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Soil microbial and biochemical properties as affected by floods in different landuse systems of Burachapori Wildlife Sanctuary, northeast India

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Abstract: Changes in soil physico-chemical and biological properties as affected by floods were studied in different landuse systems present in and around the Burachapori wildlife sanctuary. Among soil physical properties, bulk density and water holding capacity of the soil samples decreased remarkably after the flood, while soil moisture increased in all the samples. Soil was acidic in grassland as compared to other landuse systems studied. However, the pH values showed an increasing trend in all the landuse systems following floods. Soil nutrients were affected significantly ($P < 0.05$) due to floods. Microbial biomass C, N and P values (μg g^{-1}) were greatest in forest soils (C = 920.43; N = 93.62; P = 45.64), followed by homegarden (C = 482.22; N = 91.16; P = 42.16) during both pre- and post-flood conditions. Among soil nutrients nitrogen loss was intense at surface soil (0 to 10 cm) in forest (ca. 121 %), followed by agriculture (ca. 90 %) and home garden (ca. 63 %) systems. Similarly, over all nutrient loss was greatest in forest, agriculture and home garden when compared to grassland and plantations. Soil dehydrogenase activity was greater after the flood at both 0 - 10 cm and 10 - 20 cm soil depths. In the top 0 - 10 cm soil, loss of microbial biomass C after flood was over 100 % in home garden (ca. 106 %), and below 70 % in the other landuse systems studied. Nonetheless, the loss of microbial biomass was severe at sub-surface (10 - 20 cm) soil in all the landuse systems. The contribution of microbial biomass N to soil total N pool increased in the surface soil as compared to the sub-surface soil during post-flood conditions. Amongst microbial-C and nutrients, the loss of microbial N was low (≤ 50 %) in all the landuse systems when compared to microbial C and P.

Resumen: Se estudiaron los cambios en las propiedades físico-químicas y biológicas del suelo producidos por las inundaciones en diferentes sistemas de uso del suelo en el interior y alrededor del Santuario de Vida Silvestre Burachapori. Entre las propiedades físicas del suelo, la densidad aparente y la capacidad de retención de agua de las muestras de suelo disminuyeron notablemente después de la inundación, mientras que la humedad del suelo se incrementó en todas las muestras. El suelo fue ácido en los pastizales en comparación con los otros sistemas de uso del suelo estudiados. Sin embargo, los valores de pH tendieron a aumentar en todos los sistemas de uso de la tierra tras las inundaciones. Los nutrientes del suelo se vieron afectados significativamente ($P < 0.05$) debido a las inundaciones. Los valores más altos de C, N y P en la biomasa microbiana (μg g^{-1}) se registraron en los suelos forestales (C = 920.43; N = 93.62, P = 45.64), seguido por los huertos caseros (C = 482.22; N = 91.16, P = 42.16), tanto antes como después de las inundaciones. Entre los nutrientes del suelo, la pérdida

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de nitrógeno fue intensa en el suelo superficial (0 a 10 cm) en el bosque (ca. 121 %), seguido de lossistemas agrícolas (ca. 90 %) y de huerto casero (ca. 63 %). Asimismo, la pérdida general de nutrientes fue mayor en los bosques, la agricultura y los huertos caseros, en comparación con los pastizales y las plantaciones. La actividad de la deshidrogenasa del suelo fue mayor después de la inundación tanto en la profundidad del suelo de 0 - 10 cm como en la de 10 - 20 cm. En el suelo de 0 - 10 cm, la pérdida de C de la biomasa microbiana después de la inundación fue más de100 % en el huerto casero (ca. 106 %), e inferior a 70 % en los otros sistemas de uso del suelo estudiados. No obstante, la pérdida de biomasa microbiana fue severa en el suelo subsuperficial (10 - 20 cm) en todos los sistemas de uso del suelo. La contribución del Ndela biomasa microbiana al almacén total de N del suelo aumentó en el suelo superficial en comparación con el suelo subsuperficial en condiciones post-inundación. Entre el C y los nutrientes microbianos, la pérdida de N microbiano fue baja (≤ 50%) en todos los sistemas de uso del suelo en comparación con el C y el P microbiano.

Resumo: Mudanças nas propriedades biológicas e físico-químicasdo solo afetado por inundações foram estudados sob diferentes sistemas de uso do solo presentes em e ao redor do Santuário de Vida Selvagem de Burachapori. Entre as propriedades físicas do solo, a densidade aparente e a capacidade de retenção de água das amostras de solo diminuiram significativa mente depois dainundação, enquanto que a humidade do solo aumentou em todas as amostras. O solo era acídico na pastagem, em comparação com os outros sistemas de uso estudados. No entanto, os valores do pH mostraram uma tendência crescente em todos os sistemas de uso do solo na sequência das inundações. Devido às inundações, os nutrientes do solo foram afetados de forma significativa ($P < 0,05$). Os valores C, N e P ($\mu g\ g^{-1}$) da biomassa microbiana foram maiores em solos florestais (C = 920,43; N = 93,62, P = 45,64), seguido pelos quintais de casa (C = 482,22; N = 91.16, P = 42.16), quer durante as condições de pré como de pós-cheias. Entre os nutrientes do solo, a perda de azoto foi intensa na camada superficial (0 a 10 cm) em solos de floresta (ca. 121 %), seguida pelo solo agrícola (ca. 90 %) e quintal de casa (ca. 63 %). De uma forma similar,a perda global de nutrientes foi maior na floresta, agricultura e quintais de casa quando comparada com as pastagens e plantações. A atividade da desidrogenase no solo foi maior após a inundaçãoquer nas camadas de 0 - 10 cm e na de 10 - 20 cm de profundidade do solo. Na camada 0 - 10 cm de solo, a perda de C da biomassa microbiana após a inundação foi superior a 100 % no quintal de casa (cerca de 106 %), e abaixo de 70 % nos outros sistemas de uso do solo estudados. No entanto, a perda de biomassa microbiana foi severana camada sub-superfícial (10 - 20 cm) em todos os sistemas de uso do solo. A contribuição do N da biomassa microbiana no conjunto do N total no solo aumentou na sua superfície, em comparação com o solo sub-superfícial nas condições de pós-inundação. Entre o C e os nutrientes microbianos, a perda de N microbiano foi baixa (≤ 50 %) em todos os sistemas de uso do solo em relação aoverificado para o C e P microbianos.

Key words: Flood, landuse, enzyme activity, microbial biomass, soil.

Introduction

Climatic factors have become more significant in recent times due to extreme climatic events induced by intensive anthropogenic activities affecting our ecosystem in multiple ways. One of the extreme climate events being seasonal flooding of rivers due to heavy rainfall. Such flooding could cause mechanical injury to vegetation (Nilsson & Svedmark 2002; Streng *et al*. 1989) or may result in sediment deposition. In the process, soil chemistry is also altered when O_2 is depleted due to submergence and the pH of the soils shifting towards neutrality (Henderson & Patrick 1982). Nonetheless, the flood events belong to natural disturbances, which typically remove some or all organisms from an area and initiate a sequence of successive processes resulting in gradual recovery of initial ecosystem properties (Lake 2000; Ogbodo 2011). India is the worst flood-affected country in

the world after Bangladesh and accounts for one fifth of the global death count due to floods (Bhanumurthy *et al*. 2010). The most flood-prone areas in India are the Brahmaputra and Ganga River basins in Indo-Gangetic-Brahmaputra plains in north and northeast India, which carry 60 % of the nation's total river flow. The present study was carried out in one of the most vulnerable ecological setting in the Brahmaputra river basin where about 70 % of the total rainfall is mainly during monsoon season that lasts for four months (June - September). Due to heavy rainfall, river undergoes heavy discharge vis-à-vis flood causing erosion of the banks in the upper reaches and over-toping in the lower segments (Biswas *et al*. 2000; Rawat *et al*. 2013). In such cases, the major reason for the floods is the indiscriminate deforestation that leads to loosening of topsoil with rains (Bhanumurthy *et al*. 2010). This is quite evident in the northeast Himalayan mountain regions, especially in Arunachal Pradesh in the higher altitudes, causing regular floods in the down-stream state, Assam.

The flooding of yards, gardens, grassland, and other agricultural lands can expectedly have significant short and long-term effects on the soil. For instance, flooding a soil affects physical, chemical and biological processes in the soil nutrient cycling of terrestrial ecosystems (Ponnamperuma 1972). The water potential 'upshock' have been studied earlier (Kieft *et al*. 1987; Schimel *et al*.1999) on microbial community. In the present study we presumed that upshock during flood may induce multiple stress (viz., saturation, anoxia, erosion etc.) on microbial biomass and thus nutrient immobilization. While microbial biomass in soil have been established to act as 'sink' and 'source' of plant nutrients in the humid tropics, their post-flood dynamics vis-à-vis soil enzymatic activities are poorly understood. In addition, evaluating soil physico-chemical and biological properties is important to find ways to restore the soil quality and health in flooded/ or post-flood conditions. Hence, it is hypothesized that seasonal flood may reduce the nutrient immobilization in microbial biomass. Thus, the present study aims to evaluate the changes and relationships amongst soil physico-chemical, microbiological and biochemical properties as influenced by floods in different landuse systems existing in and around the Burachapori Wildlife Sanctuary (BCWLS) located in south bank of Brahmaputra River, Assam (northeast India).

Materials and methods

The study site

This study was conducted in Burachapori Wildlife Sanctuary (latitude 26° 30' 32" N to 26° 33' 40" N and longitude 92° 35' 54" E to 92° 46' 07" E) located on the south bank of the mighty river Brahmaputra in Naogaon district of Assam in North-eastern India (Fig. 1). It was declared as a reserved forest (RF) in 1974, became a wildlife sanctuary in 1995 covering an area of 44.06 km^2 with forest type being alluvial flood plains in nature. Soil was sandy loam and homogenous. Major part of the sanctuary is covered by grassland with patches of wetlands, locally known as '*beels*'. There are 14 villages with a total of 1750 households and 12038 humans dominated by immigrants belonging to Nepali, Bihari and Bengali community, and 13594 cattle population in and around the Burachapori Wildlife Sanctuary. Wild animals include tiger, elephant, wild buffalos, one horned rhinoceros, hog deer, wild boar besides birds like Bengal Florian, Black necked stork, Open billed stork, White eyed pochard, Millard, Spotbill, Large whistling teal etc.. Dominant tree species being *Lagerastroemia* sp., *Bombax* sp., *Albizzia* spp., *Dalbergia sissoo*, *Zizyphus* spp. etc., and the predominant grass are *Imperata* spp. *Cymbopogan* spp., *Alpinia* spp. etc. Besides these, witnessed aquatic macrophytes and wetland associated plant species in the sanctuary are *Azolla pinnata, Eichhornia crassipes, Lemna minor, Pistia stratiotes, Salvinia* spp., *Euryale ferox, Nelumbo nucifera, Nymphaea nouchali, Nymphoides cristatum, Nymphoides indicum, Trapa* spp., *Hydrilla verticillata, Nechamandra alternifolia, Vallisneria spiralis, Alternantha sessiles, Cyperus platystylis, Cynodon dactylon, Echinochloa stagnina, Eleocharis acutangula, Enhydra fluctuans, Hygrorhiza aristata, Ipomoea aquatica, Jussiaea repens, Polygonum flaccidum, Scirpus eriophorum, Vetiveria zizanoides, Sagittaria trifolia* etc.

The sanctuary is deeply flooded during monsoon (May to September) while it remains dry in winter (mid-November to February). During the study period, the annual mean maximum and minimum temperature varied between 33 °C and 16.7 °C respectively, annual total precipitation was 2000 mm with more than 80 % rainfall occurring during the monsoon season (May-September). Occasional rains also occurred during winter.

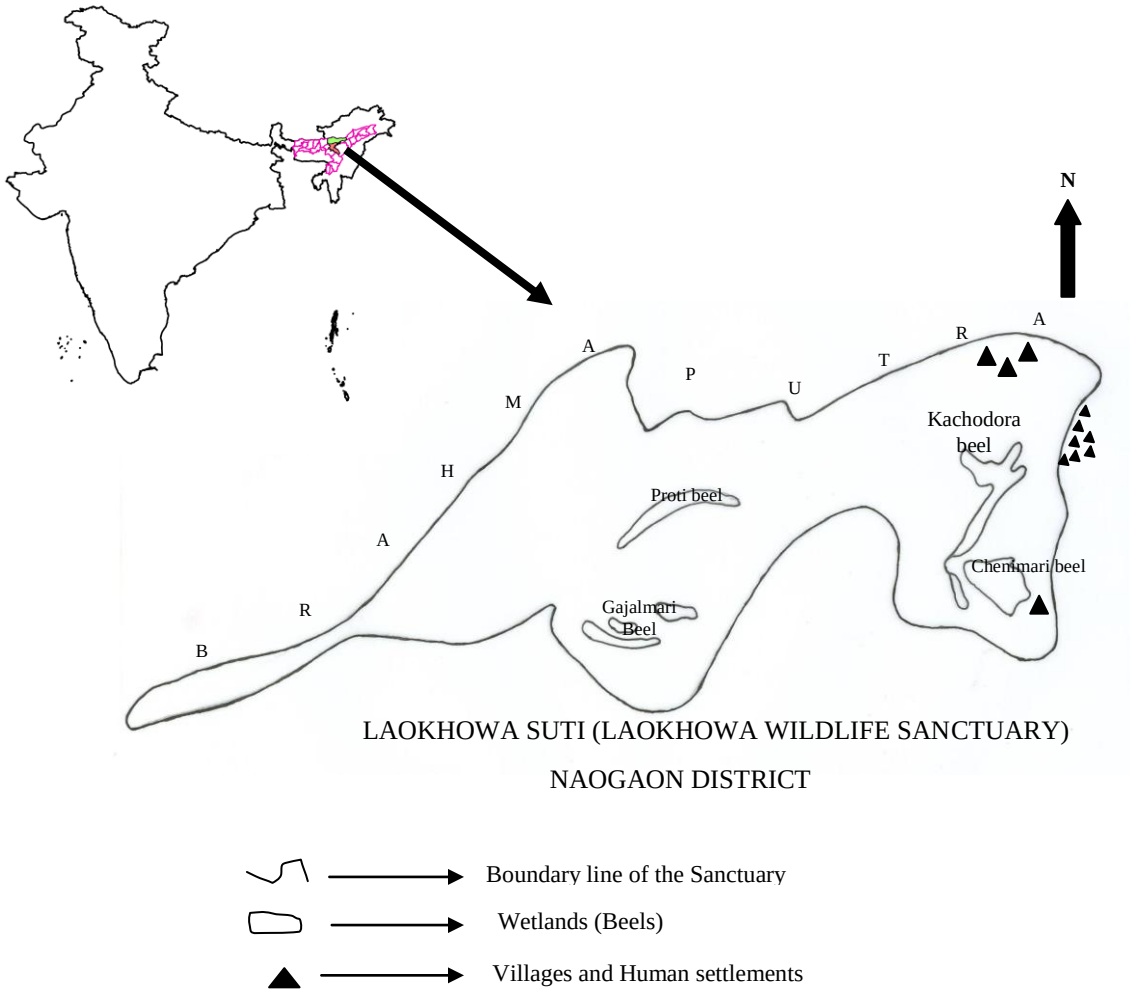

Fig. 1. Map of Burachapori Wildlife Sanctuary.

Table 1. Study site characteristics.

Landuse	Number of sites/plots	Dominant species	Size	Type & Management practices
Agriculture	5	Sesamum, Rice (occasional), *Corcorus capsularis*, *Capsicum frutescens*, *Brassica campestris, Brassica oleracea, Cucurbita moschate, Cucumis sativa, Phaseolus vulgaris, Raphanus sativus*	2-5 ha	Rainfed, irrigated during drier season & inorganic fertilized
Forest	3	*Barringtonia acutangula*, *Bombax ceiba*, *Dalbergia sissoo*, *Lagerastroemia* sp., *Albizia procera, Duabanga sonneretoides, Melia azadirachta*	3-7 ha	Riparian forest, Low alluvial savannah woodlands & Relatively undisturbed in 3rd forest stands where fire wood and other NTFPs collections allowed
Grassland	3	*Phragmites karka*, *Imperata* spp. *Saccharum* spp. *Arundo donax*, *Cyperus platystylis*	15-12 ha	Undisturbed except prescribed burning at 3rd site
Mixed Plantation	5	*Albizzia* spp., *Dalbergia sissoo, Bombax ceiba*	5-10 ha	Planted & frequent selective felling
Homegarden	10	Areca nut, Litchi, *Ananas comosus*, *Citrus reticulata*, *Capsicum frutescens*, *Sechium edule, Solanum melongena, Musa paradisiaca, Curcuma domestica*	5-15 m^2	Traditional and regularly weed and mulched with the same in the rhizosphere

Soil analysis

The study was conducted in the south bank of river Brahmaputra that had abundant grassland interspersed with a few '*beels*', mixed plantations and natural forest stands. There were human settlements on the periphery of the sanctuary that had agricultural fields being practiced on the river bank and the households did maintain home-gardens. For this study, we took 5 plots (10 × 10 m size) in agricultural fields and mixed plantation, 3 plots (25 × 25 m size) in grassland and forest stand, and 10 homegardens in the traditional households of the settlers. In all plots, except in homegardens 5 replicates of soil sample were taken using soil corer (5.5 cm inner diameter) upto 20 cm (0 - 10 and 10 - 20). In the homegarden, only three soils cores could be sampled due to their smaller size (5 - 15 m^2). While pre-flood samples were collected during September - February (2009 & 2010), the post-flood samples were collected between October - November (2009, 2010 & 2011). Site characterictics are summarized in Table 1.

All the soil samples were brought to the laboratory in polythene bags and sieved through 2 mm mesh screen, composited site-wise as well as depth-wise and then divided into three parts. One-part of the soil sample was stored in sterilized condition in deep freezer until the analysis for microbial biomass carbon (C), nitrogen (N) and phosphorus (P), and for analyses of alkaline-phosphatase and determination of dehydrogenase activity. Second part of the soil sample was used in field moist condition for the determination of pH by digital pH meter, moisture content by gravi-metric method, available phosphorus (P) by molybdenum-blue method. And, the third-part was air-dried and sieved through 2 mm mesh and used to determine the texture and bulk density using Bouyoucos hydrometric method and gravimetric method respectively as described by Allen *et al.* (1974). Water holding capacity (WHC) was deter-mined using Keen's box method. The remaining air-dried soil was ground and sieved through a 0.5 mm fine mesh screen and used for the analysis of soil organic carbon (SOC) by rapid titration method, total Kjeldhal nitrogen (TKN) using semi-micro Kjeldhal equipment (Allen *et al.* 1974; Anderson & Ingram 1993). Microbial biomass C, P and N were determined in fresh soil by chloroform-fumigation extraction (CFE) method (Brookes *et al.* 1985; Vance *et al.* 1987). Dehydrogenase and alkaline-phosphatase activities were determined using 2, 3, 5-triphenyl tetrazolium chloride (TTC) reduction method (Casida 1977) and *p*-nitrophenyl phosphate reduction method (Tabatabai & Bremner 1969), respectively.

Statistical analysis

All the data were analysed statistically using Microsoft Excel, STATISTICA 6.0, and ORIGIN 7.0. Three-way factorial Analysis of Variance (ANOVA) was used to compare the variations in soil physico-chemical and biological properties across different landuse systems, pre- and post-flood conditions and soil depth. The Pearson's correlation coefficients explaining the relation-ships among different soil physico-chemical and microbiological properties both during pre- and post-flood conditions were determined following Zar (1974). The level of significance (P) in all the cases was held at 0.05.

Results

Soil physico-chemical properties

Soil was sandy loam in all the sites, and had about 40 - 43 % moisture during the pre-flood condition. A sharp increase in soil moisture was recorded after floods in all types of land use systems (Table 2). Bulk density was greater in subsoil (10 - 20 cm) than in the top soil (0 - 10 cm) and reduced significantly after flood in all the land use systems studied (Table 3). Water holding capacity (WHC) also declined after flood in all the soil both at top and sub soil, but registered significant ($P < 0.05$) positive correlation with SOC ($r = 0.593$ and $r = 0.548$ for pre- and post-flood respectively) and available P ($r = 0.702$ and $r = 0.735$), and a significant negative correlation with TKN ($r = -0.356$ and $r = -0.351$) during both pre- and post-flood conditions (Table 4).

SOC and available P were greater in forest soil, while TKN was high in grassland, particularly at 0 - 10 cm soil depth (Table 2). Soil pH, however, increased after flood towards neutrality. At both the soil layers, soil organic C reduced considerably after flood in all land use systems; greater decline was in mixed plantation (39 %), followed by forest ecosystem (36 %), homegarden (34 %), agriculture (33 %) and lowest in grassland (29 %). Soil organic C established a significant ($P < 0.05$) positive correlation with pH ($r = 0.683$ and $r = 0.644$) and available P ($r = 0.441$ and $r = 0.587$), while TKN showed a significant negative correlation with available P ($r = -0.608$ and $r = 0.368$) during both pre - and post - flood

Table 2. Physico-chemical and biological properties of soil in different landuse system in study site affected by flood (n=5).

Soil Depth/Properties	Landuse Type/Flood Case									
	Agriculture		Forest		Grassland		Mixed plantation		Home garden	
	Pre-flood	Post-flood	Pre-flood	Post-flood	Pre-flood	Post-flood	Pre-flood	Post-flood	Pre-flood	Post-flood
0-10 cm										
Physical										
Moisture content (%)	43.22±9.04	49.17±12.36	39.56±10.05	46.14±13.96	37.61±7.45	41.29±8.02	35.81±8.77	38.04±9.03	40.51±9.44	44.20±12.98
Bulk density (g cm^3)	1.27±0.04	1.15±0.009	1.10±0.02	0.89±0.009	0.95±0.03	0.90±0.01	1.15±0.005	1.07±0.01	1.21±0.09	1.13±0.16
Water Holding Capacity (%)	51.73±4.56	48.91±3.91	57.79±5.07	54.36±4.97	45.18±4.85	43.01±4.06	49.84±4.57	47.33±5.02	53.66±5.91	52.12±6.46
Chemical										
pH	5.48±0.18	5.75±0.24	5.82±0.31	6.14±0.19	5.23±0.25	6.14±0.39	5.51±0.31	6.07±0.44	5.91±0.53	6.45±0.72
Soil Organic C (%)	1.22±0.01	0.85±0.009	2.13±0.08	1.37±0.04	1.42±0.03	1.09±0.05	1.15±0.01	0.77±0.03	1.84±0.05	1.29±0.08
Soil Organic Matter (%)	2.10±0.09	1.47±0.05	3.68±0.14	2.35±0.02	2.45±0.06	1.88±0.09	1.99±0.04	1.32±0.07	3.18±0.17	2.22±0.15
Total N (%)	0.37±0.001	0.20±0.01	0.25±0.01	0.11±0.01	0.43±0.04	0.32±0.001	0.21±0.001	0.14±0.005	0.29±0.002	0.18±0.001
Available P (μg g^{-1})	4.55±0.23	3.12±0.15	6.03±0.42	4.98±0.19	4.01±0.11	3.54±0.08	5.83±0.11	3.59±0.20	4.96±0.18	3.70±0.39
Biochemical/Microbiological										
Phosphatase	3.98±0.23	1.87±0.07	4.53±0.22	2.21±0.09	4.16±0.12	2.04±0.05	3.65±0.19	1.54±0.09	4.07±0.15	2.46±0.22
Dehydrogenase	1.41±0.09	2.86±0.05	2.98±0.04	3.80±0.07	1.92±0.05	3.15±0.11	1.70±0.09	2.29±0.06	2.73±0.09	3.45±0.09
MBC to SOC	3.63±0.12	3.83±0.11	4.33±0.16	4.60±0.17	2.90±0.09	2.27±0.07	3.13±0.11	2.81±0.09	2.64±0.09	1.82±0.03
MBN to Total N	2.10±0.04	3.32±0.09	4.13±0.33	7.01±0.62	1.45±0.03	1.53±0.01	4.30±0.23	4.80±0.31	3.27±0.17	4.02±0.77
MBP to Soil Available P	0.08±0.001	0.07±0.002	0.08±0.001	0.07±0.001	0.08±0.003	0.05±0.001	0.04±0.001	0.04±0.001	0.09±0.003	0.09±0.005
10-20 cm										
Physical										
Moisture content (%)	42.51±9.11	47.14±9.47	38.11±5.98	41.20±7.02	35.83±5.11	40.18±5.34	32.03±4.90	36.21±4.67	36.64±4.54	41.25±4.91
Bulk density (g cm^3)	1.31±0.07	1.19±0.05	1.23±0.04	1.06±0.06	1.03±0.04	0.91±0.01	1.18±0.05	1.10±0.02	1.26±0.02	1.15±0.02
Water Holding Capacity (%)	50.31±3.98	47.02±5.06	52.93±5.11	50.48±5.23	43.55±5.09	39.70±4.84	47.91±4.81	44.72±4.90	51.79±4.86	48.35±3.24
Chemical										
pH	5.42±0.11	5.67±0.15	5.80±0.17	6.11±0.13	5.21±0.17	6.08±0.24	5.47±0.11	5.94±0.19	5.84±0.15	6.40±0.21
Soil Organic C (%)	0.95±0.01	0.61±0.01	1.91±0.07	1.23±0.09	1.36±0.09	0.88±0.04	1.03±0.06	0.61±0.01	1.66±0.07	1.05±0.02
Soil Organic Matter (%)	1.63±0.09	1.05±0.05	3.29±0.14	2.11±0.11	2.34±0.09	1.52±0.03	1.78±0.05	1.05±0.01	2.87±0.15	1.80±0.10
Total N (%)	0.23±0.009	0.15±0.009	0.18±0.004	0.08±0.001	0.36±0.009	0.20±0.004	0.16±0.001	0.11±0.001	0.25±0.003	0.17±0.009
Available P (μg g^{-1})	4.09±0.14	2.97±0.11	5.86±0.56	4.55±0.33	3.48±0.14	2.14±0.18	5.25±0.38	3.42±0.35	4.87±0.22	3.19±0.26
Biochemical/Microbiological										
Phosphatase	2.91±0.09	1.14±0.11	4.26±0.14	2.18±0.08	3.79±0.17	1.83±0.12	3.13±0.15	1.40±0.05	3.88±0.16	2.11±0.07
Dehydrogenase	1.02±0.06	1.79±0.09	2.77±0.11	3.65±0.15	1.11±0.09	2.54±0.04	1.19±0.09	2.01±0.09	1.30±0.08	2.93±0.13
MBC to SOC	4.22±0.17	3.55±0.11	3.32±0.12	2.40±0.15	2.11±0.11	1.34±0.05	2.08±0.09	1.61±0.07	1.49±0.05	1.01±0.05
MBN to Total N	2.99±0.21	3.51±0.24	4.58±0.17	6.98±0.37	1.20±0.09	1.58±0.09	4.58±0.25	3.23±0.20	2.54±0.18	1.76±0.11
MBP to Soil Available P	0.07±0.002	0.05±0.001	0.06±0.001	0.05±0.003	0.07±0.001	0.06±0.001	0.04±0.001	0.02±0.001	0.06±0.004	0.07±0.004

SOC – Soil Organic Carbon; P – Phosphorous; MBC – Microbial Biomass C; MBN – Microbial Biomass N; MBP – Microbial Biomass P

Phosphatase and dehydrogenase activities have been expressed in μg p-NPP g^{-1} dry soil h^{-1} and μg TPF g^{-1} dry soil $24h^{-1}$ respectively. Values are mean of 5 replicates; ± SE.

Table 3. Three-way factorial ANOVA for soil physico-chemical and microbiological properties.

Source of Variations	Factors/F-Values						
				Interactions			
	LT (df=4)	SD (df=1)	FC (df=1)	LT*SD (df=4)	LT*FC (df=4)	SD*FC (df=1)	LT*SD*FC (df=4)
Physical Properties							
Moisture content (%)	300.34*	167.59*	519.05*	5.30*	3.62*	0.45^{ns}	6.56*
Bulk density (g cm^3)	100.04*	36.56*	129.76*	5.39*	3.73*	0.22^{ns}	0.71^{ns}
Water holding capacity (%)	225.33*	118.16*	131.71*	3.30*	0.16^{ns}	2.24^{ns}	1.04^{ns}
Chemical Properties							
pH	90.52*	6.54*	531.08*	0.22^{ns}	25.97*	0.59^{ns}	0.17^{ns}
SOC (%)	240.50*	89.91*	642.47*	1.33^{ns}	12.72*	0.52^{ns}	1.08^{ns}
TKN (%)	37.65*	34.33*	109.90*	2.22^{ns}	1.69^{ns}	2.05^{ns}	1.48^{ns}
Available P (µg g^{-1})	686.46*	276.43*	2564.88*	23.01*	48.50*	9.82*	19.17*
Microbiological Properties							
Microbial C (µg g^{-1})	32822.42*	44208.51*	60340.83*	2506.54*	1848.42*	18.25*	350.08*
Microbial N (µg g^{-1})	358.01*	1792.36*	2182.90*	66.63*	49.77*	11.04*	2.35^{ns}
Microbial P (µg g^{-1})	177.40*	349.64*	597.83*	5.05*	3.87*	0.17^{ns}	1.31^{ns}
Enzyme Activities							
Phosphatase	262.25*	327.55*	8304.88*	37.54*	15.07*	18.88*	5.13*
Dehydrogenase	762.61*	837.86*	2502.72*	45.02*	30.07*	12.10*	37.05*
% Contribution of Microbial Biomass to Soil C, N, P							
MBC/SOC (%)	220.91*	250.94*	68.27*	27.83*	2.67*	12.97*	6.22*
MBN/TKN (%)	34.46*	1.53^{ns}	7.48*	2.31^{ns}	5.11*	3.14^{ns}	0.61^{ns}
MBP/Available P (%)	87.71*	95.80*	34.21*	5.90*	6.60*	0.69^{ns}	4.66*

LT - Landuse Type; SD - Soil Depth; FC - Flood Case.

SOC - Soil Organic Carbon; TKN - Total Kjeldhal Nitrogen; P - Phosphorous; MBC - Microbial Biomass C; MBN - Microbial Biomass N; MBP - Microbial Biomass P.

Phosphatase and Dehydrogenase expressed in µg p-NPP g^{-1} dry soil h^{-1} and µg TPF g^{-1} dry soil 24h^{-1} respectively.

*Values are significant ($P < 0.05$); ns - not significant; df - degree of freedom.

conditions (Table 4). Surprisingly, soil C/N ratio inclined significantly after flooding in all the landuse systems, except in mixed plantation and home garden soils where the C/N ratio declined, particularly at 10 - 20 cm soil depth. Although not significant ($P > 0.05$), C/P ratio generally decreased after floods (Table 2). In all, both C/N and C/P ratios showed significant variations between landuse types, apart from flooding effect. But the variations were not significant between soil depths. C/N ($r = 0.589$ and $r = 0.730$), and C/P ($r = 0.541$ and $r = 0.565$) ratios had significant positive correlation ($P < 0.05$) with SOC during pre-flood as well as post-flood conditions (Table 4). On the contrary, C/N ratio had negative correlation with TKN both during pre-flood (r = -0.716) and post-flood conditions (r = -0.664). Nonetheless, the C/P ratio registered a significant positive correlation ($P < 0.05$) with TKN.

Soil microbiological properties

Among different landuse types, microbial biomass C, N and P was higher in forest ecosystem, followed by home garden soil during both pre- and post flood conditions (Fig. 1). Over all, the microbial biomass (C, N and P) declined significantly ($F = 43.02$, $P < 0.05$) after flood in all the landuse systems. While comparing soil depths, top 0 - 10 cm layer accounted for greater microbial biomass C, N and P. The contribution of microbial biomass C, N and P to soil organic C, total N and available P respectively varied significantly bet-

Table 4. Pearson's correlation co-efficient matrix (r-values) for relationships among soil physical, chemical, and microbiological properties of different landuse system during both pre-flood and post-flood (n = 90).

FC	Variables	SMC	WHC	pH	SOC	TKN	AP	PT	DH	MBC	MBN
Pre-Flood	WHC	0.415*									
	pH	0.163^{ns}	0.796*								
	SOC	0.131^{ns}	0.593*	0.683*							
	TKN	0.243^{ns}	-0.356*	-0.428*	-0.021^{ns}						
	AP	-0.146^{ns}	0.702*	0.672*	0.441*	-0.608*					
	PT	0.169^{ns}	0.387*	0.402*	0.811*	0.284*	0.314*				
	DH	0.226^{ns}	0.527*	0.571*	0.911*	0.160^{ns}	0.380*	0.929*			
	MBC	0.427*	0.707*	0.458*	0.707*	-0.061^{ns}	0.526*	0.659*	0.726*		
	MBN	0.265*	0.719*	0.604*	0.345*	-0.318*	0.752*	0.280*	0.366*	0.569*	
	MBP	0.595*	0.659*	0.578*	0.798*	0.195^{ns}	0.280*	0.759*	0.858*	0.805*	0.504*
Post-Flood	WHC	0.451*									
	pH	-0.285*	0.220^{ns}								
	SOC	0.204^{ns}	0.548*	0.644*							
	TKN	0.057^{ns}	-0.351*	-0.009^{ns}	0.064^{ns}						
	AP	0.105^{ns}	0.735*	0.225^{ns}	0.587*	-0.368*					
	PT	0.160^{ns}	0.424*	0.638*	0.857*	0.131^{ns}	0.429*				
	DH	0.173^{ns}	0.690*	0.433*	0.832*	-0.169^{ns}	0.839*	0.723*			
	MBC	0.554*	0.663*	-0.036^{ns}	0.558*	-0.162^{ns}	0.738*	0.366*	0.698*		
	MBN	0.507*	0.745*	0.008^{ns}	0.463*	-0.135^{ns}	0.689*	0.343*	0.732*	0.797*	
	MBP	0.538*	0.722*	0.405*	0.765*	-0.013^{ns}	0.541*	0.749*	0.759*	0.665*	0.695*

FC - Flood Case; SMC - Soil Moisture Content; BD - Bulk Density; WHC - Water Holding Capacity; SOC - Soil Organic Carbon; TKN - Total Kjeldhal Nitrogen; AP - Available Phosphorus; PT - Phosphatase; DH - Dehydrogenase; MBC, MBN, MBP are microbial C, N, P respectively;

*****Values are significant at $P < 0.05$ level; ns - values are not significant at $P < 0.05$ level.

ween the landuse types, soil depths and also due to flooding effect (Table 3). The percentage contribution of microbial N to soil total N increased remarkably in the top soil (0 - 10 cm), particularly during the pre-flood condition (Table 2). Contrastingly, the contribution of microbial C to SOC increased only in the top soils of forest and agricultural system, while the contribution (%) of microbial P to soil available P remained lower in top-soil (0 - 10 cm) as well as sub-soil (10 - 20 cm) layers. Soil microbial biomass C and P showed a significant positive correlation with SOC and available P respectively during both pre- and post-flood conditions (Table 4). Whilst, microbial N was negatively correlated to TKN before the flood (r = -0.318, P = 0.05), the relationship was not significant (r = -0.135) after the flood. Nonetheless, microbial C, N and P showed a significant positive correlation with soil C/N ratio. In this study, the microbial C/N ratio ranged from 2.95 to 10.10 during pre-floods and from 2.76 to 8.58 during post-flood conditions irrespective of soil depth. Over all, microbial C/N, C/P and N/P ratios varied significantly between landuse types, soil depths and also due to flooding effect.

Activity of soil enzymes (dehydrogenase and acid-phosphatase) was significantly affected by flood case and landuse type (Table 3). In contrast to dehydrogenase activity, soil phosphatase activity was higher before flood and declined sharply in all the landuse types at both the soil depths during post-flood conditions (Table 2). Nonetheless, both dehydrogenase and phosphatase activities had a strong significant positive corre-

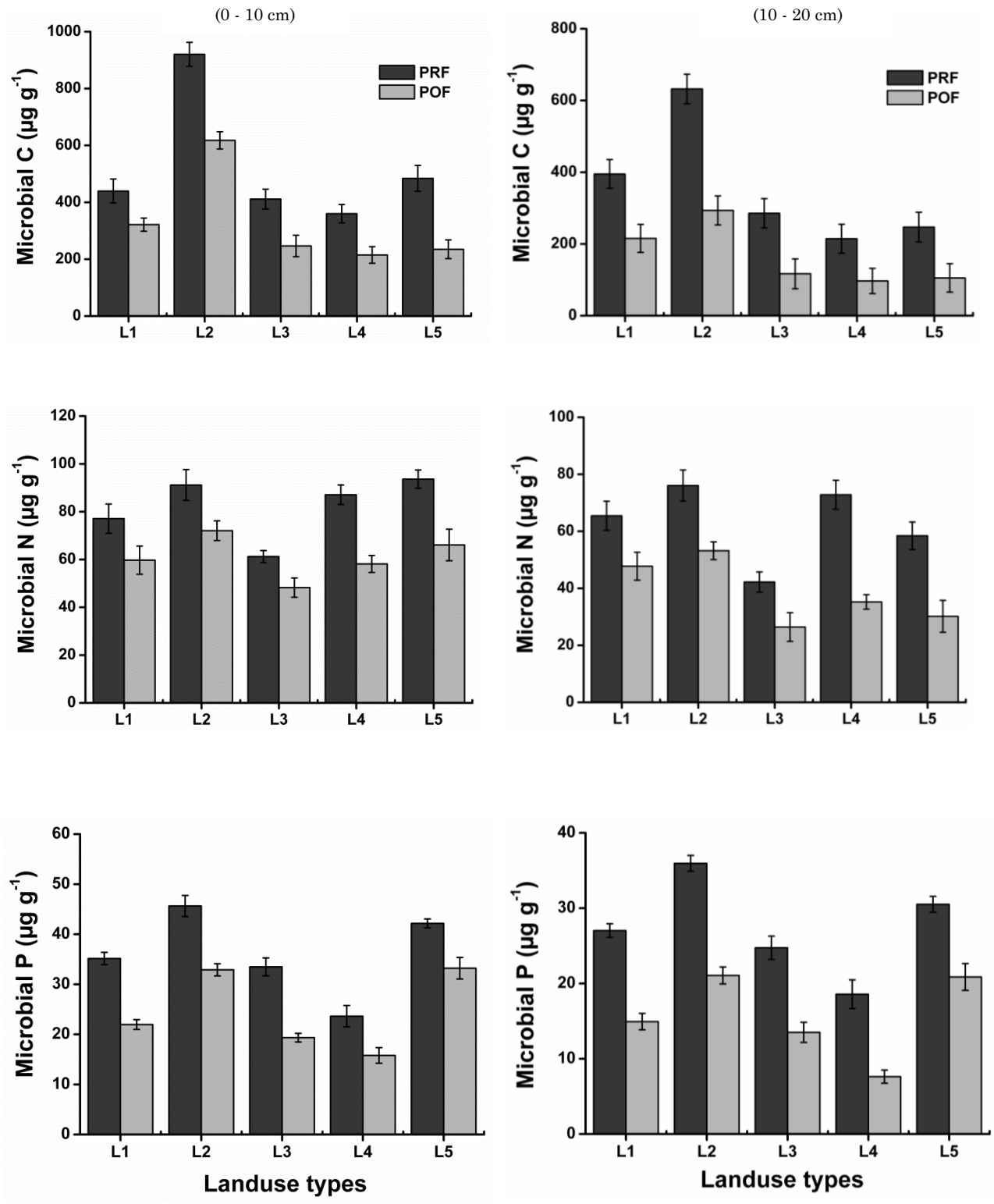

Fig. 2. Soil microbial biomass C, N and P in top (0-10 cm) and subsoil (10-20 cm) layers in different landuse systems during pre-flood (PRF) and post-flood (POF) conditions. (L1 – Agriculture; L2 – Forest; L3 – Grassland; L4 – Mixed plantation; L5 – Home Garden).

lation with microbial C, N, P and SOC and available P (Table 4).

Discussion

Due to the extreme events of rainfall, length of slope and nature of soils, the magnitude of the damage due to floods varied widely in the landuse types studied. The present study indicated both flooding effect and land use influencing the physico-chemical and biological properties of soils. The accumulation of sand and little amount of fine silt material that came along with the flood water impacted the agricultural fields by clearing the standing rice crops. Sedimentation may have also altered the surface soil properties depending upon the original source of materials brought by the flood from the upstream catchment area (Mau 2001). Subsequently this may require a biological approach of soil management after the flood for restoration, which includes weed control, soil amendments (manure/compost), microbial inoculation, growing cover crops and crop rotation. During the study, the flood lasted for upto two months leading to the sedimentation that accounted for the overall changes in surface soil properties. Apart from excessive rainfall, absence of adequate soil conservation measures in and around the BCWLS and irregular release of water from the several smaller and larger hydel-power dams in up-stream parts (Arunachal Pradesh) add to the severity of damage to the standing crops in the prevalent landuse systems.

The loss of topsoil due to the floods may lead to little changes in the soil texture. However, we observed no major shift in the soil particles, except for an increase in sand and clay contents during the post-flood conditions. Bulk density of the soil samples ranged from 0.95 to 1.27 g cm^{-3} and from 0.89 to 1.15 g cm^{-3} during before and after flood conditions respectively in all the landuse systems. However, it inclined in lower soil layers (Table 2). This could be due to lower organic matter in the lower soil and also attributed to the compaction properties of the soil. Further, addition of fine suspended materials that came along with the flood water did contribute to this behaviour. Once surface soils are eroded or washed away by such unprecedented rains, the over all bulk density of the remaining soil increased and hydraulic conductivity decreased. Due to this, plant establishment and growth could adversely be affected and eventually crop loss. Because the agriculturally essential surface soils have certain unique characters, which make them indispensable for crop production (Natarajan *et al*. 2010) as it provides vital nutrients and a habitat to millions of beneficial microorganisms.

The general trend in soil pH due to flooding is a shift towards neutrality (Henderson & Patrick 1982; Mitsch & Gosselink 2000), regardless of acidity or alkalinity prior to flooding. Our data was in agreement with this trend in pH after the floods. This could be attributed to the soil chemical reduction process upon flooding. It has earlier been reported that reduction reactions that occur under flooded conditions consume H^+ ions, causing the pH to increase in acidic soils; while the production of organic acids can cause the reduction of pH in alkaline soils (Mitsch & Gosselink 2000; Narteh & Sahrawat 1999; Ponnamperuma 1972; Ponnamperuma *et al*. 1966).

The flood caused soil erosion in different landuse systems also directed leaching of available nutrients from the soil. Amongst the landuse system studied, agricultural field, plantation area and home garden were affected severely due to soil erosion. Spink *et al*. (1998) reported that periodical flooding influences nutrient dynamics in the soils of riparian ecosystems. In specific, Lockaby *et al*. (1996); and Hagedorn *et al*. (2001) observed that both periodical and one-time floodings often led to decrease in C and N contents in soils. We did observe similar results. For instance, organic C content decreased in almost all the soil samples collected from different landuse systems. Total N content revealed rather inconsistent changes, although it decreased in the majority of soils. Loss of N from the soil or a shift in the type of inorganic-N found in the soil with inundation has been reported earlier (Lockaby *et al*. 1996). Likewise, there was a significant reduction in available P content after flooding in all the landuse types (Table 2). Reportedly, when organic matter decomposes under suitable aerobic conditions, soil moisture regime, and microbial activity, phosphate is released rapidly to the soil (Arunachalam *et al*. 1997). However, in the present study site, after the prolonged flood condition, decomposition and mineralization of organic matter are severely affected which consequently limited the release of phosphates. Moreover, the flood might have washed away significant amount of soil mycorrhizal (fungal) populations which inturn affected the phosphorus solubilisation in the soils of different landuse system, thus the normal growth and development of agricultural and home garden crops under phosphorus limitation depends upon

the need/requirement of phosphorus fertilization for those soils/crops.

When surface soils are removed due to flood and other natural disasters, the first negative biochemical effect is on the soil organic matter and microorganisms (Natarajan *et al*. 2010; Rawat *et al*. 2013). In general, upon flooding, soils become chemically reduced due to the rapid uptake remaining oxygen in soils by the aerobes which consequently might have resulted in significant reduction in nutrient availability after the flood. Moreover, the microbial decomposition of organic matter content is relatively slow, ineffective and incomplete under flooded or anaerobic soil conditions. Tropical soils contain on an average 200 mg of soil microbial biomass in every kilogram of the soil (Chander *et al*. 1997). The decrease in microbial biomass (C, N and P) after flood in the present investigation could be attributed to the loss of organic matter, soil erosion and subsequent reduction in microbial communities due to flood. This is evident from the significant positive correlations between soil C and the microbial biomass (C, N and P). Arunachalam & Arunachalam (2002) also observed similar trends in flood affected areas in Arunachal Pradesh. If an energy source is not added to soil and new biomass is not synthesized, and hence microbial biomass expectedly decline after releasing nutrients (Devi *et al*. 2014; Watanabe *et al*. 1987). This also indicates that organic matter input is necessary to maintain soil microbial activity and mineralisation process. Moreover, flood and waterlogging for one or three months (June - August) effectively prevented the aerobic decomposition of organic remains. This means that aerobic bacteria that are responsible for the oxidation of organic material cannot survive in these prolonged waterlogging conditions (Tiner 1999) which inturn lead to the lower microbial biomass after the flood.

Watanabe & Inubushi (1986) observed that microbial biomass measured by chloroform fumigation increased at the soil surface and decreased in the puddle layer during flooding. Further, they estimated that the residence time of microbial biomass N to be 33 days, which suggests that the turnover of microbial biomass is much faster in tropical-wetland soils. In the present study, the available nutrient and microbial biomass nutrients in subsurface soils in all the landuse types were lower as compared with the top soils. This further indicates that the organic amendments and fertilization of sub-surface soils are necessary to ensure rapid build-up of microbial populations and initiate nutrient cycling (Natarajan *et al*. 2010). Simultaneously, SOC, total N and available P also decreased in the soil after flooding. This may have favoured competition between plants and microbes for nutrient sources. As a result microbial C, N and P were also lower during post-flood conditions in all the landuse systems.

While dehydrogenase activity increased significantly in soils after flood (Tables 2 and 3), phosphatase activity declined in both soil depths (Table 2). Fewer studies have reported greater dehydrogenase activity in flooded soils (Baruah & Mishra 1984; Benckiser *et al*. 1984; Dkhar & Mishra 1983; Tiwari *et al*. 1989), and attributed this to decreased redox potential (Okazaki *et al*. 1983; Pedrazzini & McKee 1984). However, soil enzymatic activities had significant relationships with microbial biomass (C, N and P) which is in conformity with the observations of Dick *et al*. (1996) and McLatchey & Reddy (1998). The phosphatase activity was found to have strong significant positive correlations with SOC during both flood case (pre- and post-flood). Correspondingly, Jordan & Kremer (1994) and Aon & Colaneri (2001) have shown significant correlations amongst the activity of phosphatases (acid and alkaline) and soil organic matter. In the present study too, both phosphatase ($r = 0.911$) and dehydrogenase ($r = 0.832$) activities significantly ($P < 0.05$) correlated with soil organic C.

The relationship between soil physico-chemical and microbiological properties was significantly affected by the flood. This was marked by the inconsistent correlation among physico-chemical, biochemical and microbiological properties of soil during pre- and post flood condition. The significant negative correlation during pre-flood and insignificant negative correlation after flood conditions between TKN and microbial N confirms that prolonged flood in all the landuse systems substantially held for the nitrogen immobilisation during and after flood. Apart from enhanced nitrogen leaching, it also indicates rapid consumption of available nitrates by the anaerobic and facultative microbes during post-flood condition. However, the relationship between SOC and microbial C; and available P and microbial P remained unaffected. Dehydrogenase activity registered significant positive correlation ($P < 0.05$) with the MBC/SOC and MBN/TKN in flood affected soil, whilst in pre-flood condition, the correlation was not significant between them (Table 4). It suggests that initial colonization and recovering process of microbial activity in flooded

soil. In the present study, it was established that flood had considerable effect on the relationship between the C/P ratio and microbial biomass carbon. Evidently, there was no significant correlation between C/P ratio and MBC after flood.

In conclusion, it could be said that soil properties changed significantly after the flood. There was an increase of soil moisture content, pH, dehydrogenase activity and C/N ratio. At the same time, WHC, organic C, total N, available P, microbial nutrients and phosphatase (alkaline) activity declined after flooding in different landuse systems studied. The present results did not confirm to the nutrient immobilization in microbial biomass during upshocks, such as here in flood case, but did reveal a marked increase in soil dehydrogenase activity that is an indicator of soil biochemistry. Nonetheless, the flood affected agricultural and homegarden soils could be restored by application of essential plant nutrients such as N and P applied at normal rate as required by the local farmers in order to restore the crop yields food production system. While, soil enzymatic activity could be used as an indicator to determine soil quality, amending soil with available organic residues and ploughing after the flood could resume the microbial activity which may subsequently increase the plant available nutrients for sustaining the net productivity and ecosystem services *per se*.

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References

Allen, S. E., H. M. Grimshaw, J. A. Parkinson & C. Quarmby. 1974. *Chemical Analysis of Ecological Materials*. Blackwell Scientific Publications, Oxford. UK.

Anderson J. M. & J. S. I. Ingram. 1993. *Tropical Soil Biology and Fertility. A Handbook of Methods*. 2nd edn. CAB International, U.K.

Aon, M. A. & A. C. Colaneri. 2001. Temporal and spatial evolution of enzymatic activities and physico-chemical properties in an agricultural soil. *Applied Soil Ecology* **18**: 255-270.

Arunachalam, A. & K. Arunachalam. 2002. Dynamics of soil microbial biomass as affected by flood in the humid tropics. *Indian Journal of Soil Conservation* **30**: 21-28.

Arunachalam, K., A. Arunachalam, R. S. Tripathi & H. N. Pandey. 1997. Dynamics of microbial population during the aggregation phase of a selectively logged tropical humid forest in northeastern India. *Tropical Ecology* **38**: 333-341.

Baruah, M. & R. R. Mishra. 1984. Dehydrogenase and urease activities in rice field soils. *Soil Biology and Biochemistry* **16**: 423-424.

Benckiser, G., S. Santiago, H. U. Neue, I. Watanabe & J. C. G. Ottow. 1984. Effect of fertilization and exudation, dehydrogenase activity, iron reducing populations and Fe^{2+} formation in the rhizosphere of rice (*Oryza sativa* L.) in relation to iron toxicity. *Plant and Soil* **79**: 305-316.

Bhanumurthy, V., P. Manjusree & G. Srinivasa Rao. 2010. Flood disaster management. pp. 283-296. *In*: P. S. Roy, R. S. Dwivedi & D. Vijayan (eds.) *Remote Sensing Applications*. National Remote Sensing Centre, ISRO, Balanagar, Hyderabad, India.

Biswas, S. P., D. Baruah & A. Hazarika. 2000. An experimental study of soil conservation using herbaceous plants in Majuli Island, Assam, India. *The Environmentalist* **20**: 19-27.

Brookes, P. C., A. Landman, G. Pruden & D. S. Jenkinson. 1985. Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method for measuring microbial biomass nitrogen in soil. *Soil Biology and Biochemistry* **17**: 837-842.

Casida, L. E. 1977. Microbial metabolic activity in soil as measured by dehydrogenase determinations. *Applied and Environmental Microbiology* **34**: 630-636.

Chander, K., S. Goyal, M. C. Mundra & K. K. Kapur. 1997. Organic matter, microbial biomass and enzyme activity of soils under different crop rotations in the tropics. *Biology and Fertility of Soils* **24**: 306-310.

Devi, T. I., P. S. Yadava & S. C. Garkoti. 2014. Cattle grazing influences soil microbial biomass in sub-tropical grassland ecosystems at Nambol, Manipur, northeast India. *Tropical Ecology* **55**: 195-206.

Dick, R. P., D. P. Breakwell & R. F. Turco. 1996. Soil enzyme activities and biodiversity measurements as integrative microbiological indicators. Methods for assessing soil quality. *Soil Science Society of America Journal* **9**: 9-17.

Dkhar, M. S. & R. R. Mishra. 1983. Dehydrogenase and urease activities of maize (*Zea mays* L.) field soils. *Plant and Soil* **70**: 327-333.

Hagedorn, F., J. B. Bucher & P. Schleppi. 2001. Contrasting dynamics of dissolved inorganic and organic nitrogen in soil and surface waters of forested catchments with Gleysols. *Geoderma* **100**: 173-192.

Henderson, R. E. & W. H. Patrick Jr. 1982. Soil aeration and productivity. pp. 51-69. *In*: M. Rechcígl (ed.) *Handbook of Agricultural Productivity. Volume-I Plant Productivity*. CRC Press, Boca Raton, Florida.

Jordan, D. & R. J. Kremer. 1994. Potential use of microbial activity as an indicator of soil quality. pp. 245-249. *In*: C. E. Pankhurst, B. M. Double, V. V. S. R. Gupta & P. R. Grace (eds.) *Soil Biota-Management in Sustainable Farming Systems*. CSIRO Publications, Australia.

Kieft, L. T., E. Soroker & M. K. Firestone. 1987. Microbial biomass response to a rapid increase in water potential when a dry soil is wetted. *Soil Biology and Biochemistry* **19**: 119-126.

Lake, P. S. 2000. Disturbances, patchiness, and diversity in streams. *Journal of the North American Benthological Society* **19**: 573-592.

Lockaby, B. G., R. S. Wheat & R. G. Clawson. 1996. Influence of hydroperiod on litter conversion to soil organic matter in a floodplain forest. *Soil Science Society of America Journal* **60**: 1989-1993.

Mau, D. P. 2001. *Sediment Deposition and Trends and Transport of Phosphorus and Other Chemical Constituents, Cheney Reservoir Watershed, South-central Kansas*. U.S. Geological Survey (USGS) Water-Resources Investigations Report 01-4085, U.S.A.

Mitsch, W. J. & J. E. Gosselink. 2000. *Wetlands*. 3rd edn. John Wiley & Sons, New York, U.S.A.

McLatchey, G. P. & K. R. Reddy. 1998. Regulation of organic matter decomposition and nutrient release in a wetland soil. *Journal of Environmental Quality* **27**: 1268-1274.

Narteh, L. T. & K. L. Sahrawat. 1999. Influence of flooding on electrochemical and chemical properties of West African soils. *Geoderma* **87**: 179-207.

Natarajan, A., R. Hegde, L. G. K. Naidu, A. Raizada, R. N. Adhikari, S. L. Patil, K. Rajan & D. Sarkar. 2010. Soil and plant nutrient loss during the recent floods in North Karnataka: Implications and ameliorative measures. *Current Science* **99**: 1333-1340.

Nilsson, C. & M. Svedmark. 2002. Basic principles and ecological consequences of changing water regimes: Riparian plant communities. *Environmental Management* **30**: 468-480.

Ogbodo, E. N. 2011. Assessment of some soil fertility characteristics of Abakaliki urban flood plains of south-east Nigeria, for sustainable crop production. *World Journal of Agricultural Sciences* **7**: 489-495.

Okazaki, M., E. Hirata & K. Tensho. 1983. TTC reduction in submerged soils. *Soil Science and Plant Nutrition* **29**: 489-497.

Pedrazzini, F. R. & K. L. McKee. 1984. Effect of flooding on activities of dehydrogenase in rice (*Oryza sativa* L.) roots. *Soil Science and Plant Nutrition* **30**: 359-366.

Ponnamperuma, F. N. 1972. The chemistry of submerged soils. *Advances in Agronomy* **24**: 29-96.

Ponnamperuma, F. N., E. Martinez & T. Loy. 1966. Influence of redox potential and partial pressure of carbon dioxide on pH and the suspension effect of flooded soils. *Soil Science* **101**: 421-431.

Rawat, J. S., R. C. Joshi & M. Mesia. 2013. Estimation of erosivity index and soil loss under different land uses in the tropical foothills of eastern himalaya (India). *Tropical Ecology* **54**: 47-58.

Schimel, J. P., J. M. Gulledge, J. S. Clein-Curle, J. E. Lindstrom & J. F. Braddock. 1999. Moisture effects on microbial activity and community structure in decomposing birch litter in the Alaskan taiga. *Soil Biology and Biochemistry* **31**: 831-838.

Spink, A., R. E. Sparks, M. van Oorshot & J. T. A. Verhoeven. 1998. Nutrient dynamics of large river floodplains. *Regulated Rivers Research and Management* **14**: 203-216.

Streng, D. R., J. S. Glitzenstein & P. A. Harcombe. 1989. Woody seedling dynamics in an east Texas floodplain forest. *Ecological Monograph* **59**: 177-204.

Tabatabai, M. A. & J. M. Bremner. 1969. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry* **1**: 301-307.

Tiner, R. W. 1999. *Wetland Indicators: A Guide to Identification, Delineation, Classification and Mapping*. CRC Press LLC, Lewis Publishers, Boca Raton, Florida.

Tiwari, M. B., B. K. Tiwari & R. R. Mishra. 1989. Enzyme activity and carbon dioxide evolution from upland and wetland rice soil under three agricultural practices in hilly regions. *Biology and Fertility of Soils* **7**: 359-364.

Vance, E. D., P. C. Brookes & D. S. Jenkinson. 1987. An extraction method for measuring soil microbial biomass. *Soil Biology and Biochemistry* **19**: 703-707.

Watanabe, I. & K. Inubushi. 1986. Dynamics of available nitrogen in paddy soils. 1. Changes in available N during rice cultivation and origin of N. *Soil Science and Plant Nutrition* **32**: 37-50.

Watanabe, I., S. K. De Datta & P. A. Roger. 1987. Nitrogen cycling in wetland rice soils. pp. 239-256. *In*: J. R. Wilson (ed.) *Proceeding of Symposium on Advances in Nitrogen Cycling in Agricultural Ecosystems*. Brisbane, Australia.

Zar, J. H. 1974. *Biostatistical Analysis*. Prentice-Hall Inc., Englewood Cliffs, New Jersey.

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