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Land use effects on soil quality in a tropical forest ecosystem of Bangladesh

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Abstract

Human population pressures upon land resources have increased the need to assess impacts of land use change on soil quality. In order to assess effects of land use changes on soil quality properties in a tropical forest ecosystem of Bangladesh, soil samples were collected from adjacent well-stocked *Shorea robusta* natural forest, land reforested with Acacia, grassland and cultivated land. Land use/land cover changes (degradation of natural forest and subsequent cultivation of soils) resulted in surface compaction and significant decreases in silt and clay contents, porosity and aggregate stability, N, fulvic and labile C, and microbial biomass C. Maintenance respiration rates increased in comparison to the soils under natural forest. Use of soil deterioration index showed that soil quality deteriorated significantly (−44%) under cultivation, while in sites revegetated with fast-growing Acacia or grasses, it improved by 6–16%. Degradation of soil quality may have resulted from increased disruption of macroaggregates, reductions in microbial biomass, and loss of labile organic matter due to fire, deforestation, tillage and accelerated erosion. Improvement in soil quality and enhanced biological activity at reforested and grassland sites demonstrated the inherent resilience of these soils once revegetated with highly adaptable and fast growing Acacia (*Acacia* sp.) and grass species.

Keywords: Deforestation; Cultivation; Reforestation; Soil quality; Soil organic matter; Deterioration index

1. Introduction

The complex integration of the primary natural resources — soil, water and vegetation, is vital for maintaining terrestrial ecosystem functions and productivity. Human poverty and a continuous decline in the amount of agricultural land per person have led to indiscriminate exploitation of natural resources in developing countries of the world (Mahtab and Karim, 1992). As a result of increasing demand for firewood, timber, pasture, shelter and food crops, natural land covers, particularly tropical forests, are being degraded or converted to cropland at an alarming rate (Hall et al., 1993). These trends have led to a need to assess the impacts of deforestation and conversion on soil quality.

Land use changes, especially cultivation of deforested land may rapidly diminish soil quality, as ecologically sensitive components of the tropical forest ecosystem are not able to buffer the effects of agricultural practices. As a result, severe deterioration in soil quality may lead to a permanent degradation of land productivity (Kang and Juo, 1986; Nardi et al., 1996; Islam et al., 1999). Assessment of soil

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properties upon conversion of natural forests for varying agricultural purposes is of utmost importance to detect early changes in soil quality. The objectives of the present study were: (i) to assess and compare the changes in the biological, chemical and physical properties of soils in response to land use changes; and (ii) to explore the relationships among changes in different soil properties.

2. Materials and methods

2.1. Description of the study area

The study area (24°00′–24°05′N and 90°18′–90°24′E) was originally covered with tropical deciduous forests of *Shorea robusta*, Gaertn. f. (local name 'Sal') in the Gazipur district, Dhaka division, Bangladesh. The natural forests have been exploited through clear felling to meet the increasing demands for firewood, timber and other construction materials. Over the years, people living in the surrounding villages have often encroached upon and cultivated agricultural crops in the clear felled forest land without using any soil conservation practices. These intense human activities have hampered the regeneration of existing residual vegetation on clear-felled and degraded reforested lands. Wildlife has almost disappeared from the encroached upon forest area. In areas where the forest has been under regular protection the natural vegetation consists of well-stocked *S. robusta* locally mixed with *Albizia* spp., *Samanea saman*, *Dalbergia sissoo*, *Bombax ceiba*, *Mullacana brucifera* and patches of exotic Acacia reforestation. The distribution of clear felled areas and encroaching cultivation are related to the location of crude road and trails, but otherwise are randomly scattered and do not follow any mapped topographic or soil variations. Early reports (Brammer, 1996) indicate that the areas sampled were uniformly under *S. robusta* dominated natural forest up to the beginning of encroachment in the 1960s.

The climate of the area is subtropical monsoon with pronounced hot, wet, and cool, dry seasons. The mean annual temperature is 26°C, while the mean annual rainfall is about 180 cm. Relative humidity ranges between 65 and 96%. The soils are identified as Red-Brown Terrace soils according to Bangladesh soil classification system (Brammer, 1996), which are classified in the US Soil Taxonomy as fine loamy or clayey, oxic, hyperthermic, acidic, Typic Paleustults and in the FAO-UNESCO system as Orthi-Ferric Acrisols. These soils are imperfectly to moderately drained and occur on undulating to flat uplands.

2.2. Soil sampling and processing

In January 1992, surface soil samples were collected from two sites under each of four adjacent land use/land cover types: (1) well-stocked *S. robusta* forest, (2) reforestation (with *Acacia auriculiformis*, L. for 5 years or *A. minijiri*, L. for 7 years in pure stands at 2 m by 2 m spacing), (3) grass (Napier or *Saccharum spontaneous* for 21 years) and, (4) cultivated land (converted from forest in mid 1980s to grow mustard (*Sinupis* sp.), upland rice (*Oriza* sp.), sugarcane (*Saccharum* sp.), cotton (*Gossypium* sp.), etc.) (Table 1). For each site, 14 soil cores (1.9 cm diameter each) were randomly sampled (0–15 cm depth) and

Table 1
Effect of land use/land cover type on selected physical properties of adjacent areas of similar soils in Dhaka division, Bangladesh[a]

Land use/land cover types	Soil taxonomy	Soil texture	ρ_b (g/cm^3)	WHC (%)	Silt (%)	Clay (%)	Porosity (%)	Aggregate stability index[b]
Natural forest	Typic Paleustult	Silt loam	1.22	27.9	66.0	23.0	54.0	0.54
Reforested land	Typic Paleustult	Silt loam	1.18	30.7	55.0	25.0	55.5	0.72
Grassland	Typic Paleustult	Silt loam	1.18	28.8	54.5	25.5	55.5	0.59
Cultivated land	Typic Paleustult	Loam	1.38	22.9	36.5	20.5	48.0	0.45
LSD ($p \leq 0.05$)			0.12	ns	18.0	*	4.7	0.10

[a] Means of duplicate analysis from each of two sites for each land use/cover type ρ_b=Bulk density, SL=Silt loam, L=Loam, and WHC=Water holding capacity.

[b] Turbidity ratio.

* Indicates significant trends at $p \leq 0.10$.

mixed to obtain a composite sample that was sealed in a plastic bag. Field-moist soil samples were gently sieved through a 2 mm mesh to remove stones, roots, and large organic residues and sealed in plastic bags to store at 4°C. Soil biological analyses were carried out within 20 days of sampling after an overnight acclimatization period at room temperature.

2.3. Soil physical and chemical properties

Soil bulk density (ρ_b) was determined by the core method and total porosity was calculated assuming a particle density of 2.65 g cm^{-3}. Gravimetric water holding capacity (WHC) of soil was measured by the tube method (Wani et al., 1994). Soil particle size analysis was done by the hydrometer method. Aggregate stability (AS) was determined on 1–2 mm sieved air-dried soil aggregates by a modified turbidimetric method (Williams et al., 1966). In the turbidimetric method, 1.0 g oven-dried equivalent (ODE) amount of aggregates was placed in 35 ml polycarbonate tubes. About 20.0 ml distilled water was slowly added down the edge to the aggregates which were then shaken horizontally at 100 rpm for 2 min in the capped tubes. The tubes were turned upright and the dispersed soil was allowed to settle for 4 min. A 5.0 ml aliquot of the suspension (from the middle depth of the suspension) was drawn by a calibrated pipette, and the transmittance of the suspension at 630 nm was measured using distilled water as a blank. The suspension was poured back slowly into the polycarbonate tubes and then shaken again at 100 rpm for 5 min. The dispersed soil was again allowed to settle for 4 min. A 5.0 ml aliquot of the suspension was drawn by a calibrated pipette to measure the transmittance. The turbidity ratio (second transmittance/first transmittance) provided a measure of the water-stability of the aggregates.

Soil pH was determined in 1:2.5 soil–water slurry, using a combination glass electrode. Total carbon (C_T) and nitrogen (N_T) contents were determined on finely grounded air-dried soils by dry combustion in a LECO model CHN-600 analyzer (LECO Corp. St. Joseph, MI).

To measure extractable humic (C_{HA}) and fulvic acid (C_{FA}) C fractions, 1.0 g ODE of air-dried soil samples was shaken overnight with 0.5M NaOH (pH 13.5). The soil suspensions were centrifuged and filtered through 0.4 μm Millipore® membranes to obtain soil-free extracts. The extracts were acidified with concentrated H_2SO_4 to pH 2 for precipitation of C_{HA}, which was subsequently separated from the soluble C_{FA} by centrifugation and filtration. The precipitated C_{HA} was solubilized in 0.05M $NaHCO_3$ and purified from silica and ash contents by repeated dissolution and precipitation. Both C_{HA} and C_{FA} were determined colorimetrically by a rapid microwave digestion method (Islam and Weil, 1998).

Labile organic C (C_L) fractions, based on $KMnO_4$ reaction with soil modified from Blair et al. (1995) were measured as follows: 1.0 g ODE samples of air-dried soil were placed in clean 50 ml screw-capped centrifuge tubes with 10 ml of 0.16M $KMnO_4$ solution, then shaken at 250 rpm using a horizontal shaker for 60 min. After shaking, the contents were centrifuged at 3600×g for 5 min to obtained soil-free aliquot. The oxidation of organic C was determined by change in concentration of $KMnO_4$ in solution as measured by a spectrophotometer at 565 nm, assuming that 1 mM MnO_4 is consumed in the oxidation of 0.75 mM of organic C (Blair et al., 1995). The range for the standards was chosen to cover the sample range from 0 to 0.16M $KMnO_4$ solutions.

2.4. Soil biological properties

Total microbial biomass (C_{TMB}) was determined by the chloroform fumigation incubation method (Jenkinson and Powlson, 1976), modified as follows: about 20 g ODE of field-moist soil at 60% WHC was placed in each of two 50 ml glass beakers. The soil in one beaker was fumigated with ethanol-free chloroform for 24 h at room temperature in the dark under a vacuum in a desiccator lined with moist paper towels. After removing the chloroform vapors by three repeated evacuations of the desiccator, both fumigated and unfumigated soils were reinoculated with 0.5 g ODE of field-moist soil. Each soil sample was placed in a 1 l mason jar along with a glass vial containing 10 ml of distilled water to maintain humidity and a plastic vial containing 10 ml of 1M NaOH to trap evolved CO_2. The jars were sealed and incubated in the dark for 10 days at 25±1°C. The C_{TMB} was calculated as follows:

$$C_{TMB} = \frac{(CO_2\text{–}C_{fum} - CO_2\text{–}C_{unfum})}{K_C} = \frac{F_C}{K_C} \qquad (1)$$

where F_C is the 'flush' of CO_2 (i.e., evolution of CO_2 in fumigated soil minus the evolution of CO_2 in unfumigated soil) and K_C is the fraction (0.45) of the microbial biomass C mineralized as CO_2 for 10 days incubation at 25°C.

Active microbial biomass (C_{AMB}) of soil was measured by the glucose-nutrient induced respiration method (Van de Werf and Verstrate, 1987) and modified as follows: about 20 g ODE of soil at 60% WHC was placed in each of two 50 ml glass beakers. The soil in one beaker was amended with glucose and nutrients (120 mg glucose; 30 mg yeast extracts; 45 mg NH_4Cl; 12 mg $MgSO_4{\cdot}7H_2O$; and 10 mg KH_2PO_4). Each soil sample was placed in a 500 ml-mason jar along with a glass vial containing 10 ml of distilled water to maintain humidity and a plastic vial containing 5.0 ml of 0.5M NaOH to trap evolved CO_2. The jars were sealed and incubated in the dark for 10 h at 20°C. The C_{AMB} was measured as follows:

$$C_{AMB} = (yCO_2{-}C10_{amend} - yCO_2{-}C10_{unamend})A_{C,} \quad (2)$$

where $yCO_2{-}C10_{amend}$ and $yCO_2{-}C10_{unamend}$ are the evolution of CO_2 from the glucose-nutrient-amended and unamended soils during a 10 h incubation, respectively, and A_C is the coefficient (0.283) to convert CO_2–C into C_{AMB} (Van de Werf and Verstrate, 1987).

Basal Respiration (BR) was measured as the CO_2-evolution from unamended field-moist soil adjusted to 60% WHC for an incubation period of 10 days at 25±1°C in the dark. The BR was calculated as follows:

$$BR = \frac{(CO_2{-}C_{soil} - CO_2{-}C_{air})}{10 \text{ days}}, \quad (3)$$

where $CO_2{-}C_{soil}$ is the evolution of CO_2 from soil and $CO_2{-}C_{air}$ is the atmospheric CO_2 absorbed by 1M NaOH in a 1 l blank mason jar.

Several metabolic quotients ($C_{TMB}\ C_{org}{}^{-1}$; $C_{AMB}\ C_{org}{}^{-1}$; and $C_{AMB}\ C_{TMB}{}^{-1}$) were calculated. Specific maintenance respiration rates (qCO_2) were calculated as BR per unit of total (BR $C_{TMB}{}^{-1}$) and active (BR $C_{AMB}{}^{-1}$) microbial biomass C (Anderson and Domsch, 1990).

2.5. Calculation of soil deterioration indices

The soil deterioration index (Adejuwon and Ekanade, 1988) was computed on the assumption that the status of individual soil properties under reforestation, grass and cultivation were once the same as that of adjacent soils under the well-stocked *S. robusta* forest prior to conversion. The difference between mean values of individual soil properties under reforestation, grass and cultivation compared to baseline values of soil properties under the well-stocked *S. robusta* forest was computed and expressed as a percentage of the mean value of individual properties. These percent changes were then averaged across all soil properties to compute the soil deterioration index. Values for pH, C/N ratio, BR, silt and clay were not included in this calculation because the criteria of 'more is better' is not true or is uncertain over the range of values in the study.

2.6. Statistical analysis

One-way analyses of variance (ANOVAs) procedures were used to compare the effects of different land use/land cover managements on biological, chemical and physical properties of soil. The LSD procedure was used to separate the means of the soil properties at $p \leq 0.05$. Values of soil properties that differed at $p \leq 0.10$ were considered significant trends.

3. Results and discussion

3.1. Effects on soil physical, chemical and biological properties

Soils under cultivation had higher bulk densities (ρ_b) than the adjacent soils under well-stocked *S. robusta* natural forest, Acacia reforestation and grass, with an associated decrease in porosity and AS (Table 1). The cultivated soils were considerably lower in silt and slightly lower in clay than the adjacent soils under natural forest, most likely as a result of preferential removal of silt by accelerated water erosion during the monsoon months (Hassan and Majumder, 1990). Compared to the natural forest, aggregate stability was lower in the cultivated

soils, but higher in the reforested soils. The grassland soils had about the same aggregate stability as the naturally forested soils. Greater residual sand content combined with poorer aggregation probably accounts for the higher bulk density and decreased porosity under cultivation in comparison with the natural forest, reforested and grassland soils (Table 1).

Enhanced aggregate stability of reforested soils is consistent with greater input of labile C contributed by the high quality litter-fall and root exudates in this young, rapidly growing legume-dominated forest system. Both extracellular polysaccharides produced during decomposition of labile organic matter and fungal hyphae associated with the extensive perennial roots systems of Acacia and grass could be important binding agents for macroaggregates (Tisdale and Oades, 1982; Elliott, 1983). In contrast, organic matter in cultivated soils has less physical protection than that in the uncultivated soils because tillage periodically breaks up macroaggregates and exposes previously protected organic matter in soil macroaggregates (Nardi et al., 1996).

The pH values of the natural forest, reforested, grassland and cultivated soils varied significantly from 4.9 to 5.6 (Table 2). Natural forest and reforested soils were significantly more acidic than those of the grassland and cultivated sites. The pre-weathered parent materials, amphoteric nature of aluminum in these tropical soils, and the intense leaching of basic cations during the monsoons are all the likely contributing factors to the naturally very acid pH levels in these soils (Hassan and Majumder, 1990). Ash from biomass burning on the grasslands, and to a lesser degree on the cultivated land could have returned enough base-forming cations to increase pH of the surface soil, at least temporarily.

Total nitrogen (N_T) content of soils under cultivation were lower compared to levels in the natural forest soils. In contrast, N_T in Acacia reforested soils was significantly higher than that in the natural forest soils (Table 2), as might be expected in a system dominated by nitrogen fixing trees. The total C (C_{org}) levels tended to be higher in the reforested and grassland sites, but the variability was too high for statistical significance. The C/N ratios did not vary among the land use/land cover types. Comparatively less fulvic (C_{FA}) C fraction was extracted from soils under cultivation than in the adjacent soils under natural forest, reforestation and grass. The 77–156% reduction in soluble C_{FA} content was far greater than that for humic (C_{HA}) C fraction which was reduced by 30–79%. Total extractable C (C_{HA} and C_{FA}) as a proportions of C_{org} also tended to be lower in the cultivated soils. Labile C (C_L) as measured by $KMnO_4$ oxidation was reduced by 67–167% in soils under cultivation compared to that under natural forest, reforestation and grass. The C_L as a proportion of C_{org} was also tended to be lower in cultivated soils.

The lower levels of C_{org} and N_T in cultivated soils may have resulted from a combination of lower C inputs because of less biomass C return on harvested land and greater C losses because of aggregate disruption, increased aeration by tillage, crop residue burning, accelerated water erosion and livestock grazing (Mullar-Harvey et al., 1985; Girma, 1998). In contrast, greater C_{org} and N_T contents of the reforested soils

Table 2
Effect of land use/land cover type on soil pH, total nitrogen and selected chemical properties related to organic carbon in adjacent areas of similar soils in Dhaka division, Bangladesh[a]

Land-use/land cover types	pH (1:25)	C_{org} (g/kg) (g/kg)	N_T (g/kg)	C/N ratio ratio	C_{HA} (mg/kg)	C_{FA} (mg/kg) (mg/kg)	E_C/C_{org} (%)	C_L (g/kg) (g/kg)	C_L/C_{org} (%)
Natural forest	4.9	8.4	1.01	8.4	868.6	779.5	19.8	1.5	17.9
Reforested land	5.0	12.8	1.25	10.2	1031.3	1157.3	19.1	2.2	18.1
Grassland	5.6	12.6	1.07	11.8	1193.8	1128.9	18.6	2.4	18.8
Cultivated land	5.3	7.4	0.81	9.2	666.8	440.1	14.7	0.9	12.2
LSD ($p \leq 0.05$)	0.3	ns	0.19	ns	ns	521.6	ns	*	ns

[a] Means of duplicate analysis of two sites for each land use/cover type C_{org}=Total organic C, N_T=Total N, C_{HA}=Humic acid C, C_{FA}=Fulvic acid C, E_C=Extracted C ($C_{HA}+C_{FA}$), C_L=$KMnO_4$ oxidizable C. pH measured in 1:2.5 soil–water suspensions.

* Indicates significant trends at $p \leq 0.10$.

are probably due to higher litter production and N fixation by the leguminous Acacia (Islam et al., 1999). Also, increased contact between microorganisms and incorporated plant residues likely resulted in faster decomposition of organic matter and loss of C_{org} in the cultivated soils. The trend towards lower C_L in the cultivated soils is probably due to breakdown of aggregates and greater organic matter oxidation following deforestation and continuous tillage (Blair et al., 1995; Nardi et al., 1996).

The values of most of the measured biological properties were significantly lower in the cultivated soils than in the natural forest, reforested and grass land soils (Table 3). The total microbial biomass (C_{TMB}) was consistently about 40% lower in soils under cultivation than soils under natural forest. The effect was more pronounced (69% reduction) on active microbial biomass (C_{AMB}). In contrast, C_{AMB} contents (and to a lesser degree the C_{TMB}) in the grassland soils were higher than in the natural forest sites. Active microbial biomass as a proportion of C_{org} (C_{AMB} $C_{org}{}^{-1}$) was higher in the soils under natural forest and grassland than in soils under either reforestation or cultivation. Microbial biomass C is usually limited in size by the availability of labile C and is sensitive to variations in land-use and soil management practices, so a higher proportion of microbial biomass (C_{TMB} or C_{AMB}) is an indication of aggradation of available organic C in soils under reforestation and grass (Anderson and Domsch, 1985; Powlson et al., 1987).

Basal respiration (BR) rates did not vary significantly among sites, but tended to be somewhat higher in the soils under reforestation and grass. High rates of BR can occur either as a result of large pool of labile C substrates or rapid oxidation of a smaller pool. Thus high BR may indicate ecological stress and degradation or a high level of ecosystem productivity. A more clearly interpretable parameter is the rate of BR per unit of microbial biomass (qCO_2), high levels of which have been associated with ecosystem stresses (Killham, 1985; Islam and Weil, 2000). The qCO_2 rates were similar in all soils under perennial vegetation, but significantly higher in the cultivated soils (Table 3). Enhanced microbial activities in soils under natural forest, reforestation and grass are related to greater levels of available organic C. Thus, reforestation of the degraded lands not only increased the C_{TMB} and C_{AMB} contents, but also increased the labile fraction of C_{org}. As a result, soil microbial communities under natural forest, reforestation and grass were more biologically active and less stressed than in the cultivated soils.

Relatively higher rates of qCO_2 for the cultivated soils suggest that intense competition for the available C may favor those microorganisms which use more C energy for cell integrity and maintenance than for growth under perturbed or disturbed ecosystems. As a result, cultivated soils favor bacteria-based food webs which have low C assimilation efficiencies and faster turnover rates than the more efficient fungal-based food webs dominant in untilled or natural ecosystems (Hendrix et al., 1986).

The calculated soil deterioration index reflects the percent changes in soil properties from their values under natural forest (Fig. 1). Soils under cultivation had a significantly lower (i.e., negative) deterioration in-

Table 3
Effect of land use/land cover type on selected biological soil properties related to microbial biomass and activity in adjacent areas of similar soils in Dhaka division, Bangladesh[a]

Land-use/land cover types	C_{TMB} (mg C/kg)	C_{AMB} (mg C/kg)	C_{TMB}/C_{org} (%)	C_{AMB}/C_{org} (%)	C_{AMB}/C_{TMB} (%)	BR (mg CO_2–C/kg/d)	qCO_2:*T* (mg CO_2–C/mg biomass/d)	qCO_2:*A* (mg CO_2–C/mg biomass/d)
Natural forest	259.5	78.0	3.1	0.93	30.0	6.2	0.024	0.080
Reforested land	337.9	61.7	3.1	0.48	17.8	8.5	0.025	0.139
Grassland	394.1	104.5	3.2	0.83	26.7	8.8	0.023	0.084
Cultivated land	156.1	24.4	2.1	0.33	15.6	6.2	0.039	0.256
LSD ($p \leq 0.05$)	85.4	42.0	ns	0.23	10.4	ns	0.012	0.060

[a] Means of duplicate analysis of two sites for each land use/cover type C_{org}=Total organic C, C_{TMB}=Total microbial biomass, C_{AMB}=Active microbial biomass, BR=Basal respiration, qCO_2:*T* and *q*CO2:*A* Specific maintenance respiration rates for C_{TMB} and C_{AMB}, respectively.

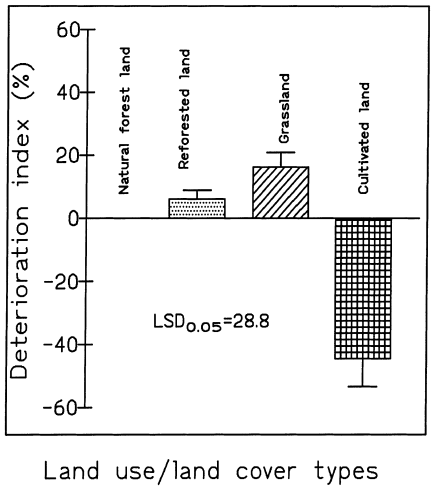

Fig. 1. Deterioration index for different land use/land cover types in a tropical forest ecosystem in Dhaka division, Bangladesh. Each deterioration index was calculated as the sum of the percentage deviations of ρ_b, AS, C_{org}, N_T, C_{TMB}, C_{AMB}, qCO_2:A, C_{FA} and C_L from their respective values under natural forest.

dex (−44%) than soils under the other land use types. In contrast, the deterioration indices for soils under grass and reforestation with fast-growing Acacia were actually positive (6–16%), indicating no significant deterioration, or even an improvement compared to natural forest. These soil deterioration indices clearly show that significant deterioration occurs in soil quality when these natural forest systems are degraded and converted for agriculture without the use of appropriate soil and water conservation practices.

3.2. Relationships among soil properties

Results show that soil biological properties responded rapidly to chemical and physical changes in soils resulting from human-induced land use/land cover alterations. There was a considerable degree of correlation between the physical properties, ρ_b and AS, and the various chemical (carbon) and biological properties measured (Table 4). As expected, ρ_b was negatively correlated with most soil properties while AS was positively correlated with the same. The relationship was reversed for qCO_2:A, since high values of this specific maintenance respiration rate and of ρ_b are both associated with soil degradation brought on by poor agricultural management (Islam and Weil, 2000). The closest correlation for both ρ_b and AS was with C_{FA}, suggesting that the fulvic acid C fraction is an important source of labile C for microbial activity that affects soil aggregation. The C_{FA} was also very closely correlated (r=0.99) with C_L as measured by $KMnO_4$ oxidation, suggesting that the latter may be useful as a very rapid and easily performed analysis for microbially functional soil organic matter. For this reason, the authors are currently developing a simplified method suitable for determining C_L in the field.

4. Conclusions

Clearing and cultivation of forested lands resulted in deterioration of soil properties compared to soils under well-stocked natural forest, Acacia reforestation

Table 4
Standardized linear relationship (r) among selected biological, chemical and physical properties of soils under different land use/land cover types in Dhaka division, Bangladesh[a]

Standardized variables	ρ_b	AS	C_{org}	N_T	C_{FA}	C_L
AS	−0.81*					
C_{org}	−0.70ns	0.74*				
N_T	−0.72*	0.87**	0.49ns			
C_{FA}	−0.93***	0.88**	0.87**	0.74*		
C_L	−0.90**	0.81*	0.89**	0.69ns	0.99***	
C_{TMB}	−0.89**	0.74*	0.73*	0.74*	0.93**	0.95***
C_{AMB}	−0.83**	0.46ns	0.64ns	0.41ns	0.78*	0.81**
qCO_2:A	0.85**	−0.47ns	−0.37ns	−0.52ns	−0.68ns	−0.67ns

[a] ρ_b=Bulk density, AS=Aggregate stability, C_{org}=Total organic C, C_{HA}=Humic acid, C_{FA}=Fulvic acid, C_L=$KMnO_4$ oxidizable C, C_{TMB}=Total microbial biomass, C_{AMB}=Active microbial biomass, BR=Basal respiration, and qCO_2:A=Specific maintenance respiration rates of C_{AMB}.

and grass. Cultivated soils had higher bulk density and lower aggregate stability. Total organic C and N, soluble and oxidizable C, total and active microbial biomass were all reduced. At the same time, specific maintenance respiration was greater on cultivated sites than in well-stocked natural forest soils. Improvement of soil properties under the Acacia reforestation and grass indicates that planting of well-adapted and fast-growing vegetative species can gradually improve soil quality and regenerate degraded lands.

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