Science of the Total Environment 521–522 (2015) 372–379

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

# Ethnopedology and soil quality of bamboo (*Bambusa* sp.) based agroforestry system

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## HIGHLIGHTS

- Farmers' folk soil knowledge system provides a framework for application and evaluation of land quality.
- Farmers' most preferred *kalo mati* (black soil) has the highest productivity.
- Soil quality index (SQI) is the best determinant of yield.
- Critical soil parameter to compute SQI may differ among land uses and soil types.

## ARTICLE INFO

*Article history:*
Received 21 January 2015
Received in revised form 15 March 2015
Accepted 16 March 2015
Available online 6 April 2015

Editor: Charlotte Poschenrieder

*Keywords:*
Soil quality index
Bamboo productivity
Folk soil type
Agroforestry systems
Local knowledge

## ABSTRACT

It is widely recognized that farmers' hold important knowledge of folk soil classification for agricultural land for its uses, yet little has been studied for traditional agroforestry systems. This article explores the ethnopedology of bamboo (*Bambusa* sp.) based agroforestry system in North East India, and establishes the relationship of soil quality index (SQI) with bamboo productivity. The study revealed four basic folk soil (mati) types: *kalo* (black soil), *lal* (red soil), *pathal* (stony soil) and *balu* (sandy soil). Of these, *lal mati* soil was the most predominant soil type (~40%) in bamboo-based agroforestry system. Soil physio-chemical parameters were studied to validate the farmers' soil hierarchal classification and also to correlate with productivity of the bamboo stand. Farmers' hierarchal folk soil classification was consistent with the laboratory scientific analysis. Culm production (i.e. measure of productivity of bamboo) was the highest (27 culms $clump^{-1}$) in kalo mati (black soil) and the lowest (19 culms $clump^{-1}$) in *balu mati* (sandy soil). Linear correlation of individual soil quality parameter with bamboo productivity explained 16 to 49% of the variability. A multiple correlation of the best fitted linear soil quality parameter (soil organic carbon or SOC, water holding capacity or WHC, total nitrogen) with productivity improved explanatory power to 53%. Development of SQI from ten relevant soil quality parameters and its correlation with bamboo productivity explained the 64% of the variation and therefore, suggest SQI as the best determinant of bamboo yield. Data presented indicate that the *kalo mati* (black soil) is sustainable or sustainable with high input. However, the other three folk soil types (red, stony and sandy soil) are also sustainable but for other land uses. Therefore, ethnopedological studies may move beyond routine laboratory analysis and incorporate SQI for assessing the sustainability of land uses managed by the farmers'. Additional research is required to incorporate principal component analysis for improving the SQI and site potential assessment. It is also important to evaluate the minimum data set (MDS) required for SQI and productivity assessment in agroforestry systems.



## 1. Introduction

Ethnopedology is the documentation and understanding of local approaches to soil perception, classification, appraisal, use and management (WinklerPrins and Sandor, 2003). Traditional knowledge of soil management according to ecosystem type has evolved over millennia. The earliest known soil classification system in the world is mentioned in the Chinese book, Yugong (2500 years BP), and the soil system classification was based on soil color, texture, and hydrologic features (Zitong, 1994). Folk soil knowledge is widely recognized as of practical value (Barrera-Bassols and Zinck, 2000; Niemeijer and Mazzucato, 2003) and is increasingly understood for its importance to sustainable soil management. Despite substantial benefits of local knowledge (e.g. high local relevance and potential sensitivity to complex environmental

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http://dx.doi.org/10.1016/j.scitotenv.2015.03.059
0048-9697/

interactions), its potential cannot be realized without input of credible scientific data (Barrios and Trejo, 2003). This concern has promoted the development of participatory knowledge integration methodologies benefiting from South–South knowledge sharing efforts (Barrios et al., 2006; Barrios et al., 2012).

The current scientific knowledge of soil is based primarily on quantitative analysis of isolated physical, chemical and biological properties. However, the interaction of these quantitative aspects determines soil quality (Granatstein and Bezdicek, 1992). The concept of soil quality (Doran and Parkin, 1996; Karlen et al., 1997) is useful to assess the condition and sustainability of soil and to guide soil research, planning, and conservation policy. Soil quality assessment provides a basic framework to evaluate the sustainability of agricultural and land management systems (Lal, 1994). Acton and Gregorich (1995) provided a practical definition of soil quality as "the soil's fitness to support crop growth without resulting in soil degradation or otherwise harming the environment". Outcomes of soil functions are not only affected by soil properties, but also by climate, landscape and management, interactions among these variables are complex. Therefore, soil functions can be better explained through considering its physical, chemical and biological properties, and also environmental factors related to it. So it is desirable to use a soil quality index (SQI) that integrates the measured soil physical, chemical and other properties into a single index that could be used as an indicator of overall soil quality (Shukla et al., 2006). Mairura et al. (2007) also reported the integration of scientific and farmers' evaluation of soil quality indicators, and emphasized the importance of selecting indicators for distinguishing productive and non-productive soils.

Soil physical and chemical parameters are evaluated to ascertain validity of folk soil type. But unless the folk soil type is related to productivity status of such land-uses through one or more SQI, the individual physical and chemical properties are often of little value to assess the overall soil health. Bamboo-based agroforestry systems are dominant ecosystems in the North East region of India, and have been intricately linked with the livelihood of the rural population for millennia (Nath and Das, 2008, 2012). Therefore, indigenous people have classified soils under bamboos on the basis of their physical appearance for sustainable management of bamboo ecosystems. These traditional systems are still being practiced by the farmers in the region. Therefore, this article aims to integrate farmer-led folk soil types with that of SQI and to explain their relationship with productivity of bamboo (*Bambusa* sp.) stands in folk soils of North East India.

## 2. Materials and methods

### 2.1. Study area

The study was conducted in Dargakona village, Cachar District, Assam, North East India (Fig. 1), where bamboo-based agroforestry system is one of the dominant managed ecosystems. The study village dates back to the British colonial rule and most of the inhabitant of villages are tea (*Camellia sinensis* (L.) Kuntze) garden laborers. Labor population of the plantation is a heterogeneous society consisting of multi-language, multi-caste, tribe and ethnicity (Pakem, 1990). The laborers in the area, like any other tea plantation site in Assam, were brought in from central and southern part of India during the early 19th century with the rise in tea industry in the state (Sengupta, 1996). Socioeconomically, the villagers are smallholders with paddy (*Oryza sativa* L.) land as the major land use system. The climate of the study site is sub-tropical warm and humid with average annual rainfall of 2226 mm, most of which is received during the southwest monsoon season (May–September). Average maximum and minimum temperatures are 30.5 °C and 20.3 °C, respectively (Nath and Das, 2012).

### 2.2. The bamboo-based agroforestry system

Bamboo forms an important component of the agroforestry systems of Barak Valley, North East India (Nath et al., 2015). *Bambusa cacharensis* R. Majumder constitute the highest priority species of villagers in this region (Nath and Das, 2008). Based on the utility and multiple uses (i.e. house construction, traditional craft preparation, selling in local markets), bamboo growers have prioritized *B. cacharensis* over other bamboo species and it is cultivated by all households in the study area (Nath and Das, 2012). For practical purpose of increasing production per unit land area, farmers have divided their agroforestry systems into different landforms depending on the suitability of the species for different land types. Each land type varies by certain environmental factors and specific vegetation types. In traditional agroforestry systems, bamboos are grown on the land of poor quality or degraded soils of the holdings, and are often managed in a separate zone within the homegardens or in the extended land where it is grown mostly in a pure patch (bamboo grove).

### 2.3. The soil quality index (SQI)

The SQI proposed by Lal (1994) was used in this study. Weighting factors of ten relevant parameters were combined into a cumulative SQI. Ten relevant parameters selected were: rooting depth, soil acidity, soil Al toxicity, water holding capacity (WHC), texture, bulk density ($\rho_b$), nutrient status, soil organic carbon (SOC), percent aggregation, and soil erosion. Cumulative rating index (CRI) is calculated based on relative weighing factor for each of these parameters. Relative weighing factor ranged from 1 to 5, where 1: None, 2: Slight, 3: Moderate, 4: Severe and 5: Extreme. CRI for the bamboo agroforestry was calculated from 100 different homegardens selected for this study. The maximum value of the CRI based on ten parameters is 50. Highly sustainable system has the CRI of $<$20. Systems were classified into: sustainable, sustainable with high input, sustainable with another land use and unsustainable systems corresponding with CRI of 20–25, 25–30, 30–40 and $>$40 respectively.

### 2.4. Criteria for identification of folk soil types

Folk soil types are developed by the land users, and the distinctions are largely based on the surface soil characteristics. Land users characterize folk soil type based on appearance (color and tilth) and performance of surface soil (WinklerPrins, 1999). Soils are distinguished by easily recognizable characteristics, such as physical appearance (e.g., color, texture, stoniness), performance (e.g., productivity, water retention capacity), and the associated vegetation cover.

### 2.5. Data collection and soil sampling strategy

Information on the prevalence of folk soil taxonomy and identification criteria for soil types including the ranking of soil were obtained by direct interaction with farmers through a formatted questionnaire (Bellon and Taylor, 1993) supported by field observations ($n = 100$). The selection criteria of farmers were the age (between 30 and 70 years old), with at least one bamboo clump in the homegarden. For the purposes of this study, interaction was confined to the tea garden laborer, the most dominant ethnic community in the study area. All interviews were conducted in the local dialect (Bengali). Respondents were specifically asked about the preferred folk soil type for bamboo cultivation (Appendix I). To assess the soil characteristics in relation to folk soil types, soil samples to 0–15 cm depth were obtained from all the 100 selected homegardens. During soil sampling, local name of each soil type and characteristics were noted based on farmers' responses. Thus, soil samples were obtained with respect to folk soil types for specific laboratory analysis of ten parameters. Farmers' folk soil ranking was validated through laboratory analytical data, and statistical analyses of physical and chemical parameters of the respective soil types.

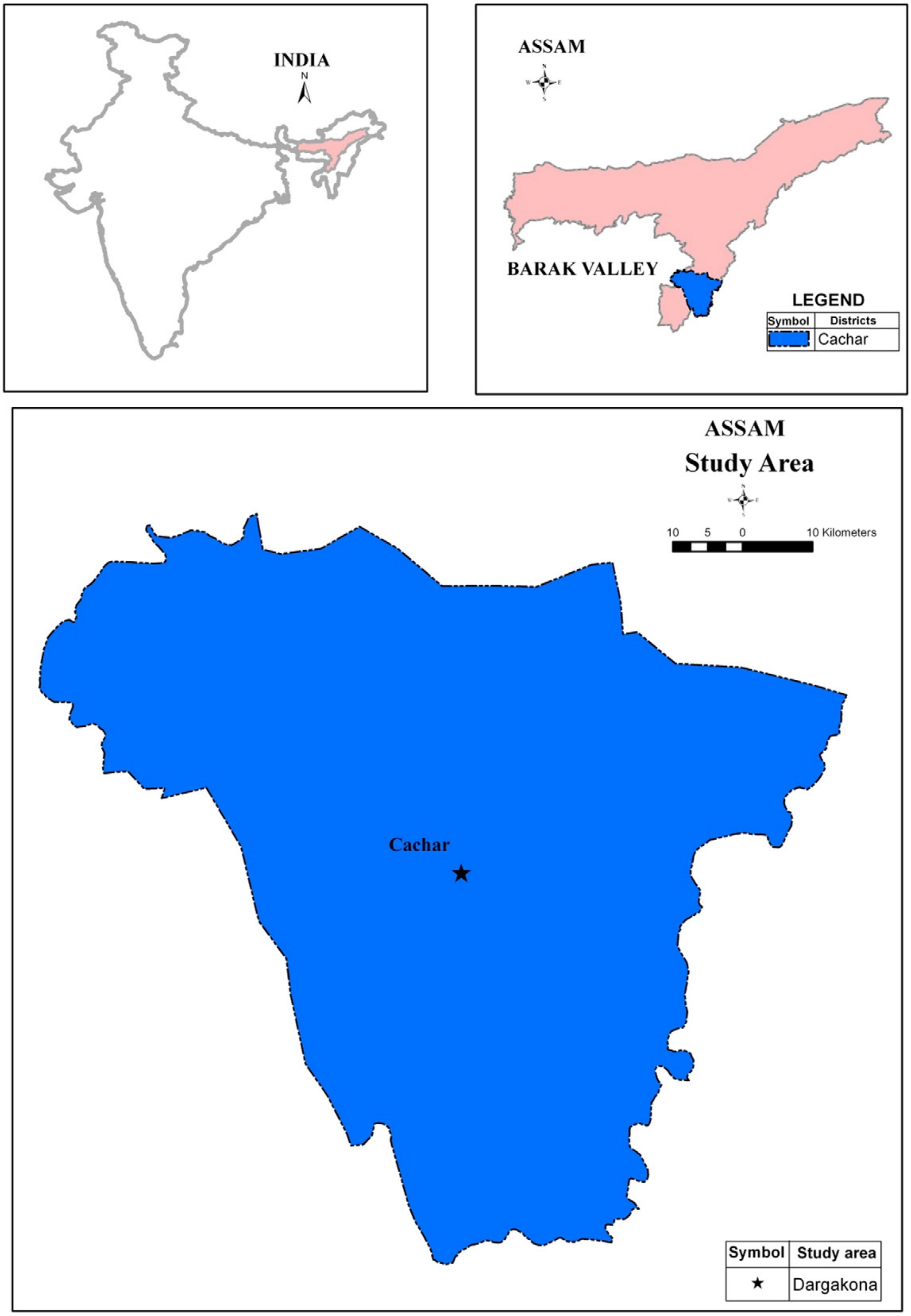


**Fig. 1.** Map of the study area.

### *2.6. Methods of soil analyses*

Soil texture was analyzed by the Bouyoucos soil hydrometer method (Gee and Bauder, 1986). Soil $\rho_b$ was determined by soil core (core diameter 5.5 cm and length 10 cm) method from duplicate soil samples after oven drying at 105 °C (Robertson et al., 1974). Soil aggregates were studied by wet sieving (Kemper and Chepil, 1965). Rooting depth was studied by trenching and soil coring (Stone and Kalisz, 1991). Keen's box method was employed for determination of WHC of soil samples (Romano and Santini, 2002). Extent of soil erosion was studied by reconnaissance survey (Lal, 1994). Soil pH was measured in 1:2.5 soil–water (w/v) suspensions with a digital pH meter (Thomas, 1996).

**Table 1**
Ethnopedological features used for local soil type classification in bamboo agroforestry.

| Farmers' soil type ranking | Soil type attribute and local soil indicator | Farmers' having soil type (%) | Farmers' soil type preference for better bamboo productivity (%) |
|---|---|---|---|
| 1. Kalo (black soil) | Black in color, not too much sandy not very clayey | 28 | 60 |
| 2. Lal (red soil) | Red in color, sandy nature but clay and silt content adequate | 42 | 21 |
| 3. Pathal (stony soil) | Brown as well as red in color, sandy and stoniness | 22 | 14 |
| 4. Balu (sandy soil) | Light brown in color and sandy | 08 | 05 |

The SOC content was determined by the Walkley and Black's rapid titration method (Jackson, 1958). Total nitrogen (N) was determined by semi-micro Kjeldahl method (Bremner, 1965). Available phosphorus (P) was estimated by the molybdenum blue method after extracting soil samples with 0.03 N ammonium fluoride in 0.025 N HCl (Olsen and Sommers, 1982). Extractable potassium (K) was extracted in 1 M ammonium acetate solution at pH 7 and concentrations were determined by a flame photometer (Thomas, 1982). Extractable aluminum (Al) was determined by the method of Bertsch et al. (1986).

### 2.7. Bamboo productivity study

Productivity of bamboo stand depends on new culm produced each year (Hunter and Wu, 2002) and was assessed by selecting eight clumps in each of the folk soil types. Care was taken in selection of homogeneous clump age for each soil type, because clump ages influence the total number of culms per clump and the rate of new culm production (Banik, 2000; Nath et al., 2006). Total numbers of culms per clump were counted for each soil type. All clumps were protected from harvesting for one year, so that indiscriminate harvesting of culms from a clump may not bias the new culm production. New culms produced in all the clump for each folk soil type were recorded to assess the productivity of the bamboo-based agroforestry system.

### 2.8. Statistical analysis

Statistical analysis of data was performed by using M.S. Excel 2003 (Microsoft Excel version, 2003). Statistical significance of treatment means was assessed at $P < 0.05$ using Tukey's test (Zar, 1999). Linear and multiple correlation coefficients were computed by using M.S. Excel 2003.

## 3. Results

### 3.1. Farmers' soil types

Direct interaction with the farmers' following schedule questionnaires supported by field observations allowed us to identify the principles on which the ethnopedological knowledge of the farming community depends. Farmers' have recognized four soil types that are locally named in vernacular as follows: *kalo* (black soil), *lal* (red soil), *pathal* (stony soil) and *balu* (sandy soil). In the farmer soil types, soil

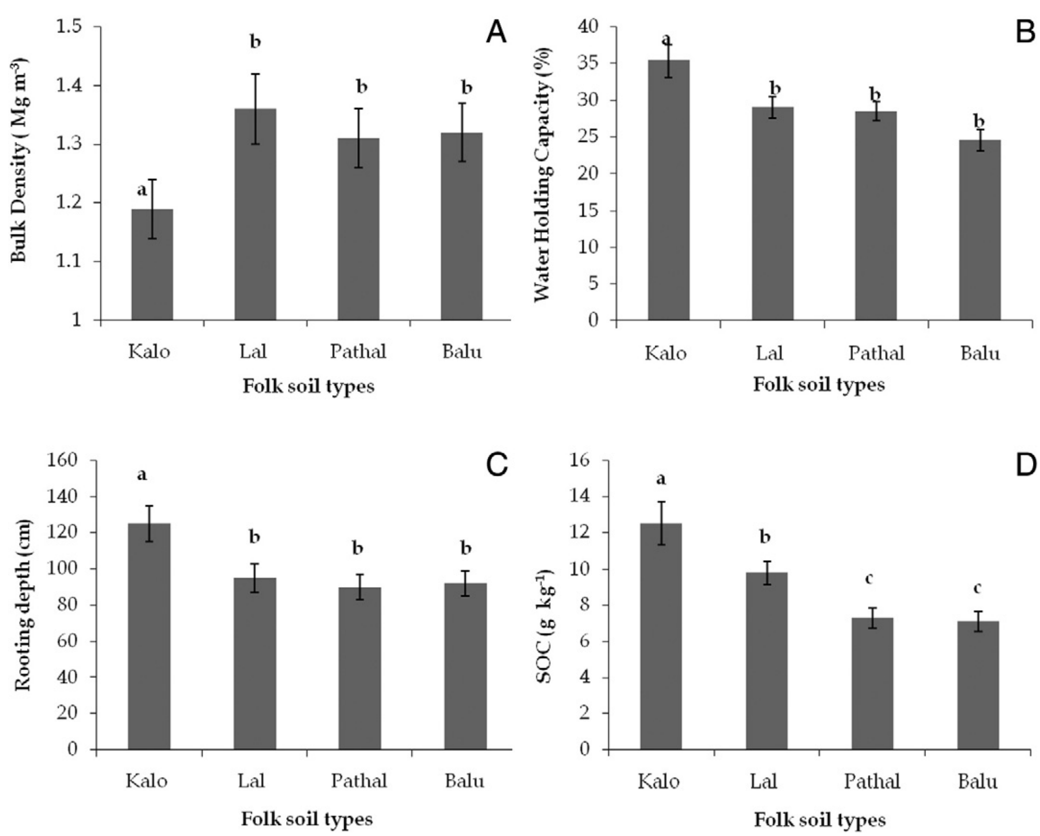


**Fig. 2.** Soil physical and chemical properties (A: bulk density, B: water holding capacity, C: rooting depths, D: soil organic carbon, E: total nitrogen, F: available phosphorus, G: exchangeable potassium, H: pH and I: exchangeable aluminum) of folk soil types in bamboo-based agroforestry systems. Values are mean ± SE. Significant differences are marked with different letters above the bar.

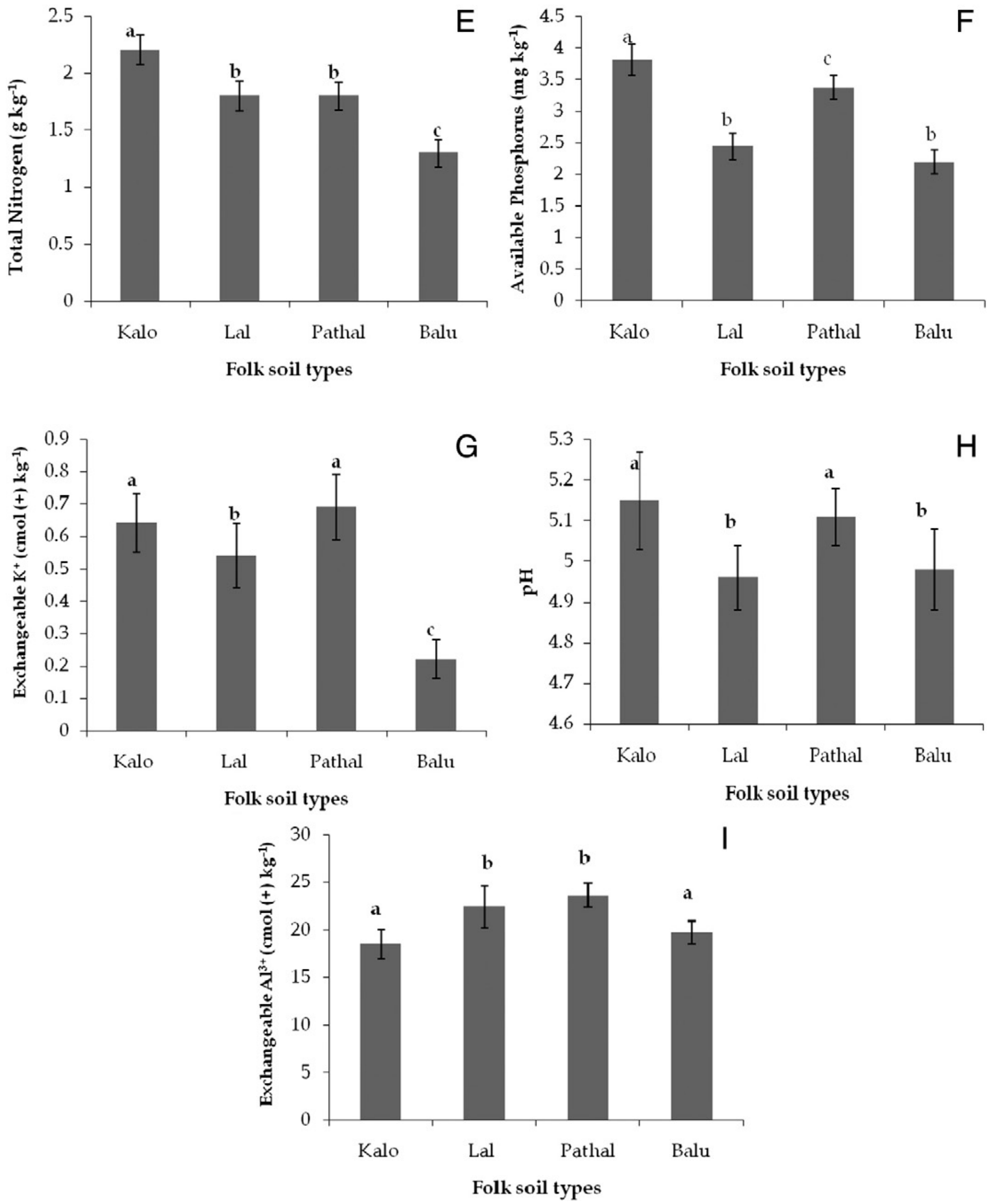


**Fig. 2** (*continued*).

appearance describes its color, texture and stoniness characteristics of the top soil layer. One or more important morphological features (e.g. color, texture and stoniness) characterize each of the folk soil type. For example, black and red soil represents the dark color of top soil layer. In a stony soil, farmers use the criteria of the presence of stones and pebbles on/in the soil. In sandy soil, farmers' use the criteria of higher proportion of sand in the top soil layer. Analysis of soil types based on farmers' knowledge revealed the dominance (42%) of *lal mati* (red soil) followed by *kalo mati* (black soil) (28%), *pathal mati* (stony soil) (22%) and *balu mati* (sandy soil) (8%) respectively, in bamboo-based agroforestry system (Table 1). The preference for better growth of bamboo was as high as 60% for *kalo mati* (black soil), 21% for *lal mati* (red soil), 14% for *pathal mati* (stony soil) and the least for *balu mati* (sandy soil) (5%).

### 3.2. Soil quality parameters

Data computed for different soil parameters for each of folk soil type is presented in Fig. 2. The weighting factor for each of the ten soil parameters were determined according to the method proposed by Lal (1994): 1: None, 2: Slight, 3: Moderate, 4: Severe and 5: Extreme. Data for all the ten soil parameters based on this weighting factor is prepared and shown in Fig. 3. All ten parameters were combined into an index to assess sustainable level of each of the folk soil type (Fig. 4). Based on the rating, *kalo mati* (black soil) is considered sustainable or sustainable with high input for bamboo agroforestry, whereas, the other three folk soil types (red, stony and sandy soil) are sustainable with other land uses.

### 3.3. Relationship of soil quality index and productivity

Bamboo productivity was measured through recording the production of new culms per clump for all folk soil types. Data in Fig. 5 show the highest number of culms (27 culms·clump$^{-1}$) produced from clumps grown in *kalo mati* (black soil) followed by that in *lal mati* (red soil) (22 culms·clump$^{-1}$), *pathal mati* (22 culms·clump$^{-1}$) (stony soil) and *balu mati* (sandy soil) (19 culms·clump$^{-1}$), respectively. The

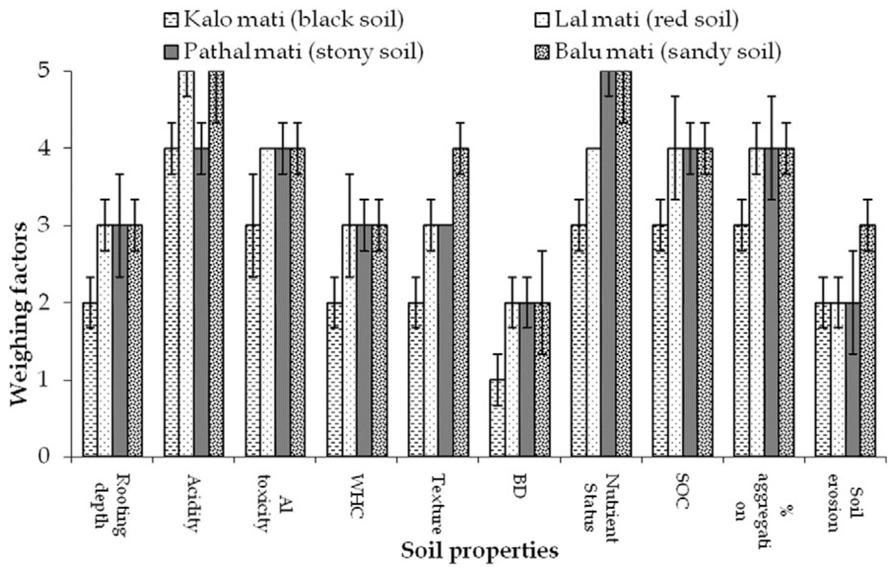


**Fig. 3.** Critical level of ten different soil quality indicators for different folk soil types. Values are mean ± SE.

culm production was linearly correlated ($y = 0.2992x + 5.1756$, $R^2 = .40$, $p < 0.05$) with the total number of culms per clump. The data on Table 2 shows linear and multiple regression equations of different soil parameters with new culm production in bamboos. Productivity of the stand was inversely correlated with the cumulative rating index (CRI) ($y = -0.918x+53.57$, $R^2 = 0.68$, $p < 0.05$) (Fig. 6). The optimum productivity was observed around the CRI value of 25.

## 4. Discussion

Folk soil classification of the bamboo-based agroforestry system incorporates hierarchical, descriptive and nominal classification from the highest to the lowest level of soil types depending on their appearance, performance and stoniness characteristics of the top soil. These distinctions are often based on characteristics important to land management. The advantage and disadvantage of the soil types mentioned by the farmers refer particularly to the WHC and inherent soil fertility. The soil taxonomy elicited by the farmers in the present study is consistent with the findings from the other studies in local soil taxonomies. In the Siaya District of Kenya, farmers base their classification on characteristics of the surface layer of the soil, taking into account the color, texture, and heaviness of working (Mango, 2000). These indicators are similar to those used by farmers in the present study (e.g. soil color and compactness) (Table 1). In northern Ethiopia (Corbeels et al., 2000) three different soil types were distinguished by farmers according to yield, topography, soil depth, color texture, WHC, and stoniness. In southern Rwanda, soils have been classified for their agricultural potential and tillage properties into nine major soil types based on criteria such as crop productivity, soil depth, soil structure, and soil color (Habarurema and Steiner, 1997). In these studies, surface soil color is the most widely used indicator by farmers to classify their soils, which was also the case in the present study—*kalo mati* is the most fertile, and *balu mati* is the least. Black color of the soil represents higher SOC content and thus high fertility and WHC. Therefore, farmers consider black soil as the best among all soil types.

Clumps grown in *kalo mati* (black soil) had higher number of culms per clump (61–74) and produced more number of new culms per clump (25–29). Similarly, clumps grown in *balu mati* (sandy soil) had less number of culms (41–51) and produced less number of new culms (14–21) per clump. Among the different soil parameters studied, and those based on highest the $R^2$ value, SOC, WHC and total N seemed to be the key soil quality parameter (Table 2). Chaudhury et al. (2005) identified total soil N, available P, dehydrogenase activity and mean

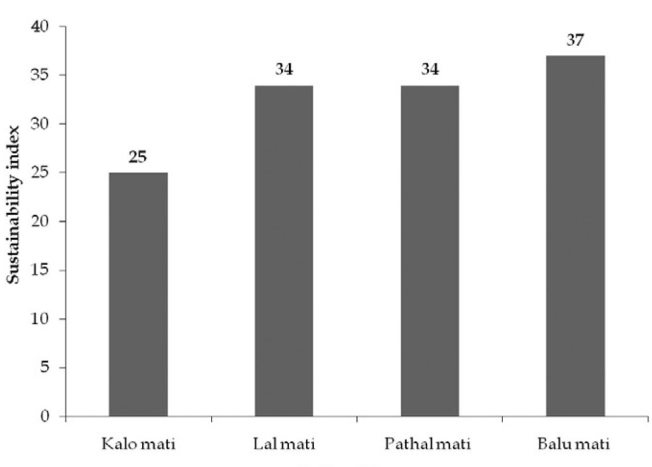


**Fig. 4.** Cumulative Rating Index (CRI) for different folk soil types (<20: highly sustainable; 20–25: sustainable; 25–30: sustainable with high input 30–40: sustainable with another land use; >40: unsustainable).

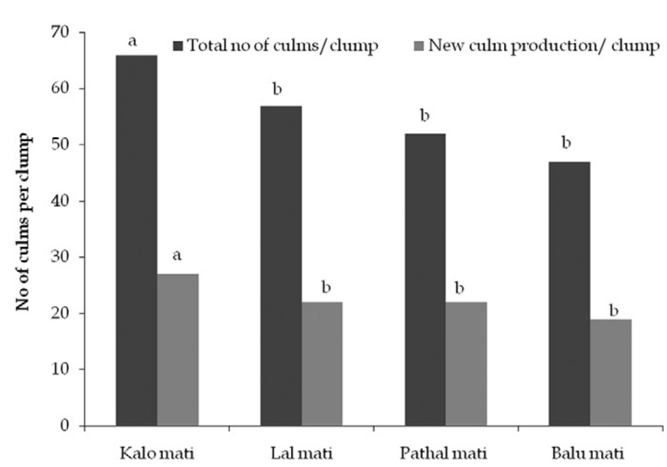


**Fig. 5.** Total number of culms/clump and culm production/clump in different folk soil types. Significant differences are marked with different letters above the bar.

**Table 2**
Linear and multiple regression equations of different soil parameter with new culm production in bamboos (*Bambusa cacharensis*).

| Parameter | Regression equation | $R^2$ | P value |
|---|---|---|---|
| SOC (g $kg^{-1}$) | $y = 1.24x + 10.89$ | 0.49 | <0.05 |
| WHC (%) | $y = 0.58x + 5.191$ | 0.45 | <0.05 |
| pH | $y = 7.68x - 15.03$ | 0.16 | NS |
| BD (Mg $m^{-3}$) | $y = -28.08x + 58.21$ | 0.21 | NS |
| Rooting depth (cm) | $y = 0.18x + 4.46$ | 0.39 | <0.05 |
| Total N (g $kg^{-1}$) | $y = 4.55x + 15.27$ | 0.44 | <0.05 |
| Available P(mg $kg^{-1}$) | $y = 4.14x + 9.754$ | 0.33 | <0.05 |
| Exchangeable $K^+$(cmol (+)$kg^{-1}$) | $y = 14.37x + 14.85$ | 0.36 | <0.05 |
| Exchangeable $Al^{3+}$(cmol (+)$kg^{-1}$) | $y = 1.0942x + 16.739$ | 0.16 | NS |
| Multiple regression equation of SOC, WHC and total N | $y = 7.61 + 1.15X_1 + 0.19X_2 + (-1.08X_3)$[a] | 0.54 | <0.05 |

[a] Where, 7.61 is the intercept (a), $X_1$ is the SOC, $X_2$ is the WHC and $X_3$ is the total N.

weight diameter of the aggregates as the key parameter for alluvial soils. For rain-fed Alfisols in semiarid tropical India, Sharma et al. (2005) identified N, K, S, microbial biomass carbon (MBC) and hydraulic conductivity ($K_s$) as the key soil quality parameter. Thus, specific soil quality parameters may differ among soil type and land use. Shukla et al. (2006) also reported that soil quality parameters may not be similar in different regions because of the land use and site specificity. However, Doran and Parkin (1996), Chen (1998) opined that critical parameter should correlate well with natural processes in the ecosystem and integrate soil physical, chemical, and biological properties and processes. Therefore, multiple correlation was computed in the present study to recognize the influence of different soil quality parameters on productivity of bamboo stand. Results revealed a high multiple correlation coefficient ($R^2 = 0.54$, $p < 0.05$) (Table 2), which is a better determinant of bamboo yield than individual soil quality parameter ($R^2 = 0.16$ to 0.49) (Table 1). Correlation of culm production with CRI (Fig. 5) showed that clumps grown in *kalo mati* (black soil) has the highest productivity. On the contrary, high CRI values were correlated with low productivity for *lal mati* (red soil), *pathal mati* (stony soil) and *balu mati* (sandy soil). Differences in CRI of *kalo mati* (black soil) to that of other folk soil type may be due to variation in litter quality and quantity, micro-climate and other inherent soil properties. In the context of sustainability of land uses, analyses of CRI showed, *kalo mati* (black soil) (CRI: 25) is superior to *lal mati* (red soil) (CRI: 34), *pathal mati* (stony soil) (CRI: 34) and *balu mati* (sandy soil) (CRI: 37). In general, there exist a negative correlation between CRI values and bamboo productivity. Based on $R^2$ value, it is evident that CRI is a better determinant of bamboo productivity than multiple or linear correlations. Numerous studies have been conducted in agroecosystems relating SQI with yield of paddy, wheat (*Triticum*

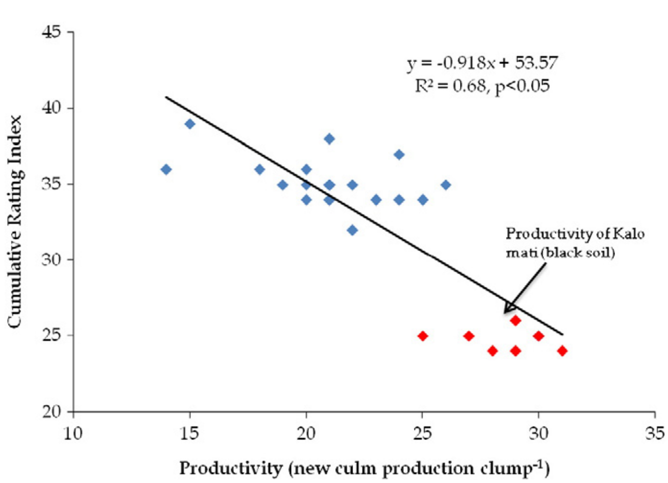


**Fig. 6.** Correlation of culm production with Cumulative Rating Index.

*aestivum* L.) or the combined system (paddy + wheat) (Mohanty et al., 2007; Armenise et al., 2013). However, such studies on agroforestry systems are scanty. Incorporating and adapting new techniques into a framework of existing management practices may increase agroforestry productivity and resilience (Isaac et al., 2009; Pauli et al., 2012).

## 5. Conclusions

The data presented support the following conclusions: (i) SOC, WHC and total N exhibited highest linear correlation and form the basis for multiple correlation with bamboo productivity, (ii) using SQI is better than linear or multiple correlation for evaluation of productivity of bamboo-based agroforestry systems, (iii) critical soil parameter to compute SQI may differ among land uses and soil types, (iv) additional research is required to incorporate principal component analysis to evaluate soil quality and site productivity assessment and (v) minimum data set required for evaluating SQI and productivity of agroforestry systems must be identified.


## Acknowledgments

This work was supported by the project grant from G. B. Pant Institute of Himalayan Environment and Development, Almora. Senior author also greatly acknowledges the research fellowship granted by the Department of Biotechnology, Government of India (BT/20/NE/2011/2014) in the form of Overseas Associateship.


## Appendix I

- How do you classify your homegarden based on vegetation type?
- How do you classify soil within the same homegarden?
- What are important factors you consider when establishing bamboo plantation?
- What are the criteria you use to distinguish different soil types?
- Do you plant bamboo in all the soil type? Why or why not?
- Do you have any preference for soil type for better bamboo production?
- Do you ever alter your vegetation based on soil type?
- Can you provide any other information on soil types of bamboo plantation?

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