International Journal of Soil Science and Agronomy Vol.2 (3), pp. 051-059, March, 2015. Available online at www.advancedscholarsjournals.org © Advanced Scholars Journals

Full length Research Paper

The different types of Soil properties and phosphorus fractions in the three cropping systems of Lower indo-Gangetic alluvial plain

Sheikh Ghulam

Department of Soil Science, Faculty of Agricultural Science, University of Delhi, India.
Email:Ghukh@yahoo.com

Accepted 05 February, 2015

The variation of soil properties and phosphorous fractions in three different cropping systems were investigated in Chinchura-Mogra and Polba-Dadpur block of Hugli District, West Bengal representing lower Indo-Gangetic alluvial plain. One perennial cropping system (mango and banana plantation) and two annual cropping systems (Paddy-paddy and paddy-potato) were selected for this study. Sampling points were selected based on established soil map of the area. Soils of each cropping systems were characterized and the samples were collected for laboratory analysis. Analysis of variance was used to establish significant differences within the cropping system and pedons. Significantly lower clay (27.1%) and organic carbon (0.33%) was recorded in paddy-potato cropping system whereas paddy-paddy cropping system recorded significantly higher clay (53.6%), soil reaction (7.14) and cation exchange capacity (17.85 c mol (p+) kg^{-1}). High available water content (12.11%) was recorded in the plantation system. The results from phosphorous fractionation studies shows that soils of plantation system recorded high Olsen-P (3.57 to 10.91 mg kg^{-1}) and calcium-P (49.20 to 73.56 mg kg^{-1}) whereas paddy-paddy cropping system having high iron-P (10.46 to 27.83 mg kg^{-1}). The epipedons compared to the endopedons of the soils had significantly higher sand, organic matter, available water capacity, phosphorous fractions and lower clay content. The results showed that most of the soil properties were to a greater extent influenced by changes in cropping systems.

Key Words: Cropping systems, epipedons, endopedons, soil properties, phosphorous fractions.

INTRODUCTION

The lower Indo-Gangetic Plain (LIGP) of India is primarily a rice based cropping system which has played a key role in realizing the food grain production level needed to sustain a burgeoning population. During 1990's, cropping system was diversified with the inclusion of short duration potato and mustard resulting in higher production per unit area per unit time. The paddy-paddy cropping system is a major cropping system in LIGP which occupies an area of 0.94 M ha. The paddy-potato (including paddy-potato-vegetables and paddy-potato-summer paddy) cropping system is a second dominant cropping system in the LIGP, covering an area of 0.58 M ha (Yadav and Subba Rao, 2001). Perennial cropping systems (Mango and banana plantation) is mainly practiced in levee portion of

Hugli and other rivers. The other cropping systems like paddy-wheat, paddy-pulses are occupied smaller area in LIGP. Continuous cropping system, intensive cultivation with high water-demanding crops has led to a decrease in groundwater levels, serious water logging and secondary salinisation which ultimately resulted to declining input factor productivity in many parts of LIGP (Ladha et al., 2003; Biswas et al., 2006; Saikh et al., 1998). Different studies have examined variation of cropping systems on soil properties in different parts of the globe (Rachman et al., 2003; Al-Kaisi et al., 2005; Mazarura and Chisango, 2012; Hubbard et al., 2013; Gathala et al., 2013). Long-term soil fertility studies have shown reduction in soil organic matter content due to continuous cropping systems (Saha et al., 2000; Varvel and Wilhelm, 2010). Like other soil properties, the forms and dynamics of soil phosphorous are also greatly affected by land use changes/cropping systems which often involve changes in vegetative cover, and biomass production and agricultural management practice (Solomon et al., 2002; Dossa et al., 2001). Majority of works in Indo-Gangetic alluvial plain has focused to assess cropping systems in terms of soil fertility and nutrient balances (Manoj Kumar et al., 2009; Biswas et al., 2006). Variation of cropping systems on soil properties and phosphorous fractions has not been conducted for dominant cropping systems of LIGP region in India, and this study will provide useful information for establishing sustainability and proper land management practices for cultivations in this region. In this context, the study was carried out to assess the variation of cropping systems on soil properties and phosphorous fractions in lower Indo-Gangetic alluvial plain.

MATERIALS AND METHODS

Study area

This study was carried out in Chinchura-Mogra and Polba-Dadpur block of Hugli District, West Bengal representing lower Indo-Gangetic alluvial plain (Figure 1). Humid subtropical climate prevails in the area with long term mean annual rainfall of 1600 mm. The lowest rainfall of 1129 mm was received in 2003 and the highest amount of 1648 mm during 1999. The mean annual air temperature is 26°C. The difference between the mean summer and mean winter soil temperature is more than 5°C. The soil temperature regime is hyperthermic. The study area belongs to Agro Ecological Zone 15.1 described as the Bengal Basin, hot moist sub humid agro ecological sub region with deep loamy to clayey alluvium derived soils, medium to high available water capacity and length of growing period of 210 to 240 days. The dominant three cropping systems practiced in this region (one perennial cropping system (Mango and Banana plantation) and two annual cropping systems (paddy-paddy and paddy-potato) were selected for this study.

Field studies

Soil map of west Bengal was used as a base map for selection of different sites for sampling (NBSS and LUP, 1992). Sampling points are selected from single mapping unit which have dominant soils of very deep, moderately well drained, coarse loamy soils on nearly level to very gently sloping uplands. Three sites were selected (Figure 2) in each cropping system, profiles were dug and soils were morphologically described (Soil Survey Staff, 2003). Soil samples were collected from each genetic horizon for laboratory analysis. Soil samples were air-dried, crushed and passed through 2-mm sieve, and physical and chemical characteristics were determined.

Laboratory study

Particle size distribution was determined by International Pipette Method (Day, 1965). Soil pH, electrical conductivity (EC) and (Cation Exchange Capacity) CEC were determined using the standard procedures (Page et al., 1982). Soil organic carbon was determined by the wet oxidation method of Walkey and Black (1934). Available Water Capacity (AWC) was calculated as the water retained between suction 0.03 and 1.5 Mpa described by Klute (1986). Different inorganic phosphorous fractions were analysed according to Petersen and Corey (1966). Available phosphorous (Olsen-P) was analysed by using 0.5 M $NaHCO_3$. 1 N NH_4Cl was used to extract easily soluble and loosely bound Phosphorous (Saloid bound P), Aluminium phosphate and iron phosphate extracted by using 0.5 N NH_4F and 0.1 N NaOH respectively. Calcium phosphate was extracted by using 0.5 N H_2SO_4.

Statistical analysis

Analysis of variance (ANOVA) was conducted using SAS (SAS Institute Inc., North Carolina, USA). Differences between three cropping systems and pedons were compared by the least significant difference (*LSD*). Differences between the means were considered to be statistically significant at $P < 0.05$.

RESULTS AND DISCUSSION

Soil morphological characteristics

Morphological properties of studied soils are shown in Table 1 indicating well drained, yellowish brown to brown, moderate medium, sub angular blocky structure silt loam to silty clay loam in surface soils identified in plantation system. The endopedon of these soils are, brown to dark brown, moderate medium to moderate fine sub angular blocky structured silt loam to silty clay in texture with violent to strong effervescence with dil. HCl at various pedal depths. The soils of paddy-potato cropping systems have well drained to moderately well drained, light yellowish brown to brown, moderate medium, sub angular block structured silt loam to sandy loam surface soils with brown to dark grayish brown, moderate medium to weak fine sub angular blocky structured loam to silt loam sub surface soils whereas paddy-paddy cropping system have somewhat poorly drained to poorly drained, dark brown to very dark gray brown, silty clay to silty clay loam surface soils with coarse strong to moderate medium, sub angular blocky structured silty clay to clayey subsurface soils. The soil colours of endopedons of paddy-paddy cropping system indicate that that they are more reduced condition due to lack of oxygen through out

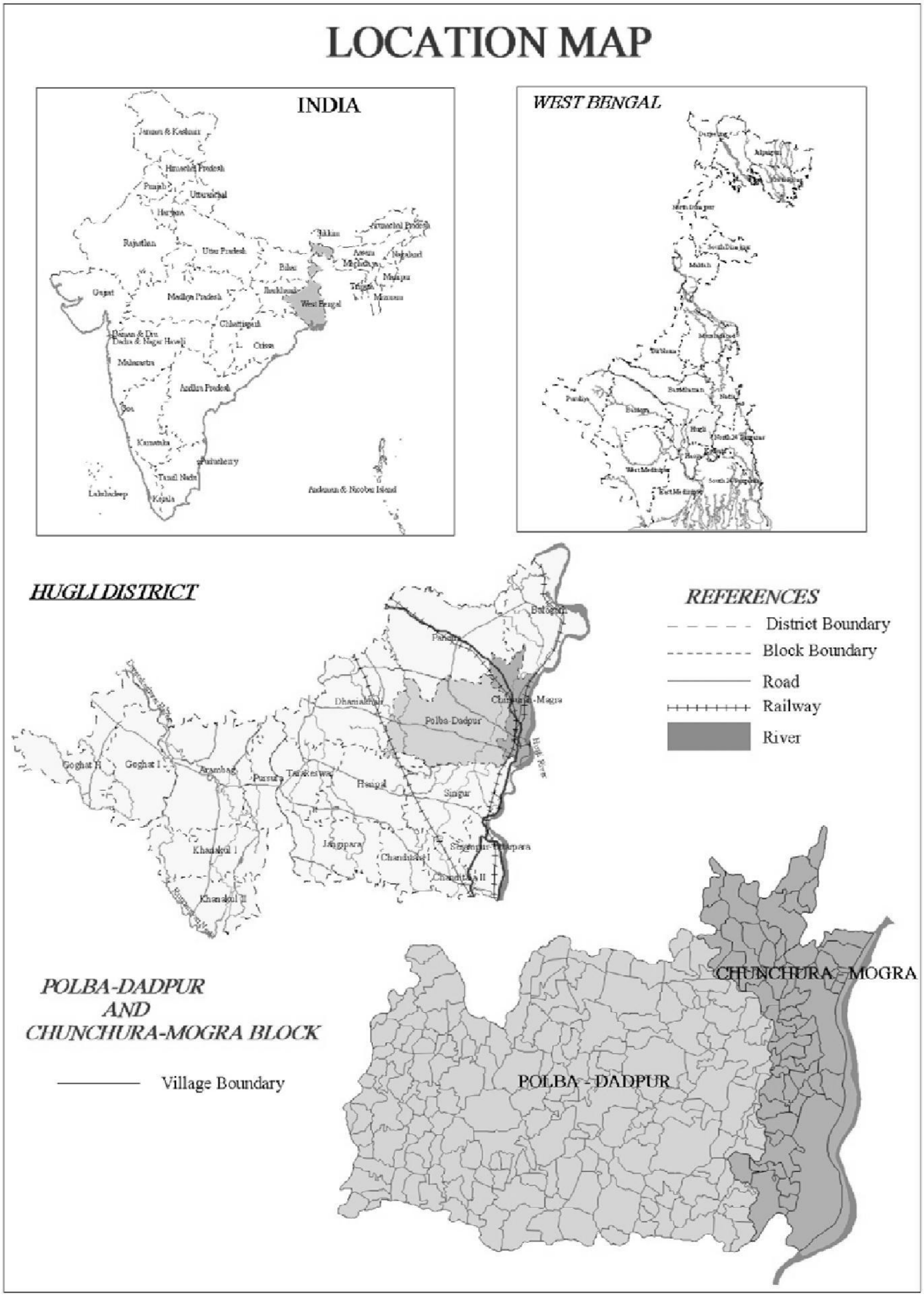

Figure 1. Study area.

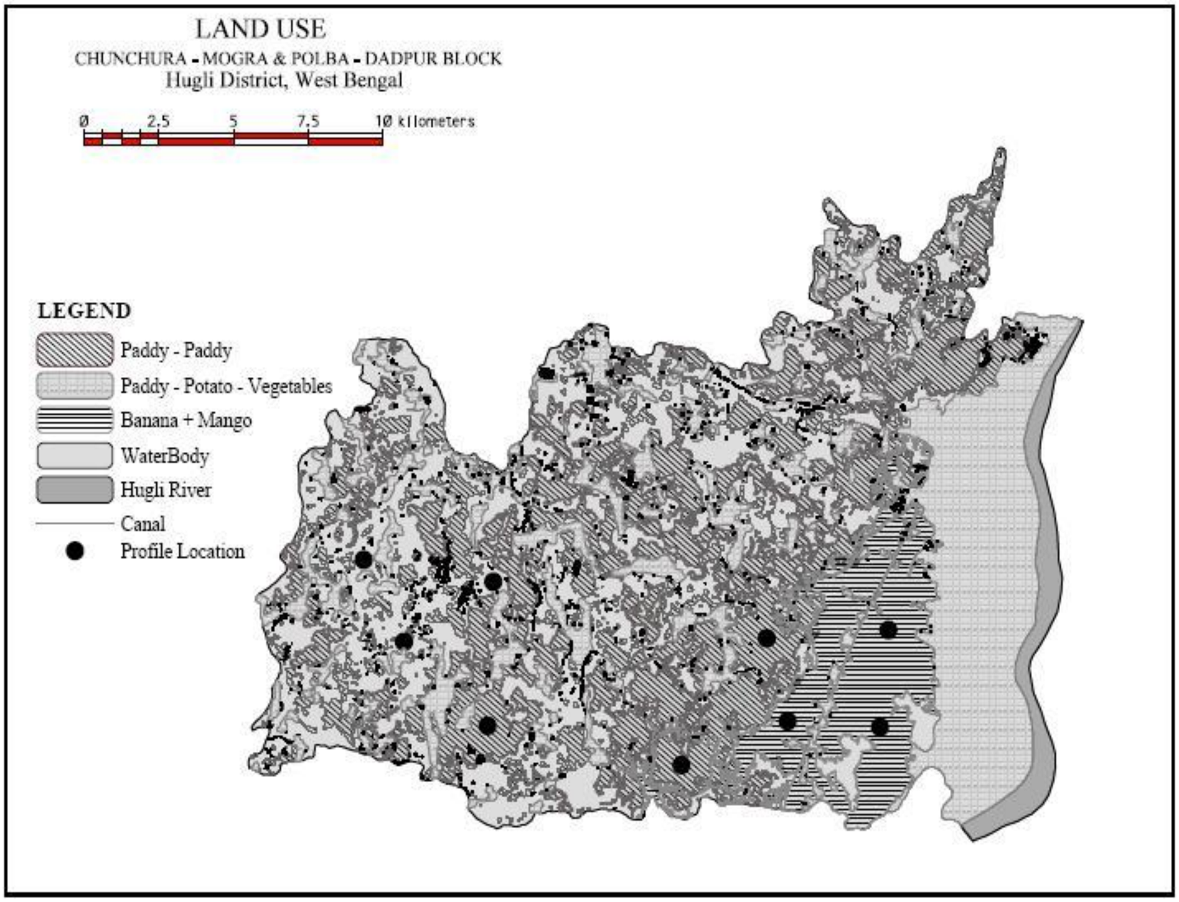

Figure 2. Sampling points.

Table 1. Selected soil morphological features associated with different cropping systems in Lower indo Gangetic alluvial plain.

Cropping system	Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistency	Mottles	Reaction with HCl	Drainage
Plantation	A	15	10YR 5/4	sil	m2sbk	fr.ss.po	-	-	WD
	Bw1	23	10YR 3/2	sicl	m2sbk	fr.ss.sp	f1f	es	
	Bw2	47	10YR 3/3	sicl	m1sbk	fr.ss.sp	-	es	
	C1	55	10YR 3/3	sic	massive	fi.s.p	f1f	ev	
Paddy-potato	Ap	25	10YR 5/3	sil	m2sbk	fr.ss.sp	f1p	-	MWD
	C1	54	10YR 4/3	sil	m2sbk	fr.ss.po	m2p	-	
	C2	28	10YR 4/3	sil	f1sbk	fr.ss.sp	m2p	-	
	C3	36	10YR 3/4	sil	f2sbk	fr.ss.po	m2p	-	
Paddy-paddy	Ap	23	10YR 3/2	sic	massive	fi.ss.p	f1p	-	PD
	Bw1	28	10YR 3/1	c	c3sbk	fi.s.p	-	-	
	Bw2	44	10YR 3/1	c	c3sbk	fi.s.p	m2p	-	
	Bw3	40	10YR 3/2	c	c3sbk	fi.s.p	m2p	-	

Sil- silt loam, sicl- silty clay loam, sic- silty clay, c- clay; m2sbk- moderate medium sub angular blocky, m1sbk- moderate weak sub angular blocky, c3sbk - coarse strong sub angular blocky, f2sbk- fine medium sub angular blocky, f1sbk- fine weak sub angular blocky; fr.ss.po- friable, slightly sticky and non plastic consistency, fr.ss.sp- friable, slightly sticky and slightly plastic consistency, fi.s.p - firm, sticky and plastic, fi.ss.p- firm, slightly sticky and plastic, fi.s.p- firm, sticky and plastic; f1f- few fine faint mottles, f1p- few fine prominent mottles, m2p- common medium prominent mottles; es- strong effervescence, ev- violent effervescence; WD- well drained, MWD- moderately well drained, PD- poorly drained.

Table 2. Particle size distribution as influenced by cropping systems and pedons.

Results	Sand (%)	Silt (%)	Clay (%)
Cropping systems			
Plantation	1.5^{c}	59.7^{a}	38.8^{b}
Paddy-potato	19.9^{a}	52.9^{a}	27.1^{c}
Paddy-paddy	9.4^{b}	37.7^{b}	53.6^{a}
LSD	2.49	6.61	7.23
Pedons			
Epipedon	16.4^{a}	49.5^{ab}	34.1^{a}
Endopedon1	14.1^{ab}	43.9^{b}	41.9^{a}
Endopedon2	9.8^{c}	51.4^{ab}	39.1^{a}
Endopedon3	11.1^{c}	52.4^{a}	37.2^{a}
LSD (P<0.05)	2.81	7.63	8.35

*means followed by same letter within the column are not significantly different at P<0.05.

Table 3. Water retention characteristics as influenced by cropping systems and pedons.

Results	Field capacity (%)	Permanent wilting point (%)	Available water content (AWC) (%)
Cropping systems			
Plantation	24.51^{b}	12.39^{b}	12.11^{a}
Paddy-potato	20.08^{c}	8.95^{c}	11.12^{a}
Paddy-paddy	25.71^{a}	16.77^{a}	8.90^{b}
LSD (P<0.05)	1.00	1.45	1.33
Pedons			
Epipedon	23.52^{ab}	11.83^{b}	11.65^{a}
Endopedon1	22.61^{bc}	12.98^{ab}	9.67^{b}
Endopedon2	24.52^{a}	14.14^{a}	10.34^{b}
Endopedon3	23.55^{ab}	12.68^{ab}	10.85^{ab}
LSD (P<0.05)	1.15	1.68	1.00

*means followed by same letter within the column are not significantly different at P<0.05

the year. Continuous submergence of the soil creates significant changes in the physical, chemical and morphological properties of the soil. The coarse strong sub angular blocky structure in the paddy-paddy cropping system was due to the intensive cultivation with mechanized tillage for the last three decades (Jung et al., 2010).

Soil physical properties

Results on particle size distribution are presented in Table 2. There was a significant variation in particle size distribution under soils of different cropping systems. Highest clay content was recorded in paddy-paddy cropping system (53.6%) and highest sand content (19.9%) was recorded in paddy-potato cropping system. The high sandiness in paddy-potato cropping system is due to continuous cropping and intensive tillage which leads to loss of fine material from the system whereas continuous puddling increases the clay content in paddy-paddy cropping system. High silt content in thirty-five year old plantation system attributed to dense cover which helps to suppress soil erosion. Deekor et al. (2012) and Kauffmann et al. (1998) found similar results of increase in silt content in plantation soils is due to development of dense cover.

Significant differences in available water content were observed between different cropping system and pedons (Table 3). Soils of paddy-paddy cropping systems retained significantly higher water both at field capacity (25.71%) and permanent wilting point (16.77%).

Table 4. Soil properties influenced by cropping systems and pedons.

Results	OC (%)	pH_w	EC (dSm^{-1})	CEC	Ca^{2+}	Mg^{2+}	Na^+	K^+
				(c mol (p+) kg^{-1})				
Cropping systems								
Plantation	0.42a	6.69b	0.18a	14.02b	10.60a	1.62a	0.46b	0.20a
Paddy-potato	0.33b	6.32b	0.19a	11.89b	5.85b	1.29b	0.31c	0.10b
Paddy-paddy	0.36a	7.14a	0.18a	17.85a	9.40a	1.50a	0.85a	0.26a
LSD (P<0.05)	0.09	0.43	0.04	1.23	1.24	0.19	0.15	0.08
Pedons								
Epipedon	0.84a	6.26b	0.21a	13.19a	7.11b	1.28b	0.43b	0.20a
Endopedon1	0.29b	6.58ab	0.15b	13.74a	7.63a	1.44a	0.50a	0.16a
Endopedon2	0.20c	6.85a	0.16ab	14.23a	8.53a	1.46a	0.65a	0.19a
Endopedon3	0.19c	7.03a	0.16ab	13.79a	7.66a	1.37a	0.51a	0.18a
LSD (P<0.05)	0.11	0.49	0.05	1.42	1.11	0.15	0.16	0.06

*means followed by same letter within the column are not significantly different at P<0.05

Significantly lower water retention was observed in both field capacity and permanent wilting point by soils of paddy-potato cropping systems. Plantation system has recorded highest available water content (12.11%), which is significantly higher than paddy-paddy cropping systems (8.90%). Higher AWC in Plantation system can be ascribed to favorable structural properties (Emadi et al., 2008) and high organic matter (Bauer and Black, 1992). In Plantation system, the high organic matter from decomposed leaf fall creating high AWC whereas high clay with unfavorable structure leads to low AWC in paddy-paddy cropping system. These results confirmed that land use systems have a greater effect on water retention in soils (Haghighi et al., 2010; Wall and Heiskanen, 2003; Li et al., 2007). Epipedon recorded significantly higher available water content than endopedons 1 and 2 which is due to high organic matter and favourable structure.

Soil chemical properties

A perusal of data in Table 4 showed that pH of soils of paddy-paddy cropping system is neutral in nature (7.14) whereas soils of paddy-potato cropping system are slightly acidic (6.32). The low pH in paddy-potato cropping system was due to removal of basic cations by cation loving crops during biomass harvesting (Marcar and Khanna, 1997) and accelerated leaching of bases from the soils by rainfall. The soil reaction of epipedon is slightly acidic compared to endopedon which is due to continuous cation uptake by plant, with subsequent release of H^+ ions, organic matter decomposition into organic acids, increased CO_2 levels through root respiration and nitrification (Juo and Manu, 1996). Epipedon recorded significantly lower pH compared to endopedon 2 and 3 and on par with endopedon 1. The general increase in pH down the profile was due to increase in basic cations. There is no significant difference in electrical conductivity observed with respect to cropping system whereas significantly higher electrical conductivity recorded in epipedon compared to endopedon 1.

The cropping systems and pedons significantly differed in organic carbon content. The highest organic carbon mean values recorded in Plantation system (0.42%) which is statistically on par with paddy-paddy cropping system (0.36%) whereas paddy-potato cropping system recorded significantly low organic carbon content (0.33%). Organic carbon decreases with increasing pedal depth. Significantly highest organic carbon recorded in epipedon compared to endopedon. The higher organic carbon detected in plantation system was probably as a result of accumulation of litter from continuous residue addition or absence of soil disturbance for an extended period (Manjoke et al., 2007) and increased carbon input through addition of root biomass by wetland paddy cultivation in paddy-paddy cropping system. Contrary to this, intensive tillage operations, crop residue burning and relatively lower amount of organic matter additions kept low organic carbon in paddy-potato cropping system (Senthilkumar et al., 2009).

The cation exchange capacity (CEC) of soil in plantation system, paddy-potato and paddy-paddy cropping system was 14.02, 11.89 and 17.85 c mol (p+) kg^{-1} respectively. The results of analysis of variance showed that significantly higher CEC was recorded in soils of paddy-paddy cropping system and paddy-potato cropping system recorded lower CEC which is statistically on par with plantation system. The higher CEC in paddy-paddy cropping system is due to presence of high clay content and lower CEC in paddy-potato cropping system

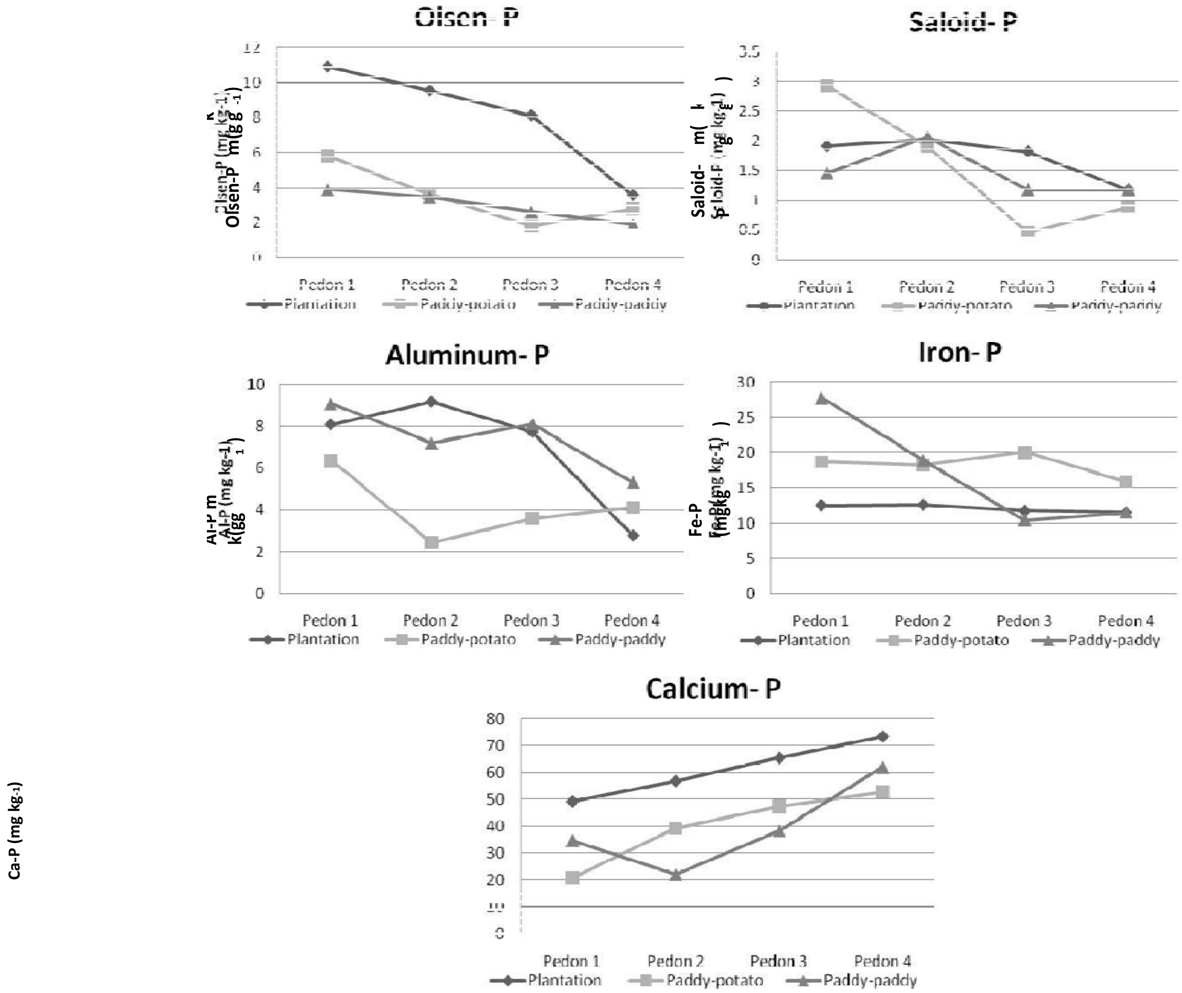

Figure 3. Influence of cropping systems on different Phosphorus fractions.

was due to the intensive cultivation and lower soil organic carbon content. Geissen et al. (2009) also found that intensive annual crop cultivation leads to very low CEC. The difference in CEC between pedons is limited. Results of exchangeable cations showed that exchangeable calcium dominated the exchange site among the basic cations in all the cropping systems. Paddy-potato cropping system recorded significantly lower exchangeable cations compared to other system. Epipedon recorded significantly lower exchangeable calcium, magnesium and sodium than endopedons. Deekor et al. (2012) opined that both clay and organic matter serve as potential sources of nutrients by attracting cations as such, soils with large amounts of clay or organic matter have higher exchange capacities than sandy soils.

Phosphorous fractions

Maintenance of adequate amounts of soil phosphorous (P) is critical for long term agricultural productivity. The amount and distribution of various forms of inorganic phosphorous in different cropping systems are presented in Figure 3. The relative abundance of inorganic P forms in the soil was generally Ca-P>Fe-P>Al-P>Saloid-P. Higher amount of Olsen-P (extracted by $NaHCO_3$) was recorded in plantation system (10.91 mg kg^{-1}) followed by paddy and paddy-potato cropping system. Soils of plantation recorded high Calcium-P (extracted by 0.5 N H_2SO_4) whereas paddy-paddy cropping system recorded higher Al-P (extracted by 0.5 N NH_4F) and Fe-P (extracted by 0.1 N NaOH) which is due to continued submergence. Patrick and Mahapatra (1968) found that poorly drained soils have larger quantities of Al-P and Fe-P compared well drained and moderately well drained soils. Srivastava and Pathak (1971) found that water-logged area had comparatively lower amounts of adsorbed phosphate and calcium phosphate and contained proportionately higher values of iron and aluminium phosphate. Epipedons recorded high Olsen P compared to endopedon irrespective of cropping

Table 5. Results of the two-way analysis of variance in important soil properties under the two cropping systems and four pedons.

Factors	df	Sand	silt	clay	OC	pH	EC	CEC	FC	PWP	AWC
Cropping systems	2	0.00	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00
Pedons	3	0.15	0.45	0.49	0.00	0.02	0.14	0.93	0.04	0.11	0.07
Cropping systems × Pedons	6	0.78	0.64	0.58	0.71	0.98	0.66	0.82	0.19	0.52	0.12

systems. Generally, Olsen-P decreased with depth whereas calcium-P increased with depth. Higher P fractions were found from the Plantation system than the cultivated fields which may be ascribed to the active biocycling of phosphorous due to the presence of perennial plant and better crop management (Solomon et al., 2002). Daroub et al. (2001) found that the effect of perennial cropping system on soil P fraction was more apparent than annual cropping system.

The results of two way analysis of variance (Table. 5) showed that cropping system is a significant factor in determining most of the important soil properties significantly ($p < 0.05$) except electrical conductivity. Organic carbon, pH and water retention at field capacity which differed by both cropping system and pedons. The interaction between these two factors had not significantly affected any of the soil properties.

Conclusions

It is concluded that there exists a strong relationship between soil properties and cropping systems. The degradation of these soil properties can negatively affect soil productivity. Identifying, quantifying and monitoring these changes are necessary to prevent soil degradation and to improve soil and land management. To prevent further degradation, it is expedient to generate appropriate environmentally friendly soil management techniques suitable for each cropping system like proper drainage system, soil test based fertilizer application in paddy-paddy cropping system, addition of organic matter, lime and crop rotation with pulses in paddy-potato cropping system, in order to enhance soil fertility and sustain food production.

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Al-Kaisi Mahdi M, Xinhua Yin, Mark A. Licht. (2005) Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils. Agric. Ecosyst. Environ. 105:635–647. http://dx.doi.org/10.1016/j.agee.2004.08.002

Bauer A, Black AL (1992). Organic matter effects on available water capacity of three soil textural groups. Soil Sci. Soc. Am. J. 56:248-254. http://dx.doi.org/10.2136/sssaj1992.03615995005600010038x

Biswas B, Ghosh DC, Dasgupta M, Trivedi N, Timsina J, Dobermann A (2006). Integrated assessment of cropping systems in the Eastern Indo-Gangetic plain. Field Crop. Res. 99:35–47. http://dx.doi.org/10.1016/j.fcr.2006.03.002

Daroub SH, Ellis BG, Robertson GP (2001). Effect of cropping and low chemical input systems on soil phosphorous fractions. Soil Sci. 166:281-291. http://dx.doi.org/10.1097/00010694-200104000-00007

Day PR (1965). Particle fractionation and particle size analysis. In: Methods of Soil Analysis. Part 1, Black, C.A, (Ed.). American Society of Agronomy Inc. Madison, WI, pp.545–567. http://dx.doi.org/10.1007/s11104-009-0044-8

Deekor TN, Iwara AI, Ogundele FO, Amiolemen SO, Ita AE (2012). Changes in Soil Properties under Different Land Use Covers in Parts of Odukpani, Cross River State, Nigeria. J. Environ. Ecol. 3:86-99.

Dossa EL, Diedhiou S, Compton JE, Assigbetse KB, Dick RP (2010). Spatial patterns of P fractions and chemical properties in soils of two native shrub communities in Senegal. Plant Soil 327:185-198. http://dx.doi.org/10.1007/s11104-009-0044-8

Emadi M, Emadi M, Baghernejad M, Fathi H, Saffari M (2008). Effect of land use change on selected soil physical and chemical properties in North Highlands of Iran. J. Appl. Sci. 8:496–502. http://dx.doi.org/10.3923/jas.2008.496.502

Gathala MK,Virender Kumar, Sharma PC, Saharawat Yashpal S, Jat HS, Mainpal Singh, Amit Kumar, Jat ML, Humphreys E, Sharma DK, Sheetal Sharma Ladha JK (2010). Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the northwestern Indo-Gangetic Plains of India. Soc. Am. J. 74:602-611.

Geissen V, Sanchez -Hernandez R, Kampichler C, Ramos- Reyes R, Sepulveda -Lozada A (2009). Effects of land-use change on some properties of tropical soils-An example from Southeast Mexico. Geoderma 151:87-97. http://dx.doi.org/10.1016/j.geoderma.2009.03.011

Haghighi F, Gorjiz YM, Shorafa M (2010). A study of the effects of land use changes on soil physical properties and organic matter. Land Degrad. Develop. 21:496–502.

Hubbard RK, Strickland TC, Phatak Sharad (2013). Effects of cover crop systems on soil physical properties and Carbon/nitrogen relationships in the coastal plain of southeastern USA. Agric. Ecosyst. Environ. 177:85–97.

Juo ASR, Manu A (1996). Nutrient effects on modification of shifting cultivation in West Africa. Agric. Ecosys. Environ. 58:49-60. http://dx.doi.org/10.1016/0167-8809(95)00656-7

Jung Ki-Yuol, Newell R. Kitchen, Kenneth A. Sudduth Kyou-Seung Lee Sun-Ok Chung (2010). Soil compaction varies by crop management system over a claypan soil landscape. Soil Till. Res. 107:1-10. http://dx.doi.org/10.1016/j.still.2009.12.007

Kauffmann S, Sombrooek W, Mantel S (1998). Soils of rain forests: Characterization and major constraints of dominant forest soils in the humid tropics. *In:* Schulte A. and Ruhiyat D. Soils of Tropical Forest Ecosystems (eds): Characteristics, Ecology and Management, Springer-Verlag, Berlin, pp. 9-20.

Klute A (1986). Water retention laboratory methods. In: Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods, (2nd ed.), A. Klute, (Ed.). American Society of Agronomy, Soil Science Society of America: Madison, WI, pp. 635–662. http://dx.doi.org/10.2136/sssabookser5.1.2ed.c26

Ladha JK, Dawe D, Pathak H, Padre AT, Yadav RL, Singh B, Singh Y, Singh Y, Singh P, Kundu AL, Sakal R, Ram N, Regmi AP, Gami SK, Bhandari AL, Amin R, Yadav CR, Bhattarai EM, Das S, Aggarwal HP, Gupta RK, Hobbs PR (2003). How extensive are yield declines in long-term rice-wheat experiments in Asia? Field Crop. Res. 81:159-180. http://dx.doi.org/10.1016/S0378-4290(02)00219-8

Li XG, Li FM, Zed R, Zhan ZY, Singh B (2007). Soil physical properties and their relations to organic carbon pools as affected by land use in an alpine pastureland. Geoderma 139:98–105. http://dx.doi.org/10.1016/j.geoderma.2007.01.006

NBSS&LUP (1992) . Soils of West Bengal for optimizing land use. NBSS publ. 27b, 48p + 4 sheets of maps.

Manjoke J, Yerokun OA, Lungu OI, Munyinda K (2007). Changes in soil organic matter and soil aggregation of a Zambian oxisol after applying lime. Int. J. Soil Sci. 2:190-196. http://dx.doi.org/10.3923/ijss.2007.190.196

Manoj Kumar, Jatav MK, Trehan SP, Lal SS (2009). Integrated nutrient management in paddy-potato cropping systems for eastern Indo-Gangatic plains of India. Potato J. 36:136-142.

Marcar NE, Khanna PK (1997). Reforestation of salt affected and acid soils. Management of Soil, Nutrients and Water in Tropical Plantation Forests, (ed.Nambiar, E.K.S. and Brown, A.G.). AC1AR Monograph, ACIAR, Canberra, Australia 43:481-525.

Mazarura U, Chisango C (2012). Effects of Long Term Cropping Systems on Soil Chemical Properties. Asian J. Agric. Rural Develop. 2:632-640.

Page AL, Miller RH, Keeney DR (1982). Method of Soil Analysis. Part 2. Chemical and Microbiological Properties, 2nd ed., Agronomy Monographs, ASA and SSA: Madison, WI.

Patrick WHJR, Mahapatra IC (1968). Transformation and availability to rice of nitrogen and phosphorus in waterlogged soils. Advan. Agron. 20:323–359. http://dx.doi.org/10.1016/S0065-2113(08)60860-3

Petersen GW, Corey RB (1966). A modified Chang and Jackson procedure for routine fractionation of inorganic soil phosphates, Soil Sci. Soc. Am. Proc. 30:563-565. http://dx.doi.org/10.2136/sssaj1966.03615995003000050012x

Rachman Achmad, Anderson SH, Gantzer CJ, Thompson AL (2003). Influence of Long -term Cropping Systems on Soil Physical Properties Related to Soil Erodibility. Soil Sci. Soc. Am. J. 67:637-644. http://dx.doi.org/10.2136/sssaj2003.6370

Saikh H, Varadachari C. Ghosh K (1998). Changes in carbon, N and P levels due to deforestation and cultivation on soil CEC and exchangeable bases. A case study in Simplipal National Park, India. Plant. Soil 204:67-75. http://dx.doi.org/10.1023/A:1004323426199

Saha MN, Saha AR, Mandal BC, Ray PK (2000). Effects of long-term jute-rice-wheat cropping system on crop yields and soil fertility In: Abrol IP, Bronson, KF, Duxbury JM. Gupta RK (Eds.) Long-term soil fertility experiments with rice-wheat rotations in South Asia. Rice-Wheat Consortium Paper Series 6. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India, pp. 94-104.

Senthilkumar S, Basso B, Kravachenko AN, Roberton GP (2009). Contemporary evidence of soil carbon loss in the U.S. corn belt. Soil. Sci. Soc. Am. J. 73:2078-2085. http://dx.doi.org/10.2136/sssaj2009.0044

Soil Survey Staff (2003). Soil survey manual, USDA, Scientific Publishers, Jodhpur.

Solomon D, Lehmann J, Mamo T, Fritzsche F, Zech W (2002). Phosphorus forms and dynamics as influenced by land use changes in the sub-humid Ethiopian highlands. Geoderma 105:21-48. http://dx.doi.org/10.1016/S0016-7061(01)00090-8

Srivastava OP, Pathak AN (1971). Available phosphorus in relation to forms of phosphate fractions in Uttar Pradesh soils. Geoderma 5:287-296. http://dx.doi.org/10.1016/0016-7061(71)90040-1

Varvel GE, Wilhelm WW (2010). Long-Term Soil Organic Carbon as Affected by Tillage and Cropping Systems. Soil Sci. Soc. Am. J. 327:185-198.

Walkey A, Black IA (1934) . An estimation of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38. http://dx.doi.org/10.1097/00010694-193401000-00003

Wall A, Heiskanen J (2003). Water-retention characteristics and related physical properties of soil on afforested agricultural land in Finland. Forest Ecol. Manage. 186:21–32. http://dx.doi.org/10.1016/S0378-1127(03)00239-1

Yadav RL, Subba Rao AVM (2001). Atlas of cropping systems in India. Project Directorate for Cropping Systems Research, Modipuram, Meerut, India, P. 96.