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Changes in Soil Physico-Chemical Properties and Fertility Status of Long-Term Cultivated Soils in Southwestern Bangladesh

Mehjabin Hossain, Md. Tareq Bin Salam

Soil, Water and Environment Discipline, Khulna University, Bangladesh-9208

ABSTRACT

Sustainable soil management is essential for maintaining proper soil health for future production of crops. A comparative study was carried out at Dumuria soil series in Khulna district to observe the current fertility and physical changes of soils over a period of time due to different land use. Soil physical (soil texture, water holding capacity, bulk density and total porosity) and chemical properties (Nitrogen (N), Phosphorous (P), Potassium (K), Sulphur (S), soil organic matter (SOM), soil organic carbon (SOC) along with cation exchange capacity (CEC), sodium absorption ratio (SAR), exchangeable sodium percentage (ESP), base saturation percentage (BSP) and % salt properties were determined. Except for the control, all the soils had silt loam texture. Water holding capacity varied from (33.57 ± 3.3 to 55.57 ± 5.2)% and all soil indicated good porosity (average 47 ± 5.59)%. Soil pH (5.96 to 7.4) indicated that the soils were neutral to alkaline in nature and had an average salt percentage (0.11% ± 0.05). The SOM was higher in natural vegetative soil (2.45 ± 0.46)% and decreased over the period of land use for cultivation. In terms of ESP and SAR, 50 to 10 years cultivated soil showed the highest value and a significant difference was observed among the treatments ($p \leq 0.05$). For BSP, 100 to 50 years cultivated soil showed the highest value and uncultivated soil showed the lowest value and was statistically insignificant among treatment ($p \leq 0.05$). Overall observation showed that long term land use resulted in a significant decline in soil quality. So, sustainable soil management should be incorporated in the development of suitable agricultural management such as the use of organic matter or incorporate organic mixed with inorganic fertilizer and adaptation of soil conservation farming. Proper strategies should be adopted to seek a sustainable solution that better addresses of soil fertility management.

Keywords: Soil physico-chemical properties, bulk density, porosity, CEC, SAR

INTRODUCTION

Soil health is a key factor for increasing agricultural production. This calls for long-term studies at fixed sites for monitoring changes in soil fertility status. The rapidly increasing human populations and the need of for land for various agricultural activities has brought about extensive land use changes and soil management practices throughout the world (Cunningham *et al*., 2005). Long-

*Corresponding author : E-mail: *tareqss_ku@rocketmail.com*

term cultivation has found to result in a statistically significant decrease in the total amount of soil organic matter (SOM) along with concentrations of all carbon compounds (Sommerfeldt *et al*., 1988). Agricultural sustainability requires periodic evaluation of soil fertility status. This is important to understand the factors which impose serious constraints on increased crop production under different land use types and for adoption of suitable land management practices (Chimdi *et al.*, 2012). However, information about the effects of land use changes on soil physico-chemical properties is essential in order to draw up appropriate recommendations for optimal and sustainable utilizations of land resources. As soil physical and chemical properties play a central role in transport and reaction of water, solutes and gases in soils, their knowledge is very important in understanding soil behavior to applied stresses and transport phenomena in soils, hence for soil conservation and planning of appropriate agricultural practices. The anthropogenic changes in land use have altered the characteristics of the Earth's surface, leading to changes in soil physico-chemical properties such as soil fertility, soil erosion sensitivity and soil moisture content (Abad *et al*., 2014). These changes may be caused by soil compaction that reduces soil volume and consequently lowers soil productivity and environmental quality (Abad *et al*., 2014). Soil physical and chemical properties have been proposed as suitable indicators for assessing the effect of land-use changes and management (Janzen *et al.*, 1992; Alvarez and Alvarez, 2000). This approach has been used extensively by several authors to monitor land-cover and land-use change patterns (Schroth *et al.*, 2002; Walker and Desanker, 2004; Yao *et al.*, 2010). Therefore, this study was carried out to in order to evaluate the influence of different land use on soil physicochemical properties in soils of Dumuria Upazilla, Khulna, Bangladesh.

MATERIALS AND METHODS

Experimental Site

The experimental site was at Chechuria village in Dumuria Upazilla under Khulna district (22°39'00''N 89°15'00''E and 22°56'00''N 89°32'00''E). Five sites have been chosen where 4 were from different ages of agricultural field and one was from uncultivated soil. All soils are in Dumuria soil series. In Table 1, details of sampling code are presented.

Collecting, Processing and Storing Soil from Sites

Composite soil sites from 0-15 cm of the were collected then air dried, ground and passed through a 2 mm sieve for nutrient analysis. This process was replicated thrice and then the soils were sent to the laboratory of Soil, Water & Environment Discipline, Khulna University for physico-chemical analyzes.

Analytical Procedure of Soil Physicochemical Properties

Chemical characterization of the sited soils included the analysis of organic matter (SOM), organic carbon (SOC), cation exchange capacity (CEC) at pH 7.0, base

TABLE 1
Site coding at different stages of soil and its cropping pattern in Dumuria Upazilla

Farming status	Stages of soil	Sampling code	Land use pattern
Under Cultivation	>100 years	A	Rice-Rice-Rice Wheat-Rice-Rice
	100-50 years	B	Wheat-Rice-Rice Vegetable-Rice-Rice
	50-10 years	C	Rice-Fallow-Rice Wheat-Fallow-Rice
	<10 years	D	Rice-Rice-Rice Rice-Rice-Fallow
Non-cultivated soil	Control	E	Natural vegetation

saturation, soil EC, soil pH, nitrogen, phosphorous, potassium and sulfur; whereas the physical characterization consists of particle size analysis, soil structure, water holding capacity (WHC), bulk density (BD) and total porosity (PT) determination. The sites were allowed to dry in the open air until friable. Organic carbon was determined using the Walkley - Black wet oxidation procedure and the soil organic matter content was determined from the organic carbon (Nelson and Sommers, 1996). Soil pH was determined in distilled water using the pH meter with a water ratio of 1:2. Available phosphorus (P) and exchangeable cations were determined. Available P was determined by Bray-1 extraction followed by molybdenum blue colorimetry (Frank *et al*., 1998). Exchangeable potassium (K^+) and sodium (Na^+) were determined by flame photometry (Vogelmann *et al*., 2010; Olorunfemi *et al*., 2016) while exchangeable magnesium (Mg^{2+}) and calcium (Ca^{2+}) were determined by atomic absorption spectrophotometer after extraction with 1M KCl 1.0 mol l^{-1} (Senjobi and Ogunkunle, 2010). The cation exchange capacity (CEC) at pH 7.0 was determined following the procedure described by Reeuwijk (2002). Soil particle sizes were determined using the hydrometer method described in Agbede and Ojeniyi (2009) and classification was carried out using the USDA classification system (Soil Survey Staff, 1999). Soil water holding capacity (WHC) was determined following the method described by Ibitoye (2006). The bulk density (BD) was obtained by the gravimetric soil core method described by (Blake and Hartage, 1986) and particle density (PD) was assumed to be 2.65 g cm^{-3} (Osunbitan *et al*., 2005; Li and Shao, 2006; Zhang *et al*., 2006; Price *et al*., 2010). Total porosity (PT) was obtained from BD and PD using the equation and relationship developed by Danielson and Sutherland (1986).

$$\% \text{ Porosity} = (1-(BD/PD) \times 100)$$

where: BD = bulk density and PD = particle density (= 2.65 Mg/m^3). The default value of 2.65 Mg/m^3 is used as a 'rule of thumb' based on the average bulk density of rock with no pore space (Fasinmirin and Olorunfemi, 2013).

BSP (%) = [(Summation of Ca^{2+}, Mg^{2+}, K^+ and Na^+ content in $cmol_c$ /kg soil) ÷ CEC ($cmol_c$ /kg soil)] x 100

$$SAR = [Na^+] \div (\sqrt{½}\ \{[Ca^{2+}] + [Mg^{2+}]\})$$
$$ESP = ([Na+] \div CEC) \times 100$$

where, BSP is base saturation percentage SAR is sodium absorption ratio and ESP is exchangeable sodium percentage. Percent of salt presented in the soil was determined by the following equation:

Salt (%) = 0.064 x EC

Statistical Analyses
The statistical analyses of the results obtained from soil sites were performed as described by Zaman *et al.*, (1982). One way ANOVA (SPSS version 16.0) was used to test for significance among the treatment means and post hoc comparison was used to compare the soil chemical properties from the different land uses.

RESULTS AND DISCUSSION

Soil Physical properties
Soil physical properties are presented in Table 2. All cultivated soils had a silt loam texture. This is due to long term soil tillage effects on soil particle size. Gülser *et al.* (2016) reported that heterogeneity and variation of soil physical parameters in a field due to soil plowing should be taken into consideration for successful agricultural management. Table 1 shows that site C had the highest percentage of moisture. This is due to charged particles of more clay enhancing the absorption site of water molecules for site C. Bulk density of the sites ranged from 1.63 to 1.26 mg/m^3 indicating that, all sites except site C are porous soils. This is due to site C contains less sand and more clay which indicates less chance of forming soil pores. It has been stated that bulk density is primarily affected by soil texture (Canarache, 1991) since well graded soils containing both fine and coarse particles results in a higher number of contact points than in a poorly graded soil (Kohnke and Franzmeier, 1995). The WHC of all soil sites ranged widely from 33.57% to 55.57%. The average WHC value was found to be significantly affected by land uses. The highest WHC value (55.57%) was recorded in uncultivated soil which also had the highest organic matter content (2.45%), This was probably due to the ability of SOM to act as a sponge in the soil, thereby retaining soil moisture. Organic matter intimately mixed with mineral soil materials has a considerable influence in increasing moisture holding capacity (FAO, 2005).

TABLE 2
Summary statistics for surface soil physical parameters under different land uses

Site code	Sand (%)	Silt (%)	Clay (%)	Textural Class Mean ± SD	WHC(%)	BD (g/cm^3)	Porosity (%)
A	23±1.27bc	60±2.75a	17±0.9c	Silt loam	33.57±3.3c	1.34± 0.05ab	49±1.33ab
B	25±1.4b	48±2.9ab	27±1.2b	Silt loam	39.57±4.3bc	1.26± 0.07c	52±1.87a
C	12±1.8c	51±3.4ab	37±2.3a	Silt loam	41.57±3.4b	1.63± 0.02a	38±0.53b
D	23±1.6bc	54±4.5ab	23±1.76bc	Silt loam	46.43±4.4ab	01.39± 0.04b	48±1.07ab
E	40±1.95a	43±3.2b	17±1.65c	loam	55.57±5.2a	1.31± 0.04ab	51±1.07a

Soil Chemical Properties

Soil pH, EC and %Salt

The results of the chemical properties of the site soils are presented in Table 3. The average pH value of all sites ranged from 5.96 to 7.4 that indicating medium acidic to mildly alkaline pH values. The pH level of the soil directly affects soil life and the availability of essential soil nutrients for plant growth. Factors such as parent material, rainfall, and type of vegetation are dominant in determining the pH of soils. Analysis of variance of the soil properties between land uses showed that the pH distribution is homogenous ($p \geq 0.05$) among the different treatments. In terms of soil EC, the average value ranged from 0.52 ds/m to 2.7 ds/m that indicate non saline to slightly saline characteristics. Percent salt varies from 0.03 to 0.14 that indicates that all site soil carries minimal amount of salt that shows good soil behavior.

Total Nitrogen and Available Phosphorus

Total nitrogen of all sites ranged from 0.83 to 2.9%. The nitrogen value significantly differed among the land uses. Site E showed the highest value. This may due to higher nitrogen mineralization of nitrogen in the natural vegetative soil due to continuous addition of organic matter. Sommerfeldt, (1988) found that long-term annual manure applications increase soil organic matter and nitrogen that is very similar to our result. The available phosphorus of all sites ranged from 3.73 mg/kg to 12.16 mg/kg. The available phosphorus was not significantly different among the land uses. Site D slightly have lower values than soils where as site B showed the highest value. This may be due to soil organic matter being the main source of available Phosphorus (Mamo and Haque, 1987). The availability of phosphorus under most soils declined due to the impact of fixation, abundant crop harvest and erosion (Yeshaneh, 2015). Soils with inherent pH values between 6 to

TABLE 3
Summary statistics for surface soil chemical parameters under different land uses

	Sites				
	A	**B**	**C**	**D**	**E**
Soil Parameters	**Mean ± SD**				
pH	5.96±0.30c	6.6±0.39b	7.4±0.45a	6.16±0.6b	6.25±0.5b
EC (ds/m)	1.18±0.03ab	1.83±0.04ab	2.7±0.06a	0.52±0.024b	2.25±0.035a
OC (%)	0.72±0.07ab	0.27±0.03b	1.09±0.06a	0.31±0.04b	1.42±0.12a
SOM (%)	1.24±0.11bc	0.47±0.12c	1.88±0.18 b	0.54±0.15c	2.45±0.46a
Total Nitrogen (%)	2.30±0.87b	0.83±0.14c	2.37±0.89 b	1.33±0.72bc	2.9±0.94a
Available Phosphorus (mg/kg)	9.92±1.13b	12.16±2.2a	11.01±1.7a	3.73±0.9c	3.89±0.6c
Potassium (mg/kg)	120.91±7.7a	44.08±3.32b	26.05±2.2c	45.34±3.87b	76.83±6.45ab
Sulfur (mg/kg)	23.58±3.34b c	45.05±6.65b	75.79±3.5a	57.26±5.58a b	14.74±2.89c
CEC (cmolc/kg)	4.78±1.23b	5.18± 1.03a	5.52± 1.01a	4.65± 1.03b	4.75± 1.05b
SAR	0.074±0.02b	0.095 ± 0.039a	0.096± 0.023a	0.074 ± 0.04b	0.089±0.031a b
ESP (%)	2.71± 0.75ab	2.65± 0.68ab	2.95± 0.98a	2.14± 0.64b	2.48±0.88ab
BSP (%)	78.68± 11.94bc	84.83± 11.94a	80.79± 10.94b	79.80± 14.94b	76.95± 13.94c
%Salt	0.08±0.02ab	0.12±0.06ab	0.17±0.04a	0.03±0.001b	0.14±0.01a

7.5 with moist and warm conditions are ideal for P-availability, while pH values below 5.5 and between 7.5 and 8.5 limits P-availability to plants due to fixation by aluminum, iron, or calcium, often associated with soil parent materials (Soil Survey Staff, 2009).

Potassium and Sulfur

The potassium of all sites ranged from 120.91 mg/kg to 26.05 mg/kg. The potassium value significantly differs among the land uses with site C showed the lowest value. This may due to the decrease in clay content creating a barrier to build water-stable aggregates thus decreasing K content. This result supports the study of Zhang and He, (2014). The sulfur concentration of all sites ranged from 75.79 mg/kg to 14.74 mg/kg and was significantly different with land use Site E had slightly lower values because it was in uncultivated soil where sulfur containing fertilizer had not been applied.

Soil Organic Carbon and Organic Matter

Soil organic carbon (SOC) of the site soils varied from 0.27 % to 1.42% and soil organic matter (SOM) of site soils varied from 0.47 % to 2.45%. Organic carbon which is an index of soil organic matter differed among the different land uses. The SOC was found to be higher in the control soil as the site had been uncultivated with natural addition of organic residue. A great number of studies have reported similar observations. Yimer *et al.* (2007) in Ethiopia also compared croplands, forestlands and grazing lands and found that soil organic C and total N decreased in croplands compared to forestlands. Soils underlying native vegetation (e.g., undisturbed) generally feature high SOM as a result of ample litter cover, organic inputs, root growth and decay, and abundant burrowing fauna (Price *et al*. 2010).

Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP)

SAR values ranged from 0.074% to 0.096% and ESP values from 2.14% to 2.95%. Soils that have more than 6% ESP are considered to have structural stability problems related to potential dispersion (van de Graaff and Patterson 2001). Though there is a difference among the values of ESP, all sites had good structural stability.

Base Saturation Percentage (BSP)

In all sites, the base saturation percentage ranged from 76.95% to 84.83%. Soils with 70% or greater BS are unlikely to limit agronomic crop growth due to acidity. Base saturation was higher in all sites indicating future possibilities of limiting crop production.

Correlation between soil properties

There was a considerable degree of correlation among the various chemical properties measured (Table 4). The linear correlation analysis of the five soil chemical properties for the study area showed significant correlation soil attribute pairs ($P \leq 0.01$; $P \leq 0.05$) (Table 4).

CONCLUSION

This research evaluated and characterized physiochemical properties of soils of similar geological and climatic conditions but under different land use in Southwestern Bangladesh. All soils had good porosity and almost similar texture. Uncultivated soil had the highest organic matter content and is an indication of the affinity of organic matter for water. Soils with high organic matter content

TABLE 4
Correlations: N, P, K, S, Ca, Mg, % OC, % OM, %S with %OC and %OM

	N	P	K	S	Ca	Mg	%OC	%OM
% OC	0.566	0.204*	0.656	-0.007	0.710	0.657*	1	
	0.055	0.524	0.020	0.983**	0.010	0.020	1	
% OM	0.563	0.206	0.655*	-0.005	0.708	0.659	0.732*	1
	0.057	0.522**	0.021	0.989**	0.010	0.020	0.576	1

Cell Contents: Pearson correlation, P-Value (*$*p \leq 0.01$ & $**p \leq 0.05$*)

and clay particles demonstrated high CEC values. Uncultivated soil naturally had the highest organic carbon value compared to cultivated soil. Long term land use significantly declines soil organic carbon thus impacting negatively climate in global C-sequestration. In terms of ESP and SAR, site C showed the highest value and a significant difference was observed among the treatments ($p \leq 0.05$). In BSP, site B showed the highest value and site E showed the lowest value and was statistically insignificant among treatments ($p \leq 0.05$). Overall observation showed that long term land use exhibited a significant decline in soil quality. Land uses and soil management appear to be good predictor of soil fertility status. Success in soil management depends on the understanding of how the soil responds to agricultural practices over time. So, sustainable soil management should be incorporated in the development of suitable agricultural management such as use of organic matter or incorporation of organic mix inorganic fertilizer or so on.

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