [50], which found that these factors affect K⁺ distribution and enhance depletion in the soil system. Another study [51], also revealed that soil management practices, particle size distribution, degree of weathering, mineralogy, climatic conditions, soil development, cultivation intensity, and the parent material from which the soil is formed, determine the variation of K⁺ distribution.

3.2 Variability of Soil NPK Nutrients and Implications on Crop Nutrient Requirements

This study assessed the variation in properties of LULC and the mean percentage of these properties at 0-20cm depth. The findings showed no significant difference (P > 0.01) between the soils under some LULC systems for NPK. This partly implies the deficiencies of soil NPK macronutrients which are also limiting crop growth. Table 6 shows the critical values of soil NPK macronutrients required for crop growth.

Table 6 Critical values of soil NPK macronutrients for determining crop nutrient requirements.

Properties	Critical values				
	Very low	Low	Medium	High	Very high
K (cmol/kg)	< 0.1	0.1-0.3	0.3-0.6	0.6-1.2	>1.2
Bray 2-P (mg/kg)	< 7	7-16	16-46	>46	
Total N (%)	< 0.5	0.5-1.25	1.25-2.25	2.25-3.0	>3.0

Source: Adapted from the paper published by [52-54]

According to the rates obtained by [52-54], soil NPK macronutrients in the study areas displayed variations based on land use types and altitudes. On the one hand, soil N content was very low in all land uses and altitudinal classes, implying the dire need for the application of NPK fertilizers in

this area to boost yields. On the other hand, P content varied and ranged from very low to medium at different altitudes and in different land uses as a result of erosion and inherent low-P status of the parent material. Finally, the values of K content showed consistent variations with decreasing elevation, ranging from very high to high with differences in farmlands, mostly due to human activities which caused the increased depletion of soil. This has been confirmed by similar studies conducted in the North West Region [55, 56]. These deficiencies are highly linked to the acidity of soils in this region as reported by [56]. P deficiency is partly explained by the long-term nutrient mining, inter-annual crop cultivation, increased soil erosion, and soil acidity [55], which are commonplace in the North West Region of Cameroon. The balanced high concentrations of NPK are needed for crop growth and obtaining high yields [55]. The amount of phosphorus absorbed by soils is highly related to those of exchangeable aluminum, total iron, and organic matter, as well as low pH [56, 57]. The deficiency of phosphorus (P) is especially the major limiting factor to crop productivity in tropical regions [58]. Nitrogen is highly mobile and therefore easily lost [56], thereby necessitating the continuous fertilizer application for crop growth and development.

4. Conclusion

This study revealed considerable soil NPK macronutrients variability in the study area across different altitudinal classes and land use types. The conversion of natural forest and grazing land to farmland and eucalyptus plantation greatly affected nitrogen, phosphorus, and potassium concentrations at different topographic profiles in the North West Region of Cameroon. These land use conversions, mainly caused by deforestation, significantly reduce ($P < 0.001$) the concentrations of soil NPK macronutrients particularly in farmlands, resulting in a series of issues associated with environmental and resource sustainability. Consequently, land use change combined with elevation class affected soil NPK nutrients, as observed in the selected sites. This study, therefore, provides baseline information on the selection of effective soil improvement methods and/or additives to increase the concentrations of soil NPK macronutrients and crop yields. Thus, a proper selection of appropriate NPK chemical fertilizer types and adequate application rates, the effective use of organic manures, land preparation, and cropping practices that increase pH, soil organic matter (OM) and organic carbon (SOC) content, whose presence are linked to that of soil macronutrients (NPK). It is therefore imperative to further investigate the suitability of different types of chemical fertilizers on various agricultural plots for the judicious use of suitable types of soil NPK fertilizers by farmers and their required quantities, as well as appropriate timing. This would help to reduce crop yield gaps and improve farmers income and livelihood in rain-fed cropping systems.

Author Contributions

Mbibueh designed the research, did data collection and wrote the manuscript with Fokeng. Tume did the statistical data analysis, edited and improved the manuscript.

Competing Interests

The authors have declared that no competing interests exist.

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