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SOIL QUALITY ASSESSMENT USING SOIL ORGANIC CARBON, TOTAL NITROGEN AND MICROBIAL PROPERTIES IN HILLY AGRO-ECOSYSTEM

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ABSTRACT

Assessment of soil quality is an invaluable tool in determining the sustainability and environmental impact of agricultural ecosystems. The study was conducted to assess the quality of soils under traditional cultivation practices, i.e. shifting cultivation, agriculture practice, forestry plantations of *Pinus kesiya*, *Alnus nepalensis*, *Parkia roxburghii*, *Michelia oblonga* and *Gmelina arborea*) and modified agro-forestry system of agri-horti-silvi-pastoral system using soil organic carbon (SOC), soil total nitrogen (STN) and soil microbial biomass C (SMBC) and N (SMBN) at ICAR Complex for NEH Region, Umiam, Meghalaya, India. The shifting cultivated areas had the lowest SMBC value of 192 mg kg^{-1} while soil under *M. oblonga* plantation had significantly ($P < 0.05$) highest value of 478 mg kg^{-1}. The proportion of SMBC to total soil organic carbon (SOC) was in the range of 0.9 to 1.9% across all the systems. The forestry plantation soils had higher SMBC and SMBN as a percentage of SOC and STN respectively than the cultivated arable land soils. The study suggests that the forestry followed by agri-horti-silvi-pastoral system seems to be of better option for sustainable crop production with maintenance of soil quality/health under tropical agro-ecosystems of North-east India.

Key words: Hilly ecosystem, organic carbon, soil quality, SMBC, SMBN, total nitrogen

INTRODUCTION

Soil quality is the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health and thus has profound effects on the health and productivity of a given ecosystem and the environment related to it. Soil organic matter (SOM) is a key component as it influences soil biological, physical and chemical properties that define soil quality (Doran and Parkin, 1994). The soil organic carbon (SOC), soil total nitrogen (STN) and soil microbial C (SMBC) and N (SMBN) are some of the soil properties that are used as basic indicators in assessing soil quality. The soil microbial biomass (SMB) is a small but key component of the active soil organic matter (SOM) pool and serves as a source and sink of soil nutrients (Smith and Paul, 1990). It has been used to understand soil nutrient dynamics and as an ecological marker. The SOM and STN are the major determinants and indicators of soil quality and fertility and are closely related to soil productivity in an agricultural ecosystem (Reeves, 1997; Al-Kaisi *et al.*, 2005). The reduction of SOC and STN will lead to a decrease in soil fertility, soil nutrient supply, porosity and an increase in soil erosion (Gray and Morant, 2003).

Recent global concerns over increased atmospheric CO_2, which can potentially alter the Earth's climate systems, have resulted in raising interest in studying SOM dynamics and carbon sequestration capacity in various ecosystems. The public concern about the issue of global climate change has emphasized the need for developing and implementing strategies of agro-ecosystem management that will reduce carbon dioxide concentration in atmosphere as well as improve the soil fertility. SOC storage and the dynamics of C stock change in agro-ecosystems are important in evaluating the impact of agro-ecosystem management on global climate change. Soils represent an important terrestrial stock of C and approximately 2-3 times as much as terrestrial vegetation and atmosphere; and the C in SOM of agricultural land is composed of dominant terrestrial C stock (Janzen *et al.,* 1997). Thus, the dynamics of SOC, as affected by agro-ecosystem to a large extent, affects the CO_2 concentration in the atmosphere as well as even the global climate change (Huang *et al*., 2007).

The north-eastern Himalayan region of India lies between 21°50' and 29°34' N latitude and 85°34' and 97°50' E longitude with an altitude ranging from 75 to >5000 m masl belonging to different ethnic origins and cultural groups. Slash-and-burn shifting cultivation, locally known as *Jhum*, is the predominant form of agriculture in the hill tracts of north-eastern India with reduced fallow cycle of 2-3 years (yr), for 10-15 years in the past, which resulted in loss of biodiversity and severe soil erosion, leading to depletion of soil productivity. Shifting cultivation, raised beds along the slopes, and unabated deforestation have led to serious degradation of soil, water, flora and faunal resources with a soil loss of 30.2-170.2 t ha^{-1} yr^{-1} (Patiram and Sharma, 2006). Almost 36.64% of total geographical area is degraded as a result of shifting cultivation in north-eastern India, which is almost 2-fold more than the national average of 20.17% (Bhatt *et al.,* 2006). The burning and cultivation of land in the process of jhuming causes a rapid decline in SOC content, which is the main indicator of soil quality and is responsible for a number of soil properties in plant-animal ecosystem (Tiessen *et al.,* 1994). Numerous farming system models through integrated approach of various combinations of agroforestry components have been introduced to complement soil conservation measures for long-term sustainable production (Sharma, 1997) to replace the slash-and-burn cultivation in view of the socioeconomic conditions, topography, soil and climatic conditions of that particular region for livelihood, income generation and food security of inhabitants (Bhatt *et al.,* 2006).

Recent interest in evaluating the soil quality has been stimulated by increasing awareness that soil is a critically important component of the Earth's biosphere as it functions not only in the production of food and fibre but also in the maintenance of environmental quality as related to agro-ecosystem management and in formulating and evaluating sustainable agricultural and land use policies. Assessment of soil quality under different agro-ecosystems using SOC, STN and SMB is therefore of utmost importance for sustainable crop production and to maintain soil health. However, there is dearth of information on soil quality in the north-eastern Himalayan region. Hence, the present study was carried out under traditional farming systems, forestry under various multipurpose tree species and modified systems to assess the soil quality using SOC, STN and SMB contents of soil for sustainable crop production and soil productivity.

MATERIALS AND METHODS

Site description

The exploratory study was carried out in different agro-ecosystems that were initiated in 1983 at the ICAR-Complex for Northeastern Hill Region, Umiam located in the east *Khasi* Hills of Meghalaya, India (25º41' N; 91º 63' E; 980 m mean above sea level). The data-set of soil physicochemical properties after completion of 30 years of farming systems (2014) were used to get a comprehensive idea about the changes in soil quality. The region receives an average annual rainfall of 2,439 mm with a high degree of temporal and spatial variation; 80% rainfall is received between April to October, the period when the land is most prone to erosion hazards. The experiment was laid out in a completely randomized block design with seven treatments mainly under three land use systems replicated 3 times. Shifting cultivation (*Jhum*), agriculture, forestry, and agri-horti-silvi-pastoral systems were having a net plot size of 1.65, 0.64, 1.03 and 2.94 ha, respectively, with average slope of 32 to 53%. The traditional eco-systems were shifting cultivation and agriculture system, most predominant in this agro-climatic situation. The most common crops under shifting cultivation were ginger (*Zingiber officinalis)*, turmeric (*Curcuma longa*), colocasia (*Colocasia esculenta*), maize (*Zea mays*), and paddy (*Oryza sativa*). Ginger/turmeric was cultivated during 1st year (1983) and upland paddy/maize was grown during 2nd year in shifting cultivation. Thereafter, the plots were kept fallow for 3 years and this cycle was repeated on the same land and the crop rotation continued. Agriculture is being practiced with crops like maize (*Zea mays*), soybean (*Glycine max*), paddy (*Oryza sativa*), tapioca (*Manihot esculenta*), colocasia (*Colocasia esculenta*), pea (*Pisum sativum*), mustard (*Brassica juncea*), etc. The multipurpose tree species (MPTs) considered for soil sampling under forestry agro-ecosystem were *Khasi* pine (*Pinus kesiya*), Alder (*Alnus nepalensis*), Champak (*Michelia oblonga*), Gumhar (*Gmelina arboria*) and teak (*Tectona grandis*). The details about the various multipurpose trees are as under:

Forest tree species	Local name	Family	Environmental requirements	Uses
Pinus kesiya Royle ex. Gordon	*Khasi* pine	Pinaceae	Temperature (15-30°C), rainfall (1200-2200 mm), soil (alluvial, red and peat), altitude (1000-2000 m), evergreen	Fuel wood, char-coal and building materials, boxes and paper pulp.
Alnus nepalensis D. Don	Alder	Betulaceae	Temperature (10-30°C), rainfall (900-3500 mm), soil (alluvial, red and Peat), altitude (0-2000 m), desiduous	Fodder, wind break, nitrogen fixation (soil N-enricher) and conservation/waste-land reclamation
Michelia champaca Linn	Champa	Magloniaceae	Temperature (15-40°C), rainfall (1200-2200 mm), soil (fertile alluvial or red), altitude (200-1200 m), evergreen.	Ornamental, fuel wood, timber, fodder
Gmelina arborea Linn	Gamahar	Verbenaceae	Temperature (15-35°C), Rainfall (700–2400 mm), Soil (well drained fertile uplands), Altitude (sea level to 600 m)	Timber wood, fuel wood
Tectona grandis Linn	Teak	Verbenaceae	Temperature (15-35°C), rainfall (700–2400 mm), soil (well drained fertile uplands), altitude (sea level to 600 m)	Timber wood, fuel wood, wind break

The modified agro-ecosystem i.e. agri-horti-silvi-pastoral system comprised of agricultural crops, horticultural crops (pineapple, *Ananus squennssa*; citrus, *Citrus* sp.), alder tree (*Alnus nepalensis*), and fodder grasses. The fodder species in agri-horti-silvi-pastoral system and livestock-based land-use systems were stylo (*Stylosanthes guyanensis*), guinea (*Panicum maxicum*), setaria (*Setaria sphacelata*) and a local grass (*Imperata cylindrica*). Initially, N, P and K fertilizers @ 100-120, 70 and 50 kg ha^{-1} yr^{-1}, respectively, farmyard manure @ 20 t ha^{-1} and lime @ 2 t ha^{-1} were applied to all the systems, except shifting cultivated plots. Thereafter, manure, fertilizers and lime were applied to agriculture, agri-horti-silvi-pastoral systems as per the crop requirement.

Soil sampling and analysis

Seasonal soil samples from experimental plots/treatments were collected from surface soil (0-10 cm depth) underneath the canopies of the trees (about 10 cm away from the tree base) and in the arable lands, from within the planted rows and interrow areas with a 5 cm^2 soil coring tool. Each soil sample was a composite of four soil cores collected at north, south, east and west coordinates. After removing visible plant residues and pebbles, the field fresh moist soil samples were sieved with a 2-mm mesh sieve. Part of the sample was stored in plastic bags at 4°C for soil microbial biomass (SMB) determinations. The remaining part was air-dried for determination of soil physical and chemical properties. All the measurements were conducted within 7 days of sampling. Before determination of SMBC and N, moisture content was determined and the results expressed on oven-dried basis. The soil particle size distribution was determined by the Bouyoucos hydrometer method. Soil pH was measured in 1:2.5 soil-water suspensions with glass electrode pH meter. Organic C was determined by using the Walkley-Black wet oxidation method (Nelson and Sommers, 1982). Total N was determined by Kjeldahl digestion procedure (Bremner and Mulvancy, 1982). Exchangeable bases were determined by extraction with neutral 1N NH_4OAc. Potassium in the extract was determined with flame photometer while calcium (Ca) and magnesium (Mg) were determined using the Spectronic-70 spectrophotometer (Tucker and Kurtz, 1960). Available phosphorus (P) was extracted by Bray P1 method. The P concentration in the extract was determined colorimetrically (John, 1970). Soil microbial biomass C and N were determined by the chloroform-fumigation incubation (CFI) method as per Jenkinson and Powlson (1976). Shade-dried, 0.5 mm-sieved soil (10 g) was placed in a 50 mL beaker in which 1.0 mL distilled water was added and kept in an air-tight desiccator. Fumigation was carried out with ethanol-free chloroform by applying vacuum until the chloroform clearly evaporated. The tap of the desiccator was closed, and desiccator was kept in dark for 5 days. After incubation, the soils were transferred into 125 mL extraction bottles, and the samples were shaken with 0.5M potassium sulfate (K_2SO_4) for 0.5 hours and filtered through Whatman No. 42 filter paper. The MBC was calculated from the net amount of total C (fumigated C and non-fumigated C) using a factor of 2.64 (Vance *et al.*, 1987). Microbial biomass N (MBN) was determined in the digested K_2SO_4 extract from the net amount of total N from fumigated and non-fumigated soils and multiplied by a factor of 1.46 (Brookes *et al.*, 1982). The data were subjected to statistical analysis to ascertain significant differences among the agro-ecosystems. Statistical analysis was carried out using standard analysis of variance (Gomez and Gomez, 1984). To determine the significance of the difference between the means of two treatments, least significant difference (LSD) was computed at 5% probability level. Simple linear correlation coefficients were derived to establish the relationship between microbial biomass and soil properties.

RESULTS AND DISCUSSION

Soil texture, reaction, available nutrients and exchangeable bases

Selected physical and chemical properties of soils are shown in Table 1. The soils of all the agro-ecosystems have similar type of soil texture i.e. clay loam. This reflects the origin of the soils from the same parent material and suggests that differences in the soils chemical and microbial properties were due to management rather than inherent differences. The soils reactions were highly acidic in nature, pH ranging in between 4.17 and 5.04. The soil of the forestry plantation had the lowest soil pH than agro-ecosystem soils. This might due to the fact that all the forestry plantations were kept at higher elevation. The basic cations were lost through leaching and runoff as a result of torrential rainfall (>2000 mm per annum), and increased Al toxicity might have contributed to the build-up of soil acidity in forestry plantations, where soil amendments and soil conservation measures were not advocated.

The available N substantially increased in all the forestry species over the other agro-ecosystems. Significantly more available N was recorded in teak plantation (465.50 mg kg^{-1}) followed by alder species (404.73 mg kg^{-1}) in comparison to other systems. Agri-horti-silvi-pastoral system had received marginally higher available N (251.1 mg kg^{-1}) than the traditional practices in

Table 1: Selected physicochemical properties of various agro-ecosystems

Agro-ecosystems	Particle size distribution ($g\ kg^{-1}$)			pH	Available macro-nutrients ($mg\ kg^{-1}$)			Exchangeable bases ($cmol\ kg^{-1}$)	
	Sand	Silt	Clay		N	P	K	Ca	Mg
Traditional									
Shifting cultivation	41.9	27.5	30.6	4.81	220.25	5.27	150.42	2.97	1.84
Agriculture	40.1	28.5	31.4	5.03	234.28	10.68	211.44	3.01	1.95
Forestry plantation									
Pinus kesiya	40.3	24.2	35.5	4.72	325.47	22.40	88.75	2.05	1.17
Alnus nepalensis	36.7	28.3	36.0	5.04	404.73	17.25	96.41	2.22	1.55
Michelia oblonga	33.0	32.2	34.8	4.17	372.48	29.85	85.40	2.11	1.69
Gmelina arboria	45.1	28.4	30.4	4.85	380.26	25.09	115.24	2.80	1.84
Tectona grandis	47.2	23.9	28.9	4.22	465.50	27.88	98.22	2.35	1.37
Modified									
Agri-horti-silvi-pastoral	37.4	29.4	33.2	4.92	251.10	9.03	176.61	3.05	1.70
$LSD_{0.05}$	1.98	1.24	0.76	0.13	12.55	3.90	9.88	0.11	0.08

this area. It can be inferred from the results that the organic-matter accumulation was considerably greater under forestry plantations due to the litter under the trees and the recycling of plant nutrients by the deep roots of trees favoured most build-up of available N in the soils. Available P varied greatly among the systems, ranging from 5.27 to 29.85 mg kg^{-1}. Higher available P content was found in forestry plantation (range 17.25 to 29.85 mg kg^{-1}), particularly in champaka (*Michelia oblonga*) followed by teak. However, reverse trend was followed in case of available K content. Forestry plantations received lower available K content (mean 80.8 mg kg^{-1}) as compared to other traditional and modified agro-ecosystems. Externally added P fertilizers, along with organic manure in agriculture and agri-horti-silvi-pastoral systems and burning of crop residues in shifting cultivation, contributed to the maximum accumulation of available K in soil.

The forestry plantation soils had significantly ($P \leq 0.05$) low exchangeable bases (Ca, Mg) compared to other agro-ecosystem soils (Table 1). These results may be partly attributed to the higher leaching losses of bases under the influence of high intensity rainfall at undulating topography. The soils under shifting cultivated areas had higher exchangeable Ca and Mg (2.97 and 1.84 cmol kg^{-1}, respectively). The burning of crop residues after one cropping season under shifting cultivation practice also cause liming effect of ashes of burned vegetation with corresponding increase in the exchangeable bases (Nounamo *et al.*, 2002).

Soil organic carbon and total nitrogen

The soil organic C (SOC) and soil total N (STN) varied significantly in all the soils (Table 2) indicating that the agroecosystem induced effect on SOC and STN extend as far as the surface soil is concerned. The SOC and STN values were relatively high in the soils of forestry plantations, except in teak, followed by the modified land use system and traditional systems. A significant positive relationship has been reported between SOC and STN in different tropical agroecosystems (Adeboye *et al.,* 2006). The increased plant biomass produced under natural habitat probably resulted in increased returns of organic materials to the soil in the form of decaying roots, litter and crop residues (Haynes and Naidu, 1998), thus the highest SOC in forestry soil. Among the various forest plantation, pines produced the highest organic carbon (35.42 g kg^{-1}) in soil followed by champaka (33.61 g kg^{-1}). The superiority of these plantations in improving soil properties was mainly due to higher fine root biomass and greater leaf fall of these tree species and quality litter production, leading to improvement in C status of soil (Saha *et al.,* 2007). Annual cropping reduces the C losses from soils. The arable land use system soils had higher STN than the plantation systems with concomitant lower C/N ratio which is an indication of higher degree of humification and easy mineralization of organic N (Bai *et al.,* 2005). The availability of water-soluble organic C

Table 2: Soil organic carbon (SOC), total nitrogen (N) and microbial properties of various agro-ecosystems

Agro-ecosystems	SOC ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	C/N ratio	SMBC ($mg\ kg^{-1}$)	SMBN ($mg\ kg^{-1}$)	SMBC/ SMBN	SMBC/ SOC	SMBN/ total N
Traditional								
Shifting cultivation	20.90	1.62	12.90	192.35	20.90	9.20	0.92	1.29
Agriculture	27.08	1.88	14.40	288.13	25.65	11.23	1.06	1.36
Forestry plantation								
Pinus kesiya	35.42	1.54	23.00	388.36	30.84	12.59	1.10	2.00
Alnus nepalensis	32.20	1.42	22.67	452.25	42.55	10.63	1.41	3.00
Michelia oblonga	33.61	1.35	24.90	478.22	40.26	11.88	1.42	2.98
Gmelina arboria	28.66	1.58	18.14	427.30	38.94	10.97	1.49	2.46
Tectona grandis	25.45	1.22	20.86	409.55	29.20	14.03	1.61	2.39
Modified								
Agri-horti-silvi-pastoral	30.35	1.96	15.48	342.20	33.28	10.28	1.13	1.70
$LSD_{0.05}$	1.96	0.12	-	12.41	2.37	-	-	-

from rhizodeposition products which are the main energy sources for microorganisms and enhances their activity may be partly responsible for the lower C/N ratios obtained in the arable soils.

Soil microbial biomass carbon (C) and nitrogen (N)

Values of the soil microbial biomass C (SMBC) and N (SMBN) in all the forestry land use systems were significantly higher in the surface soil as compared to other land use systems (Table 2). This indicated the importance of this surface soil layer for microbial meditated processes such as nutrient cycling and decomposition. Loss of this surface soil through human or natural disturbances would be detrimental to the functioning of these ecosystems. The SMBC values ranged from 388.36-478.22 mg kg^{-1} among the forestry plantations and 192.35-288.13 mg kg^{-1} in the traditional land use systems. These values are in accordance with the values reported by Anderson and Domsch (1989) in other terrestrial ecosystems. The soil under shifting cultivation had lowest value of SMBC (192.35 mg kg^{-1}) in surface soil. The clearing of crop residues by burning which resulted in relatively low SOC (20.90 g kg^{-1}) may be the reason for this result. This finding is supported by the findings of Biederbeck *et al.* (1980) that SOC loss increases and microbial biomass declines when residues are removed by burning. The SMBN values obtained in the present study were 20.90-42.55 mg kg^{-1} at surface soil (Table 3). The forestry land use systems which had higher SOC and STN also had higher SMBN values. The relatively higher SMBN value in agri-horti-silvi-pastoral systems (33.28 mg kg^{-1}) might be attributed to the application of inorganic fertilizer and increased carbon inputs in this modified system. The SMBC/SMBN ratio has often been used to describe the structure of microbial community (Moore *et al.*, 2000). A low SMBC/SMBN ratio indicates that the microbial biomass contains a higher proportion of bacteria whereas a high value suggests that fungi predominate in microbial population (Campbell *et al.*, 1991). The SMBC/SMBN ratios obtained in this study were relatively high (10.28-12.59), except in shifting cultivation (9.20) which reveals the predominance of microorganisms in these soils. These results may be due to greater C and N inputs, which are of a quality stimulating greater soil microbial biomass production into the surface soil (Sparling, 1992). The SMBC and SMBN when expressed as percentages of SOC and STN, respectively, give an estimation of the quantities of nutrients in microbial biomass, organic matter dynamics and substrate availability in soils (Moore *et al.*, 2000). Smith and Paul (1990) estimated that SMBC accounted for 2-5% of SOC and SMBN for 1-5% of STN. In present study, SMBC accounted for between 0.9 to 1.6% SOC while SMBN was 1.3 to 3.0% STN (Table 2). The range of SMBC as a percentage of SOC obtained in this study is comparable to the range of 0.99 to 4.30% reported for some New Zealand soils by (Sparling, 1992). The SMBN as a percentage of STN

Table 3: Matrix of correlation coefficients for soil chemical and microbial properties of various agro-ecosystems

Variables*	SOC	Total N	SMBC	SMBN
SOC	-	-	-	-
Total N	0.892***	-	-	-
SMBC	0.411***	-0.327	-	-
SMBN	0.549***	-0.569***	0.895	-

* SOC = Soil organic carbon, Total N = total nitrogen; SMBC = Soil microbial biomass carbon, and SMBN = Soil microbial biomass nitrogen

obtained are lower than the ranges reported in literature by other workers for arable, pasture and forestry systems (Moore *et al.*, 2000).

Correlation of soil organic carbon and total nitrogen and microbial properties

Correlation analysis of SOC, STN and SMB values of the surface soil revealed significant correlations between the variables assayed (Table 3). SOC was strongly related (P ≤0.0001) to STN (r = 0.892), SMBN (r = 0.549) and SMBC (r = 0.411) while STN was significantly related to SMBN (r = 0.569, P ≤0.0001). These results indicated that SMBN levels in the soils were determined by SOC and STN at the surface soil. Numerous other studies in terrestrial ecosystems have reported strong correlations between SMBN and STN (Moore *et al.*, 2000). The micro-organisms at this lower depth possibly are subjected to stress factor of oxygen availability. The microorganisms at this depth could be substrate availability as a result of higher proportion of soil organic matter.

Conclusions: The present study suggests that forestry plantations are a good measure to improve the soil quality especially in terms of SOC and STN. The surface soil was the main site for microbially-meditated processes of nutrient cycling and decomposition in all the land use systems. The clearing of forest/natural vegetation undergrowth by burning under shifting cultivation and poor stocking of plantations impaired the soil quality. However, modified land use system performed better than traditional systems with suitable agronomic practices and conservation measures. There was discernable effect of land use system on soil microbial biomass. The microorganisms were more active in plantation soils due to more C and N immobilization by microbial biomass therein. The SOC, STN, biomass C and N in SOC and STN all seemed suitable diagnostic indicators of the quality of soil of these land use systems.

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