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Effect of shifting cultivation and fallow on soil quality index in Mokokchung district, Nagaland, India

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Abstract

Background: Shifting cultivation is a major agriculture practice in the Nagaland state of India. This study examines the effect of shifting cultivation and the length of the fallow period on soil quality index (SQI). Four sites were selected for the study, viz., a shifting cultivation site (SCS), a 3-year-old fallow land (FL-3), a 7-year-old fallow land (FL-7), and a 12-year-old fallow land (FL-12). Soil parameters were recorded seasonally and SQI was calculated from the minimum data set.

Results: With the increase in the fallow period, the values of conductivity, soil organic carbon, available nitrogen, available phosphorus, exchangeable potassium, moisture, clay, and cation exchange capacity of soil increased. Meanwhile, soil pH and bulk density decreased with fallow duration. The additive SQI_a values were in the order SCS < FL-3 < FL-12 < FL-7; meanwhile, the weighted SQI_w values were in the order SCS < FL-3 < FL-7 < FL-12. It is also observed that the SQI value decreases with the increase in soil depth under both the weighted and additive indexes. SCS with the lowest SQI value reflects the reduced soil organic carbon (SOC) and macronutrients. Increased SOC levels in site FL-12 (2.88–3.94%) may be one reason for its higher SQI value.

Conclusions: Our study highlights that unsustainable practices of shifting cultivation and reduction in the fallow period negatively affect soil quality. Furthermore, the study also recommends the use of the weighted method of SQI as it agrees with the reports of land use causing alteration in the soil quality. Our findings may be utilized to quickly access and disseminate information to the stakeholders and aid in constructing local soil quality index maps of the region. There is an urgent need for a rapid, cost and resource-efficient soil quality assessment and SQI may be one tool that achieves this goal.

Keywords: Shifting cultivation, Jhum, Soil quality index, Soil health, Seasonal variation, Nagaland, India

Introduction

Shifting cultivation is the main form of agriculture in the region of North-East India (Upadhaya et al. 2020). The cycle of shifting cultivation begins with the removal and burning of vegetation to convert forest land into a cultivation area. Next, the soil goes through a cultivation period lasting one or more years, followed by a fallow period (15–20 years), which allows the soil to recover its nutrients (Stygler et al. 2007). These practices degrade soil quality by removing nutrients from the soil. This is further impacted by excessive use of chemicals and inadequate irrigation practices (Medhe et al. 2012). Shifting cultivation has also been reported to decrease soil microbial biomass (Kendawang et al. 2005). Such reduction of the microbial biomass reduces certain enzymatic activities vital for soil health and functioning (Bilen and Turan 2022).

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A long fallow period ensures the re-establishment of woody vegetation, allowing for soil restoration (Mertz et al. 2009). However, several factors such as the increased human population, land degradation, organic matter reduction, and the subsequent nutrient imbalance exert tremendous pressure on agriculture and sustainability goals (Tauqeer et al. 2022a). This has led to an unsustainable form of shifting cultivation that employs a reduced fallow period, threatening soil biodiversity and conservation strategies (Van et al. 2008). A reduction in the fallow cycle lowers the soil fertility and yield, increases soil erosion, and causes watershed siltation (Ziegler et al. 2009). There are also concerning reports on shifting cultivation contributing significantly to global warming (Fearnside 2005). This is because the conversion of forest areas to arable land releases considerable CO_2 (Brown and Lugo 1990). Soil photon tolerance affects the radiation absorption capacity of the soil (Sayyed et al. 2018). However, it is reported that an increase in solar irradiance is detrimental to various photochemical processes in plants (Mama et al. 2021). Akram et al. (2018a) report that paddy rice fields treated with N fertilizers produce considerably higher greenhouse gases. Subsequently, the use of excessive fertilizers, synthetic agrochemicals, dumping effluents, and waste may also increase heavy metal toxins in the adjacent vegetation (Tauqeer et al. 2022b). These ultimately affect the physico-chemical properties of soil which influence the sorption, desorption, and degradation of pollutants and runoffs (Akram et al. 2018b). Therefore, it is critical to monitor and evaluate the soil quality and establish indicators that correspond to changes in land use and soil quality (Moffat 2003).

One widely used and accepted method to estimate soil quality is by utilization of the soil quality index (SQI). SQI incorporates complex soil properties to generate a numerical value. Such numerical values are easy to interpret for the local stakeholders and researchers alike (Mukhopadhyay et al. 2016). The SQI value ranges from 0 to 1. A higher value denotes a higher soil quality, and vice versa (Mukherjee and Lal 2014). The generation of such a numerical value enables one to compare soil quality under different land uses effectively (Gelaw et al. 2015). Furthermore, the relationship between SQI and productivity has also been reported. The weighted method of SQI, in particular, possesses a high correlation with yield (Vasu et al. 2016). SQI thus functions as a decision-making tool that aids in forming policies and multi-decision making (Karlen and Stott 1994). As such, SQI assists not only in monitoring the productivity of a site but also contributes significantly to the myriad of sustainable management goals (Andrews et al. 2002).

There is a dramatic decrease in the fallow period in the region of Nagaland, North-East India. The fallow cycle as short as 3 years to 1 year is common in the region, which may dramatically alter soil quality (Bhuyan 2019). Mishra et al. (2021) report on the implementation of SQI to estimate the effect of shifting cultivation on the soils of Kohima district, Nagaland, India. They conclude that continued cultivation may lead to the depletion of soil nutrients and cause soil degradation. However, no information of this sort is available in the present study site of Mokokchung district, Nagaland. Therefore, it is necessary to fill this gap by developing the SQI of this particular region to assist in its management. The region's mountains are undergoing rapid deforestation and unsustainable farming practices are rampant. Therefore, it is vital to know the effects of such practices on soil quality to ensure efficient productivity and livelihood security. Thus, we hypothesize that shifting cultivation and fallow period have an impact on soil quality, which the SQI is expected to reflect. The study is, thus, conducted with the following objectives:

1. Comparison of soil parameters between the shifting cultivation site and fallow lands of varying ages.
2. Recording the seasonal variation of the soil parameters in the selected sites.
3. Developing SQI for all the selected sites and comparing them.

Materials and methods

Site selection

The study sites were selected from the region of Mokokchung district, Nagaland, North-East India (Fig. 1A–C). The region experiences a mean annual air temperature of 27 °C and an annual average rainfall of about 2500 mm with a humid subtropical climate. Shifting cultivation is the primary means of farming for the indigenous inhabitants in the region. The preliminary study consisted of site screening and oral interviews with the local inhabitants to determine the cultivation period and age of the fallow lands. Four sites were selected based on the information received (Fig. 2A–D) and their respective GPS coordinates were recorded (Table 1). Shifting cultivation site (SCS): A shifting cultivation site or Jhum land in its 3rd cycle of cultivation. This site employs the practice of monocropping of cassava plantations (*Manihot esculenta*). This site may be termed a degraded shifting cultivation site. Fallow land 3 (FL-3): An abandoned Jhum land in its 3rd year of fallow with no active disturbances, consisting mainly of *Macaranga* sp., *Thysanolaena* sp., *Eupatorium* sp., *Thysanolaena maxima, Sonchus* sp., *Ageratum* sp. and patches of *Artocarpus heterophyllus*

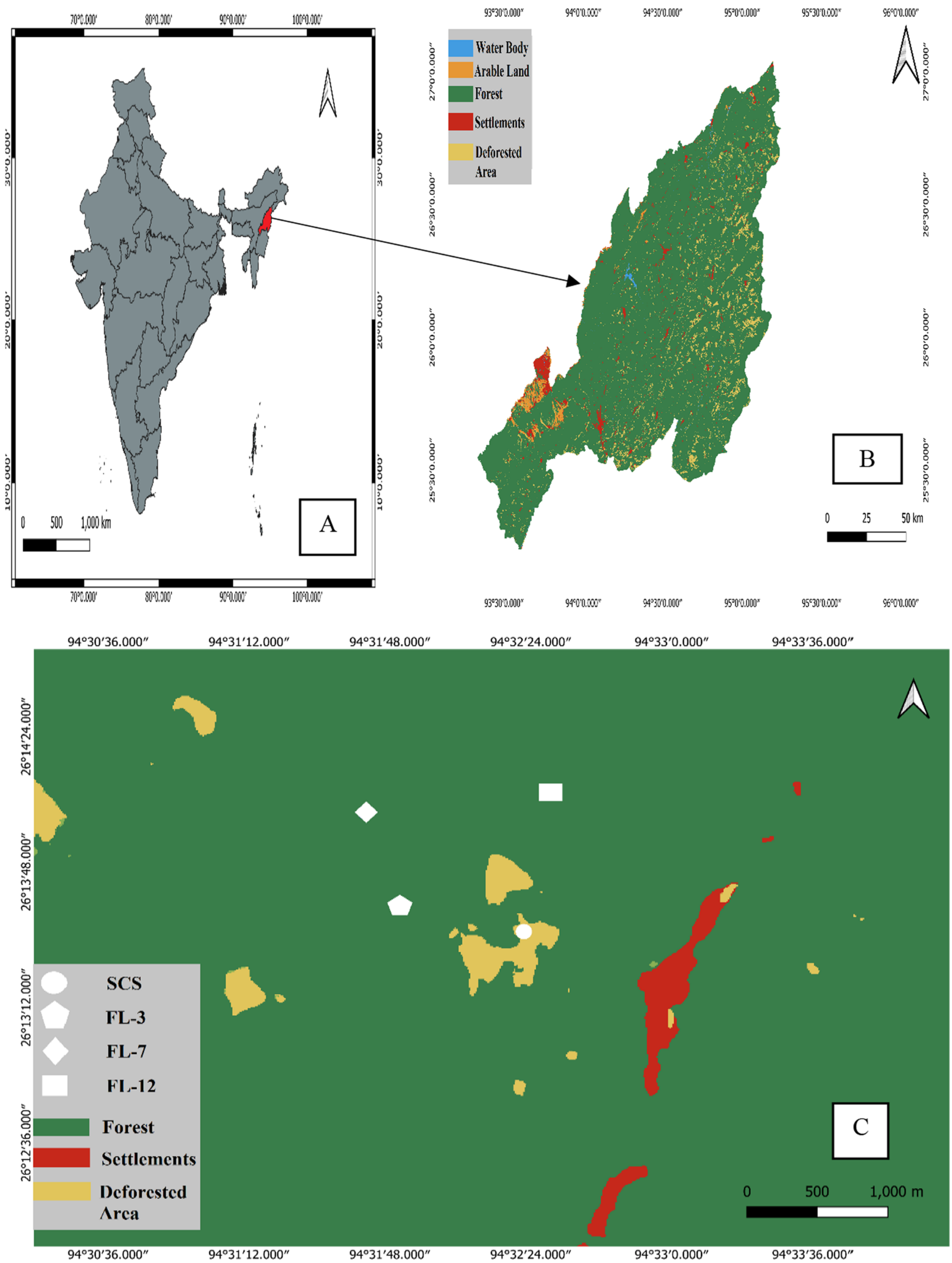

Fig. 1 **A** India map with Nagaland state highlighted in red. **B** Land use map of Nagaland, displaying the various land use in the region. **C** Land use map of the study area under Mokokchung district, Nagaland, India, displaying SCS (shifting cultivation site), FL-3 (Fallow land 3), FL-7 (Fallow land 7) and FL-12 (Fallow land 12)

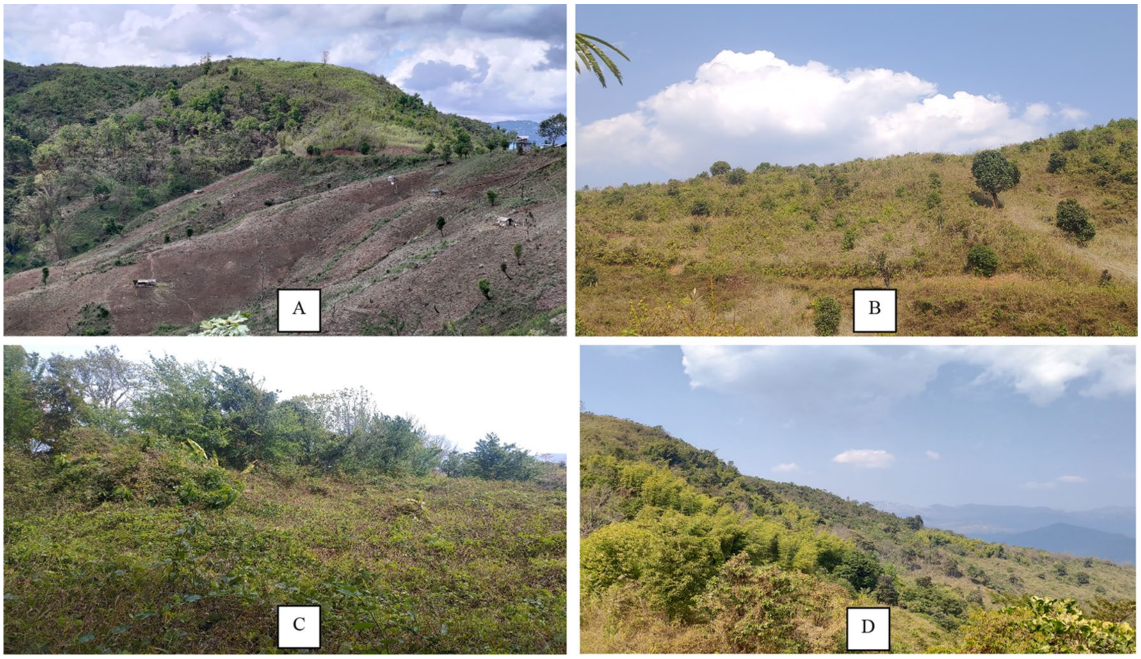

Fig. 2 Photographic view of **A** Shifting cultivation site (SCS), **B** Fallow land 3 (FL-3), **C** Fallow land 7 (FL-7), and **D** Fallow land 12 (FL-12)

retained pre-burning. Fallow land 7 (FL-7): This fallow land is in its 7th year of fallow, with no anthropogenic disturbances, and consists mainly of *Pueraria* sp., *Mikania* sp., *Persea fructifera*, *Angiopteris evecta*, *Eupatorium* sp., *Persicaria chinensis*, *Thysanolaena maxima*, *Sonchus* sp., *Musa* sp., *Artemisia vulagris* and *Spatholobus* sp. Fallow land 12 (FL-12): Finally, a fallow land in its 12th year of fallow, with no anthropogenic disturbances. Vegetation consists mainly of *Ageratum conyzoides*, *Albizia chinensis*, *Angiopteris* sp., *Artemisia vulagris*, *Sonchus* sp., *Phyllanthus emblica*, *Azadirachta indica*, *Schima wallichi*, *Persea fructifera*, *Thysanolaena maxima*, *Anthocephalus cadamba*, *Terminalia myriocarpa*, *Polygonum molle*, *Bambusa* sp. and *Musa* sp.

Soil analysis

Soil samples were collected depthwise, i.e., 0–10 cm, 10–20 cm and 20–30 cm from each of the study sites from spring–winter, i.e., spring (March–May 2020), summer (June–August 2020), autumn (September–November 2020) and winter (December 2020–February 2021). All soil tests were performed by utilizing air-dried samples sieved through a 2 mm nylon sieve except for bulk density and soil moisture. pH and electrical conductivity (EC) were recorded using a digital pH meter and EC meter, respectively. The gravimetric method was utilized for the estimation of soil moisture (Misra 1968), clay content was determined via pipette method (Piper 1942), bulk density (BD) via core sampler method (Allen 1989), soil organic carbon (SOC) via Walkley and Black method (1934), available nitrogen (N_{av}) by utilizing Kjeldahl method (1883), available phosphorus (P_{av}) via Bray's no. 1 extract method (Bray and Kurtz 1945) using UV–Vis spectrophotometer, exchangeable potassium (K_{ex}) using flame photometer (Photometric method) as per Trivedy and Goel (1986), and cation exchange capacity (CEC) following Bower et al. (1952). All tests were performed in triplicates and expressed as mean ± standard deviation.

Selection of minimum data set

For the selection of the minimum data set (MDS), principal component analysis (PCA) was first performed via SPSS version 26.0. Factors obtained from the varimax rotation with eigenvalues of > 1 that explained at least 5% of the variation in the data set were retained as the MDS for each site, respectively (Mandal et al. 2008). A Pearson's correlation test was implemented to decrease redundancy among the highly weighted variables to aid in the MDS screening (Guo et al. 2018; Yu et al. 2018). After completion of screening, MDS with the highest scores were retained from each of the Principal Components.

Indicator scoring

Next, the scores of each indicator from the MDS were assigned a value that ranged from 0 to 1, through a linear scoring function (Raiesi 2017; Yu et al. 2018) using two equations, i.e., lower is better (Eq. 1) and higher is better (Eq. 2). Meanwhile, for those parameters that possessed optimum range functions, indicators were tagged as good until a certain threshold level and as bad above the threshold level:

$$\mathrm{Ls} = \frac{Y\min}{Y} \quad (1)$$

$$\mathrm{Ls} = \frac{Y}{Y\max} \quad (2)$$

where Ls represents the linear score, Y is the value of the indicator selected in the MDS, $Y_{\min}$, and $Y_{\max}$ are the minimum and maximum values of the selected indicator.

Soil quality index For the calculation of SQI for the different sites, two equations were utilized, namely, the additive quality index and the weighted quality index.

1. Additive quality index: This was estimated as per Nabiollahi et al. (2017):

$$\mathrm{SQI(additive)} = \sum_{i=1}^{n} \mathrm{Si}/n \quad (3)$$

2. Weighted quality index: This was estimated as per Raiesi (2017):

$$\mathrm{SQI}\left(\mathrm{weighted}\right) = \sum_{i=1}^{n} \mathrm{WiSi} \quad (4)$$

where n is the number of variables retained in the MDS, S_i represents the score of the variable in the data set and W_i is the value of the weighted factor.

Statistical analyses and map generation

All statistical analyses for ANOVA and PCA were performed in SPSS version 26.0. One-way ANOVA was performed to compare the seasonal variation of soil and also to compare the means of each soil depth between the different sites that were statistically different at a 5% level by DMRT ($p<0.05$). All maps were generated by utilizing QGIS version 3.16.16.

Results

Comparison of mean values of soil parameters between sites

The depthwise mean values of soil parameters from the different study sites (0–10 cm, 10–20 cm, 20–30 cm) are given in Table 2.

Overall soil depth (0–30 cm)

Soil pH was reported to be lower under the fallow lands and higher under SCS. The EC values were also reported to be lower under SCS (0.094 dS m^{-1}) and higher under FL-12 (0.736 dS m^{-1}). Similarly, the SOC, N_{av}, K_{ex}, P_{av}, soil moisture, and BD values, respectively, were all considerably lower under SCS. Clay content and CEC values also decreased under SCS (20.25%) and increased with the implementation of fallow.

Soil depth 0–10 cm

The result of the comparison of soil parameters under the 0–10 cm depth is presented in Table 2. FL-12 exhibited lower pH values; meanwhile, SCS depicted higher pH values ($p=0.010$, $F=5.869$). The EC values were also reported to be lower under SCS (0.094 dS m^{-1}) and higher under FL-12 (0.736 dS m^{-1}) ($p\leq0.001$, $F=51.378$). The SOC values were also significantly lower under SCS ($p\leq0.001$, $F=27.380$). The N_{av} values were lower under SCS (320.71 kg ha^{-1}) and significantly higher under FL-12 (542.99 kg ha^{-1}) ($p\leq0.001$, $F=18.046$). A similar trend was also observed for K_{ex} and P_{av}, with lower values under SCS ($p=0.037$, $F=3.916$ and $p=0.006$, $F=6.854$, respectively). No significant difference was observed in the moisture content between the different study sites ($p=0.284$, $F=1.425$). Higher BD values were reported under SCS, whereas lower BD values were reported under the various fallow lands ($p\leq0.001$, $F=20.67$). Clay content and CEC values were both reported to be lower under SCS, which then increased with the implementation of fallow ($p\leq0.001$, $F=17.539$ and $p\leq0.018$, $F=4.963$, respectively).

Soil depth 10–20 cm

The result of the comparison of soil parameters under the 10–20 cm depth is presented in Table 2. Significantly higher pH and EC values were recorded under SCS ($p=0.24$, $F=4.540$ and $p\leq0.001$, $F=46.477$, respectively). Meanwhile, the SOC values were lower under SCS (1.33%) and higher at FL-12 (3.38%) ($p\leq0.001$, $F=28.738$). Similar trends were reported for N_{av}, K_{ex}, P_{av} and soil moisture content with significantly lower values under SCS ($p\leq0.001$, $F=12.922$; $p=0.010$, $F=6.003$; $p=0.005$, $F=7.354$ and $p=0.003$, $F=8.028$, respectively). Soil samples under SCS were reported to display significantly higher BD values ($p\leq0.001$, $F=18.120$). Finally, clay content and CEC values were also reported to be significantly lower under SCS and higher under the fallow lands ($p\leq0.001$, $F=26.984$ and $p\leq0.001$, $F=32.265$, respectively).

Soil depth 20–30 cm

The result of the comparison of soil parameters under the 20–30 cm depth is presented in Table 2. Significantly lower soil pH values were reported under FL-12 ($p=0.026$, $F=4.440$). Meanwhile, the EC values were higher under FL-12 and lower under SCS ($p\leq0.001$, $F=49.185$). SOC values were also drastically lowered under SCS, as compared to the fallow lands ($p \leq 0.001$, $F = 22.092$). N_{av}, K_{ex}, P_{av} and soil moisture values were significantly higher under the fallow lands as compared with the SCS ($p = 0.001$, $F = 11.437$; $p = 0.031$, $F = 4.172$; $p = 0.011$, $F = 5.732$ and $p = 0.023$, $F = 4.581$, respectively). Soil samples collected under SCS had significantly higher BD values ($p \leq 0.001$, $F = 15.113$). Finally, clay content and CEC values were significantly higher under FL-12 and lower under SCS ($p \leq 0.001$, $F = 30.472$ and $p \leq 0.001$, $F = 15.982$, respectively).

Seasonal variation of soil properties of each site

One-way ANOVA with p and F values of the seasonal variation of soil parameters are presented in Table 3.

SCS

Depthwise (0–10 cm, 10–20 cm, 20–30 cm) seasonal variations of soil parameters for SCS are presented in Table 4. Significant variation of pH was recorded under the 0–10 cm ($p \leq 0.001$) and 20–30 cm ($p = 0.048$) depth. The lower value of pH was observed during winter (5.4 ± 0.04); meanwhile, a higher pH value was recorded during autumn (5.9 ± 0.10). EC values varied significantly across all soil depths ($p \leq 0.001$). The lowest value of EC was recorded during winter (0.085 ± 0.002 dS m^{-1}), while the highest EC value was reported during summer (0.161 ± 0.014 dS m^{-1}). The seasonal variation of SOC was restricted to the 0–10 cm depth ($p = 0.042$), with higher SOC values during autumn and lower SOC values during winter. Meanwhile, N_{av} varied significantly across all soil depths ($p \leq 0.001$). The lowest N_{av} value of 146.00 ± 9.8 kg ha^{-1} was recorded during winter (20–30 cm), while the highest N_{av} value of 391.33 ± 10.1 kg ha^{-1} was observed during the autumn season (0–10 cm). K_{ex} also varied significantly across all soil depths ($p = 0.001$, $p = 0.016$ and $p \leq 0.001$, respectively). The highest K_{ex} value was observed during autumn (133.72 ± 5.56 kg ha^{-1}), while the lowest K_{ex} value was recorded during winter (65.93 ± 3.81 kg ha^{-1}). Likewise, P_{av} displayed significant seasonal variation at all soil depths ($p \leq 0.001$). The highest P_{av} value of 27.7 ± 1.35 kg ha^{-1} was recorded during summer, while the lowest P_{av} value of 8.16 ± 0.24 kg ha^{-1} was observed during winter. Soil moisture varied significantly across all depths ($p \leq 0.001$, $p = 0.001$ and $p \leq 0.001$, respectively). The highest moisture value was recorded during autumn (43.8 ± 0.9%), while the lowest moisture value was observed during winter (27.0 ± 0.7%). BD varied significantly for all depths ($p = 0.040$, $p \leq 0.001$ and $p \leq 0.001$, respectively). The highest BD value of 2.88 ± 0.05 g cm^{-3} was recorded during winter, while a minimum BD value of 1.66 ± 0.03 g cm^{-3} was observed during spring. A significant variation in clay content was recorded at the 0–10 cm ($p = 0.001$) and 10–20 cm ($p = 0.040$) depth, respectively. The highest clay value of 28.3 ± 0.47% was observed during autumn, while the lowest clay value of 18.1 ± 1.02% was observed during winter. Finally, CEC displayed significant variation across all soil depths ($p \leq 0.001$, $p = 0.009$ and $p = 0.002$, respectively), with higher values during autumn.

FL-3

Depthwise (0–10 cm, 10–20 cm, 20–30 cm) seasonal variations of soil parameters for FL-3 are presented in Table 4. pH varied significantly under the 10–20 cm ($p \leq 0.001$) and 20–30 cm ($p = 0.003$) depth. The lowest pH value was recorded during spring (5.0 ± 0.16), while the highest pH value was observed during autumn (5.7 ± 0.59). There was a significant seasonal variation of EC across all soil depths ($p \leq 0.001$), with the lowest value recorded during winter (0.228 ± 0.005 dS m^{-1}) and the highest value recorded during summer (0.543 ± 0.004 dS m^{-1}), respectively. Similarly, the SOC values varied significantly across all soil depths ($p \leq 0.001$, $p = 0.001$ and $p = 0.001$, respectively). N_{av} varied significantly across all soil depths ($p \leq 0.001$, $p = 0.001$ and $p \leq 0.001$, respectively), with the lowest value of 202.00 ± 7.3 kg ha^{-1} observed during winter and the highest value of 451.33 ± 5.2 kg ha^{-1} during autumn (0–10 cm). A similar trend was recorded for K_{ex}, P_{av} and moisture with significant seasonal variation across all soil depths. BD also displayed significant variation across all soil depths ($p = 0.009$, $p = 0.004$ and $p \leq 0.001$, respectively). A maximum BD value of 1.93 ± 0.03 g cm^{-3} was recorded during winter, while a minimum value of 1.22 ± 0.18 g cm^{-3} was observed during spring. The clay content value under the 0–10 cm depth varies significantly with the season ($p \leq 0.001$). Meanwhile, CEC displayed seasonal variation across all soil depths ($p = 0.013$, $p = 0.006$ and $p \leq 0.001$, respectively).

FL-7

Depthwise (0–10 cm, 10–20 cm, 20–30 cm) seasonal variation of soil parameters for FL-7 is given in Table 5. There was a significant variation of pH under the 0–10 cm ($p = 0.002$) and 10–20 cm ($p \leq 0.001$) depth, with lower pH values recorded during winter and higher pH values during autumn. EC values, meanwhile, varied significantly across all soil depths ($p \leq 0.001$). The lowest value of EC was recorded during spring (0.510 ± 0.008 dS m^{-1}), while the highest value of EC was recorded during summer (0.636 ± 0.016 dS m^{-1}). The seasonal variation of SOC was also significant across all soil depths ($p \leq 0.001$, $p = 0.001$ and $p = 0.047$, respectively). The highest value of SOC was recorded during spring (3.23 ± 0.18%), while the lowest value of SOC was recorded during winter (2.08 ± 0.10%). Likewise, it is observed that there was significant variation of N_{av}, K_{ex}, P_{av}, Soil moisture, and BD across all soil depths during the study period. Meanwhile, clay content varied significantly only under 0–10 cm of depth ($p = 0.048$). The highest clay value was recorded during autumn (34.3 ± 0.94%), while the lowest value of clay was recorded during winter (28.3 ± 0.47%). Likewise, CEC displayed significant variation only within the 0–10 cm depth ($p = 0.021$). The highest CEC value was recorded during autumn (32.28 ± 0.7 meq $100g^{-1}$), while the lowest value was recorded during winter (27.03 ± 0.5 meq $100g^{-1}$).

FL-12

Depthwise (0–10 cm, 10–20 cm, 20–30 cm) seasonal variation of soil parameters for FL-12 is given in Table 5. There was a significant seasonal variation of pH values ($p = 0.034$, $p = 0.017$ and $p = 0.014$, respectively) and EC values ($p \leq 0.001$) across all soil depths. Seasonal variation of SOC values was significant for the 20–30 cm depth only ($p = 0.040$). The highest value of SOC was reported during autumn (4.12 ± 0.18%), while the lowest SOC value was recorded during winter (2.56 ± 0.18%). Meanwhile, N_{av}, K_{ex} and P_{av} varied significantly across all soil depths. Soil moisture varied significantly for the 0–10 cm ($p = 0.001$) and 10–20 cm ($p = 0.033$) depth, with the highest moisture value observed during autumn (59.47 ± 0.8%) and the lowest moisture value observed during winter (46.30 ± 1.4%). BD also varied significantly for all depths ($p = 0.014$, $p \leq 0.001$ and $p \leq 0.001$, respectively). A maximum BD value of 1.16 ± 0.02 g cm^{-3} was recorded during winter, while a minimum BD value of 0.96 ± 0.04 g cm^{-3} was observed during autumn. Significant seasonal variation in clay content was observed at the 10–20 cm depth ($p = 0.041$). The highest value of clay was observed during autumn (37.2 ± 0.71%), while the lowest value of clay was reported during winter (30.8 ± 1.22%). Finally, CEC displayed significant variation across all soil depths ($p = 0.002$, $p \leq 0.001$ and $p \leq 0.001$, respectively). The highest CEC value was recorded during autumn (37.27 ± 1.34 meq $100g^{-1}$), while the lowest value was recorded during spring (25.68 ± 0.3 meq $100g^{-1}$).

Soil quality index comparison

Comparison of depthwise (0–10 cm, 10–20 cm, 20–30 cm) SQI of the different land use sites is presented under Fig. 3 (weighted index, i.e., SQI_w) and Fig. 4 (additive index, i.e., SQI_a). The factors retained after data

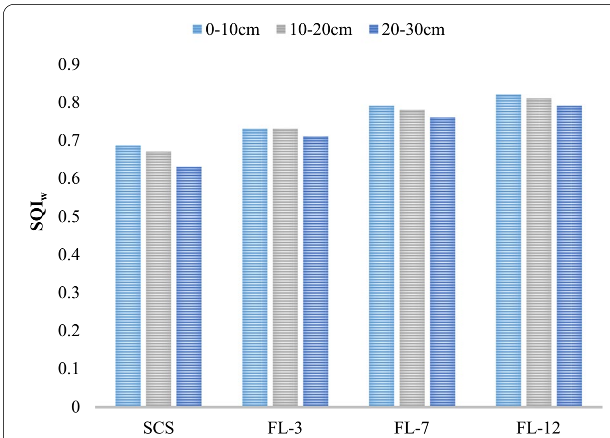

Fig. 3 Comparison of depthwise (0–10 cm, 10–20 cm, 20–30 cm) soil quality index (SQI_w) of the different land use sites using a weighted index. SCS (shifting cultivation site), FL-3 (Fallow land 3), FL-7 (Fallow land 7) and FL-12 (Fallow land 12)

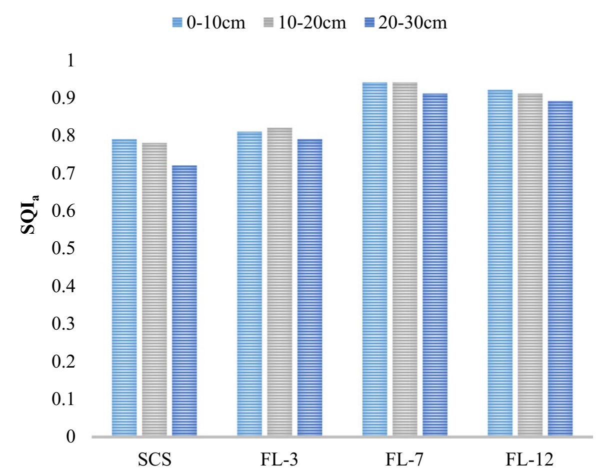

Fig. 4 Comparison of depthwise (0–10 cm, 10–20 cm, 20–30 cm) soil quality index (SQI) of the different land use sites using an additive index. SCS (shifting cultivation site), FL-3 (Fallow land 3), FL-7 (Fallow land 7) and FL-12 (Fallow land 12)

Table 1 GPS coordinates of study sites

Site	Coordinates	Elevation (m)
SCS	26° 13′ 31.50″ N 94° 32′ 22.220″ E	1058
FL-3	26° 13′ 38.558″ N 94° 31′ 50.190″ E	875
FL-7	26° 14′ 03.845″ N 94° 31′ 41.711″ E	864
FL-12	26° 14′ 08.55″ N 94° 32′ 28.45″ E	980

Geographic coordinates of SCS (shifting cultivation site), FL-3 (Fallow land 3), FL-7 (Fallow land 7) and FL-12 (Fallow land 12). North (N) and East (E)

Table 2 Depthwise comparison of the mean values of soil parameters between the different study sites

Soil depth (cm)	Sites	pH	EC (dS m^{-1})	SOC (%)	N_{av} (kg ha^{-1})	K_{ex} (kg ha^{-1})	P_{av} (kg ha^{-1})	Moisture (%)	BD (g cm^{-3})	Clay (%)	CEC (meq $100g^{-1}$)
0–10	SCS	5.60^{a}	0.094^{a}	1.86^{a}	320.71^{a}	117.51^{a}	20.44^{a}	33.67^{a}	1.62^{b}	23.82^{a}	14.50^{a}
	FL-3	5.22^{ab}	0.404^{b}	2.18^{b}	353.08^{a}	129.31^{ab}	26.92^{ab}	37.27^{a}	1.45^{b}	26.60^{b}	19.85^{a}
	FL-7	5.17^{b}	0.586^{c}	3.10^{c}	534.90^{b}	200.70^{bc}	34.94^{bc}	44.97^{a}	1.04^{a}	32.25^{c}	31.04^{ab}
	FL-12	4.88^{b}	0.736^{d}	3.94^{d}	542.99^{b}	214.75^{c}	36.32^{c}	46.52^{a}	1.01^{a}	34.70^{c}	44.65^{b}
10–20	SCS	5.60^{a}	0.110^{a}	1.33^{a}	267.99^{a}	96.31^{a}	18.69^{a}	33.97^{a}	2.27^{b}	21.70^{a}	14.27^{a}
	FL-3	5.22^{ab}	0.389^{b}	2.17^{b}	352.83^{a}	112.16^{b}	25.41^{ab}	36.47^{a}	1.47^{b}	25.80^{b}	18.79^{ab}
	FL-7	5.00^{b}	0.573^{c}	2.80^{c}	478.79^{b}	185.07^{b}	32.63^{bc}	47.43^{b}	1.08^{a}	31.12^{c}	29.90^{c}
	FL-12	5.00^{b}	0.704^{d}	3.38^{d}	482.88^{b}	200.99^{b}	33.76^{c}	54.14^{b}	1.04^{a}	33.75^{c}	29.90^{c}
20–30	SCS	5.57^{a}	0.108^{a}	1.18^{a}	235.16^{a}	104.07^{a}	18.18^{a}	33.20^{a}	2.29^{c}	20.25^{a}	13.36^{a}
	FL-3	5.22^{ab}	0.375^{b}	1.76^{b}	273.60^{a}	112.83^{a}	23.11^{ab}	34.12^{a}	1.79^{b}	25.00^{b}	18.22^{a}
	FL-7	5.12^{b}	0.561^{c}	2.36^{c}	428.04^{b}	178.28^{ab}	29.27^{bc}	43.96^{ab}	1.10^{a}	30.12^{c}	28.01^{b}
	FL-12	4.87^{b}	0.682^{d}	2.88^{d}	428.77^{b}	199.30^{c}	32.65^{c}	51.03^{b}	1.07^{a}	32.25^{c}	28.01^{b}

Values are expressed as mean. Means in the same column with different superscripts (a, b, c, d) in their respective soil depth (0–10 cm, 10–20 cm, 20–30 cm) are significantly different at 5% level by Duncan's multiple range test ($p < 0.05$). Meanwhile, means with the same or combination of similar superscripts (a, b, c, d) in their respective soil depth are not significantly different at 5% level by Duncan's multiple range test. SCS (shifting cultivation site), FL-3 (Fallow land 3), FL-7 (Fallow land 7) and FL-12 (Fallow land 12). Soil pH (pH), electrical conductivity (EC), soil organic carbon (SOC), available nitrogen (N_{av}), exchangeable potassium (K_{ex}), available phosphorus (P_{av}), soil moisture (Moisture), bulk density (BD), soil clay content (Clay) and cation exchange capacity (CEC)

Table 3 One-way ANOVA with *p* and *F* values of the seasonal variation of soil parameters from the different land use

Parameters	Soil depth (cm)	SCS		FL-3		FL-7		FL-12	
		p-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value	*p*-value	*F*-value
CEC	0–10	**< 0.001**	23.53	**0.013**	6.89	**0.021**	5.74	**0.002**	13.62
	10–20	**0.009**	8.007	**0.006**	9.20	0.909	0.177	**< 0.001**	21.92
	20–30	**0.002**	13.07	**< 0.001**	35.46	0.570	0.716	**< 0.001**	22.19
EC	0–10	**< 0.001**	31.7	**< 0.001**	406.39	**< 0.001**	21.62	**< 0.001**	38.60
	10–20	**< 0.001**	77.03	**< 0.001**	199.3	**< 0.001**	24.28	**< 0.001**	28.67
	20–30	**< 0.001**	64.79	**< 0.001**	424.06	**< 0.001**	30.49	**< 0.001**	21.42
Moisture	0–10	**< 0.001**	124.39	**< 0.001**	307.39	**< 0.001**	163.67	**0.001**	14.14
	10–20	**0.001**	17.35	**0.002**	13.81	**< 0.001**	35.97	**0.033**	4.87
	20–30	**< 0.001**	22.977	**< 0.001**	20.31	**< 0.001**	81.51	0.472	925
P_{av}	0–10	**< 0.001**	74.04	**< 0.001**	59.54	0.110	2.78	**0.001**	18.75
	10–20	**< 0.001**	126.963	**< 0.001**	75.36	**0.001**	15.36	**0.002**	12.15
	20–30	**< 0.001**	45.826	**0.003**	11.92	0.298	1.454	**0.002**	12.00
K_{ex}	0–10	**0.001**	18.13	**< 0.001**	30.90	**< 0.001**	93.74	**< 0.001**	88.60
	10–20	**0.016**	6.43	**0.001**	17.85	**< 0.001**	121.84	**< 0.001**	26.89
	20–30	**< 0.001**	40.61	**< 0.001**	33.66	**< 0.001**	28.39	**< 0.001**	120.27
N_{av}	0–10	**< 0.001**	125.01	**< 0.001**	184.34	**< 0.001**	36.18	**0.004**	10.29
	10–20	**< 0.001**	113.57	**0.001**	16.22	**< 0.001**	33.43	**< 0.001**	26.15
	20–30	**0.001**	16.19	**< 0.001**	16.91	**< 0.001**	37.18	**0.003**	11.02
BD	0–10	**0.040**	4.45	**0.009**	7.73	**< 0.001**	19.74	**0.014**	6.77
	10–20	**< 0.001**	151.94	**0.004**	10.54	**0.003**	10.78	**< 0.001**	30.24
	20–30	**< 0.001**	184.73	**< 0.001**	25.84	**0.001**	14.12	**< 0.001**	55.03
SOC	0–10	**0.042**	4.40	**< 0.001**	48.84	**0.001**	16.18	0.173	2.14
	10–20	0.183	2.06	**0.001**	16.38	**< 0.001**	27.83	0.233	1.75
	20–30	0.385	1.15	**0.001**	17.68	**0.047**	4.17	**0.040**	4.46
Clay	0–10	**0.001**	15.21	**< 0.001**	27.95	**0.048**	4.13	0.150	2.33
	10–20	**0.040**	4.47	0.371	1.19	0.057	3.84	**0.041**	4.45
	20–30	0.120	2.64	0.195	1.98	0.208	1.89	0.561	0.732
pH	0–10	**< 0.001**	22.96	0.148	2.35	**0.002**	13.72	**0.034**	4.76
	10–20	0.235	1.745	**< 0.001**	41.24	**< 0.001**	22.57	**0.017**	6.32
	20–30	**0.048**	4.12	**0.003**	10.85	0.355	1.24	**0.014**	6.78

Bold font indicates a significant result ($p < 0.05$). SCS (shifting cultivation site), FL-3 (Fallow land 3), FL-7 (Fallow land 7) and FL-12 (Fallow land 12). Cation exchange capacity (CEC), electrical conductivity (EC), soil moisture (Moisture), available phosphorus (P_{av}), exchangeable potassium (K_{ex}), available nitrogen (N_{av}), bulk density (BD), soil organic carbon (SOC), soil clay content(Clay) and soil pH (pH)

normalization and varimax rotation (with Kaiser Normalization) of the principal component analysis (PCA) explained a total variance of 79.97% for SCS, 80.26% for FL-3, 74.02% for FL-7 and 72.47% for FL-12, respectively (Table 6). The different factors retained under each Principal Component (PC) are as follows: CEC for PC-1, BD for PC-2 and clay for PC-3 were retained as MDS for SCS. Meanwhile, SOC for PC-1, Moisture for PC-2 and pH for PC3 were selected as MDS at FL-3. Under FL-7, we record that P_{av} for PC-1 and CEC for PC-2 were retained as MDS. Finally, at FL-12, Moisture for PC-1 and SOC for PC-2 were retained as MDS. Next, the scores for the selected indicators (MDS) were computed and the SQI was calculated for the four sites accordingly. For the additive index, the SQI_a ranged from 0.79 (0–10 cm), 0.78 (10–20 cm) and 0.72 (20–30 cm) for SCS; 0.81 (0–10 cm), 0.82 (10–20 cm) and 0.79 (20–30 cm) for FL-3; 0.94 (0–10 cm), 0.94 (10–20 cm) and 0.91 (20–30 cm) for FL-7 and finally, 0.92 (0–10 cm), 0.91 (10–20 cm) and 0.89 (20–30 cm) for FL-12, respectively. For the weighted index, the SQI_w ranged from 0.68 (0–10 cm), 0.67 (10–20 cm) and 0.63 (20–30 cm) for SCS; 0.73 (0–10 cm), 0.73 (10–20 cm) and 0.71 (20–30 cm) for FL-3; 0.79 (0–10 cm), 0.78 (10–20 cm) and 0.76 (20–30 cm) for FL-7; 0.82 (0–10 cm), 0.81 (10–20 cm) and 0.79(20–30 cm) for FL-12, respectively. The SQI_a was in the order SCS < FL-3 < FL-12 < FL-7; meanwhile, for SQI_w, it was in the order SCS < FL-3 < FL-7 < FL-12, respectively.

Table 4 Depthwise seasonal variation of soil parameters at SCS and FL-3

Site	Season	Soil depth (cm)	pH	EC (dS m^{-1})	SOC (%)	N_{av} (kg ha^{-1})	K_{ex} (kg ha^{-1})	P_{av} (kg ha^{-1})	Moisture (%)	BD (g cm^{-3})	Clay (%)	CEC (meq $100g^{-1}$)
SCS	Spring	0–10	5.5 ± 0.02	0.091 ± 0.001	2.11 ± 0.01	314.00 ± 8.2	118.40 ± 1.69	23.00 ± 0.89	29.0 ± 0.8	1.66 ± 0.03	22.3 ± 1.24	13.35 ± 1.3
		10–20	5.8 ± 0.08	0.088 ± 0.002	1.37 ± 0.02	223.00 ± 5.0	94.33 ± 3.39	21.53 ± 0.41	32.6 ± 2.8	2.30 ± 0.08	20.1 ± 1.54	14.30 ± 2.09
		20–30	5.4 ± 0.13	0.096 ± 0.001	1.10 ± 0.16	211.00 ± 9.0	114.16 ± 8.98	25.08 ± 1.14	33.0 ± 3.2	2.71 ± 0.01	19.3 ± 2.05	12.03 ± 0.8
	Summer	0–10	5.6 ± 0.03	0.161 ± 0.014	1.74 ± 0.21	320.88 ± 5.2	132.53 ± 13.48	27.70 ± 1.35	37.7 ± 1.4	1.33 ± 0.24	22.6 ± 2.05	15.75 ± 2.1
		10–20	5.5 ± 0.24	0.142 ± 0.001	1.33 ± 0.07	319.66 ± 14.1	95.95 ± 16.97	21.75 ± 1.25	34.9 ± 2.1	2.19 ± 0.09	20.2 ± 2.40	14.71 ± 1.6
		20–30	5.8 ± 0.09	0.135 ± 0.005	1.19 ± 0.14	305.33 ± 9.6	109.78 ± 6.13	19.95 ± 2.53	30.7 ± 1.7	1.48 ± 0.11	18.9 ± 3.02	13.38 ± 2.8
	Autumn	0–10	5.9 ± 0.10	0.120 ± 0.008	2.16 ± 0.39	391.33 ± 10.1	133.72 ± 5.56	21.06 ± 1.63	43.8 ± 0.9	1.70 ± 0.30	28.3 ± 0.47	19.28 ± 0.3
		10–20	5.7 ± 0.16	0.120 ± 0.007	1.46 ± 0.18	337.00 ± 2.9	117.75 ± 6.46	22.02 ± 0.78	41.1 ± 1.2	1.72 ± 0.04	26.0 ± 2.44	18.35 ± 0.8
		20–30	5.6 ± 0.13	0.116 ± 0.004	1.37 ± 0.26	278.33 ± 47.4	126.42 ± 2.04	19.58 ± 1.05	42.1 ± 0.3	2.72 ± 0.05	24.7 ± 3.63	18.38 ± 0.6
	Winter	0–10	5.4 ± 0.04	0.087 ± 0.000	1.44 ± 0.03	252.66 ± 2.6	85.93 ± 1.71	10.00 ± 0.88	24.2 ± 1.1	1.79 ± 0.01	22.1 ± 0.26	9.70 ± 1.2
		10–20	5.4 ± 0.16	0.091 ± 0.002	1.19 ± 0.07	192.33 ± 10.9	77.23 ± 1.32	9.46 ± 0.12	27.3 ± 0.7	2.88 ± 0.05	20.5 ± 0.63	9.72 ± 0.1
		20–30	5.5 ± 0.03	0.085 ± 0.002	1.08 ± 0.01	146.00 ± 9.8	65.93 ± 3.81	8.16 ± 0.24	27.0 ± 0.7	2.28 ± 0.02	18.1 ± 1.02	9.66 ± 0.04
FL–3	Spring	0–10	5.0 ± 0.16	0.417 ± 0.003	2.02 ± 0.12	341.66 ± 6.7	112.18 ± 7.33	30.50 ± 1.22	32.2 ± 0.9	1.42 ± 0.02	24.1 ± 0.62	18.34 ± 2.05
		10–20	5.1 ± 0.12	0.411 ± 0.001	1.93 ± 0.22	377.66 ± 13.1	91.65 ± 8.60	27.03 ± 0.91	34.0 ± 0.8	1.45 ± 0.01	24.4 ± 1.74	17.46 ± 1.1
		20–30	5.1 ± 0.07	0.403 ± 0.009	1.40 ± 0.28	299.73 ± 17.2	102.32 ± 0.57	22.23 ± 2.98	33.2 ± 2.6	1.86 ± 0.05	22.7 ± 2.33	17.44 ± 0.1
	Summer	0–10	5.1 ± 0.09	0.543 ± 0.004	2.81 ± 0.24	324.00 ± 10.0	145.46 ± 5.76	28.90 ± 0.28	39.5 ± 0.4	1.43 ± 0.01	27.1 ± 0.82	23.18 ± 1.1
		10–20	5.7 ± 0.06	0.552 ± 0.019	2.78 ± 0.23	371.66 ± 23.6	131.83 ± 2.99	28.30 ± 1.41	35.7 ± 2.8	1.22 ± 0.18	26.4 ± 1.22	21.96 ± 2.1
		20–30	5.1 ± 0.14	0.530 ± 0.007	2.31 ± 0.18	356.67 ± 20.5	117.56 ± 12.65	27.43 ± 1.08	31.8 ± 2.0	1.73 ± 0.03	26.7 ± 0.88	20.87 ± 1.1
	Autumn	0–10	5.7 ± 0.59	0.372 ± 0.013	2.13 ± 0.18	451.33 ± 5.2	171.36 ± 15.39	30.72 ± 1.90	48.8 ± 0.8	1.30 ± 0.15	29.3 ± 0.47	22.12 ± 2.57
		10–20	5.0 ± 0.24	0.355 ± 0.004	2.30 ± 0.27	379.00 ± 13.7	135.26 ± 11.96	28.68 ± 0.53	47.1 ± 0.8	1.48 ± 0.01	27.3 ± 1.24	19.77 ± 0.3
		20–30	5.7 ± 0.36	0.342 ± 0.010	1.93 ± 0.22	236.00 ± 38.1	148.36 ± 3.18	26.22 ± 2.40	45.5 ± 1.5	1.65 ± 0.01	26.0 ± 2.44	19.72 ± 0.4
	Winter	0–10	5.1 ± 0.16	0.285 ± 0.002	1.76 ± 0.04	295.33 ± 5.2	91.26 ± 1.10	17.56 ± 0.33	28.6 ± 0.4	1.67 ± 0.01	26.0 ± 0.16	15.76 ± 1.2
		10–20	5.1 ± 0.20	0.240 ± 0.016	1.70 ± 0.01	283.00 ± 12.2	89.76 ± 6.99	17.17 ± 0.22	29.1 ± 3.6	1.76 ± 0.02	25.1 ± 2.24	16.00 ± 0.08
		20–30	5.0 ± 0.32	0.228 ± 0.005	1.40 ± 0.05	202.00 ± 7.3	83.10 ± 3.14	16.58 ± 0.40	26.0 ± 3.6	1.93 ± 0.03	24.6 ± 0.49	14.86 ± 0.1

Values are expressed as mean ± standard deviation. SCS (shifting cultivation site) and FL-3 (Fallow land 3). Soil pH (pH), electrical conductivity (EC), soil organic carbon (SOC), available nitrogen (N_{av}), exchangeable potassium (K_{ex}), available phosphorus (P_{av}), soil moisture (Moisture), bulk density (BD), soil clay content (Clay) and cation exchange capacity (CEC)

Table 5 Depthwise mean values of seasonal variation in soil parameters at FL-7 and FL-12

Site	Season	Soil depth (cm)	pH	EC (dS m^{-1})	SOC (%)	N_{av} (kg ha^{-1})	K_{ex} (kg ha^{-1})	P_{av} (kg ha^{-1})	Moisture (%)	BD (g cm^{-3})	Clay (%)	CEC (meq $100g^{-1}$)
FL-7	Spring	0–10	5.2 ± 0.15	0.521 ± 0.009	3.51 ± 0.18	545.00 ± 9.0	201.56 ± 10.31	34.50 ± 4.11	40.33 ± 1.6	1.12 ± 0.01	32.2 ± 2.28	30.46 ± 1.1
		10–20	5.1 ± 0.04	0.510 ± 0.008	3.15 ± 0.11	494.33 ± 11.0	186.83 ± 7.45	31.16 ± 0.86	42.90 ± 1.2	1.11 ± 0.02	31.6 ± 1.83	30.03 ± 4.04
		20–30	5.2 ± 0.09	0.504 ± 0.004	2.16 ± 0.11	474.66 ± 12.4	165.73 ± 22.10	27.80 ± 0.50	37.63 ± 2.9	1.21 ± 0.06	30.8 ± 1.23	27.21 ± 1.2
	Summer	0–10	5.3 ± 0.08	0.636 ± 0.016	3.23 ± 0.16	557.00 ± 12.8	218.88 ± 7.86	37.38 ± 1.68	50.25 ± 0.5	1.03 ± 0.03	32.6 ± 0.47	31.95 ± 0.8
		10–20	5.2 ± 0.08	0.623 ± 0.028	2.74 ± 0.10	503.22 ± 15.2	213.23 ± 4.09	35.63 ± 0.57	51.59 ± 3.5	1.09 ± 0.01	31.9 ± 0.77	30.01 ± 0.7
		20–30	5.0 ± 0.12	0.613 ± 0.004	2.44 ± 0.36	391.00 ± 8.9	217.10 ± 3.47	31.60 ± 1.96	50.07 ± 0.4	1.11 ± 0.01	28.7 ± 0.55	28.10 ± 1.4
	Autumn	0–10	5.4 ± 0.05	0.625 ± 0.024	3.13 ± 0.13	583.63 ± 19.9	258.96 ± 10.20	36.45 ± 0.76	57.86 ± 1.3	0.97 ± 0.01	34.3 ± 0.94	32.28 ± 0.7
		10–20	5.2 ± 0.16	0.609 ± 0.004	2.99 ± 0.02	506.31 ± 11.4	225.40 ± 9.36	33.71 ± 0.40	57.21 ± 1.4	0.99 ± 0.01	32.7 ± 1.92	31.31 ± 1.5
		20–30	5.3 ± 0.26	0.580 ± 0.022	2.76 ± 0.15	463.43 ± 6.1	217.56 ± 14.05	31.66 ± 1.05	56.27 ± 0.9	0.99 ± 0.01	30.3 ± 0.61	29.72 ± 1.3
	Winter	0–10	4.8 ± 0.08	0.564 ± 0.009	2.54 ± 0.03	454.00 ± 7.4	123.43 ± 1.81	31.43 ± 0.41	31.46 ± 1.2	1.07 ± 0.01	29.9 ± 0.16	29.50 ± 0.7
		10–20	4.5 ± 0.02	0.552 ± 0.001	2.40 ± 0.08	411.33 ± 2.0	114.66 ± 1.24	30.03 ± 0.20	38.10 ± 0.6	1.16 ± 0.05	28.3 ± 0.47	29.43 ± 3.6
		20–30	5.0 ± 0.19	0.548 ± 0.004	2.08 ± 0.10	383.10 ± 14.6	112.73 ± 2.50	26.02 ± 1.30	31.90 ± 1.5	1.11 ± 0.01	30.7 ± 1.28	27.03 ± 0.5
FL-12	Spring	0–10	4.5 ± 0.21	0.684 ± 0.007	4.08 ± 0.25	545.66 ± 10.6	206.43 ± 18.92	38.61 ± 0.62	52.15 ± 0.8	1.01 ± 0.01	33.9 ± 3.77	29.79 ± 5.4
		10–20	4.8 ± 0.11	0.670 ± 0.001	3.75 ± 0.10	554.66 ± 30.4	184.10 ± 13.23	37.07 ± 1.58	52.66 ± 3.4	1.04 ± 0.03	32.0 ± 2.16	26.07 ± 4.1
		20–30	5.1 ± 0.23	0.664 ± 0.006	2.72 ± 0.22	388.00 ± 13.4	188.52 ± 6.50	34.91 ± 2.57	49.06 ± 0.6	1.03 ± 0.01	31.2 ± 1.11	25.68 ± 0.4
	Summer	0–10	5.0 ± 0.17	0.836 ± 0.020	3.85 ± 0.04	563.00 ± 25.8	233.24 ± 8.279	40.66 ± 1.21	55.06 ± 1.0	1.00 ± 0.01	36.0 ± 2.02	33.51 ± 1.56
		10–20	5.1 ± 0.08	0.761 ± 0.009	3.43 ± 0.14	459.44 ± 14.7	247.63 ± 17.10	38.13 ± 1.80	56.20 ± 0.9	1.00 ± 0.01	34.9 ± 1.30	31.25 ± 1.4
		20–30	5.1 ± 0.02	0.747 ± 0.018	3.11 ± 0.20	427.33 ± 21.8	213.67 ± 7.96	37.63 ± 1.721	52.28 ± 3.6	1.10 ± 0.01	33.6 ± 2.25	30.56 ± 3.3
	Autumn	0–10	5.0 ± 0.04	0.743 ± 0.022	4.12 ± 0.18	573.00 ± 13.1	294.46 ± 3.41	36.93 ± 3.00	59.47 ± 0.8	0.96 ± 0.04	37.2 ± 0.71	37.27 ± 1.34
		10–20	5.2 ± 0.07	0.735 ± 0.018	3.30 ± 0.13	512.11 ± 10.5	252.13 ± 25.38	34.21 ± 0.89	58.07 ± 0.7	1.00 ± 0.01	35.8 ± 0.18	35.99 ± 0.07
		20–30	5.0 ± 0.04	0.653 ± 0.016	3.13 ± 0.08	497.76 ± 2.1	279.83 ± 14.09	33.61 ± 1.09	56.51 ± 1.2	0.99 ± 0.01	33.3 ± 3.68	33.78 ± 1.6
	Winter	0–10	4.8 ± 0.13	0.683 ± 0.009	3.72 ± 0.11	490.33 ± 10.2	124.90 ± 2.84	29.10 ± 0.16	49.39 ± 1.4	1.07 ± 0.01	31.7 ± 1.28	29.36 ± 1.6
		10–20	4.9 ± 0.08	0.653 ± 0.016	3.04 ± 0.02	405.33 ± 4.9	120.12 ± 6.33	25.63 ± 3.81	49.66 ± 3.7	1.14 ± 0.01	32.3 ± 0.49	28.90 ± 0.1
		20–30	4.3 ± 0.30	0.667 ± 0.005	2.56 ± 0.18	402.00 ± 32.6	115.21 ± 1.78	24.46 ± 1.22	46.30 ± 1.4	1.16 ± 0.02	30.8 ± 1.22	29.26 ± 0.2

Values are expressed as mean ± standard deviation. FL-7 (Fallow land 7) and FL-12 (Fallow land 12). Soil pH (pH), electrical conductivity (EC), soil organic carbon (SOC), available nitrogen (N_{av}), exchangeable potassium (K_{ex}), available phosphorus (P_{av}), soil moisture (Moisture), bulk density (BD), soil clay content (Clay) and cation exchange capacity (CEC)

Table 6 Principal component analysis (PCA) result with factor loadings of the different soil parameters from the study sites

Site	SCS			FL-3			FL-7		FL-12	
Principal Component	**PC-1**	**PC-2**	**PC-3**	**PC-1**	**PC-2**	**PC-3**	**PC-1**	**PC-2**	**PC-1**	**PC-2**
Eigen value	5.63	1.33	1.02	5.82	1.16	1.03	5.92	1.47	5.59	1.165
%Variance	56.37	13.34	10.26	58.278	11.635	10.357	59.23	14.78	55.91	16.55
%Cumulative frequency	56.37	69.71	79.97	58.278	69.912	80.269	59.23	74.02	55.91	72.47
Factor loadings										
CEC	**0.852**	0.226	0.344	0.604	0.438	0.457	0.306	**0.845**	0.886	0.319
EC	0.845	0.134	0.007	0.799	− 0.038	0.463	0.069	0.829	0.402	0.565
Moisture	0.782	0.123	0.408	0.249	**0.854**	0.198	0.445	0.782	**0.896**	0.301
P_{av}	0.737	0.484	− 0.112	0.731	0.498	0.233	**0.875**	0.279	0.393	0.736
K_{ex}	0.672	0.602	0.167	0.362	0.804	0.279	0.681	0.615	0.871	0.360
N_{av}	0.595	0.553	0.394	0.775	0.349	− 0.046	0.830	0.200	0.296	0.769
BD	− 0.365	− **0.857**	− 0.035	− 0.814	− 0.366	0.023	0.248	− 0.842	− 0.630	-0.570
SOC	0.048	0.845	0.400	**0.891**	0.300	0.092	0.798	0.168	− 0.237	**0.899**
Clay	− 0.003	0.152	**0.888**	0.208	0.763	− 0.095	0.757	0.175	0.507	0.491
pH	0.326	0.144	0.667	0.063	0.110	**0.905**	0.732	0.320	0.791	-0.116

Bold indicates the highest loaded factors in their respective columns which are retained for minimum data set (MDS). PC-1 (Principal Component one), PC-2 (Principal Component two) and PC-3 (Principal Component three). Cation exchange capacity (CEC), electrical conductivity (EC), soil moisture (Moisture), available phosphorus (P_{av}), exchangeable potassium (K_{ex}), available nitrogen (N_{av}), bulk density (BD), soil organic carbon (SOC), soil clay content (Clay) and soil pH (pH). SCS (shifting cultivation site), FL-3 (Fallow land 3), FL-7 (Fallow land 7) and FL-12 (Fallow land 12)

Discussion

Comparison of mean soil parameter between sites

We observed that soil quality (depthwise) followed the order 0–10 cm > 10–20 cm > 20–30 cm, for all the study sites. Soil pH was recorded to be highest under SCS across all soil depths. The significantly higher soil pH under SCS may be attributed to the practice of burning vegetation and spraying salts. We also observed that soil pH value decreases with an increase in the fallow period. Lowered pH values (more acidic) under the fallow land may be due to higher organic matter input from above-ground biomass and its undisturbed nature. Brady and Weil (2002) report that organic matter in the form of litter and compost reduces soil pH. Furthermore, soil pH was reported to be lower in the upper soil depth (0–10 cm). The higher rate of decomposition in the upper humus-rich layer may be one reason for the increased pH values in this zone (0–10 cm). With regards to EC, we observed that an increase in the fallow period led to an increase in the EC values. Tellen and Yerima (2018) similarly reported on the higher EC values in forest land as compared to cultivated land. They further stated that the use of basic chemical fertilizer in the selected areas of the Northwest region of Cameroon did not significantly increase the soil EC value, but stressed the need for organic fertigation. Higher EC values in the 0–10 cm depth may also be attributed to higher SOC values in the upper soil layer. The higher SOC allows for increased water retention and higher conductivity in the soil (Hawkins et al. 2017). A decrease in both the moisture content and EC values were observed with the increase in soil depth across all the study sites. SCS possessed the lowest SOC values amongst all the study sites, following the order SCS < FL-3 < FL-7 < FL-12. Continuous cropping and soil tillage practices break down and remove organic residues from the soil, depleting SOC (Chandel and Hadda 2018). Meanwhile, an increase in the fallow period allows for additional litter decomposition and turnover rate, improving SOC values. SOC has been reported to aid the structural stability of soil by increasing its CEC and moisture content (Leeper and Uren 1993). The higher SOC in the upper soil layer (0–10 cm) may also be attributed to active litter decomposition in this zone (0–10 cm). Therefore, we observe that the depletion of SOC levels under SCS, due to intensive continued cropping, also reduces the CEC values of soil. Our findings are supported by Yimer et al. (2008), who also reported on the higher CEC values under forest soil as compared to croplands. Significantly higher N_{av}, P_{av} and K_{ex} values were observed under land with higher fallow periods, i.e., FL-7 and FL-12 as compared to sites with no fallow period or land that employed shorter fallow periods, i.e., SCS and FL-3, respectively. The increased addition of organic matter through litter-fall and greater root biomass may be one factor for the higher macronutrients in the fallow sites (Neha and Sharma 2020). Furthermore, higher soil organic matter elevates soil aeration, protects the micro-nutrients from oxidation, and also increases the abundance of chelating agents, resulting in increased nutrient availability (Singh et al. 2000; Dhaliwal and

Dhaliwal 2019). Zolfaghari and Hajabbasi (2008) report that the conversion of forest into cultivated land significantly increased its BD values. We report a similar observation, where the BD values were higher under SCS and significantly lower in the fallow lands. This may be attributed to the higher organic matter and moisture content in the fallow sites as compared to SCS. Meanwhile, an increase in BD values with the increase in soil depth is due to a combination of reduced organic matter content and aggregation of soil, which increases compaction of the soil (Stockfisch et al. 1999; Chauhan et al. 2019). In the comparison of the four sites, we conclude that unsustainable farming practices result in soil compaction, low infiltration, and decreased nutrients in the soil. Meanwhile, with the implementation of fallow, there is more organic matter input from vegetation, an increase in clay and moisture content, and a reduction in BD and pH values (Getachew et al. 2012; Javad et al. 2014; Neha and Sharma 2020). Similar reports on the negative impacts of shifting cultivation by the ethnic inhabitants and the reduced fallow on the soils of the North-East region have been documented (Osman et al. 2013; Mishra et al. 2017, 2021).

Seasonal variation of soil properties

The onset of heavy rainfall during summer and autumn increases the moisture content in the soil. In contrast, with winter receiving little to no rainfall, soil moisture decreases. Therefore, soil moisture follows the expected seasonal trends, i.e., winter < spring < summer < autumn. While higher values of soil pH (less acidic) are observed during autumn, lower values of pH are observed during winter. During winter, the decreased pH value may be attributed to a combination of organic acid released via decomposition and decreased moisture content. Meanwhile, with the onset of the rainy season, there is a restoration of moisture which increases the soil pH value. A similar report on the relationship between moisture and pH has been established by Baruah et al. (2018) on the soils of Assam, India. They reported a decreased pH value of 4.36 during winter and an increased pH value of 4.73 during the monsoon (rainy) season, respectively. Guojo et al. (2020) similarly report that an increase in temperature (0.5–2 °C) significantly increased pH value (0.42–0.67). We record a similar trend, wherein pH value increases as soil temperature rises. Higher EC values were recorded during the rainy season at all the different land use sites. This may be attributed to a surge in rainfall which increases the leaching of salts present from the rhizosphere network into the soil (Tesfahunegn and Gebru 2020). Similarly, higher values of soil clay content were recorded during the rainy season. Variation in rainfall patterns alters the soil texture which affects the deposition–transportation process. This results in higher clay content during the warmer period, which is accompanied by rainfall, in comparison to the colder periods which receive lower precipitation (Tesfahunegn and Gebru 2020). Although there are reports on higher SOC values during the colder season, due to a lack of disturbance that prevents the exposure of organic matter to oxidation (Asima et al. 2020), we observe a conflicting trend. We recorded higher SOC values during the warmer (summer and autumn) periods in the present study. This may likely be attributed to higher carbon input from the decomposition of litter during the warmer season, which eventually increases SOC levels (Zhao et al. 2009). Furthermore, there also exists a positive correlation between SOC and CEC. Tesfahunegn and Gebru (2020) report that a proportional rise in CEC is observed with soil management practices that increase soil moisture and SOC. We have also observed a similar trend, where moisture, clay, and CEC are higher during the rainy season and vice versa. Thus, the increased levels of SOC during the summer and autumn season additionally lead to higher negative colloid that increases CEC values in the soil (Dutta et al. 2011). The primary nutrients, i.e., N_{av}, P_{av} and K_{ex} increased with the onset of warmer seasons (summer–autumn). These higher levels of nutrients during the warmer period may be attributed to the increased moisture content, improved mineralization, and decomposition of organic matter. Meanwhile, during the colder seasons, microbial activity decreases, causing soil nutrients to drop. Mahajan et al. (2020) also established that higher soil nutrients may be due to higher input of litter through a surge in organic matter accumulation and higher biomass production and the subsequent increase in microbial activity. The onset of winter leads to abiotic conditions, such as decreased temperature and moisture, limiting the microbial activity, and consequently resulting in lower mineralization and decomposition. Concerning BD, the higher influx of rain during the rainy season and the increased organic matter from litter lower the BD values. Meanwhile, with the transition to winter, moisture level decreases which cause an increase in BD values. Similar reports on seasonal variation of soil properties have been observed by other researchers (Moebius et al. 2007; Neha and Sharma 2020). It is vital to monitor the seasonal variation of soil parameters, as some indicators are sensitive and vary significantly, while some remain relatively stable across seasons (Omer et al. 2018).

Soil quality index comparison

The implementation of SQI to assess soil quality of different land use enables efficient comparison and generation of user-friendly data. We observed that under SCS, three Principal Components (PC) with their respective MDS viz., CEC, BD and clay were retained. Therefore, this site is characterized by reduced CEC and clay values, while the BD value increases. Osman et al. (2013) similarly reported the higher BD values under soils of shifting cultivation sites due to the reduced clay content. Meanwhile, SOC and moisture were retained as indicators of soil quality at sites FL-3 and FL-12, respectively. This corresponds to the higher SOC and moisture content in the soil that implements the fallow period. pH, meanwhile, was also retained as a quality indicator under FL-3. This may be attributed to the lowered pH value due to higher organic matter and litter decomposition at this site (Chandel and Hadda 2018). At FL-7, CEC and P_{av} were retained as MDS. This corresponds to higher CEC values under fallow lands due to increased organic matter content. Furthermore, P_{av} may be selected due to its higher mineralization process and its ability to promote plant growth. Similarly, Mishra et al. (2021) selected P_{av} as an indicator of soil quality in their study on shifting cultivation in the North-eastern Himalayan region.

We observe that SQI increases with an increase in the fallow period for both indexes. In the present study, we observe the values of $SQI_a > SQI_w$. We further report that in both weighted and additive indexes, the SQI decreases with the increase in soil depth and vice versa (Figs. 3, 4). The only exception to this is at site FL-7, where we observe that in the additive index method (SQI_a), the middle layer, i.e., 10–20 cm depth, displayed the highest SQI value. Triantafyllidis et al. (2018) and Yeilagi et al. (2021) also report a similar variance and conclude that SQI_w (weighted index) reported the optimal result and outperformed the SQI_a (additive index) as per their findings. Likewise, we recommend the values of the SQI_w, as it agrees with the reports of land use causing alteration in the soil. This is further in conformity with our results, wherein the soil quality increased with the implementation of the fallow period. In the comparison of all sites, it is observed that FL-12 had the highest SQI, while SCS had the lowest SQI. This is in agreement with Singh et al. (2013), who has reported on the higher SQI in forests (0.93) as compared to shifting cultivation sites (0.60). The increase in SQI value with the fallow period increases, as evident in the present study, may be attributed to the significantly higher SOC values (2.88–3.94%) under FL-12. The SOC levels build up over time due to a lack of anthropogenic disturbances and an increased litter deposition rate. Meanwhile, continued anthropogenic disturbances and lack of a proper fallow period degrade the soil under SCS, reducing its SQI value. It is reported that reduced SOC, macronutrients, and a lower response to fertilizers negatively impact productivity (Pal et al. 2012; Venkanna et al. 2014). We observe a similar trend in the present study, where the lowest SQI represents SCS with its lowered SOC and macronutrients, as compared to the other sites that employ the fallow period. Furthermore, the higher SQI in the order FL-3 < FL-7 < FL-12, denotes the rise in productivity of the soil as the age of fallow increases. SQI_w (weighted) has been reported to correlate positively with crop yield (Vasu et al. 2016).

Conclusions

The present study examined the effcts of shifting cultivation and fallow on soil quality in the Nagaland state, North-East India. This is to enable easier information dissemination. From the study of both the selected soil parameters and SQI, it is evident that unsustainable soil practices degrade soil quality, while fallow periods regenerate soil quality. Furthermore, the weighted SQI_w provided more accurate results than the additive SQI_a, among the different land use sites. We also conclude that MDS can be used to assess soil quality faster while at the same time reducing workload and costs. Monitoring SQI will provide local stakeholders and policymakers with an accurate assessment of the region and aid them in identifying unsustainable practices. The present study does not work on the various soil biological agents and productivity index. Hence, future work focusing on the above parameters will allow for a better understanding of the various processes that contribute to soil health. Nonetheless, there is an urgent need for an efficient and swift soil quality assessment and management in the region, and SQI may be one of the many tools to achieve this goal. The following recommendations can be made for the sustainable practices and management of shifting cultivation sites.

1. It is critical to sensitize stakeholders and indigenous inhabitants to the negative effects of shifting cultivation on soil health.
2. The information on the importance of maintaining an optimum fallow period should be properly disseminated among the ethnic inhabitants.
3. Monitoring land use with SQI is helpful to decision-makings that will increase crop productivity, sustainability, and livelihood security.
4. The current work may be utilized as baseline data to develop local soil quality index maps of the region. The maps will assist local policymakers in managing soil resources efficiently.
5. Future work on incorporating biological and productivity indices will also enable a better understanding of the soil health in the region.

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