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Understanding the effect of shifting cultivation practice (slash-burn-cultivation-abandonment) on soil physicochemical properties in the North-eastern Himalayan region

Entendiendo el efecto de la agricultura itinerante (tala-quema-cultivo-abandono) en las propiedades fisico-químicas del suelo en la región del Noroeste del Himalaya

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Abstract

Shifting cultivation (jhum cultivation), a common practice of converting forest land into agricultural land by slash and burn is threatening the ecosystem. This study assesses the effect of shifting cultivation cycles on soil quality in the North-eastern Himalayan region using a minimum of soil properties. To achieve this goal, a soil quality index (SQI) approach and multivariate techniques were used for surface (0-30 cm) and subsurface (30-70 cm) layers of soils in the forest, jhum land, and jhum fallow areas. The highest variability among land uses was found for clay content, SOC (soil organic carbon), exchangeable Mg and K, CEC (cation exchange capacity), and the Ca/Mg relationship. On the contrary, the lowest variation was recorded in bulk density (BD), porosity, and pH. The results of the principal component analysis (PCA) show BD, soil texture, available nitrogen (Nav), available phosphorus (Pav), available potassium (Kav), calcium (Ca) and sodium (Na) as the major indicators of soil quality. The study indicated that surface layers of forest soils have a lower soil quality when compared to jhum lands. Although jhum lands show a better soil quality compared to forests, their continued cultivation without any fertilisation and subsequent depletion of the soil nutrients can cause a degradation of soil quality as observed in jhum fallow lands. The use of these selected indicators for soil quality assessment was useful in terms of saving time and costs.

Keywords: Land management; traditional agricultural systems; jhum; forest; soil quality index.

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Resumen

La agricultura itinerante (*jhum*), una práctica común para convertir tierras forestales en tierras agrícolas mediante la tala y quema, podría amenazar la provisión de servicios ecosistémicos. El presente estudio tuvo como objetivo evaluar el efecto de los ciclos de cultivo itinerante sobre la calidad del suelo en la región del noreste del Himalaya utilizando el mínimo número posible de propiedades del suelo. Para lograr este objetivo, se utilizó un enfoque de índice de calidad del suelo (SQI) y técnicas multivariadas para horizontes superficiales (0-30 cm) y subsuperficiales (30-70 cm) de suelos en las áreas de bosque, tierras cultivadas y barbecho. La mayor variabilidad entre los usos de la tierra se encontró para el contenido de arcilla, CO (carbono orgánico del suelo), Mg y K intercambiables, CEC (capacidad de intercambio catiónico) y relación Ca/Mg. Por el contrario, la menor variación se registró en densidad aparente (BD), porosidad y pH. Los resultados del análisis de componentes principales (ACP) mostraron BD, textura del suelo, nitrógeno disponible (Nav), fósforo disponible (Pav), potasio disponible (Kav), calcio (Ca) y sodio (Na) como los principales indicadores capaces de explicar la calidad del suelo. Los resultados indicaron que las capas superficiales de los suelos forestales tienen una menor calidad de suelo en comparación con las tierras cultivadas. Aunque las tierras cultivadas muestran una mejor calidad del suelo en comparación con los bosques, su cultivo continuo sin fertilización y el consiguiente agotamiento de los nutrientes del suelo pueden causar una degradación de la calidad del suelo como se observa en las tierras en barbecho. El uso de estos indicadores seleccionados en la evaluación de la calidad del suelo fue útil en términos de reducción en el costo y el tiempo de análisis.

Palabras clave: Gestion de tierras; sistemas agrícolas tradicionales; *Jhum*; Bosque; Índice de calidad del suelo.

1. Introduction

Soils are key resources for human activities and natural ecosystems (Rodrigo-Comino, López-Vicente, et al., 2020), therefore establish suitable indicators to assess their quality has been key for scholars around the world such as in the Mediterranean belt (e.g. Ceccarelli, Bajocco, Perini, & Salvati, 2014; Colantoni, Ferrara, Perini, & Salvati, 2015; Sánchez-Navarro et al., 2015). However, due to the wide ranges of human activities and under an eminent climate change that modifies the main soil physicochemical properties, a clear regional methodological approaches still non-well known (Assefa, Elias, Soromessa, & Ayele, 2020; Coyle et al., 2017; Gbejewoh, Keesstra, & Blancquaert, 2021). For example, the process of converting the forest land by slash and burn into annual crops called “shifting cultivation” (Singh, Bordoloi, Kumar, Hazarika & Parmar et al., 2014). This is a common practice carried out in Africa, Asia and Latin America and able to contribute to 70, 50 and 16% of the total deforestation, respectively (FAO, 1957; Inoue et al. 2010; Chaplot, Bouahom & Valentin, 2010).

The Northeastern Himalayan (NEH) region of India is characterized by unique agro-ecological conditions, which makes it the centre of speciation for many plant species (Mishra & Sarkar, 2020). It is one of the twelve biodiversity hot-spots in the world, having 65% of its area under forests and 16% under agriculture (Saha, Chaudhary & Somasundaram, 2012). The major agriculture practice and source of income in the NEH is the shifting cultivation locally known as *jhum* (Yadav, 2013). This shifting cultivation cycle is characterized by certain stages, starting from the selection of site, slashing and burning of native vegetation, crop cultivation from 1 to 2 years and leaving the land abandoned from 10 to 12 years. The same cycle is continuously repeated for so many decades but sometimes unfavourable changes in soil quality have been noticed. In the last few decades, specifically, shifting cultivation is leading to rapid changes in land uses in the Nagaland state of NEH (Patel, Karmakar, Sanjog, Kumar & Chowdhury et al., 2013; Chase & Singh, 2014).

The intensive crop cultivation with no external input from 2 to 4 years after slashing and burning the native forest is causing a significant decline in soil quality (Ayoubi, Khormali, Sahrawat & Rodrigues De Lima, 2011; Sarkar et al., 2015). For example, Handayani (2004) reported that the cultivated fields after the clearance in the tropical forest of Sumatra resulted in a high loss of organic matter, a reduction in labile carbon (C) pools and a drastically declining in biological activity. The continuous cultivation in deforested sites is also able to reduce soil cation exchange capacity (CEC), as it was demonstrated in Ethiopia (Mulugeta, Karlton, & Olsson, 2005; Nega & Heluf, 2009). Sulieman, Saeed, Hassaballa, & Rodrigo-Comino (2018) also reported the lower values of CEC and other soil properties in urban soils, due to intensive human interferences in Sudan. A reduction in these parameters can lead to various deleterious effects such as soil erosion, biodiversity loss, acidification, soil compaction, desertification and climate

change (Chase & Singh, 2014; Rodrigo-Comino, Terol, Mora, Giménez-Morera, & Cerdà, 2020; Salehi, Wilhelmsson, & Soderberg, 2008; Salvati, Bajocco, Ceccarelli, Zitti, & Perini, 2011).

The studies on the effects of forest conversion to temporary agricultural lands (*jhum*) on the dynamics of organic C stock and soil health have recently received the attention of policymakers and forest managers (IPCC, 2007). Earlier reports from the NEH region indicates that the cycle of conversion from the forest into *jhum* lands and from *jhum* land into fallow *jhum* territories show negatively influences on the physicochemical properties of soil, with a loss of soil organic carbon (SOC) (Ramakrishnan and Toky, 1981; Aruchalam, 2002). For example, Sarkar et al. (2015) reported an increase in the concentration of plant-available phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) after burning but a drastic decrease in SOC content. Ribeiro Filho, Adams, & Murrieta (2013) reviewed the literature published on this topic and discussed the soil variables used to evaluate the effect of the *jhum* cultivation. According to them, texture, structure, density, colour, retention of humidity, and temperature were considered as the main physical soil properties, meanwhile, pH, dynamics of macronutrients, CEC, SOM, total carbon (Total C) and total nitrogen (Total N) were the most important chemical ones. Thus, we can observe that inconsistent conclusions have been drawn from different studies because of the limits of the understanding of the effects of the *jhum* cycle on soil quality in both the short and long-term. Moreover, studies evaluating the influence of different land use on soil quality under tropical and sub-humid forest conditions are also limited (Enaruvbe & Atafo, 2019; Lohbeck, Poorter, Martínez-Ramos & Bongers, 2015; Poorter et al., 2015). Hence, it is important to evaluate the influence of the *jhum* cycle on soil quality, and specifically, in the NEH region of India, where it occupies 1.47 million hectares and mainly is practised by tribal communities.

Many kinds of soil quality indexes (SQI) have been developed to assess the soil quality under different land uses and climatic conditions across the world (e.g. Marzaioli, D'Ascoli, De Pascale, & Rutigliano 2010; Li, Zhang, Wang, & Yu., 2013; Rodrigo-Comino, Keshavarzi, Bagherzadeh & Brevik 2019). For example, Mishra et al. (2017) worked out the soil quality of *jhum* lands in comparison to tropical semi-evergreen forests of Nagaland in India, using PCA-LSF-SQIw (principal component analysis-linear scoring functions-weighted soil quality index) approach. These results demonstrated that these indexes can be applied to *jhum* areas. All of this information should be included as a useful tool to design suitable and effective land management plans by reducing the number of variables and conclusions obtained for each type of land use. However, there is a lack of information about that currently. We state that it is necessary to fill this gap considering the sustainable development goals and clear objectives to achieve land degradation neutrality by policymakers and stakeholders (Visser, Keesstra, Maas, de Cleen & Molenaar, 2019).

Given these facts, the current study aims to focus on studying the variability in soil properties under forest, *jhum* land, and *jhum* fallow land, using the minimum number of soil properties to assess the possible soil quality changes prior to designing a land management plan. To achieve this goal, a combination of multivariate statistical analysis and soil weighted quality indexes are applied in the NEH. We hypothesize that principal component analysis (PCA) and minimum dataset (MDS), in combination with additive and weighted index methods, are the best approaches to obtain useful information for policymakers and land managers at the first stage of a holistic and regional geographic evaluation.

2. Methods

2.1. Study area

The study was carried out in the Kohima district of Nagaland. Situated in the NEH region of India (25°40'–25°67' N, 94°07'–94°12'E), the district occupies an area of about 1,463 km². The elevation ranges from 690 to 1261 m a.s.l. The average annual rainfall is 1,831 mm, where 90% is distributed from May to October. The monthly mean temperature in the district ranges between 27–32 °C (Mishra, Jangir & Francaviglia, 2019). The majority of the forest areas are situated in the Kohima region and are classified as tropical wet evergreen forest. The major tree species of the selected forest sites (>25 years old) are *Alnus nepalensis*, *Duabanga grandiflora*, *Gmelina arborea*, *Grevillea robusta*, *Melia azadirachta*, *Macaranga denticulate*, and *Pinus kesiya*. In *jhum* lands, mainly it can be found the upland rice (*Oryza sativa*) which is cultivated under conventional practices such as dry seeding with no proper arrangement of sowing, water supply and weeding (Rathore, 2008). The other important species include maize (*Zea mays*), cowpea (*Vigna unguiculata*), Colocasia (*Colocasia esculenta*), chilli (*Capsicum annum*), pumpkin (*Cucurbita peto*), and brinjal (*Solanum melongena*). *Alnus nepalensis* is the unique tree that can be found in fallow *jhum* lands along, which is combined with common weeds (*Eleusine indica*; *Amaranthus viridis*; *Chromolaena*

odorata; *Mimosa pudica*; and *Imperata cylindrica*). On the other, the *jhum* fields selected in this study were one-year-old (cleared the previous year for cultivation). Finally, the fallow *jhum* lands were left as fallow for more than five years after cultivation. A brief description of sampling sites (Figure 1, prepared in Arc-GIS) is presented in Table 1. Soils can be classified as Acrisols (IUSS-WRB, 2015), and are derived from tertiary rocks, belongs to Barail and Disang series, respectively. The soils contain fine loamy to clay loam texture and with limited depth, usually characterized by low organic matter and base saturation. However, the accumulation of clay in the sub-surface horizon can be found.

2.2. Soil sampling and analysis

A total of 12 sites were randomly selected in the forest (5), *jhum* (4) and fallow *jhum* (3) lands and soil profiles were excavated, in mid-slope, up to bedrock to study the variability in soil properties (Figure 2). Fifty soil samples (horizon wise) were collected: 21 in the forest, 16 in *jhum* and 13 in *jhum* fallows. Replicated soil samples (three) were immediately stored in polyethene bags and subsequently processed before laboratory analysis.

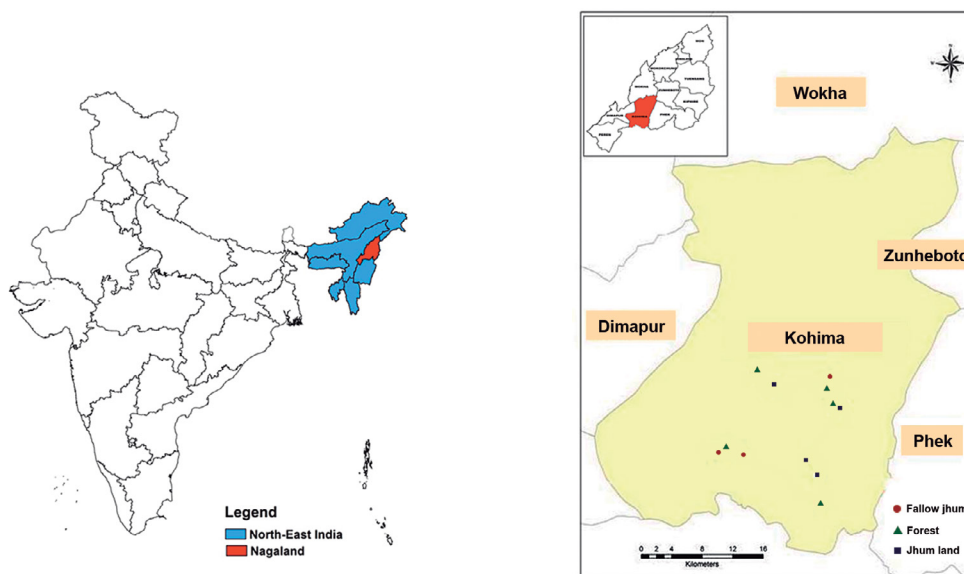
The samples were air-dried at room temperature (22°C) to constant weight and sieved through a 2-mm sieve to exclude litter, roots and coarse particles. The hydrometer method was employed for particle size analysis (Klute, 1986) to calculate clay, silt and sand contents. Bulk density (BD) was estimated by the core method (Blake and Hartge, 1986). Total porosity was calculated from the bulk density results assuming a particle density of 2.65 g cm⁻³ (USDA, 2004) Soil pH was determined in 1:2 soil-water suspensions using a digital pH meter. Soil organic carbon (SOC) (Walkley and Black, 1934), available phosphorus (Pav) (Bray & Kurtz, 1945), and available nitrogen (Subbiah & Asija, 1956) (Nav) was determined following the earlier described standard methods. Available potassium (Kav), cation exchange capacity (CEC) and exchangeable cations (Ca, Na, K, and Mg) were estimated by 1 N ammonium acetate (pH 7.0) method (Schollenberger and Simon, 1945; Summer and Miller, 1996). Base saturation (BS) was estimated as the ratio of total bases to CEC.

Table 1. Land use, label, size and geographical information of the studied sites

Land use	Label	Village	Geographic coordinates (Lat./Long.)	Altitude (m a.s.l.)	Major vegetation	Soil depth (cm)
Forest	FS1	Khonoma	25.64305556; 94.01719444	1,531	<i>Alnus nepalensis</i> , <i>Melia azadirach</i>	70
	FS2	Mariema	25.73411111; 94.05388889	1,296	<i>Grevillea robusta</i>	103
	FS3	Jakhama	25.57552778; 94.12863889	1,626	<i>Alnus nepalensis</i> , <i>Duabanga grandiflora</i> , <i>Gmelina arborea</i> , <i>Melia azadirach</i> , <i>Macaranga denticulate</i> , <i>Pinus kesiya</i>	118
	FS4	Chedma	25.6935; 94.14297222	1,426	<i>Grevillea robusta</i>	98
	FS5	Rusoma	25.71122222; 94.13558333	1,402	<i>Grevillea robusta</i>	92
<i>Jhum</i>	Jh1	Mariema	25.74566667; 94.08555556	1,300	Rice	70
	Jh2	Kewama	25.60925; 94.12419444	1,600	Rice	83
	Jh3	Chedma	25.68833333; 94.15102778	1,375	Beans, chili, <i>Colocasia</i>	78
	Jh4	Phesema	25.62672222; 94.11077778	1,625	Maize, pumpkin, <i>Colocasia</i>	73
Fallow <i>jhum</i>	FJh1	Khonoma	25.63577778; 94.00780556	1,854	<i>Eluesine indica</i> , <i>Amaranthus viridis</i> , <i>Chromolaena odorata</i> , <i>Mimosa pudica</i> , <i>Imperata cylindrica</i>	103
	FJh2	Khonoma	25.79792; 94.70644444	1,400	<i>Alnus nepalensis</i> , <i>Eluesine indica</i> , <i>Amaranthus viridis</i> , <i>Chromolaena odorata</i> ,	56
	FJh3	Rusoma	25.72533333; 94.13922222	1,458	<i>Alnus nepalensis</i> , <i>Chromolaena odorata</i> , <i>Mimosa pudica</i>	80

Own elaboration

Figure 1. Sampling point sites in different land use



Own elaboration

2.3. Data analysis

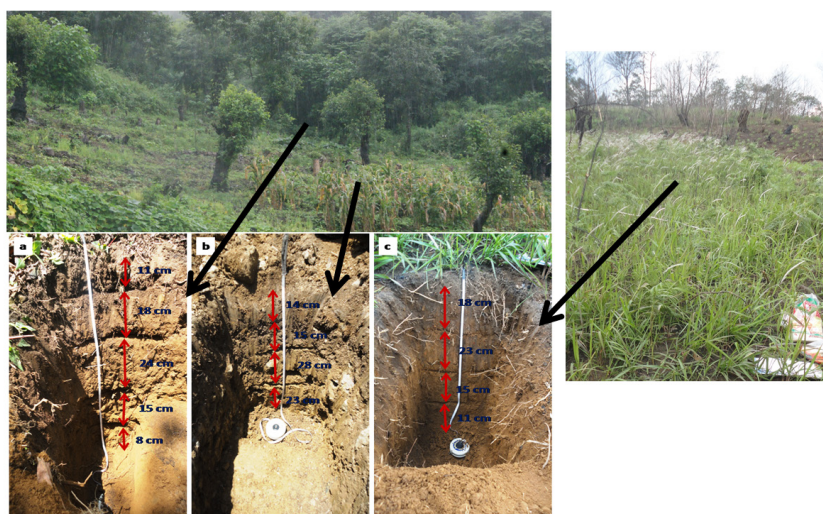
2.3.1. Descriptive statistics and variability analysis

General statistics parameters such as minimum and maximum values, mean, standard deviation, the coefficient of variation and skewness were calculated for each land use, using the whole soil profile data. To check the normality of the data, a Shapiro-Wilks test was also carried out. After that, the variability of the measured soil properties among land-use types was tested using a one-way analysis of variance (ANOVA) followed by Duncan's multiple range test ($p < 0.05$).

2.3.2. Soil quality index evaluation

As the depth of different horizons was not homogenized, so weighted mean of SQI values at two different depths (0-30 and 30-70 cm) was fixed. This will also represent the dynamic soil quality (0-30 cm), which is more influenced by anthropogenic practices, while, the inherent soil quality of the different land uses is represented by 30-70 cm depth. In Figure 2, soil profiles from the study sites are illustrated.

Figure 2. Excavated soil profiles (a: forest; b: *jhum* and c: fallow *jhum*)



Own elaboration

The dataset of the 17 soil physicochemical properties of each land use was subjected to PCA (Andrews, Karlen, & Mitchell, 2002; Liu, Zhou, Shen, Li, Liang, Wang, & Sun, 2014). The objective of PCA was to reduce the dimension of data while minimising the loss of information (Armenise, Redmile-Gordon, Stellacci, Ciccarese, & Rubino, 2013). After running the PCA, the soil variable with high eigenvalues in each principal component (PC) under each land use is included in the minimum dataset (MDS) and considered best representatives explaining the variability (Andrews et al., 2002). Then, linear scoring functions (LSFs) were used to transform the selected variables, by arranging them in ascending order ('more is better' function) or descending order ('less is better' functions) (Andrews, Flora, Mitchell, & Karlen, 2003). Later, the additive and weighted SQI was calculated using the methodology described by Vasu et al. (2016). All tests were performed using SPSS Version 16.0 (IBM Corporation, Armonk, NY).

3. Results

3.1. Soil properties under different land use

Physical and chemical soils properties from forest, *jhum*, and fallow *jhum* are presented in Suppl. Material 1, 2 and 3, respectively. Also, in suppl. material 4, 5 and 6, the variation of soil properties along the soil profiles are depicted. Among the three different land-use types, a higher mean value of BD is recorded in the *jhum* lands (1.06 Mg m^{-3}), followed by the forest (1.02 Mg m^{-3}) and the fallow *jhum* (0.90 Mg m^{-3}). The mean clay content is higher (28.3%) in forest lands than *jhum* and fallow *jhum* (21.9 and 14.3%, respectively). Soils under fallow *jhum* are relatively more porous (66.2%) than the soils of the other two land uses. The forest soils register acidic to slightly acidic values (pH 3.56-6.25) in reaction, whereas soils of *jhum* land and fallow *jhum* are slightly acidic to neutral (Table 3 and 4). The mean value of SOC is the highest in fallow *jhum* (1.6%), followed by the forests (1.2%) and *jhum* lands (1.0%). However, under different land uses, the SOC content ranges from 0.4 to 3.1% (forest), 0.40 to 1.6% (*jhum*), and 0.4 to 3.2% (fallow *jhum*), respectively. A higher mean value of CEC is recorded in forests ($5.19 \text{ cmol (p+) kg}^{-1}$), followed by *jhum* ($4.46 \text{ cmol (p+) kg}^{-1}$) and *jhum* fallow ($3.97 \text{ cmol (p+) kg}^{-1}$). In the case of exchangeable cations, the value of Ca ($1.74 \text{ cmol (p+) kg}^{-1}$) K ($1.00 \text{ cmol (p+) kg}^{-1}$) and Ca: Mg (1.87) are the highest for forest soils, whereas fallow *jhum* has the highest Mg ($2.08 \text{ cmol (p+) kg}^{-1}$). Ex. Na content registers the maximum values ($0.85 \text{ cmol (p+) kg}^{-1}$) in *jhum* lands. Among the primary macronutrients, Nav ($418.68 \text{ kg ha}^{-1}$) and Kav ($256.65 \text{ kg ha}^{-1}$) content reach the maximum values in forest soils, whereas *jhum* land soils have more Pav content (27.96 kg ha^{-1}).

Table 2. Effect of land use on soil properties

Soil parameter (unit)	Forest Mean (\pm SD)	<i>Jhum</i> Mean (\pm SD)	Fallow <i>jhum</i> Mean (\pm SD)
BD (Mg m^{-3})	1.02 (\pm 0.13)	1.06 (\pm 0.11)	0.89 (\pm 0.08)
Silt (%)	25.7 (\pm 5.32)a	31.7 (\pm 6.84)a	42.7 (\pm 8.26)b
Clay (%)	27.0 (\pm 10.89)	21.8 (\pm 8.72)	14.7 (\pm 6.54)
Sand (%)	47.1 (\pm 15.45)	46.3 (\pm 9.97)	42.5 (\pm 14.19)
Porosity (%)	61.5 (\pm 5.00)	59.8 (\pm 4.27)	66.2 (\pm 3.30)
pH (1:2)	5.26 (\pm 0.49)	5.93 (\pm 0.63)	5.13 (\pm 0.69)
SOC (%)	1.2 (\pm 0.54)	1.0 (\pm 0.35)	1.6 (\pm 1.09)
Exch. Ca (cmol (p+) kg^{-1})	1.69 (\pm 0.82)	1.45 (\pm 0.29)	1.67 (\pm 1.06)
Exch. Mg (cmol (p+) kg^{-1})	0.87 (\pm 1.02)	1.61 (\pm 1.04)	2.11 (\pm 0.76)
Exch. Na (cmol (p+) kg^{-1})	0.70 (\pm 0.14)	0.85 (\pm 0.11)	0.58 (\pm 0.024)
Exch. K (cmol (p+) kg^{-1})	0.93 (\pm 1.02)	0.83 (\pm 0.34)	0.75 (\pm 0.25)
CEC (cmol (p+) kg^{-1})	5.39 (\pm 2.97)	4.46 (\pm 1.88)	3.93 (\pm 1.37)
Ca/Mg	1.87 (\pm 1.24)	1.14 (\pm 0.48)	0.93 (\pm 0.47)
Av. N (kg ha^{-1})	423.71 (\pm 58.15)	359.40 (\pm 46.65)	408.03 (\pm 138.62)
Av. P (kg ha^{-1})	26.80 (\pm 1.96)	27.96 (\pm 6.92)	26.07 (\pm 1.65)
Av. K (kg ha^{-1})	256.16 (\pm 53.00)	221.62 (\pm 22.28)	244.27 (\pm 11.94)

a and b indicate significant differences ($P < 0.05$) among different land uses. BD: Bulk density; SOC: Soil Organic Carbon; Exch. Ca: Exchangeable Calcium; Exch. Mg: Exchangeable Magnesium; Exch. Na: Exchangeable Sodium; Exch. K: Exchangeable Potassium; CEC: Cation Exchange Capacity; BS: Base Saturation; Av. N: Available Nitrogen; Av. P: Available Phosphorus; Av. K: Available Potassium

Own elaboration

However, the results of ANOVA indicated that soil properties did not vary significantly ($p < 0.05$) among the land uses, except for silt particles ($F = 6.198, p = 0.020$). To confirm that, we used the coefficient of variation (CV) to assess the variability of soil properties in each land use. Clay, SOC, CEC, BS, and Ca/Mg register the highest variability ($CV > 35\%$) in all three land-use types. In *jhum* fallow land, all the exchangeable cations (Ca, Mg, Na, and K) highly change, whereas, in forest land, Ca and K show a higher variability among exchangeable cations. Moreover, the variation is low ($CV < 0.15\%$) for BD, porosity, and pH in all the land uses.

3.2. Principal component analysis

The results of PCA for the forest, *jhum* and fallow *jhum* are presented in table 3, 4 and 5, respectively. In the forest, five PCs explained 85% of the total variance (Table 3). In PC 1, BD (-0.93), porosity (0.93) and exchangeable Mg (0.86) are the highest weighted properties. Among them, BD can be selected as an indicator of correlation among the highly weighed properties indicate that they are highly and significantly correlated. In PC 2, clay (0.93), sand (-0.95), and BS (0.79) were highly weighed and after correlation (Supplementary information Table S2) and is retained in MDS. Similarly, in PC 3, pH (-0.74), SOC (0.75), Ca: Mg (-0.74) and Nav (0.77) are highly weighed, but only Nav is included in MDS after they are found to be highly correlated. However, in PC 4 and PC 5, only exchangeable Na (0.91) and Pav (0.99) are highly weighed and hence retained in MDS. Thus, BD, sand, Nav, Exch. Na and Pav are the five soil quality indicators selected for evaluating soil quality under forest.

Table 3. Result of principal components, eigenvalues and component matrix variables of forest sites

Principal components	PC1	PC2	PC3	PC4	PC5
Eigen values	5.4	3.1	2.6	2.0	1.0
% variance	32.3	18.0	15.8	11.7	6.0
% Cumulative variance	32.3	51.1	66.9	78.7	84.7
Weightage factor	0.38	0.22	0.19	0.14	0.07
Factor loadings (Rotated component matrix)					
BD	-0.93*	-0.00	-0.20	0.17	0.06
Silt	0.02	0.65	0.23	-0.48	0.09
Clay	0.08	0.93	0.16	0.04	0.02
Sand	-0.07	-0.95*	-0.20	0.16	-0.05
porosity	0.93	0.00	0.20	-0.17	-0.06
pH	0.02	-0.10	-0.74	-0.05	-0.08
SOC	0.43	0.09	0.75	0.37	0.03
CEC	0.65	0.03	0.30	0.49	-0.03
Exch. Ca.	-0.65	0.03	0.06	-0.34	0.40
Exch. Mg.	-0.86	-0.21	0.26	-0.12	0.13
Ca:Mg	0.45	-0.05	-0.74	0.34	0.16
Exch. Na.	-0.06	-0.02	0.12	0.91*	0.03
Exch. K.	0.28	0.69	-0.11	0.58	-0.12
BS	-0.10	0.79	-0.21	0.44	-0.16
Av. N	0.27	0.07	0.77*	0.03	0.10
Av. P	-0.19	-0.01	0.08	0.02	0.92*
Av. K	0.61	0.42	0.15	0.48	0.18

*: factors identified as the indicators retained in the Minimum Data Set. PC: Principal components; BD: Bulk density; SOC: Soil Organic Carbon; Exch. Ca: Exchangeable Calcium; Exch. Mg: Exchangeable Magnesium; Exch. Na: Exchangeable Sodium; Exch. K: Exchangeable Potassium; CEC: Cation Exchange Capacity; BS: Base Saturation; Av. N: Available Nitrogen; Av. P: Available Phosphorus; Av. K: Available Potassium

Own elaboration

In the *jhum* land, five PCs explained 87.6% of the total variability. In PC 1, BD (-0.915), porosity (0.91), SOC (0.84), Ex. Mg (-0.77) and BS (0.90) were highly weighed properties (Table 4). The correlation among them indicate a significant relationship, hence, only BD is selected as an SQ indicator. From PC 2, sand (-0.80), silt (-0.78) and Ca/Mg (0.78) is selected and after the correlation analysis, sand is

retained in MDS. In PC 3, clay (0.82) and Kav (0.84) are highly weighted but, only Kav is chosen for MDS because of its relatively higher loading factor than clay. However, in PC 4 and PC 5, only exchangeable Ca (0.80) and Na (0.75) are highly weighted and retained in MDS. Thus, BD, sand, Kav, Exch. Ca and Na are selected in MDS for soil quality evaluation of the jhum land.

Table 4. Result of Principal components, eigenvalues and component matrix variables of Jhum sites

Principal components	PC1	PC2	PC3	PC4	PC5
Eigen values	7.0	2.8	2.5	1.3	1.1
% variance	41.4	16.7	14.7	8.0	6.6
% Cumulative variance	41.4	58.1	72.9	80.9	87.6
Weightage factor	0.4	0.1	0.1	0.0	0.0
Factor loadings (Rotated component matrix)					
BD	-0.91*	-0.05	-0.10	-0.26	-0.18
Silt	0.04	-0.78	-0.36	0.31	-0.10
Clay	-0.34	-0.13	0.82	-0.35	-0.16
Sand	0.24	0.80*	-0.36	0.02	0.22
porosity	0.91	0.05	0.10	0.26	0.18
pH	0.25	0.35	-0.12	0.65	0.40
SOC	0.84	-0.10	0.24	-0.03	-0.15
CEC	0.70	0.55	-0.12	0.18	0.12
Exch. Ca.	0.03	0.15	0.27	-0.80*	-0.09
Exch. Mg.	-0.77	-0.31	0.41	-0.13	-0.17
Ca:Mg	0.30	0.78	-0.22	0.33	-0.18
Exch. Na.	0.11	0.11	-0.06	0.07	0.95*
Exch. K.	-0.27	0.71	0.29	0.32	0.32
BS	-0.90	-0.04	0.32	0.10	-0.02
Av. N	0.37	0.34	-0.09	0.65	-0.19
Av. P	-0.68	-0.49	0.00	-0.07	0.18
Av. K	0.45	0.09	0.84*	-0.19	0.05

*: factor loadings considered highly weighed; asterisk: factors identified as the indicators retained in the Minimum Data Set. PC: Principal components; BD: Bulk density; SOC: Soil Organic Carbon; Exch. Ca: Exchangeable Calcium; Exch. Mg: Exchangeable Magnesium; Exch. Na: Exchangeable Sodium; Exch. K: Exchangeable Potassium; CEC: Cation Exchange Capacity; BS: Base Saturation; Av. N: Available Nitrogen; Av. P: Available Phosphorus; Av. K: Available Potassium

Own elaboration

In the *fallow* jhum lands, four PCs can explain 88% of the variability (Table 5). In PC 1, BD, porosity, Exch, Mg, and Kav are considered as highly weighed properties. Among them, BD is retained in MDS, showing after the correlation analysis a significant relationship. In PC 2, Exch. Ca, Na, Ca/Mg, and Nav is the selected properties. After observing the correlation results, Nav is only the selected variable. In PC 3, clay, Exch. K and BS are the most interrelated properties, but only clay is used in MDS. Finally, in PC 4, silt is the only highly weighed property, therefore, and it is also selected. Thus, BD, silt, clay and Nav are selected as soil quality indicators for the jhum fallow land.

Table 5. Result of Principal components, eigenvalues and component matrix variables of fallow *jhum* sites

Principal components	PC1	PC2	PC3	PC4
Eigen values	5.1	4.6	3.3	1.8
% variance	30.5	27.2	19.6	10.8
% Cumulative variance	30.5	57.8	77.4	88.3
Weightage factor	0.3	0.3	0.2	0.1
Factor loadings (Rotated component matrix)				
BD	-0.89*	-0.15	0.33	-0.03
Silt	-0.12	-0.04	-0.01	-0.95*
Clay	-0.11	0.14	0.90*	0.05

Sand	0.17	-0.07	-0.64	0.68
porosity	0.89	0.15	-0.33	0.03
pH	-0.48	-0.71	-0.27	0.22
SOC	0.66	0.67	-0.24	0.17
CEC	0.57	0.09	-0.53	0.37
Exch. Ca.	0.20	0.88	0.16	0.26
Exch. Mg.	0.75	0.05	0.43	0.43
Ca:Mg	-0.34	0.87	-0.16	0.00
Exch. Na.	0.22	0.77	0.43	-0.35
Exch. K.	-0.05	0.12	-0.82	0.41
BS	-0.03	0.37	0.80	0.08
Av. N	0.07	-0.91*	-0.10	-0.09
Av. P	0.60	-0.15	0.17	-0.58
Av. K	0.75	-0.33	0.38	-0.08

*: factor loadings considered highly weighed; asterisk: factors identified as the indicators retained in the Minimum Data Set. PC: Principal components; BD: Bulk density; SOC: Soil Organic Carbon; Exch. Ca: Exchangeable Calcium; Exch. Mg: Exchangeable Magnesium; Exch. Na: Exchangeable Sodium; Exch. K: Exchangeable Potassium; CEC: Cation Exchange Capacity; BS: Base Saturation; Av. N: Available Nitrogen; Av. P: Available Phosphorus; Av. K: Available Potassium

Own elaboration

3.3. Soil quality under different land uses

Additive and weighted SQIs (Table 6) for the soils in the three different land-use types are calculated to find out the impact of land uses on soil quality. For the surface soil layer, additive SQI shows the highest values as follows: *jhum* > forest > fallow *jhum*. For the subsurface soil (30-70 cm), the same trend is also observed. The weighted SQI of all the three-land use also follows the same trend as additive SQI. Moreover, in both additive and weighted index methods, the SQIs are similar for both surface and subsurface soils. In the surface soil, the mean value of both SQI is significantly different for three land uses. *Jhum* soils obtain the highest SQIs (3.90 and 0.78), followed by the forest (3.34 and 0.68) and fallow *jhum* (2.61 and 0.66). Similarly, mean SQI values significantly vary for surface and subsurface soil layers, but SQIs are not significantly different for the forest and *jhum*. However, fallow *jhum* has the lowest value of SQIs.

Table 6. Soil quality index (SQI) values for different land uses sites at two depths

Parameters	Forest			<i>Jhum</i>			Fallow <i>jhum</i>		
	ID	Depth (cm)		ID	Depth (cm)		ID	Depth (cm)	
		0-30	30-70		0-30	30-70		0-30	30-70
Additive index	FS1	3.27	3.48	Jh1	4.15	3.97	Fjh1	2.46	2.55
	FS2	3.14	3.02	Jh2	3.68	3.54	Fjh2	2.45	2.28
	FS3	3.55	3.63	Jh3	3.67	3.75	Fjh3	2.90	3.11
	FS4	3.15	3.44	Jh4	4.07	3.94	-	-	-
	FS5	3.59	3.51	-	-	-	-	-	-
	Mean (±SD)	3.34 (±0.21)b	3.42 (±0.23)b	Mean (±SD)	3.90 (±0.25)c	3.80 (±0.19)b	Mean (±SD)	2.61 (±0.25)a	2.64 (±0.42)a
Weighted index	FS1	0.66	0.71	Jh1	0.82	0.81	Fjh1	0.67	0.68
	FS2	0.65	0.63	Jh2	0.76	0.74	Fjh2	0.62	0.58
	FS3	0.74	0.75	Jh3	0.76	0.79	Fjh3	0.70	0.77
	FS4	0.70	0.76	Jh4	0.79	0.78	-	-	-
	FS5	0.69	0.69	-	-	-	-	-	-
	Mean (±SD)	0.68 (±0.03)a	0.70 (±0.05)ab	Mean (±SD)	0.78 (±0.02)b	0.78 (±0.02)b	Mean (±SD)	0.66 (±0.04)a	0.67 (±0.09)a

*For site labels see Table 1

Own elaboration

4. Discussion

4.1. Soil quality indicators

The soil physicochemical properties under three different land uses were evaluated for their capability to serve as potential indicators for monitoring soil quality changes due to shifting cultivation in the NEH region of India. Firstly, it is important to remark that we recorded the highest mean value of BD in *jhum* lands, followed by forest and fallows *jhum*, meanwhile, a reverse trend was observed for SOC content. These results were consistent with the findings of Sharma, Gairola, Ghildiyal, & Suyal (2010) who reported that BD and organic C were negatively correlated (-0.45) in soils of western Himalayas. Moreover, it is a well-established fact that BD and C are inversely proportional to each other (Post & Kwon, 2000; Pulido, Schnabel, Lavado-Contador, Miralles Mellado, Ortega & Pérez, 2013), as the lower value of BD in the soil is an indicator of higher SOM content and good aeration (NRC, 1981). Leskiw (1998) also reported that forest soils should be slightly acidic for proper nutrient supply. Similarly, soils under forest areas in our study were acidic to slightly acidic as compared to other land use. The variation observed in clay, SOC, Exch. cations and CEC under the studied land uses may be attributed to a combination of intrinsic factors such as weathering, erosion, deposition, and soil-forming processes and extrinsic ones such as management practices (Pulido et al., 2020; Vasu et al., 2016).

As many as twenty-one soil properties were suggested as potential indicators for soil quality evaluation under different ecosystems by earlier studies (Askari & Holden, 2015). However, the use of PCA showed to be a useful tool to reduce the possible number of variables. In this way, it is important to remark that the BD was repeated as MDS for all the land uses, indicating its effectiveness as an indicator for soil quality monitoring in the *jhum* cultivation system. The importance of BD as an SQ indicator was also indicated by Askari & Holden (2015) in their study in the grassland of Ireland, coinciding with other authors, because it plays an important role in the regulation of water transmission (Rawls et al., 1998) and root penetration (Pierce, Larson, Dowdy, & Graham 1983). The values of BD in the forest and fallow *jhum* were lower than the *jhum* lands and it generally increased according to the depth. Generally, BD increases with profile depth, due to the variation in organic matter content, porosity and compaction (Askari & Ozdemir, 2003; Chaudhari, Ahire, Ahire, Chkravarty, & Maity, 2013).

Soil texture was also reported as an important soil quality indicator in earlier studies (Brejda & Moorman, 2001; Cho, Zoebisch & Ranamukhaarachchi, 2004; Shukla, Lal, & Ebinger 2006). Our results were also consistent with these earlier studies, as sand was obtained for the forest and *jhum* as soil quality indicator, meanwhile, clay and silt were indicators for fallow *jhum*. Recently, Vinhal-Freitas, Correa, Wendling, Bobul'skác, & Ferreira. (2017) also reported the importance of soil textural classes in evaluating the soil functions and their quality, specifically, in tropical ecosystems like in our study area. The variation in textural classes among land uses was also reported in our study. According to Rao & Wagenet (1985), differences in clay content along the soil profile depth is the result of weathering, erosion, deposition, and soil-forming processes. In our case, possibly, this kind of variation can be also generated by these processes regarding the total rainfall and high mean temperatures.

In the current study, macronutrients (Nav and Pav) were obtained as the soil indicators for forest sites, while in *jhum* areas only Kav was selected as an SQ indicator. The significance of macronutrients in MDS can be attributed to their importance in sustaining plant productivity and soil fertility. As in this study, Kav and Nav were also selected as SQ indicators for restoration of degraded lands in the alpine region of the Qinghai-Tibetan Plateau of China (Dong et al., 2012). In *jhum* lands, Exch. Ca²⁺ and Na⁺ were also considered in PCA, while Na⁺ was selected for forest sites. Soil chemical properties, like CEC (Khaledian et al., 2017) and extractable anion and cations have been used as effective chemical indicators of soil quality. In most of the sites, the value of CEC was found to be decreasing with depth. These results are in the line with the findings of Khan and Kamalkar (2012), who reported that in upland soils, the values of CEC decrease with depth, due to its correspondence with the clay content (Bhaskar, Butte & Utpal Brauah, 2005).

4.2. Effect of land use on SQI

Deriving SQI from a concrete number of parameters, using PCA and MDS, was demonstrated as a useful approach to evaluate the sustainability of land use. The quality of the studied soils was influenced by land use and soil layers. In the surface layer (0-30cm), *jhum* land soils show better SQIs in comparison to the forest and fallow *jhum*. A higher value of additive and weighted SQI in *jhum* lands can be supported

by the fact that before the cultivation, vegetation was slashed and burned in fields, which increases the availability of nutrients (P, K, Ca and Mg) (Lungmuanaa et al., 2017) and results in a better fertility status in surface layers. Moreover, the ash of burned biomass releases alkaline cations which help in maintaining neutral pH level and the availability of soil nutrients (Dikici & Yilmaz, 2006). But as Granged, Zavala, Jordan & Moreno (2011) observed, these effects were short-term (8-12 months).

The relatively better quality of soils under shifting cultivation was also reported by other above-mentioned authors. However, this improved status of nutrients can decline in subsequent years, due to cultivation, leaching, runoff and soil erosion as registered by other authors in Mizoram state of India (Tawnenga, Shankar & Tripathi, 1997). The slightly lower value of SQI in the forest sites in comparison to the *jhum* ones can be supported by the fact that much of the nutrient reserve of tropical forests is stored in plant tissue but critical nutrient limitation will occur if biomass is removed (Dalling, Heineman, Lopez, Wright, & Turner 2016). A lower value of additive and weighted SQI in fallow *jhum* lands may be attributed to the fast growth of the second successive vegetation during the fallow period. In the fallow *jhum* lands, a soil recovery process takes place and over the years, organic matter, N, and CEC can increase (Mendoza-Vega & Messing, 2005). Also, the age of vegetation (shrub and perennial grass species) can determine the magnitude of the improvement in soil quality as Caravaca et al. (2003) observed in of Murcia Province of southeastern Spain. Our findings indicate that the conversion of forests into *jhum* lands will not hamper the soil quality in NEH. But the cultivation in subsequent years can make the soil more prone to erosion, compaction, degradation of physical attributes, SOC loss, and reduction in nutrient availability, which will go to reduce soil quality.

Finally, we can highlight some issues related to our consideration of analyzing our results separately instead of all together. Firstly, we considered that it is vital to compare three types of land uses, although inside each type of use we obtained by PCA high eigenvalues for PC1-5. The main goal was to find variables to distinguish sites as much as possible inside each type of use instead of between different type of use as it is common. To confirm with another method our hypothesis, we also use the SQI. In the future, we will consider the use of the whole data set (including all three types of use) to look for eigenvalues with lower values. Secondly, it would be interesting to use one dimension and not complexity data for modifying the application of the PCA in this study. The initial data matrix could be transformed. One possibility could be the centered log-ratio transformation to the working matrix $\text{clr}(x)$ as it was developed by Kholodov et al. (2019) according to the equation: $\text{clr}(x) = [\log\{x_1/g(x)\}, \dots, \log\{x_i/g(x)\}]$, where x would denote the initial data, and $g(x)$ their geometric mean. Perhaps because the matrix transformation was not carried out our results were based on specific agronomic factors such as BD with one of the smallest variation coefficient.

5. Conclusions

We identified that BD, soil texture, Nav, Pav, Kav, Exch. Ca and Na is the major indicators of soil quality in NEH, India. The use of these selected indicators in soil quality assessment was really useful in terms of reduction in analysis cost and time. The study indicated that surface layers of forests soils have a lower soil quality when compared to the *jhum* lands. Although the *jhum* lands show a better soil quality compared to forests, their continued cultivation without fertilization and subsequent depletion of the soil nutrients can cause a degradation of soil quality as observed in the fallow *jhum* lands. However, further studies, including some biological indicators such as enzyme activities and microbial counts would be needed to better understand the complexity of shifting cultivation and to assess the soil functions in the studied region and design effective and correct land use management plans.

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Appendix

Appendix 1. Descriptive statistics of soil properties used for soil quality assessment in forest areas

Variable (unit)	Min	Max	Mean	Std. dev	CV	Skewness
BD (Mgm ⁻³)	0.76	1.31	1.03	0.13	0.12	0.43
Silt (%)	18.1	38.2	26.4	6.0	0.2	0.6
Clay (%)	15.0	53.3	28.2	1.3	0.4	0.6
Sand (%)	21.8	66.2	45.2	15.2	0.3	-0.0
Porosity (%)	50.7	71.3	61.3	4.7	0.0	-0.4
pH (1:2)	3.56	6.25	5.29	0.60	0.11	-1.17
SOC (%)	0.4	3.1	1.1	0.6	0.6	1.5
Exch. Ca (cmol (p+) kg ⁻¹)	0.71	3.70	1.74	0.88	0.50	0.99
Exch. Mg (cmol (p+) kg ⁻¹)	0.25	3.38	1.87	0.80	0.66	1.33
Exch. Na (cmol (p+) kg ⁻¹)	0.36	0.93	0.70	0.18	0.26	-0.56
Exch. K (cmol (p+) kg ⁻¹)	0.27	3.07	1.00	1.03	1.03	1.32
CEC (cmol (p+) kg ⁻¹)	1.79	16.29	5.19	3.57	0.69	1.78
BS (%)	7.1	58.3	21.1	12.4	0.6	1.6
Ca/Mg	0.65	5.21	1.87	1.24	0.66	1.55
Av. N (kg ha ⁻¹)	224.00	638.62	418.68	97.70	0.23	0.11
Av. P (kg ha ⁻¹)	19.68	38.50	27.02	4.69	0.17	0.90
Av. K (kg ha ⁻¹)	112.00	336.00	256.65	67.44	0.26	-0.35

BD: Bulk density; SOC: Soil Organic Carbon; Exch. Ca: Exchangeable Calcium; Exch. Mg: Exchangeable Magnesium; Exch. Na: Exchangeable Sodium; Exch. K: Exchangeable Potassium; CEC: Cation Exchange Capacity; BS: Base Saturation; Av. N: Available Nitrogen; Av. P: Available Phosphorus; Av. K: Available Potassium

Own elaboration

Appendix 2. Descriptive statistics of soil properties used for soil quality assessment in *jhum* land

Variable	Min	Max	Mean	Std. dev	CV	Skewness
BD (Mg m ⁻³)	0.93	1.32	1.06	0.11	0.11	1.27
Silt (%)	18.5	49.6	31.7	10.0	0.3	0.5
Clay (%)	6.7	41.0	21.8	9.4	0.4	0.1
Sand (%)	26.5	63.5	46.3	11.3	0.2	-0.1
Porosity (%)	50.1	64.9	59.8	4.2	0.0	-1.2
pH (1:2)	4.55	7.05	5.9	0.73	0.12	0.11
SOC (%)	0.4	1.6	1.0	0.4	0.4	-0.0
Exch. Ca (cmol (p+) kg ⁻¹)	0.99	2.19	1.46	0.37	0.25	0.89
Exch. Mg (cmol (p+) kg ⁻¹)	0.72	4.40	1.61	1.04	0.42	1.81
Exch. Na (cmol (p+) kg ⁻¹)	0.61	1.72	0.85	0.26	0.30	2.84
Exch. K (cmol (p+) kg ⁻¹)	0.38	1.64	0.84	0.37	0.45	0.86
CEC (cmol (p+) kg ⁻¹)	1.75	7.26	4.46	1.90	0.43	0.10
BS (%)	8.6	55.6	25.2	14.9	0.5	0.9
Ca/Mg	0.31	1.65	1.14	0.48	0.42	-0.52
Av. N (kg ha ⁻¹)	246.40	456.96	359.39	63.51	0.18	-0.32
Av. P (kg ha ⁻¹)	11.54	38.90	27.96	7.14	0.26	-0.55
Av. K (kg ha ⁻¹)	168.80	272.00	221.63	29.78	0.13	-0.14

BD: Bulk density; SOC: Soil Organic Carbon; Exch. Ca: Exchangeable Calcium; Exch. Mg: Exchangeable Magnesium; Exch. Na: Exchangeable Sodium; Exch. K: Exchangeable Potassium; CEC: Cation Exchange Capacity; BS: Base Saturation; Av. N: Available Nitrogen; Av. P: Available Phosphorus; Av. K: Available Potassium

Own elaboration

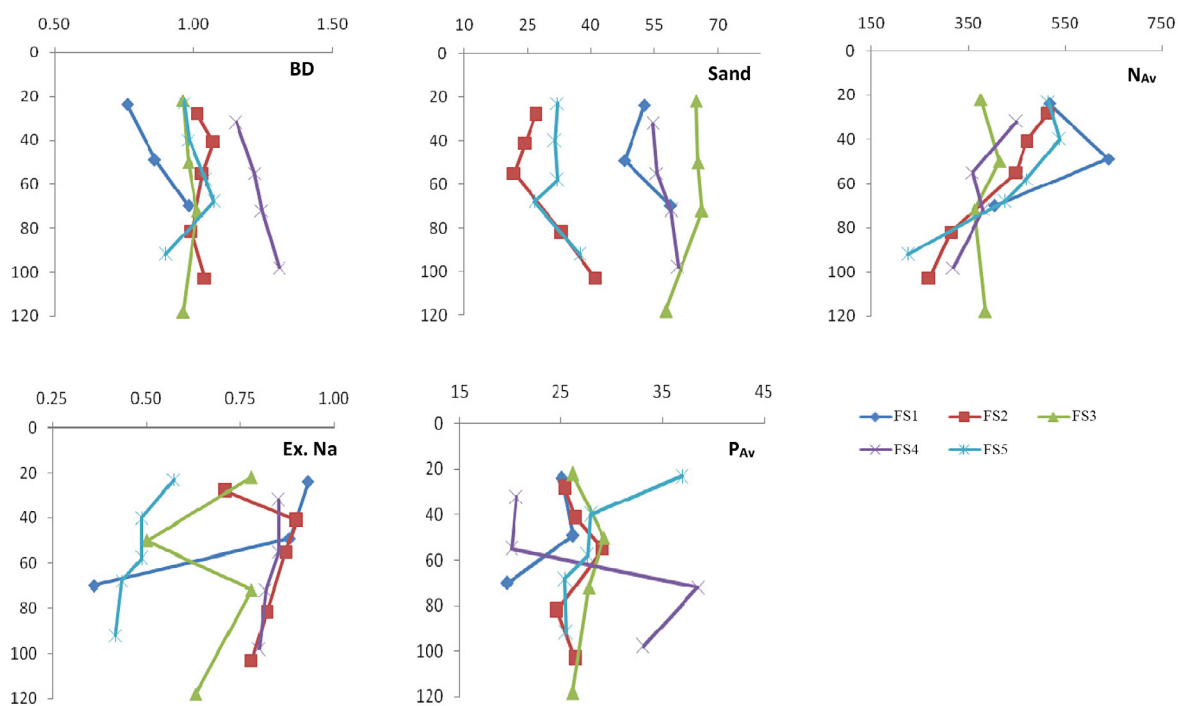
Appendix 3. Descriptive statistics of soil properties used for soil quality assessment in fallow *jhum* areas

Variable	Min	Max	Mean	Std. dev	CV	Skewness
BD (Mg m ⁻³)	0.74	1.07	0.90	0.11	0.13	0.36
Silt (%)	26.8	59.9	42.4	9.9	0.2	0.5
Clay (%)	1.6	29.2	14.2	9.3	0.6	0.3
Sand (%)	23.8	59.0	43.2	13.0	0.3	-0.3
Porosity (%)	59.5	72.2	66.2	4.3	0.0	-0.3
pH (1:2)	4.22	6.08	5.19	0.66	0.13	0.00
SOC (%)	0.4	3.2	1.6	1.0	0.6	0.5
Exch. Ca (cmol (p+) kg ⁻¹)	0.59	3.87	1.60	1.05	0.66	1.27
Exch. Mg (cmol (p+) kg ⁻¹)	1.22	6.34	2.08	1.33	0.64	3.18
Exch. Na (cmol (p+) kg ⁻¹)	0.29	0.77	0.56	0.22	0.39	-0.50
Exch. K (cmol (p+) kg ⁻¹)	0.34	1.32	0.76	0.28	0.37	0.11
CEC (cmol (p+) kg ⁻¹)	1.97	7.20	3.97	1.63	0.41	0.62
BS (%)	50.6	215.6	121.6	45.1	0.3	0.4
Ca/Mg	0.28	3.17	0.90	0.76	0.85	2.52
Av. N (kg ha ⁻¹)	179.20	417.69	229.76	140.49	0.34	-0.14
Av. P (kg ha ⁻¹)	19.26	29.79	25.94	3.50	0.13	-0.65
Av. K (kg ha ⁻¹)	144.00	347.00	243.57	53.05	0.22	-0.04

BD: Bulk density; SOC: Soil Organic Carbon; Exch. Ca: Exchangeable Calcium; Exch. Mg: Exchangeable Magnesium; Exch. Na: Exchangeable Sodium; Exch. K: Exchangeable Potassium; CEC: Cation Exchange Capacity; BS: Base Saturation; Av. N: Available Nitrogen; Av. P: Available Phosphorus; Av. K: Available Potassium

Own elaboration

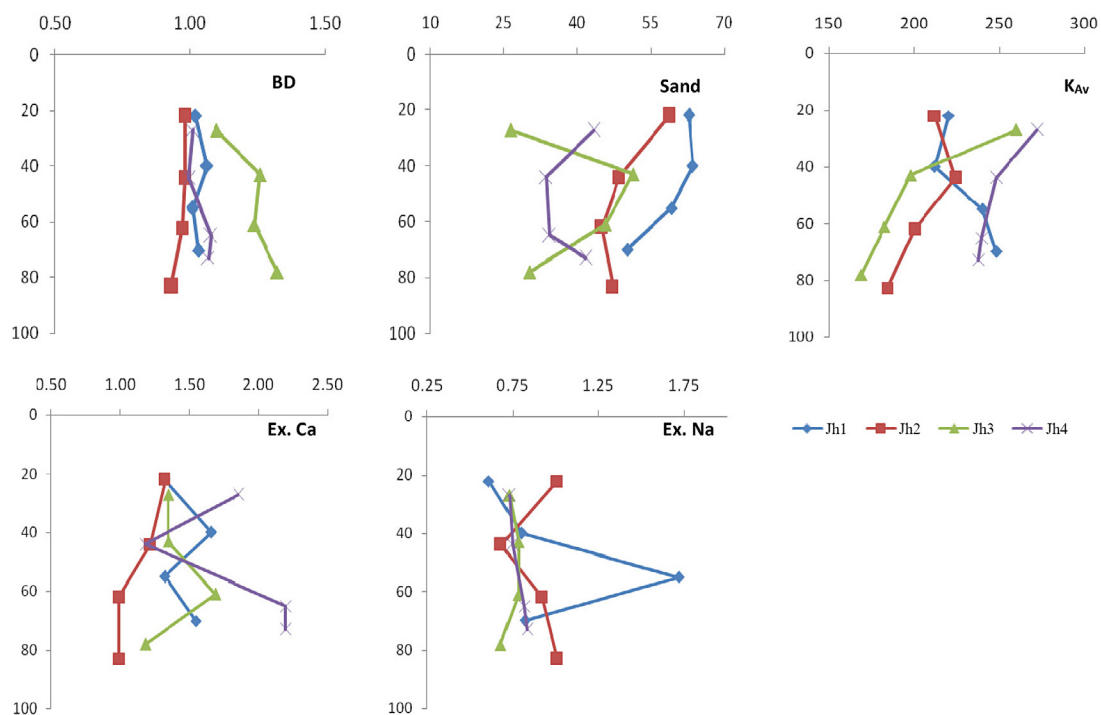
Appendix 4. Depth-wise distribution of soil indicators selected after principal component analysis for each profile under Forests



*BD: Bulk density (gm cc⁻³), Sand (%), N_{av}: Available Nitrogen (kg ha⁻¹), Exch. Na: Exchangeable Sodium (cmol (p⁺) kg⁻¹), P_{av}: Available Phosphorus (kg ha⁻¹)

Own elaboration

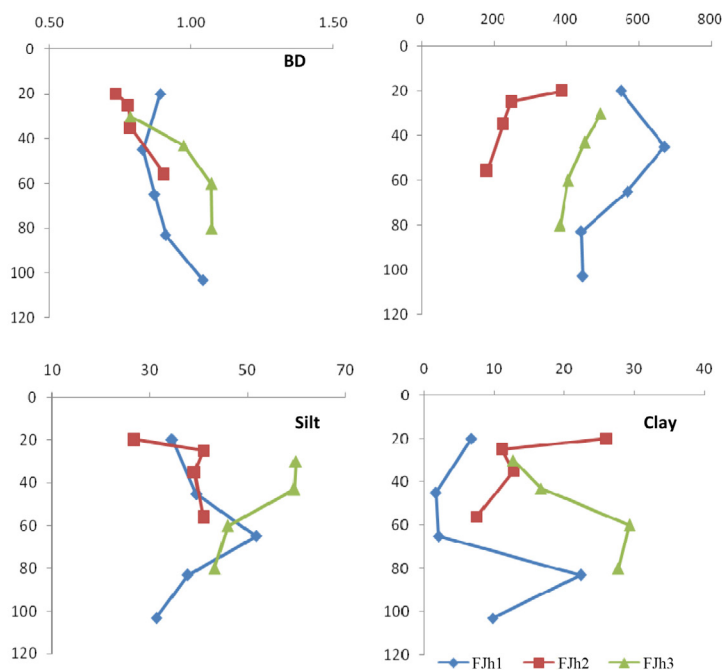
Appendix 5. Depth-wise distribution of soil indicators, selected after principal component analysis, for each profile under Jhum lands



*BD: Bulk density (gm cc^{-3}), Sand (%), K_{av} : Available Potassium (kg ha^{-1}), Exch. Ca: Exchangeable Calcium ($\text{cmol (p}^+) \text{ kg}^{-1}$), Exch. Na: Exchangeable Sodium ($\text{cmol (p}^+) \text{ kg}^{-1}$)

Own elaboration

Appendix 6. Depth-wise distribution of soil indicators, selected after principal component analysis, for each profile under fallow jhum lands.



*BD: Bulk density (gm cc^{-3}), N_{av} : Available Nitrogen (kgha^{-1}), Silt (%), Clay (%)

Own elaboration

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