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THE IMPACT OF TRADITIONAL LAND USE MANAGEMENT ON SOIL QUALITY IN NORTHEASTERN HIMALAYAS (INDIA)

Gaurav Mishra[1] • Jesús Rodrigo-Comino[2,3]

[1] Rain Forest Research Institute
Indian Council of Forestry Research and Education
785001 Jorhat, Assam: India
e-mail: gaurav.mishra215@gmail.com

[2] Department of Physical Geography
University of Trier
54296 Trier: Germany

[3] Soil Erosion and Degradation Research Group
Department of Geography, University of Valencia
Blasco Ibàñez, 28, 46010 Valencia: Spain
e-mail: jesus.rodrigo@uv.es (corresponding author)

Abstract

In the Northeast Himalayas (NEH) region, four major conventional land-use types are forest, *Jhum* lands, fallow *Jhum* lands and plantations, but little is known about their sustainability and responses to changes. We collected soil samples at two uniform depths (0-15 and 15-30 cm) from the Zunheboto district of Nagaland (India). The dataset was statistically analyzed by conducting an ANOVA-one way, principal component analysis (PCA) and calculating an additive soil quality index (SQIa). Our results confirmed that sand content, bulk density (BD), porosity, soil organic carbon (SOC), cation exchange capacity (CEC), exchangeable calcium and potassium showed significant statistical differences among soil depths depending on the land use management. PCA results showed that soil texture, BD, porosity, SOC and exchangeable cations could be considered the major indicators to define soil quality. After estimating the SQIa, *Jhum* soils showed the highest values at the surface, while at 15-30 cm soil depth, fallow *Jhum* soils phase showed the highest ones. The conversion from natural forest to plantation does not hamper the SQ, but their conversion into *Jhum* may even increase it, for a shorter duration. However, after 1-2 year of cultivation and conversion from *Jhum* into fallow *Jhum* land, soil quality could be reduced.

Key words

land use management • Forests • cropland • soil quality • Northeast Himalayas

Introduction

The topic of human impact on soil quality in cultivated mountainous areas in non-developing regions using traditional methods since decades to subsist by changing the land use types is poorly studied. An example of this type of areas is the North-Eastern Hilly region of India (NEH). The NEH is one of the twelve biodiversity hot spots in the world due to its geographical position, favourable climate and biodiversity richness (Choudhury et al., 2016). It is covered by forests (65%), agricultural land (16%) and fallow lands (Saha et al., 2012). Shifting cultivation (locally called as *Jhum*) is one of the major sources of livelihood for most of the tribal farmers in NEH (Yadav, 2013). Approximately, 86% of the total cultivated area of NEH is under the practice of *Jhum* cultivation, with a maximum extension in the state of Nagaland (Patel et al., 2013). In the last few decades, *Jhum* cultivation led to a rapid change in land uses in Nagaland (Chase & Singh, 2014; Sulieman et al., 2018), as the fallow period is decreasing, due to increase in population and food demand.

In other regions cultivated by this traditional farming, it was noted that intensive crop cultivation with no external input for 2-4 years after slash and burn of native forest are causing a significant decline in soil quality. For example, Handayani (2004) reported that cultivation after the clearance of forest in Sumatra resulted in the loss of organic matter (OM) content and reduction in labile C pools, declining subsequently biological activity. Continuous cultivation in deforested areas reduces soil cation exchange capacity (CEC) (Mulugeta et al., 2005; Nega & Heluf, 2009). Intensive farming and site-specific changes in land-use patterns of the deforested areas may lead to various deleterious effects such as soil erosion, biodiversity loss, acidification, soil compaction, desertification and climate change (Salehi et al., 2008; Vorlaufer et al., 2017; Norman, 2020). Recently, studies on the effects of forest conversion to temporary agricultural lands on the dynamics of organic C stock and soil health are currently receiving the attention of policymakers and forest managers (IPCC, 2007). Some reports suggests that shifting fallows after 2-3 year intensive cropping acts as a sink of soil organic C and soil organic C content increases with increasing the age of fallows (Ramakrishnan & Toky, 1981; Arunachalam, 2002; Grogan et al., 2012). However, leaving the fields abandoned for ~15 years with grasses (*Imperata cylindrica*) as secondary successive vegetation and resuming crop cultivation for 3-5 years did not improve soil quality (Handayani, 2004). Thus, inconsistent conclusions had been drawn from different studies, defaulting our understanding of the effects of land-use changes on soil quality and their indicators in both short and long-term periods.

Soil productivity in *Jhum* lands was maintained due to partially combusted biomass, associated nutrients, mainly stored in the organic form, and nutrients held in the mineral form on the exchange sites of SOC (Palm et al., 1996; Bahr et al., 2014). In the absence of vegetation, generated SOC remains prone to the accelerated erosion and lost during the first and second year of cropping phase. Bahr et al. (2014) reported that almost 14-20% of SOC in topsoil layers had been lost during the cropping phase.

Moreover, studies evaluating the influence of different land-use types on soil quality under tropical and sub-humid forest conditions are also limited (Lohbeck et al., 2015; Poorter et al., 2015). Hence, it is important to evaluate the influence of land-use changes on soil quality indicators as it was reported by other studies in arid and semi-arid areas (Rodrigo-Comino et al., 2018; Keshavarzi et al., 2020). To achieve this kind of evaluations, different multivariate statistical methods have been already developed such as principal component analysis (PCA), factor analysis (FA) or correlation analysis (CA), which are mainly used to segregate soil parameters and environmental plot characteristics contributing more towards observed soil quality (Ozan et al., 2008; Beniston et al., 2015).

Therefore, according to the mentioned lack of studies related to soil quality indicators after different land uses changes in conventional agricultural fields in the Himalayas, the main aims of this research were to determine: (1) if there are differences among soil properties at different depths and land use management; (2) which soil quality indicators play a key role in explaining soil quality; and, (3) to evaluate the soil quality using minimum data set (MDS) by additive index method.

Materials and methods

Study area

This study was carried out in the Zunheboto district situated in the region of Nagaland, Northeastern Himalaya (India). The district, located at 25°97'N, 94°52'E, occupies an area of about 1255 km^2 with an average elevation of about 1800 m asl. (Fig. 1). The average sum of annual precipitation is close to 2000 mm, where 90% of it uses to occur from May to October. Temperature varies from a minimum of 10°C to maximum values of 22°C during the year. The majority of the forest area in the Zunheboto district is classified as montane wet temperate forest (FSI, 2009). The major tree species of this area are typically evergreen with *Alnus nepalensis, Quercus* sps., *Magnolia champaca*, *Schima walichi*, and *Betula alniodes.* Plantations were raised by the local communities as per their need or based on timber values. They mainly consist of Pine (*Pinus kesiya*), Hollock (*Terminaliya myrocarpa*), Alder (*Alnus nepalensis*), Gamari (*Gmelina arborea*) among others. In croplands, mainly upland rice (*Oryza sativa*) is cultivated. Maize (*Zea mays*), cowpea (*Vigna unguiculata*), Colocasia (*Colocasia esculenta*), chilli (*Capsicum annuum*), pumpkin (*Cucurbita peto*), and brinjal (*Solanum melongena*) are also usually grown. Fallow lands mainly consist of trees along with common weeds (*Eluesine indica*; *Amaranthus viridis*; *Chromolaena odorata*; *Mimosa pudica*;

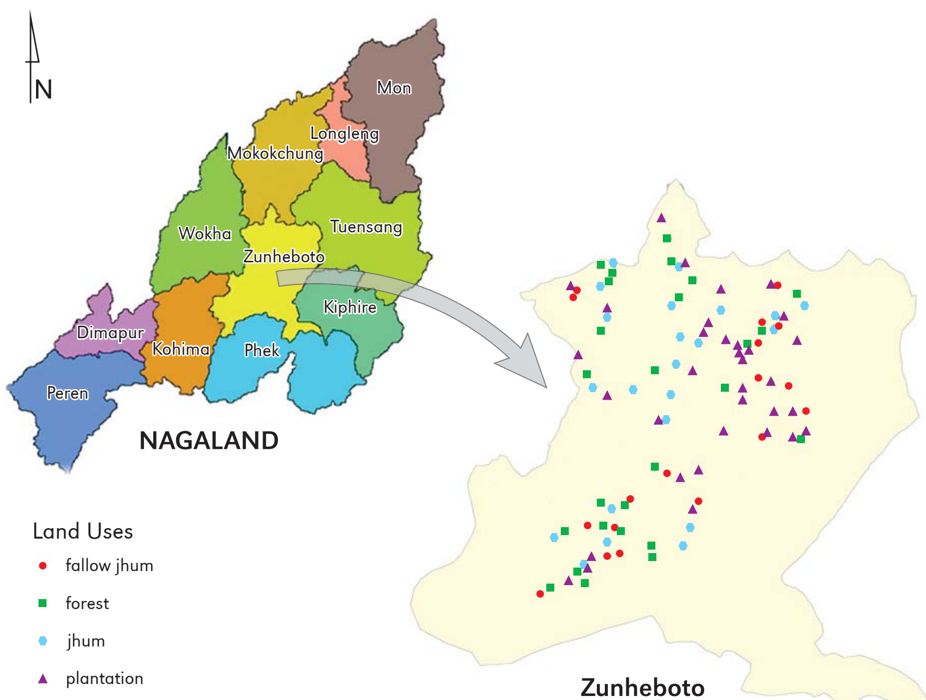

Figure 1. Study area, Zunheboto, Nagaland (India). Different colors indicate each land use (fallow *Jhum*, forest, *Jhum* and plantations, respectively)

and *Imperata cylindrica*) of the region. The *Jhum* fields selected in this study were cropped one and fallow *Jhum* lands were those, which were left as fallow for more than five years, after cultivation.

Soil sampling and analysis

During 2016-17, 88 different land uses sites were selected, based on altitude, aspect and inclination gradient (Fig. 2). At each site, soil samples from two different depths were collected. Sampling depth was fixed at 0-15 cm and 15-30 cm depth, considering that 0-15 cm soil depth is more dynamic, during cropping phase. We hypothesize that as an indication of dynamic soil quality, soil properties at surface (0-15 cm) level can be considered vital in *jhum* lands, whereas the inherent quality of the soil at 15-30 cm, could be more relevant in forests and plantations. The samples were air-dried and sieved through 2-mm sieve to exclude litter, roots and coarse particles. Soil samples were analyzed for soil texture, bulk density (BD), porosity, pH and soil organic carbon (SOC). The particle size distribution was obtained by the hydrometer method (Klute, 1986). BD was calculated by the core method with a copper cylinder of known volume (134.16 cm^3) (Blake & Hartge, 1986), meanwhile, total porosity was calculated from the bulk density values assuming the obtained particle density (USDA- NRCS, 2004). Soil pH value was determined in 1:2 soil water suspension using digital pH-meter. Soil organic carbon (SOC) was analyzed following the method by Walkley and Black (1934).

Available phosphorus (P) was determined following the standard method of Bray and Kurtz (1945). Also, available potassium (K), cation exchange capacity (CEC) and exchangeable cations (Ca, Na, and Mg) were estimated by 1 *N* ammonium acetate (pH 7.0) method (Schollenberger & Simon, 1945; Sumner & Miller, 1996). Exchangeable aluminium

Figure 2. Soil sample collection from different land use systems (A: forest; B: *Jhum*; C: fallow *Jhum* and D: plantation)

(Al) was extracted with 1N KCl solution and titrated with 0.1N NaOH (McLean, 1965).

Statistical analysis

To assess the statistical differences among soil properties under different land uses, an ANOVA-one-way test was conducted per land use and soil depth. To check the normality of the data, a Shapiro-Wilks test was also carried out. Also, the variance was checked. If they failed, a Kruskal-Wallis One Way Analysis of Variance on Ranks was performed. SigmaPlot 13.0 (Systat Inc.) was the statistical program used to analyze the data. After that, PCA was conducted using SPSS 23.0 (IBM, USA). Firstly, a Pearson correlation was conducted to assess which soil property and quality indicator could be correlated. However, as the tables are too big due to the several soil properties used, these results were not included (they can be sent after a formal request).

To identify which driving factors condition soil properties and quality indicators, PCA was carried out. With this technique, we were able to group similar variables into dimensions, without distinguishing between independent and dependent variables. The first step was to centre and normalize the variables. Then, we verified them making a Kaiser-Mayer-Olkin (KMO) test of sphericity. Moreover, an orthogonal rotation method (Varimax), and a correlation matrix, using factors with Eigenvalues > 1 were applied. Soil properties and quality indicators used to achieve our main objective in this research should model the phenomenon pretended to be detected (relationships among them) in the closest possible way, registering specifically the most significant parameters that affect soil distribution and pedogenesis (Shukla et al., 2006). PCA was carried out for the above-mentioned different land uses plantation (P), *Jhum* land (crop) (J), fallow *Jhum* land (FJ) and forest (f) and at different depths (0-15 and 15-30 cm).

Soil quality index (SQI)

The SQI was calculated using depth-wise data of all land-use sites. The SQI was calculated using an additive index approach at both the depths (Abdel Rahman et al., 2019; Mukherjee & Lal, 2014). The transformed scores from each soil depth were added for the calculation of the additive index. The variability

Table 1. Soil properties (part 1) and comparison among different soil depths

Land use	Soil depth	Clay [%]	Silt [%]	Sand [%]	BD [g cm^{-3}]	Porosity [%]	pH	SOC [%]
P	0-15	26.6±14.4	25.4±10.2	48±18.5	0.80±0.1	69.9±4.1	4.8±0.5	3.2±1.1
	15-30	26.4±13.5	26.5±12.0	47.1±17.9	0.84±0.1	68.3±3.3	4.6±0.4	2.3±1.0
Diff.		p<0.861*	p<0.920	p<0.710*	p<0.114*	p<0.119	p<0.228	**p<0.004**
J	0-15	27±17.2	26±14.5	47±26.1	0.77±0.1	71.1±4.2	4.8±0.6	3.1±1.6
	15-30	11.9±15.6	14.3±11.7	73.8±27.0	0.82±0.1	69.0±4.9	4.7±0.4	3.0±4.9
Diff.		p<0.070	p<0.089	**p<0.042**	p<0.170	p<0.170	p<0.849*	p<0.905
FJ	0-15	20.2±16.2	30.0±19.3	49.8±23.0	0.81±0.1	69.5±4.5	4.8±0.6	3.7±1.1
	15-30	16.0±14.4	29.6±22.4	54.4±25.0	0.87±0.1	67.3±3.9	4.7±0.5	2.7±2.2
Diff.		p<0.347*	p<0.689*	p<0.631*	p<0.164*	**p<0.050**	p<0.716*	**p<0.001**
F	0-15	24.4±14.9	33.3±13.7	42.4±17.8	0.98±0.7	63.1±24.7	4.7±0.5	2.9±1.2
	15-30	12.4±15.7	37.9±20.4	49.7±25.3	0.87±0.1	67.1±5.2	4.7±0.4	2.1±0.8
Diff.		p<0.054	p<0.467	p<0.572*	p<0.459*	p<0.459*	p<0.541	**p<0.012**

* Shapiro-Wilk test failed, Kruskal-Wallis One Way Analysis of Variance on Ranks was performed; ±: Standard deviation; P: Plantation; J: *Jhum*; FJ: Fallow *Jhum*; F: Forest; BD: Bulk density; SOC: Soil organic carbon.

of calculated SQI among land-use types was tested with one-way analysis of variance (ANOVA) followed by Duncan's test ($P < 0.05$) and the results depicted in box plots.

Results

Soil properties at different depth under diverse land uses

Soil texture was similar to all the land uses, clay content was higher than 20% and a high sand fraction (> 40%). In *Jhum* lands, a significant increase was noticed in sand percentage, at 15-30 cm soil depth, while the fine fractions decreased. These results confirm that BD increases and porosity decrease at the sub-surface, making these layers heavier and defaulting water flows. A similar dynamic is also registered in fallow *Jhum* lands, where an increase in BD generates a decrease of porosity, showing statistical differences between soil depths ($p < 0.050$). The pH values do not show any differences among soil depths. On the contrary, SOC registers statistical differences among soil depths in plantation areas, fallow lands and forest. Only *Jhum* land shows similar values among soil depths.

Table 1 and 2 shows that plantation and forest have more homogeneous values among soil depths. In all land uses, CEC decreases from the top layer to the sub-surface one, showing a significant statistical difference in a fallow *Jhum* land. Also, exchangeable Ca, Mg, Na and K register a decrease from 0-15 cm to 15-30 cm, showing more significant in *Jhum* and fallow *Jhum* land. The Al content increases in the plantation, *Jhum* and fallow *Jhum* land, and only decrease in forestry areas. Regarding P and K, in cultivated areas (plantation, *Jhum* and fallow *Jhum*), a decrease from 0-15 cm to 15-30 cm can be observed. Only in the forest, soil nutrients contents (P and K) increase at the sub-surface layers.

Principal component analysis

For all the land use management types, a PCA was carried out and the total variance explained after rotation sums of square loadings with the obtained components are summarized in Table 3. In general, almost all the results are

Table 2. Soil properties and comparison among different soil depths (part 2)

Land use	Soil depth	CEC [cmol (p^+) kg^{-1}]	Ex.Ca [cmol (p^+) kg^{-1}]	Ex. Mg [cmol (p^+) kg^{-1}]	Ex. Na [cmol (p^+) kg^{-1}]	Ex.K [cmol (p^+) kg^{-1}]	Al [cmol (p^+) kg^{-1}]	P [ppm]	K [ppm]
P	0-15	17.4±5.0	1.9±0.4	1.0±0.7	3.3±3.0	2.0±0.9	3.9±2.7	10.1±3.1	50.4±15.5
	15-30	13.9±4.3	1.9±0.3	0.8±0.6	2.9±2.6	1.7±0.9	4.4±2.3	9.4±3.9	46.9±19.7
Diff.		p<0.815*	**p<0.006**	p<0.658*	p<0.338*	p<0.237*	p<0.316*	p<0.129*	p<0.129*
J	0-15	17.5±5.5	2.0±0.4	0.6±0.7	1.6±0.2	2.0±0.8	2.6±2.0	11.4±4.8	56.9±24.0
	15-30	15.0±6.3	1.7±0.5	0.4±0.3	1.5±0.4	1.5±0.6	3.9±2.1	10.0±6.5	50.0±32.4
Diff.		p<0.069	p<0.227	p<0.275*	p<0.220*	**p<0.043**	p<0.071	p<0.062*	p<0.062*
FJ	0-15	15.9±5.2	2.0±0.4	1.0±0.8	3.5±3.0	2.2±1.1	3.8±2.7	8.5±1.6	42.5±8.2
	15-30	11.6±4.0	1.6±0.5	0.9±0.7	2.6±2.3	1.5±0.6	4.1±2.7	8.0±1.8	39.8±9.0
Diff.		**p<0.010**	**p<0.009**	p<0.282*	p<0.824*	**p<0.005**	p<0.788*	p<0.352	p<0.352
F	0-15	12.3±3.7	2.0±0.4	0.8±0.4	1.7±0.7	1.9±0.9	4.5±3.2	9.1±3.3	45.7±16.7
	15-30	11.9±5.3	1.9±0.4	0.6±0.4	1.7±0.8	1.5±0.7	4.1±2.1	9.9±6.2	49.4±30.9
Diff.		p<0.203	p<0.760	p<0.467*	p<0.083*	p<0.080*	p<0.879*	p<0.630*	p<0.630

* Shapiro-Wilk test failed, Kruskal-Wallis One Way Analysis of Variance on Ranks was performed; ±: Standard deviation; P: Plantation; J: *Jhum*; FJ: Fallow *Jhum*; F: Forest; CEC: Cation-exchange capacity; Ex.Ca: exchangeable calcium; Ex. Mg: exchangeable magnesium; Ex.K: exchangeable potassium; Al: Aluminum; P: Phosphorus; K: Potassium.

Table 3. Total variance explained after performing a rotation sum of squared loadings

	Plantation		*Jhum*		Fallow *Jhum*		Forest	
Component	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
1	18.5	24.6	27.6	40.1	21.8	26.7	16.4	24.1
2	34.8	44.7	43.9	67.2	38.0	48.5	31.6	47.8
3	50.8	63.1	58.9	86.7	54.1	66.4	46.7	69.5
4	65.2	79.9	69.9	98.0	68.1	80.1	61.6	88.3
5	75.7	-	80.4	-	80.4	89.1	72.6	-
6	84.0	-	-	-	-	-	82.8	-

*Results are presented in cumulative %.

Table 4. PCA (Principal component analysis) results for plantation land use

	0-15 cm						15-30 cm			
Variables	1	2	3	4	5	6	1	2	3	4
Clay	**-0.86**	-0.26	-0.03	0.01	-0.01	-0.06	-0.45	0.69	-0.23	-0.12
Sand	0.73	0.39	-0.01	0.08	-0.45	-0.06	0.97	-0.19	0.06	0.08
Silt	-0.11	-0.34	0.07	-0.15	**0.83**	0.19	-0.85	-0.30	0.10	0.00
BD	0.18	**0.95**	0.07	0.10	-0.14	0.02	-0.10	-0.94	-0.03	-0.11
Porosity	-0.19	-0.95	-0.07	-0.10	0.14	-0.02	0.09	**0.94**	0.02	0.12
pH	0.78	0.34	-0.29	0.03	0.11	0.08	0.32	-0.36	-0.10	0.82
SOC	0.19	-0.28	0.38	0.51	0.10	0.38	0.15	-0.13	**0.88**	0.38
CEC	-0.13	0.00	0.34	0.32	0.70	-0.25	0.15	-0.13	0.88	0.38
ex.Ca	-0.02	0.06	-0.16	0.14	0.02	**0.92**	-0.20	0.38	0.43	0.77
ex.Mg	-0.01	0.11	-0.17	**0.86**	0.01	-0.13	**0.84**	0.02	0.35	0.10
ex.Na	0.02	0.09	0.09	0.85	-0.07	0.32	-0.05	-0.01	0.28	**0.93**
ex.K	0.36	0.23	-0.36	0.51	0.28	0.09	-0.72	-0.03	0.63	0.14
Al	-0.78	0.19	-0.02	-0.08	0.18	0.07	0.54	-0.34	0.30	-0.43
P	-0.06	0.07	**0.96**	-0.04	0.11	-0.08	0.01	0.87	-0.26	-0.37
K	-0.06	0.07	0.96	-0.04	0.11	-0.08	0.02	-0.04	0.83	-0.15
Component 1: Clay, sand, pH, Al Component 2: BD, Porosity Component 3: P, K. Component 4: SOC, ex. Mg, ex. Na, ex, K Component 5: Silt, CEC Component 6: SOC, ex. Ca							Component 1: Sand, silt, ex. Mg, ex. K, Al Component 2: Clay, BD, porosity, P Component 3: SOC, CEC, ex. K, K Component 4: pH, ex. Ca, ex. Na, Al			

*Selected values correspond to the values >0.5 or >-0.5. BD: Bulk density; SOC: Soil organic carbon; CEC: Cation-exchange capacity; Ex.Ca: exchangeable calcium; Ex. Mg: exchangeable magnesium; Ex.K: exchangeable potassium; Al: Aluminum; P: Phosphorus; K: Potassium.

*Bold and underlined factors identified the indicators retained in the MDS and used to calculate SQI.

close to 80%, showing high confidence in the obtained results. In plantation land use, total variance in surface (84.0%) and sub-surface (79.9%) soils is explained by six and four components, respectively. At 0-15 cm depth, clay (-0.86) was highly weighed property in Principal component (PC) 1, so it was selected as an SQ indicator, due to its high weight in PCA analysis (Tab. 4). Similarly, BD, P, ex. Mg, silt and ex. Ca were selected as SQ indicator from different PCs at 0-15 cm soil depth. At 15-30 cm, ex. Mg, porosity, SOC and ex. Na was the selected soil SQ indicator in plantation soil, after PCA. In *Jhum* lands, sand, SOC, porosity, ex. Mg and ex Ca were the selected and K, porosity, ex Mg and ex. K was chosen as SQ indicator for 0-15 and 15-30 cm depth, respectively (Tab. 5). However, in fallow *Jhum* lands, the selected parameters were, CEC, silt, clay, ex. Na and ex Na at 0-15 cm and for 15-30 cm ex. Mg, porosity, SOC, pH and Al were considered as SQ indicator (Tab. 6). Finally in forestry areas, for 0-15 cm, SOC, clay, BD, ex. K, silt and ex. Na was selected as SQ indicator (Tab. 7). Further at 15-30 cm, ex. K, porosity, SOC and ex. Na were highly weighted soil properties after PCA, so they are also selected.

Table 5. PCA (Principal component analysis) results for *Jhum* land use

	0-15 cm					15-30 cm			
Variables	1	2	3	4	5	1	2	3	4
Clay	-0.75	-0.10	0.16	0.03	-0.31	0.97	-0.03	-0.13	0.20
Sand	**0.95**	0.07	-0.04	0.02	0.14	-0.99	-0.02	0.10	-0.10
Silt	-0.81	-0.02	-0.12	-0.08	0.10	0.99	0.08	-0.05	-0.03
BD	0.09	-0.04	-0.97	-0.08	-0.12	0.08	-0.95	0.30	-0.05
Porosity	-0.09	0.04	**0.97**	0.08	0.12	-0.08	**0.95**	-0.30	0.05
pH	0.81	0.30	-0.11	0.13	-0.04	-0.66	-0.37	0.61	0.23
SOC	0.22	**0.90**	0.06	0.19	0.23	0.38	0.88	0.15	-0.23
CEC	0.22	0.90	0.06	0.19	0.23	0.38	0.88	0.15	-0.23
ex.Ca	-0.35	0.38	0.26	-0.07	**0.74**	0.91	0.37	0.12	0.16
ex.Mg	0.22	0.06	-0.06	**0.85**	0.01	0.02	-0.21	**0.97**	0.11
ex.Na	-0.49	-0.31	0.05	0.53	0.11	0.03	-0.03	0.96	-0.11
ex.K	0.03	0.24	0.20	0.67	0.00	0.20	-0.12	-0.06	**0.96**
Al	0.73	-0.20	-0.40	0.15	0.08	-0.71	0.14	-0.10	-0.60
P	-0.29	0.60	0.00	-0.26	-0.46	0.16	-0.58	-0.64	0.37
K	0.44	0.13	0.14	0.06	0.74	**0.99**	0.09	0.09	0.10
Component 1: Clay, sand, silt, pH, Al, K						Component 1: Clay, sand, silt, pH, ex. Ca, Al, K			
Component 2: SOC, CEC, P						Component 2: BD, porosity, SOC, CEC			
Component 3: BD, porosity						Component 3: pH, ex. Mg, ex. Na, P			
Component 4: ex. Mg, ex. Na, ex, K						Component 4: pH, ex. K, Al			
Component 5: ex. Ca, K									

*Selected values correspond to the values >0.5 or >-0.5. BD: Bulk density; SOC: Soil organic carbon; CEC: Cation-exchange capacity; Ex.Ca: exchangeable calcium; Ex. Mg: exchangeable magnesium; Ex.K: exchangeable potassium; Al: Aluminum; P: Phosphorus; K: Potassium.

*Bold and underlined factors identified the indicators retained in the MDS and used to calculate SQI.

Table 6. PCA (Principal component analysis) results for fallow *Jhum* land use

	0-15 cm					15-30 cm				
Variables	1	2	3	4	5	1	2	3	4	5
Clay	0.07	0.15	**0.89**	0.15	0.14	0.90	-0.04	0.20	-0.17	-0.11
Sand	-0.03	0.63	-0.65	-0.01	-0.17	-0.37	0.77	0.00	0.38	-0.21
Silt	-0.03	**-0.87**	0.03	-0.11	0.09	-0.17	-0.84	-0.12	-0.32	0.31
BD	-0.54	-0.65	-0.09	0.30	0.10	0.09	-0.91	-0.08	0.19	-0.19
Porosity	0.54	0.65	0.09	-0.30	-0.10	-0.09	**0.92**	0.07	-0.20	0.17
pH	-0.44	0.00	-0.66	0.31	0.21	0.19	-0.01	-0.14	**0.86**	0.12
SOC	0.94	0.13	0.15	-0.01	0.00	0.02	0.05	**0.97**	-0.17	0.02
CEC	**0.94**	0.13	0.15	-0.01	0.00	0.02	0.05	0.97	-0.17	0.02
ex.Ca	0.46	0.51	0.30	0.14	-0.39	0.47	0.45	0.62	0.08	-0.14
ex.Mg	-0.13	-0.09	0.05	-0.05	**0.81**	**0.83**	-0.19	-0.12	0.26	0.10
ex.Na	-0.13	-0.05	0.12	**0.92**	-0.16	0.80	0.12	0.03	-0.13	0.40
ex.K	-0.43	-0.10	0.12	0.62	0.47	0.82	-0.23	-0.07	0.18	-0.02
Al	0.31	-0.27	-0.19	-0.21	0.62	0.12	0.02	0.02	0.35	**0.90**
P	0.12	-0.03	0.66	-0.02	-0.46	0.32	-0.02	0.32	-0.79	-0.32
K	0.41	0.11	-0.32	0.71	-0.26	0.80	0.10	0.45	-0.17	-0.04
Component 1: BD, porosity, pH, SOC, CEC						Component 1: Clay, ex. Ca, ex. Mg, ex. K, K				
Component 2: Sand, silt, BD, porosity, ex. Ca						Component 2: Sand, silt, BD, porosity, ex. Ca				
Component 3: Clay, sand, pH, P						Component 3: SOC, CEC, ex. Ca				
Component 4: ex. Na, ex, K, K						Component 4: pH, P				
Component 5: ex. Mg, Al, K						Component 5: ex. Na, ex. Al				

*Selected values correspond to the values >0.5 or >-0.5. BD: Bulk density; SOC: Soil organic carbon; CEC: Cation-exchange capacity; Ex.Ca: exchangeable calcium; Ex. Mg: exchangeable magnesium; Ex.K: exchangeable potassium; Al: Aluminum; P: Phosphorus; K: Potassium.

*Bold and underlined factors identified the indicators retained in the MDS and used to calculate SQI.

Soil quality under different land uses

In Plantation, for 0-15 cm soil depth clay, BD, P, ex. Mg, silt and ex. Ca from PC 1, PC2, PC3, PC4, PC5 and PC6, while for 15-30 cm, ex. Mg, porosity, SOC and ex. Na are selected as indicators for MDS. In *Jhum* lands, sand, SOC, porosity, ex. Mg, ex. Ca in 0-15 cm and K, porosity, ex. Mg, ex. K at 15-30 cm is considered as indicators. For fallow *Jhum* land and forest soil, selected indicators are mentioned in their respective Tables 6 and 7. Using these MDS, additive SQIs for the soils under four land-use types at two different depths (0-15 and 15-30 cm), were calculated. The detailed information of the intra-variations of each land related to SQI is provided in Figure 3. In Table 8, the results of additive SQI are summarized and it is found that land uses have a significant effect on soil quality at both depths. For the surface soil (0-15 cm) layer, additive SQI is in the order of *Jhum* (3.51) > plantation (3.29) > forest (3.27) > fallow *Jhum* land (2.13). Moreover, fallow *Jhum* lands have significantly lower ($F = 24.445$, $p = 0.00$) value of SQI than other land uses. However, at 15-30 cm layer, the trend is different. Fallow *Jhum* lands have significantly the highest ($F = 15.585$, $p = 0.00$) value of additive SQI (3.01), followed by *Jhum* (2.52). Although, forest (2.18) and plantations (2.15) soils have a more or less similar value of SQI.

Table 7. PCA (Principal component analysis) results for forest land use

	0-15 cm						15-30 cm			
Variables	1	2	3	4	5	6	1	2	3	4
Clay	-0.01	**-0.92**	0.13	-0.16	0.16	-0.06	-0.45	0.69	-0.23	-0.12
Sand	-0.08	0.77	-0.02	0.10	0.54	0.00	0.97	-0.19	0.06	0.08
Silt	0.14	0.00	-0.13	0.03	**-0.88**	0.05	-0.85	-0.30	0.10	0.00
BD	0.05	-0.05	**0.99**	0.01	0.05	0.00	-0.10	-0.94	-0.03	-0.11
Porosity	-0.05	0.05	-0.99	-0.01	-0.05	0.00	0.09	**0.94**	0.02	0.12
pH	-0.06	0.60	0.25	0.40	0.06	0.49	0.32	-0.36	-0.10	0.82
SOC	**0.95**	-0.04	0.10	-0.03	-0.13	-0.14	0.15	-0.13	**0.88**	0.38
CEC	0.95	-0.04	0.10	-0.03	-0.13	-0.14	0.15	-0.13	0.88	0.38
ex.Ca	0.44	-0.22	-0.11	-0.39	0.34	0.40	-0.20	0.38	0.43	0.77
ex.Mg	-0.13	-0.14	0.20	0.69	0.09	0.54	0.84	0.02	0.35	0.10
ex.Na	-0.28	0.15	-0.05	-0.03	-0.14	**0.84**	-0.05	-0.01	0.28	**0.93**
ex.K	-0.10	0.14	0.03	**0.85**	-0.05	-0.09	**-0.72**	-0.03	0.63	0.14
Al	0.17	0.36	-0.10	0.61	0.40	-0.14	0.54	-0.34	0.30	-0.43
P	-0.08	-0.35	0.20	-0.56	0.28	-0.26	0.01	0.87	-0.26	-0.37
K	0.54	0.38	-0.28	0.03	0.35	-0.06	0.02	-0.04	0.83	-0.15
Component 1: SOC, CEC, ex. Ca, K Component 2: Clay, sand, pH Component 3: BD, porosity Component 4: ex. Mg, ex. K, Al, P Component 5: Sand, silt, Al Component 6: pH, ex. Ca, ex. Mg, ex. Na							Component 1: Clay, sand, silt, ex. K, Al Component 2: Clay, BD, porosity, P Component 3: SOC, CEC, ex. Ca, ex. K, K Component 4: pH, ex. Ca, ex. Na, Al			

*Selected values correspond to the values >0.5 or >-0.5. BD: Bulk density; SOC: Soil organic carbon; CEC: Cation-exchange capacity; Ex.Ca: exchangeable calcium; Ex. Mg: exchangeable magnesium; Ex.K: exchangeable potassium; Al: Aluminum; P: Phosphorus; K: Potassium.

*Bold and underlined factors identified the indicators retained in the MDS and used to calculate SQI.

Table 8. Mean additive soil quality index (SQI_a) values for different land uses sites at two different soil depths

Land use	Additive index (Mean ±SD)	
	Depth [cm]	
	0-15	15-30
Plantation (n = 29)	3.29 (±0.44)$_b$	2.15 (±0.54)$_a$
Jhum (n = 18)	3.51 (±0.51)$_b$	2.52 (±0.34)$_b$
Fallow *Jhum* (n = 18)	2.13 (±0.68)$_a$	3.01 (±0.50)$_c$
Forest (n = 22)	3.27 (±0.49)$_b$	2.18 (±0.36)$_a$

*Values followed by the same letter in each columns are not significantly different at p = 0.05 (Duncan's multiple-range test).

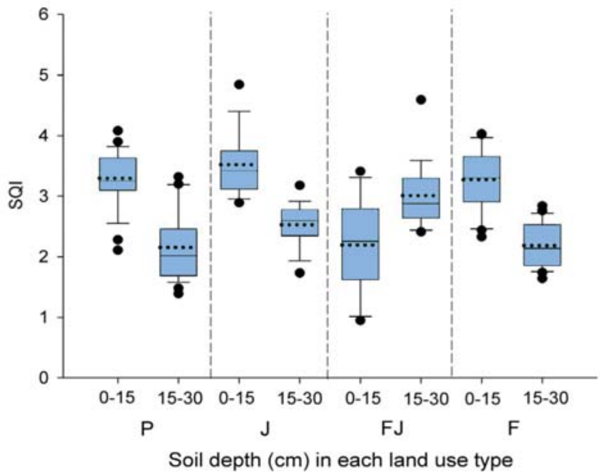

Figure 3. Soil quality index (SQI) values for different land uses sites at two different soil depths

Discussion

Soil quality assessment and the relationships among soil properties and quality indicators are vital to understanding how humans have to manage their soil resource (Armenise et al., 2013). Therefore, this paper can be considered as one of the first approaches to give new insights about information for developing suitable land management plans or tools to apply effective nature based-solutions for rural inhabitants. However, we acknowledge that further work in this area is much needed yet as other authors in this region also demonstrated (Singh et al., 2014; Lenka et al., 2017), for example, by increasing the soil sample number or analyzing soil properties during different seasons.

Regarding our results, we observed that the mean clay content for the surface layers was higher for *Jhum* land than for other land uses, which may be attributed due to the shift from forested area to cultivable ones and further soil particle breakdown (Iticha et al., 2016). Moreover, a drastic significant increase in sand content from 15 cm coincided with the similar findings obtained by Rao and Wagenet (1985), who reported that differences in soil texture with increasing soil depth because of the high weathering ratios, erosion-deposition dynamics and soil-forming factors. Although there was no significant difference in BD values, an increase in values along the depth was noticed in all the land uses, which can be explained by the effects of soil compaction. As Bogunovic et al., (2017) reported, after transform forestry areas with Stagnosols into vineyards, soil compaction measured by soil penetration resistance and bulk density confirmed a drastically increase at the subsurface layers. Also, Williams and Brevik (2010) found in sandy soils this effect due to the tractor passes in South Georgia. On the contrary, in Mediterranean areas, after the abandonment and vegetation recovery, Bienes et al., (2016) observed that bulk density decreased due to the reduction of tillage practices and trampling effect. In forest soils, a reverse trend in BD was also observed. Moreover, this variation in BD values with elevation (Hanawalt & Whittaker, 1976) and its negative correlation with organic matter (Sharma et al., 2010) is already well defined. Regarding the porosity values, the results also showed a decrease in-depth for all land uses and differences were non-significant, except for fallow lands, where the significant decrease was observed. This can be supported with results of Deuchars et al. (1999), who reported that due to the conversion from forest land into pastures or agricultural lands, soils became compact (coinciding with the increase in BD) and their porosity will subsequently decrease. Similarly, Kizilkaya and Dengiz (2010) also reported that cultivation leads to compaction and a decrease in porosity. The soils of this region are highly acidic due to leaching of bases from the exchange complex under prevailing high rainfall and hilly topography (Singh et al., 2014), so no significant difference was observed in the pH values at different soil depths and land uses.

SOC content was higher in the surface of all land uses and an inverse relationship with the BD values except for forests. We hypothesize that it is due to the high amount of litterfall and slow decomposition of organic matter in forest areas (Agren et al., 2013; Mishra et al., 2017). Moreover, SOC content was significantly influenced by soil depth in plantation, fallow *Jhum* lands and forests. There are several studies throughout the world indicating a decrease of SOC from forest to grassland and cropland (Powlson et al., 2011; Don et al., 2011). However, we could not confirm these general results from our finding as for the surface soil (0-15 cm) layer, SOC contents were fallow *Jhum* > plantation> *Jhum* > forest. These results are in the line with Mendoza-Vega and Messing, (2005), who reported that a soil recovery process took place in fallow lands and an increase over the time in SOC can be recorded. Similarly, Sarkar et al., (2015) also reported a significant rise in SOC with the increase in the fallow period.

CEC was strongly influenced by physical (e.g., texture) and chemical (e.g., pH and SOC) properties (Khaledian et al., 2017). Accordingly, in our study also, CEC is found to decrease in-depth for all land uses, but a significant difference was noticed only in fallow *Jhum* land soils. Brady and Weil (2008) also reported that SOM, which is positively correlated with SOC, has the highest CEC values. Our results are also in the line of these findings, as fallow *Jhum* land soils showed a significant decrease in SOC values with an increase in soil depth, and subsequently, in CEC too. Also, Zeraatpishe and Khormali, (2012) reported that SOC can affect the pH values, as CEC in Iran. In SE Asia, Bruun et al., (2009) observed clear impacts of swidden cultivation on carbon storage and soil quality considering the intensification from the traditional production systems to the modern ones. They highlighted that the time-averaged aboveground carbon stocks decline depending on the reduction of about 4 or 6 years in fallow periods of traditional swidden cultivation the transformation or into oil palm plantations, respectively. We also coincide that the effects of soil management is fundamental to understand soil quality changes.

Among the Ex. cations, only Ca^{2+} and K^{+}, showed some significant differences among soil depths, in the plantation, *Jhum* and fallow *Jhum* soils. Vasu et al., (2016) also reported that the variations in clay content, SOC, Ex. cations and CEC may be attributed to a combination of intrinsic (weathering, erosion, deposition and soil-forming processes) and extrinsic (management practices) factors.

In this way, PCA allows us to select different soil quality indicators for each different land use. Our results, mainly soil texture, BD, porosity, SOC and ex cations were come up as potential indicators of soil quality. These findings were consistent with earlier studies of Brejda and Moorman (2001), Cho et al. (2004) and Shukla et al. (2006), who also reported that soil texture, can be considered as an important indicator in soil quality assessment. Moreover, Vinhal-Freitasa et al. (2017) reported that soil textural classes are of great importance in evaluating soil functions and quality in tropical ecosystems like our study area, NE India. Importance of other physical properties like BD and porosity as SQ indicator was already established by several researchers, as they play an important role in the regulation of water transmission, root penetration, retention of nutrients and water, soil erosion and runoff (Al-Shammary et al., 2018). Similarly, the importance of SOC as a self-sufficient soil quality indicator is advocated by Lal (2002), as it plays an important role in nutrient supply, soil moisture retention and soil aggregate stability. Soil chemical properties such as cation exchange capacity and extractable anion and cations have all been used as effective chemical indicators of soil quality. In all the land uses, their values were found to decrease with the depth due to its correspondence with the clay content (Bhaskar et al., 2005; Khan & Kamalkar, 2012).

Deriving SQI, using PCA and MDS from a specific number of parameters, is a useful approach to evaluate land uses in terms of its sustainability. The soil quality of the studied district was strongly influenced by the land use and soil depth. In topsoil (0-15cm), *Jhum* soils had the best SQI in comparison to other land uses. Although, no significant differences were observed among the SQI value of fallow *Jhum* land, forest and plantation soils. In *Jhum* lands, before the cultivation, secondary vegetation was slashed and burned in fields, which may increase the availability of nutrients (P, K, Ca and Mg) in surface layers (Lungmuana et al., 2018), increasing the results of SQI. Moreover, the burning of plant biomass and subsequent release of alkaline cations can increase soil pH (Dikici & Yilmaz, 2006), and also contributes to maintaining the availability of nutrients. Reports from other parts obtained similar results (Singh et al., 2014 and Mishra et al., 2017), which are supporting better soil quality in *Jhum* lands. This improved status of soils boosts the crop growth in 1-2 year of cultivation, but a decline in subsequent years due to cultivation, leaching, runoff and erosion (Tawnenga et al., 1997). *Jhum* lands were converted into fallow *Jhum* lands with degraded quality as reported in this study. Soil erosion is another recognized issue related to these types of land use transformation and changes in management systems. Gafur et al., (2003) reported that soil erosion under fallow lands can usually reach 3 Mg ha^{-1} yr^{-1}. However, during the cultivation year, this amount could even exceed six times as high, which is particularly unsustainable, considering the tolerable soil erosion rates mentioned by other authors in the past (Verheijen et al., 2009).

Forest and plantation soils had less value of SQI in comparison to cropland, which can be supported with the well-known fact that, much of the nutrient reserve in tropical regions is stored in plant tissue, but critical nutrient limitation will occur, if biomass is removed (Dalling et al., 2016). A higher value of SQI in fallow *Jhum* lands at 15-30 cm soil depth may be attributed due to the fast growth of the secondary succession vegetation during the fallow phases. However, as other authors mentioned in India, these soil responses significantly can vary at different spatial scales due to the slope inclination, parent material and aspect (Prokop et al., 2018).

This types of research can also have a relevant impact related to human population growth and the impacts of land-use changes on food security (Brevik et al., 2020, 2019). This is a novel aspect highlighted by the pioneer and recently study conducted by Behera et al. (2016). They considered that the food production, diversity and quality was more elevated in the Jhum lands and traditional cash-cropping compared to any of the modern cash-crop systems. In a literature review, Grogan et al., (2012) recommended some possibilities for improving shifting cultivation in India. The main ones are related to nutrient and water supplementation, optimizing crop choice, extending the site use period, enhancing the fallow recovery rate, and controlling the burns and their environmental impacts. They also suggest the use of inter-row cropping between contour hedgerows, the use of terraces or vegetation cover to reduce soil erosion. These are not new methods that are highly implemented in other vulnerable territories such as the Mediterranean belt or countries such as Iran or China affected by soil pollution, erosion or nutrient depletion (e.g. Durán Zuazo et al., 2011; Novara et al., 2013; Yu et al., 2017; Yazdanbakhsh et al., 2020).

Conclusion

Land-use changes are well known to be a driving factor of physical, chemical and biological soil variations. In this study, the soil quality of four different sequential land uses worked by traditional farmers groups in the Himalayas were evaluated, at two soil depths. Our main findings confirmed that *Jhum* soils obtained the best soil quality at the surface layer. At the sub-surface, the highest soil quality index result was obtained for the fallow *Jhum* soils. We claim that soil quality in this region can be resumed in a specific set of soil properties. Therefore, data reduction techniques such as PCA and SQI were confirmed as techniques to identify soil quality indicators. Using these indicators, we were able to evaluate soil quality being more productive in terms of time- and money- consuming.

Editors' note:
Unless otherwise stated, the sources of tables and figures are the authors', on the basis of their own research.

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