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Research Article

Changes in soil exchangeable nutrients across different land uses in steep slopes of Mizoram, North-east India

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Abstract
Land use change resulting from anthropogenic pressure on land has led to degraded soil quality, especially in the hilly tropical regions where ecosystems are generally fragile and susceptible to soil degradation from cultivation. Hence, sustainable land uses and management practices are crucial for agricultural production and ecological balance, particularly in these regions. The present study investigates the impact of various hill land uses (Natural forest-NAF, *Jhum* fallow-JF, Home garden-HG, *Acacia pennata* plantation-AP and Current *Jhum*-CJ) on soil exchangeable nutrients in steeply sloping agro-ecosystems of Mizoram, North-east India. Soil samples were collected from three different depths (0-10, 10-20 & 20-30 cm) and analyzed for pH, P_{avail}, Na, K, Mg, Mn and Ca. Our results indicated that land use and soil depths had a significant impact on soil pH, P_{avail} and soil exchangeable cations ($p<0.05$). Conversion of native forests for cultivation negatively affected soil properties as indicated by the reduced soil exchangeable cations in cultivated lands (AP & CJ) in relation to the natural forest (NAF) and *Jhum* fallow (JF). Soils under longer periods of fallow (>12 years) led to increases in soil available nutrients indicating the role of vegetation cover in conserving and enhancing soil available nutrients and vice-versa. In addition, Home garden (HG) showed moderately higher available soil nutrients signifying the role of sustainable management practices such as the addition of organic amendments and mixed cropping, leading to increased soil available nutrient content.

Keywords: Anthropogenic pressure, Exchangeable nutrients, Land use change, Sustainability

INTRODUCTION

Land use change induced by anthropogenic actions has been a major issue in the past few decades, fuelled by the alarming rate of growth in human populations. This has exerted immense pressure on Earth's most valuable natural resources, such as forest ecosystems and their soils. Globally, land use change and management practices are the most dominating factors that influence soils' major properties and ecological processes (Lal, 2001; Tripathi *et al.,* 2012; Valle Junior *et al*., 2014; Pacheco *et al*., 2018). Unsustainable land use and management practices which lead to soil health deterioration can be regarded as a severe challenge for food security and environmental sustainability worldwide (Lal, 2009). However, this issue is more pronounced in the developing regions experiencing pressure due to an increase in the human population (Pricope *et al*., 2013; Tully *et al*., 2015) and where conversion of natural forests and grasslands to other land uses such as croplands and uncontrolled grazing have degraded the soil properties (Gregory *et al*., 2015; Valera *et al*., 2016).

The impact of land use change on soil properties is more pronounced in the hilly regions as it can greatly degrade soil quality with increased soil loss through runoff and erosion (Singh *et al*., 2015; Wapongnungsang *et al*., 2018; Lalnunzira and Tripathi, 2018). Shifting cultivation (*Jhum*) is a major issue in most tropical regions, especially in North-east India, where this practice is the most prominent form of agriculture, leading to loss of vegetation cover while inducing land use change. The decrease in the fallow period has led to soil degradation, while the increase in the fallow period following shifting cultivation has been observed to enhance SOM and increase nutrient content due to changing belowground dynamics (Wapongnungsang *et al*., 2017; Hauchhum and Tripathi, 2017; Singha and Tripathi, 2017). The study area (Mizoram) is characterized by extreme slopes and undulating physiographic conditions. Thus, cultivation under such conditions becomes intricate, thereby threatening the region's sustainability by affecting the primary source of livelihood for the majority of the rural population of Mizoram (Tripathi *et al*., 2017).

Shifting cultivation is one of the major farming practices that cause land degradation due to shortening the fallow length. Therefore, it is necessary to develop policies and strategies aimed at sustainable *Jhum* farming systems or other sustainable farming alternatives in the state to minimize deforestation and loss of soil fertility (Grogan *et al*., 2012; Tripathi *et al.,* 2017). Appropriate soil management practices and other favourable integrated land use management activities are indispensable in maintaining soil physical, chemical and biological properties. Therefore, it is crucial to evaluate the impacts of land use activities on soil properties and fertility for sustainable agricultural productivity (Fesha *et al*., 2002). However, studies are still limited in the Northeast region of India on qualitative changes in the soil (Singh *et al*., 2015; Manpoong *et al*., 2019; Ovung & Tripathi, 2020; Ovung *et al*., 2021). In order to overcome undesirable changes in soil properties leading to reduced productivity and poor ecosystem functioning due to land use change, there is a need to understand how the soil responds to a particular land use system. This study was an attempt to quantify and study the pattern of changes in exchangeable nutrients under soils of various land uses in steep slopes of Mizoram, North-east India.

MATERIALS AND METHODS

Study area

Mizoram is a hilly state located at the southernmost part of the North-east region of India, lying between 92° 15´ to 93° 29´ E Long and 21°58´ to 24° 35´ N Lat, and covers an area of 21,081 km^2 (Fig 1.), endowed with considerable coverage of green foliage amounting to about 85.4 % of its total geographical area under forest area (India State of Forest Report, 2019). The state enjoys a moist sub-tropical to moist tropical climate and the region is influenced by monsoons, raining heavily from May to September with little rain in the dry winter season. The mean min and max temperature vary from 9°C to 24°C during winter and 24°C to 32°C during summer (Tripathi *et al*., 2017). The state receives an annual rainfall of about 2100 mm-3000 mm. Inceptisols are the most common soil order found in the state, which are generally composed of sandy loam and clay loamy soil with high organic carbon richness (Colney and Nautiyal, 2013).

Description of study sites

The study sites fall within the two adjoining districts of Aizawl and Mamit, which share a similar type of climate, vegetation and soil. Five different land use systems, namely; *Acacia pennata* plantation (AP); Home garden (HG); Current *Jhum* (CJ); 12-15 years old *Jhum* fallow (JF), along with a Natural forest (NAF) were selected for the experiment from the two districts. A total of 15 study sites (5 land use types x 3 site replicates) were located and identified within the two districts.

Soil sampling

Replicated soil samples were randomly collected from each site by inserting a 10 cm scaled soil corer having an inner diameter of 5.2 cm. Soil samples were drawn from three different depths i.e. 0-10 cm, 10-20 cm and 20-30 cm. Within each site, samples were collected from 2 locations and composited for each depth as a single replicate and this way 3 random soil samples were collected. A total of 90 samples (2 composite samples x 3 depths x 3 site replicates x 5 land use types) were collected for this study.

Soil laboratory analysis

Soil pH was measured on the basis of the potentiometric principle (Peech, 1965) in a 1:2.5 soil/water solution using a pH meter. For the analysis of soil exchangeable nutrients (P_{avail}, Ca, Mg, Na, K and Mn) air dried soil samples were extracted in Mehlich-I solution (0.05 M HCl + 0.025 M H_2SO_4) and analyzed using the inductively coupled plasma spectrometer (iCAP6300 series, Thermo scientific).

Statistical analysis

The data obtained are presented as mean and standard error (SE). The resulting data were subjected to a two-way analysis of variance (ANOVA). Significant differences among soil variables were determined and the least significant difference (LSD) were calculated to determine significant differences between means at $p \leq 0.05$. All statistical analysis was carried out using open source OPSTAT (free Online Agriculture Data Analysis Tool developed by O.P. Sheoran, Computer Programmer at CCS HAU, Hisar, India).

RESULTS AND DISCUSSION

Effect of land use and soil depths on soil pH and P_{avail}

Soil pH was acidic in all the land use systems and the value decreased with increasing depth. Soil pH was highest in CJ (5.4) and lowest in AP (4.7) at the surface soil layer (Table 1). Soil pH significantly varied among

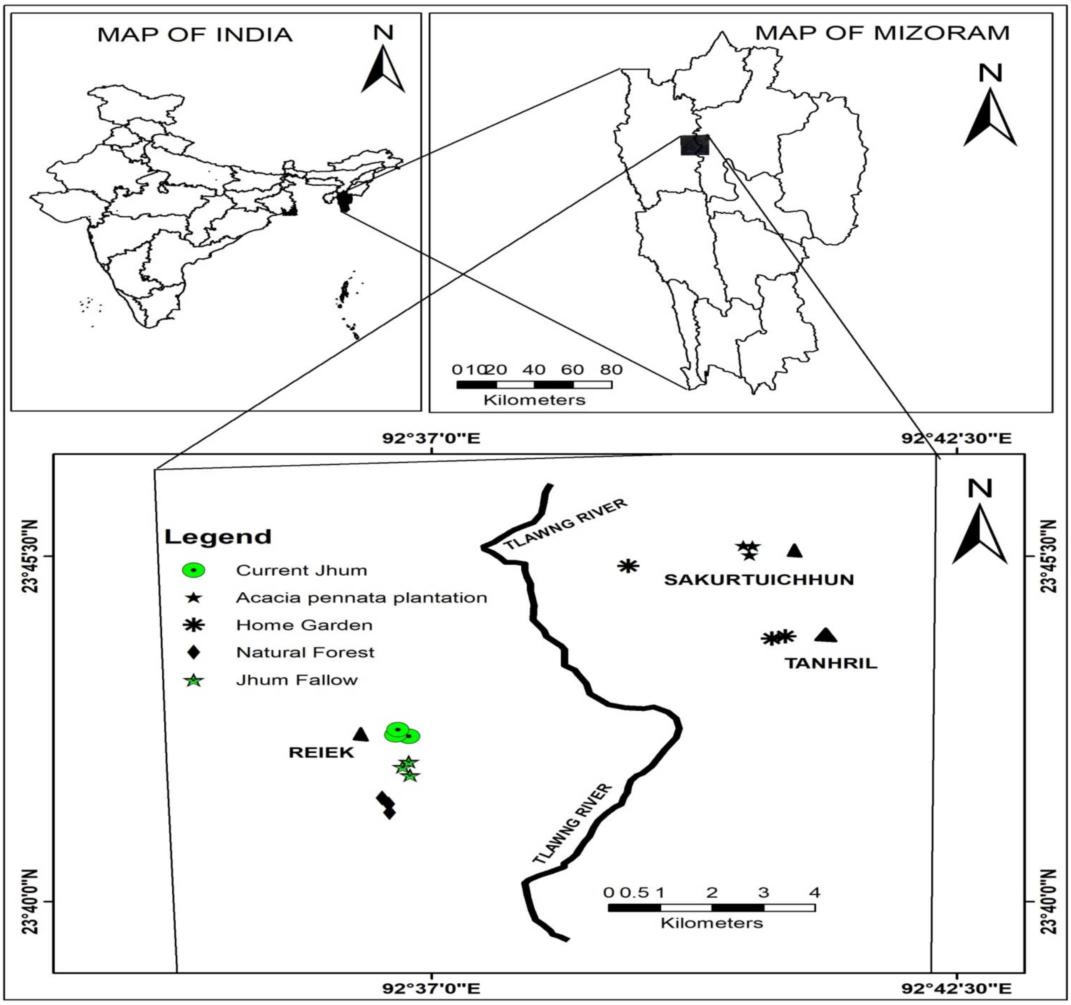

Fig. 1. *Map showing study area and different land use systems (study sites) in Aizawl and Mamit districts of Mizoram, North-east India.*

different land use systems (L) and soil depths (D) ($p<0.05$). Soil pH was highly acidic at the sub-surface soil depths (10-20 and 20-30 cm) in all the land uses. Higher soil pH in the surface layer of CJ is well attributed to the release of cations as a result of the traditional slash and burn technique in the CJ land use system. Burning enhances the release of nutrients in the soil and thus increasing the soil pH (Moraes *et al*., 1996). The higher values of pH in the cultivated lands (HG, AP and CJ) may also result from the conversion of natural forest into cultivation, which leads to an increment in pH at the surface and the sub-surface soil layers (Lumbanraja *et al*., 1998). The present values of pH are in accordance with other findings from the study area, indicating a strongly acidic nature of reaction in these soils (Grogan *et al*., 2012; Tripathi *et al*., 2017; Lungmuana *et al*., 2017).

P_{avail} concentrations in soil were significantly affected by different land use systems (L), soil depths (D) and their interactions (LxD) ($p<0.05$). The highest value at the surface layer (0-10 cm) was reported from HG followed by JF and the least in AP with values of 30.83, 20.35 and 7.26 mg kg^{-1}, respectively (Table 1). Highest P_{avail} in HG at the surface layer (0-10 cm) may be related to the addition of organic manure in the form of animal waste by the land owners. Whereas the moderately higher P_{avail} in JF and NAF may be attributed to net P mineralization as a result of the continuous addition and input of leaf and root litters in these land uses. Sarkar *et al*. (2010) reported that P_{avail} of soil increased with the addition and presence of litter on the soil surface. In comparison, the decrease in soil P_{avail} with increasing soil depth may also be linked to the decrease SOM content that contributes significantly to the P pool in the soils of the study area. In addition, SOM influences P_{avail} through anion replacement of H_2PO_4 from adsorption sites and the formation of organophosphate complexes which are readily taken up by plants as reported in different studies (Tripathi *et al*., 2012; Nega and Heluf, 2013; Yihenew and Getachew, 2013). Our values of P_{avail} falls within the range of low to medium among the various land use systems and soil depths as per the range of Cottenie (1980). In addition, studies by Tekalign *et al*. (2002) and Abebe and Endalkachew

Table 1. Effect of different land use systems (Natural forest–NAF, *Jhum* fallow–JF, Home garden–HG, *Acacia pennata* plantation–AP & Current *Jhum* –CJ) and soil depth (0-10, 10-20 & 20-30 cm) on soil pH and exchangeable cations.

Land uses	Soil pH & exchangeable cations (mg kg^{-1}, dry soil basis)						
NAF	**pH**	**P_{avail}**	**Na**	**Mg**	**K**	**Ca**	**Mn**
(0-10)	4.8 ±0.10	14.21 ±0.22	20.49 ±2.62	366.89 ±1.77	198.27±8.99	281.87±22.8	193.11±4.1
(10-20)	4.7 ±0.03	10.38 ±0.25	22.54 ±1.28	225.33 ±1.71	132.91±2.09	143.19±6.18	122.6±1.4
(20-30)	4.5 ±0.13	4.61 ±0.24	11.89 ±1.06	215.88 ±2.00	117.79±1.57	124.57±2.06	103.01±1.8
JF							
(0-10)	4.8 ±0.12	20.35 ±2.02	21.27 ±1.27	751.32±21.4	812.52 ±22.2	217.94±21.3	353.8±24
(10-20)	4.6 ±0.03	5.95 ±0.38	25.85 ±1.47	315.22±10.5	214.39 ±25.3	117.31±3.32	173.3±14
(20-30)	4.5 ±0.06	3.66 ±0.21	18.73 ±2.22	247.6±18.32	108.53 ±13.7	84.83±5.31	96.65±5.2
HG							
(0-10)	5.1 ±0.07	30.83 ±2.27	27.11 ±2.29	441.24±17.3	224.79±14.2	720.10±30.1	102.1±9.2
(10-20)	4.5 ±0.07	12.57 ±1.23	17.39 ±1.01	202.32±24.8	87.47±7.52	596.30±20.0	33.94±1.3
(20-30)	4.3 ±0.09	9.03 ±0.67	18.66 ±1.70	173.81 ±1.5	60.65 ±8.63	453.10±15.1	16.48±2.1
AP							
(0-10)	4.9 ±0.07	7.26 ±0.12	16.84 ±1.69	207.42±10.3	169.21±15.5	610.10±21.54	131.9±13.6
(10-20)	4.5 ±0.07	4.13 ±0.15	13.20 ±1.33	86.59 ±2.46	101.35±10.2	193.19±20.5	69.92 ±7.28
(20-30)	4.2 ±0.11	3.51 ±0.21	15.94 ±1.43	57.46 ±1.99	78.32 ±15.13	132.69±12.8	52.35 ±3.15
CJ							
(0-10)	5.4 ±0.22	9.65 ±0.35	18.29 ±0.96	276.20 ±2.25	369.63±13.4	119.65±20.7	146.1±16.1
(10-20)	4.7 ±0.30	5.40 ±0.14	17.76 ±1.55	146.92 ±2.45	160.02 ±9.70	148.57 ±0.77	55.15±11.5
(20-30)	4.3 ±0.06	4.48 ±0.18	14.13 ±1.60	127.69 ±1.78	131.98 ±2.78	136.02 ±8.81	70.54 ±2.02
$LSD_{0.05}$							
L=	0.215	1.487	2.739	19.113	22.045	36.642	17.029
D=	0.167	1.152	2.122	14.805	17.076	28.383	13.191
L x D=	0.373	2.575	4.745	33.105	38.183	63.465	29.496

Note: L=Land use system, D=Soil depth, L x D=Land use system x Soil depth, $LSD_{0.05}$: $p<0.05$, NS=Non-significant.

(2012) reported that P_{avail} in Inceptisols and Vertisols are typically low as a result of various processes such as erosion, fixation and abundant crop harvests, especially in tropical regions.

Effect of land use and soil depths on exchangeable cations (Na, Mg, K, Ca & Mn)

The highest concentrations of exchangeable Mg, K and Mn were recorded from JF in all the soil depths among all the land uses studied. In the surface layer (0-10 cm), the concentrations of Mg, K and Mn in JF were 751.3, 812.5 and 353.8 mg kg^{-1}, respectively (Table 1). The concentrations of Mg (207.4 mg kg^{-1}) and K (169.2 mg kg^{-1}) in the surface layer (0-10 cm) were minimum in AP. However, Mn and Ca were low in HG (102.1 mg kg^{-1}) and CJ (119.7 mg kg^{-1}) at the surface layer (0-10 cm). Ca concentration was substantially higher in HG than other land uses in all soil depths with values amounting to 720.1, 315.2 and 247.6 mg kg^{-1} at the 0-10, 10-20 and 20-30 cm soil depths, respectively. The highest Na content was reported from HG with a value of 27.11 mg kg^{-1} and least in AP with a value of 16.84 mg kg^{-1} (Table 4.3) in the surface layer (0-10 cm). Cation vales were significantly affected by different land use systems (L), soil depths (D), along with their interaction (LxD) ($p<0.05$). As a general trend, Mg, K, Ca, and Mn reflected depreciating values with increasing depth in all the land use systems (Table 1). Soil exchangeable cations (Na, Mg, K, Ca & Mn) were significantly affected by different land use systems, soil depths and an interaction effect of both factors, which are in accordance with various other studies from semi-tropical and tropical regions of Nigeria and Ethiopia (Aytenew and Kibret, 2016; Ufot *et al*., 2016). The higher values of exchangeable Mg, K and Mn in JF may be related to the emergence and presence of herbaceous vegetation and canopy cover that sheltered the soil, evading the soil from the direct impact of rainfall and minimising the loss of nutrients through runoff and erosion. In addition, Ramakrishnan and Kushwaha (2001) indicated that longer fallow periods (>20 years) tends to conserve more soil available nutrients leading to better crop productivity in comparison to younger fallow lands. The length of fallow period plays a vital role in promoting soil nutrients; therefore, longer period of fallow favours nutrient conservation (Ovung and Tripathi, 2020). Wapongnungsang *et al*., (2017) also indicated that a fallow period of more than 10 years leads to greater soil conservation of nutrients than shorter fallow during cultivation throughout the cropping season. The elevated levels of P_{avail}, Na and Ca concentrations in HG may be attributable to the application of animal and household waste like dung and ash since these amendments are an important source of Ca, P, K and other nutrients (Voundi Nkana, 1998; Ovung *et al*., 2021). In addition, incorporation of conservation tillage, manure application and adoption of integrated agroforestry-based cropping systems are vital in minimizing adverse impacts on soil quality and efficient use of nutrients (Loria *et al*., 2016). In comparison to the other land use systems, the lower values of exchangeable Na, Mg, K, Ca and Mn in cultivated soils of AP and CJ may also be attributed to the nutrient uptake by plants for their growth and development. In the present study, lower values of exchangeable Na, K, Ca and Mg in cultivated lands (AP and CJ) with higher concentrations in the surface layer (0-10 cm) were in conformity with the study carried out by Yimer *et al*. (2008) in Ethiopia where the values of the elements were observed to be lower in cultivated lands than in grasslands or native forests. The greater concentration of Mg, K, Ca and Mn in the surface layer (0-10 cm) than the sub-surface layers (10-20 & 20-30 cm) can be related to the higher availability of plant and animal residues in the surface layer than beneath. Furthermore, it can also be attributed to vegetation's role, which pumps the bases from sub-surface layer to surface layers (Yimer *et al*., 2008). Our findings are also in accordance with the work of Kiflu and Beyene (2013) where they indicated higher nutrient content in the surface soil layer as a result of organic residue accumulation and related biological activity across different land uses in southern Ethiopia.

Effect of land use and soil depths on cation exchange capacity (CEC)

Cation exchange capacity (CEC) was highest in JF at the surface layer with a value of 9.53 c mol kg^{-1}. Whereas, in HG the same was higher in 10-20 and 20-30 cm soil depth with values of 4.94 and 3.91 c mol kg^{-1}, respectively (Fig. 2). The lowest values of CEC at the surface layer (0-10 cm) was reported from CJ (3.90 c mol kg^{-1}). However, the same in AP was lower in 10-20 and 20-30 cm with values of 2.01 c mol kg^{-1} and 1.41 c mol kg^{-1}. The CEC across various land uses ranged from 3.90 to 9.53 c mol kg^{-1} at the surface layer (0-10 cm). CEC was also observed to change in all the land use systems with a decrease with increasing soil depths. Land use systems (L), soil depths (D) and interaction of both these factors were observed to have a significant effect ($p<0.05$) on the soil CEC concentrations. The highest CEC in the surface layer of JF may be attributed to the greater vegetation cover and less disturbances to the soil in comparison to other land use systems. In contrast, the highest CEC at the 10-20 and 20-30 cm soil layer of HG may be related to the continuous organic amendments and their subsequent leaching down the depth. Our findings have some vital implications and indicate that CEC changes are susceptible to changes in management practices such as use of organic amendments and other inherent properties

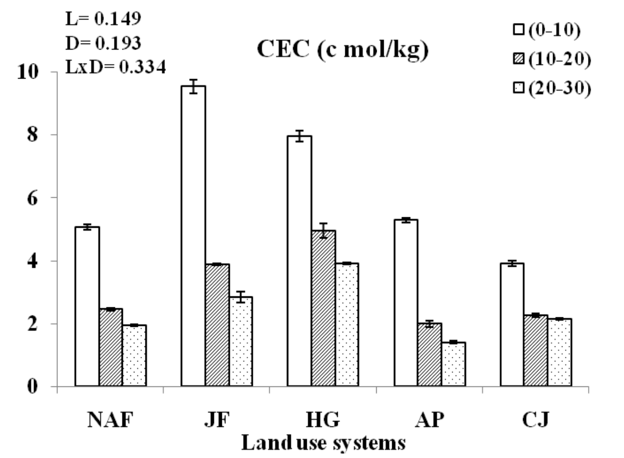

Fig. 2. *Effect of land use systems (Natural forest–NAF, Jhum fallow–JF, Home garden–HG, Acacia pennata plantation–AP & Current Jhum–CJ) and soil depths (0-10, 10-20 & 20-30 cm) on soil ECEC concentrations. (L= Land use system, D= Soil depth, LxD=Land use system x Soil depth, $LSD_{0.05}$: p<0.05, NS=Non-significant).*

such as soil particle size distribution and SOC content in the soil. Ovung *et al*. (2021) also indicated that CEC values are susceptible to changes in land uses and have a significant impact on their values in the soil surface layer across various land use systems in Mizoram. Wu (2011) further grouped CEC values of <10 c mol kg^{-1}, 10-20 c mol kg^{-1} and >20 c mol kg^{-1} as weak, moderate, and high fertility soils. Our values of CEC ranged from 3.90 to 9.53 c mol kg^{-1} across the various land use systems and soil depths and fall under the classification of weak fertility as given by Wu (2011).

Conclusion

The present study concluded that the clearing of native forests for cultivation led to negative feedbacks on soil properties as indicated by the poorer soil exchangeable cations (P_{avail}, Na, Mg & K) in cultivated lands (AP and CJ) in relation to natural forest and fallow lands in Mizoram, North-east India. Soils with longer fallow length, as in the case of JF land use with a fallow length of >12 years, exhibited positive changes in soil available nutrients including Mn, K, Mg and P_{avail}, indicating the role of vegetation cover in conserving available soil nutrients. The present findings signify that conversion of native forests and fallow lands to various land use induces degradation of soil quality and disrupts sustainability and conventional functioning of ecosystems due to different management practices. It is also suggested that in order to balance the loss in soil exchangeable nutrients due to land use change, there is a need to incorporate sustainable practices *viz*., terracing, mixed cropping, the addition of organic residues, mulching, cover crops, minimum tillage farming practices and other approaches aimed at conservation and rejuvenation of soil exchangeable nutrients in steeply sloped tropical regions.

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Conflict of interest

The authors declare that they have no conflict of interest.

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