Characterization of soil enzyme activities and physicochemical characteristics of tea soil under waterlogging

Ipsita Duarah,[a] Dhruba K. Deka,[b] Debojeet Borah,[b] Hari P. Deka Boruah,[a]* Reshita Baruah,[b] Trilukya Lahan,[b] Uttpal Baruah[b] and T.S. Barman[b]

[a]Biotechnology Division, CSIR- NEIST, Jorhat 785006, Assam, India
[b]Plant improvement division, Tocklai Experimental Station, TRA, Jorhat 785008, Assam, India

ABSTRACT: Understanding of soil properties to maintain the soil health and crop productivity in agricultural ecosystem is vital. As a consequence, soil type and its related chemical and biological characters are being evaluated to determine the quality of soil. In this study, soil properties in tea monocropping areas were evaluated for 21 tea gardens under waterlogged condition from North Bank (NB), South Bank (SB) of the Assam and Dooars region of West Bengal (WB). A total of 260 samples from 21 tea gardens were collected for three season including pre-rainy (January–May), rainy (June–September) and post-rainy (October–December) and evaluated for different chemical and biological activities. It was found that the NB soil type was sandy to silty loam with an average age of 43 to 80 years while the SB soil type was loam to silty loam with an average age of 50 to 70 years. The soil underlying tea gardens in WB was sandy loam to heavy soil with sandy patches and the age of cultivation was above 70 years. The soils of all the tea gardens were mildly acidic (pH values from 3.6 to 5.9). The moisture content, soil respiration and temperature of the soils in each of the gardens showed significant variation. A mixed clustering was obtained for the tea gardens with much variation during pre-and post rainy based on studied soil parameters. It was also found that there was a significant correlation during the post-rainy seasons for enzyme activities including urease, phosphatase and dehydrogenase ($P<0.05$), respectively. During pre-rainy, six principal factors influence the soil characteristics with a variance level of 49.26%. During rainy, principal factors urease and phosphatase showed negative effects over the other soil factors whereas in post-rainy pH was the significant principal factor followed by urease, moisture and temperature at the variance level of 25.97%. From the observation it could be concluded that the variations in soil physical, chemical and biological properties were observed among soils from tea gardens of Assam and WB. These variations in soil characteristics under waterlogged conditions were due to variation in the soil texture, management practice. The present finding will help in improvement of tea production by establishing correlation with soil characters.

Keywords: Soil enzymes; Correlation; Tea; Mono-cropping; Soil properties

Introduction

Soil physicochemical properties and soil enzyme activities are very sensitive to natural and anthropogenic activities.[1,2] These factors play key biological roles in soil systems.[3,4] For example, they catalyze several important reactions necessary for the life cycles of micro-organisms in soil and facilitate the stabilization of soil structure, the decomposition of organic wastes, the formation of organic matter and nutrient cycling.[5] Soil enzymes are constantly being synthesized, accumulated, inactivated and decomposed in the soil; therefore, soil biochemical activities have been found to be very responsive to soil conservation and patterns of use by humans such as non tillage, organic amendment, crop rotation and cultivation.[1,6–10]

Among the soil enzymes, phosphatases are a broad group of enzymes that catalyze the hydrolysis of esters and anhydrides of phosphoric acids.[11] The release and availability of phosphates depends on the soil pH. Once released, phosphatase catalyses the hydrolysis of organic phosphate to inorganic phosphate; therefore, it is an important link between biologically available and unavailable phosphorus.[11,12] Dehydrogenase enzyme activity is commonly used as an indicator of biological activity in soils.[7,13] Dehydrogenases are known to oxidize soil organic matter by transferring protons and electrons from substrates to acceptors in the respiration pathways of soil micro-organisms. In addition, deydrogenases are closely related to soil, air and water conditions.[14–16] Similarly, urease is responsible for the hydrolysis of urea fertilizer applied to soil into NH_3 and CO_2.[17,18] Accordingly, urease activity in soils has received a great deal of attention since it was first reported by Rotini.[19] Furthermore, many studies conducted to evaluate the activity of all of the aforementioned enzymes have demonstrated that they are responsive to human activities.[7,13,17,18] Conversely, few studies have been conducted to evaluate the soil enzyme activity of tea monocropping areas.[20–22]

*Author for correspondence. E-mail: dekaboruah@yahoo.com; dekabaruahhp@rrljorhat.res.in

Tea cultivation has been conducted in the Assam and Dooars regions of West Bengal (WB) for centuries. Tea (*Cammelia sinensis* L. (O) Kuntze) is a perennial crop that survives for more than 100 years, but is very much susceptible to drought and water logging. The production of tea depends on the nature of soil and other ecological factors such as microbial activity. Localized accumulation of water or an increase in the water table to the root zone (less than 90 cm depth) for extended periods can cause stunted growth, defoliation or the death of plants. Due to various factors, water logging in plantation areas has been increasing at an alarming rate in North-East (NE) India. Understanding the possible roles of the aforementioned soil enzymes is vital to maintaining the soil health and fertility management in agricultural ecosystems. Indeed, enzymes may have significant effects on soil biology, environmental management, growth and nutrient uptake by plants growing in such areas. In addition, the physical, chemical, biological and biochemical properties of soil are very important for its behavior.[23,24] Moreover, the factors that are most closely related to nutrient cycles, such as soil respiration, microbial biomass, nitrogen mineralization capacity and the activities of soil enzymes, can be used to determine if the soil quality has deteriorated.[25] Although there is a wealth of information regarding the nutrient status of soil underlying tea monocropping areas in NE India and Dooars region of WB, little work has been done regarding the soil physical, chemical and biological activity of the tea gardens in this area. Therefore, we analysed biochemical and chemical characters of tea soils including the phosphatase, urease, and dehydrogenase activity, and the percentage of C, P and N in soil samples collected from water logged areas of different Tea gardens in Assam and West Bengal.

Materials and Methods

Study Site

Soil samples were collected from a plantation with an area of 9248.35 ha that contained 21 individual Tea Gardens located in different regions along the south bank (SB) and north bank (NB) of River Brahmaputra of Assam and Dooars region of WB (see Table 1). A total of 260 sampling locations were selected from 21 gardens and then sampled during pre-rainy, rainy and post-rainy season, respectively. The year that crops at each garden were first planted was collected from records maintained by the garden.

Table 1: Brief description of the Tea Gardens

Region	Name of garden	Age of garden (Yrs)	Area (ha)	Type of cultivation (Race)	Soil type	Longitude/ Latitude
South Bank (Assam)	Jalannagar	50	216.02	Old seed jat (Assam)	Silt loam	94°55′E - 27°28′ N
	Nandanban	46	097.43	Betjan (Assam)	Loam	95°27′E - 27°27′ N
	Dinjan	69	487.00	Chumaijan, Betjat (Assam)	Silty loam	95°48′E - 27°33′ N
	Thanai	51	476.76	Old seed jat (Assam)	Loam	95°20′E - 27°32′ N
	Greenwood	73	581.51	Old seed jat (Assam)	Loam	95°10′E - 27°31′ N
	Maijan	50	479.41	Rongagora jat (Assam)	Loam	95°00′E - 27°30′ N
North bank (Assam)	Monabag	80	240.60	Old seed jat (Assam)	Sandy loam	92°30′E -26°47′ N
	Monmohinipur	50	387.00	Old seed jat (Assam)	Sandy loam	92°29′E -26°49′ N
	Gingia	53	432.92	Tingamara (Assam)	Sandy loam	93°14′E -26°49′ N
	Nyagogra	43	685.00	Kharijan (Assam)	Silty loam	93°36′E -26°52′ N
	Dufflagarh	47	683.53	Betjan (Assam)	Loamy sandy	93°31′E -26°54′ N
Dooars (West Bengal)	Telepara	89	548.00	Kharijan, Betjan (Assam)	Sandy Loam	88°00′E - 26°43′ N
	Totapara	95	378.13	Tingmara, Kharijan (Assam)	Sandy Loam	89°00′E - 26°49′ N
	Kalabari	*94*	*287.00*	*Dangri Manipuri (Assam)*	*Heavy Soil*	88°53′E - 26°46′ N
	Huldibari	89	883.00	Indigenous (Assam)	Sandy Soil	88°59′E - 26°46′ N
	Ethelbari	89	272.52	Dangri Manipuri (Assam)	Heavy Soil	89°12′E - 26°37′ N
	Cooch Behar	*70*	*224.26*	*Kharijan, Betjan (Assam)*	*Sandy Soil*	89°14′E - 26°31′ N
	Danguajhar	97	659.58	Endong (Assam)	Sandy Loam	88°41′E - 26°34′ N
	Joypur	89	328.00	Old seed jat (Assam)	Sandy Loam	88°38′E - 26°36′ N
	Noweranuddy	97	251.44	N 18, Old seed jat (China)	Heavy Soil	88°44′E - 26°44′ N
	Baintgoorie	89	650.00	Dangri Manipuri (Assam)	Sandy Loam	88°40′E - 26°45′ N

Data were taken from the inventory of each tea garden.

Soil Sampling

Top soil samples were collected between August and February between two rows of the tea plants using intact soil core systems. Average of ten soil samples were collected from each garden from the bulk sampling representing ten sites in each location. The samples collected were immediately stored at 4°C and brought to the laboratory for soil analysis. All the soil analysis was done within 4 weeks of collection.

Physicochemical Properties of Soil

The soil pH was determined in 1:2.5 soil:water suspensions using an automatic glass electrode pH meter (Systronic model-361). The percentage of organic C was determined by Walkley and Black[26] while phosphorus was evaluated by the phospho molybdic acid methods.[27] The soil moisture content was determined after drying the soil samples at 105°C until a constant weight was obtained. The soil temperature and respiration were quantified using infra red gas analyzer, equipped with soil temperature and respiration assemblage CCIAS-1 (IRGA-CCIRAS-I) at the site.

Soil Enzyme Assay

The enzyme activity of phosphatase was determined using the method described by Tabatabai and Bremner.[28] All values were expressed as µg of *p*-nitrophenol released from *p*-nitrophenyl-phosphate that was cleaved by phosphatase in 0.1 g of soil. The optical density was recorded at 430 nm using an Analyticzena (SPECORD 210) spectrophotometer and total phosphatase activity was calculated from standard curve prepared using *p*-nitrophenol-phosphate.

The 2,3,5-triphenyl tetrazolium chloride (TTC) reduction technique[29] was used to measure the soil dehydrogenase activity. Briefly, fresh soil (5 g) was added to a test tube that contained 5 ml of 0.1% TTC solution and then shaken until the sample was well mixed. The samples were then incubated at 30°C for 24 hr in the dark. The Tri phenyl formazen (INTF) released was then extracted in methanol and measured by reading the optical density at 485 nm. The dehydrogenase activity of soil was compared from standard curve prepared using sodium hydrosulphide and expressed as mg INTF g^{-1} dry soil hr^{-1}.

The urease activity was measured using the method described by McGarity and Myers.[30] The amount of NH_4-N released by the urease enzyme was calculated using a reference-calibrated curve and expressed as NH_4-N mg g^{-1} of dry soil hr^{-1}.

Statistical Analyses

Analysis of variance (ANOVA) was done to compare the soil physicochemical properties and enzyme activities among the individual region. Mean significance differences were compared by the Duncan's Multiple Range Test (DMRT) at $P < 0.05$. In addition, cluster and Pearson's correlation analysis was done to establish the similarity and relationship among the tea gardens of three regions. Finally, the data were subjected to factor analysis for establishment of the most influencing factors. All statistical analyses were conducted using SPSS Pc++ 11.5 (USA).

Results

Tea Gardens

The SB and NB tea gardens of Assam were between >43 and >80 years old while the WB tea gardens were between 70 and 97 years old cultivations (see Table 1). The soil type of the SB tea gardens was loam to silty loam, while sandy loam to silty loam was found in the NB tea gardens. The soil in the tea gardens of WB was found to be a mixture of sandy loam, heavy soil and sandy soil with sandy patches. The Nandanban tea garden had the smallest area (97.43 ha) while the Huldibari tea garden had the largest area (883 ha).

Soil Physicochemical Properties

The soil pH and moisture content recorded for the pre-rainy, rainy and post-rainy seasons are shown in Table 2. The pH for the individual tea gardens were varied from 3.4 to 5.8, with values of 3.4–4.5, 4.4–5.6 and 5.0–5.8 being observed during the pre-rainy, rainy and post-rainy seasons, respectively. In addition, the moisture content of soil collected from the tea gardens of Assam and West Bengal differed significantly. During the pre-rainy season, the lowest moisture contents observed were 14%, 11% and 13% for the SB, NB and Dooars regions, respectively, while the highest contents were approximately 18.2%, 20% and 30.5%, respectively. In addition, the percentage of moisture content during rainy season ranged 12.6–27.2, 22.3–24.1 and 18.2–34.5 for the SB, NB and Dooars regions, respectively, while the percentage of moisture content during the post rainy for the SB, NB and Dooars regions were ranged 10.9–17.0, 10.8–19.8 and 10.7–24.0, respectively.

Total organic carbon and soil from tea gardens of

Table 2: pH and moisture content of soils from tea gardens in Assam and West Bengal

Region	Name of garden	pH			Moisture content (%)		
		Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
South-Bank (Assam)	Maijan	4.3 (3.6-4.4)a	5.0 (4.8-5.5)a	5.7 (5.6-5.7)a	18.2(14.3-26.2)a	20.7 (10.8-23.5)b	17.0 (16.1-18.4)a
	Greenwood	4.5 (3.9-4.8)a	4.4 (4.4-4.8)c	5.5 (5.1-5.8)b	14.4 (12.5-24.6)d	21.3 (14.8-22.9)b	13.7 (13.3-17.9)c
	Thanai	3.9 (3.8-4.5)a	5.0 (4.5-5.3)a	5.8 (5.7-6.0)a	15.5 (13.8-19.4)c	20.9 (17.9-22.3)b	12.5 (10.5-18.6)d
	Dinjan	4.3 (4.1-4.7)a	5.0 (4.8-5.3)a	5.7 (5.2-5.9)a	17.0 (14.5-17.5)b	24.0 (21.4-11.8)b	15.9 (10.4-17.6)b
	Nandanban	4.1 (3.9-4.5)a	4.9 (4.8-5.0)b	5.5 (5.2-5.8)b	15.0 (13.3-17.4)c	27.2 (24.6-29.6)a	10.9 (05.6-16.8)e
	Jalannagar	3.4 (3.9-4.4)b	4.9 (4.5-5.0)b	5.2 (5.1-5.8)c	18.0 (14.9-20.9)a	12.6 (10.2-18.6)c	15.7 (14.9-18.6)b
North – bank (Assam)	Monabag	4.5 (4.4-4.6)a	5.1 (5.1-5.4)c	5.0 (4.2-5.3)c	11.0 (10.4-11.7)d	22.3 (19.8-28.6)b	17.9 (16.0-18.4)d
	Monmohinipur	4.2 (3.8-4.8)b	5.4 (5.2-6.7)b	5.3 (4.6-5.5)a	19.4 (15.9-20.7)b	23.4 (18.3-25.5)ab	10.8 (08.7-13.0)e
	Gingia	4.2 (3.9-4.5)b	5.2 (5.3-5.8)bc	5.0 (4.3-5.5)c	15.7 (13.4-20.9)c	23.9 (23.1-26.3)ab	19.9 (17.5-21.4)a
	Nyagogra	4.5 (3.5-5.0)a	5.4 (5.6-5.9)b	5.1 (4.7-5.1)b	20.0 (17.0-20.2)a	23.7 (18.8-28.4)ab	19.0 (16.0-20.3)b
	Dufflagarh	4.0 (3.9-4.3)c	5.6 (5.6-5.8)a	5.3 (4.6-5.5)a	19.1 (17.2-21.5)ab	24.1 (20.1-28.9)a	19.8 (16.3-21.5)ab
Dooars (West Bengal)	Telepara	3.9 (3.6-4.4)a	5.0 (4.8-6.0)a	5.3 (5.2-5.9)b	17.4 (16.1-20.7)e	33.0 (25.0-40.6)ab	17.6 (16.1-18.4)c
	Totapara	4.4 (3.9-4.8)a	4.8 (4.2-5.0)a	5.5 (5.2-5.8)a	18.1 (18.2-19.1)e	34.5 (27.4-43.9)a	15.6 (13.3-17.9)cd
	Kalabari	4.1 (3.8-4.5)a	4.9 (4.8-5.4)a	5.5 (5.1-5.8)a	23.8 (22.3-27.4)b	30.1 (12.0-40.8)c	16.1 (10.5-18.6)c
	Huldibari	4.2 (4.1-4.7)a	4.7 (4.4-4.7)a	5.6 (5.0-5.8)a	16.7 (14.7-17.4)d	28.2 (16.3-42.4)d	24.0 (10.4-70.6)a
	Ethelbari	4.2 (3.9-4.5)a	5.0 (4.6-5.3)a	5.7 (5.7-6.0)a	14.0 (10.4-15.6)f	19.5 (14.9-22.1)fg	14.4 (12.3-20.4)d
	Cooch Behar	4.1 (3.9-4.4)a	4.9 (4.8-5.1)a	5.6 (5.2-5.9)a	13.1 (09.4-16.2)f	19.8 (16.8-28.4)fg	16.1 (14.7-17.4)cd
	Danguajhar	4.2 (3.9-4.8)a	4.9 (4.8-5.1)a	5.7 (5.6-5.7)a	14.8 (19.7-38.7)f	23.2 (19.5-36.0)e	12.3 (10.4-15.6)e
	Joypur	3.9 (3.8-4.0)a	4.9 (4.9-5.4)a	5.2 (5.1-5.8)b	17.6 (04.9-27.0)d	20.7 (17.8-31.7)f	10.7 (09.4-16.2)e
	Noweranuddy	4.2 (4.1-4.7)a	4.6 (4.4-4.9)a	5.4 (5.2-5.9)ab	30.5 (29.5-34.9)a	18.2 (10.1-38.7)g	11.6 (08.7-13.0)e
	Baintgoorie	4.3 (3.9-4.5)a	4.7 (4.5-5.0)a	5.6 (5.1-5.8)a	21.0 (19.8-24.5)c	32.5 (28.7-40.3)b	20.6 (17.5-21.4)b

Data are the means of ten observations at each garden; data in parenthesis are the minimum and maximum observed values; mean values within the column followed by similar letters are not significantly different from each other according to DMRT at $p<0.05$.

Assam and WB are shown in Table 3. Total organic C in NB tea gardens was found the highest in post-rainy season (1.66–1.80%) for all tea gardens followed by rainy and pre-rainy seasons except Nayagogra tea garden. In Nayagogra, the highest organic C was found in post-monsoon followed by pre-monsoon (0.41%) and monsoon (0.31%), respectively. On the other hand, reverse organic C-content was found for SB. In SB, the highest organic C content (0.99%) was found for pre-rainy followed by rainy (0.58–0.89%) and post-rainy seasons (0.35–0.62%), respectively.

A characteristically different organic C content (0.23–1.67%) was found in Dooars regions tea gardens of WB. In pre-rainy, Ethelbari tea garden showed the lowest organic C (0.23%) and the highest by Baintgoorie tea gardens (1.67%), respectively. Similarly, in rainy the lowest organic C was showed by Kalabari tea garden (0.52%), the highest by Baintgoorie (1.44%) and in post-rainy Coochbehar (0.56%) was the lowest and Kalabari (1.67%) found to be the highest. Amongst all the tea gardens of Assam and WB, tea garden Dufflagarh tea garden of NB showed the lowest organic C (0.19%) in pre-rainy and found the highest for Manabag (1.80%), respectively.

The temperature of soils in gardens in the Dooars region varied significantly (see Table 4) among the tea gardens as well as to seasons. Specifically, the mean soil temperature in the NB region ranged 21°C to 26°C over the three seasons while it ranged from 17°C to 22°C for the SB region and from 24°C to 36°C for the Dooars region. Similarly, the mean respiration in the NB tea gardens over the three periods ranged from 0.87 to 5 μmol $m^{-2}s^{-1}$; for SB 1.02–3.98 μmol $m^{-2}s^{-1}$; while Dooars region were 0.42–13.1 μmol $m^{-2}s^{-1}$, respectively.

Enzyme Activity

Dehydrogenase activity

The dehydrogenase activity of tea gardens of NB, SB and Dooars regions is depicted in Figure 1. A significantly highest dehydrogenase activity was found at Maijan tea garden over the three seasons in the SB. The lowest and highest values observed in SB during the pre-rainy season were 0.28 μg g^{-1} hr^{-1} and 0.052 μg g^{-1} hr^{-1}, while those observed during the rainy and post-rainy were 0.1–0.2 μg g^{-1} hr^{-1} and 0.4–1.5 mg g^{-1} hr^{-1}, respectively. On the other hand, compared to rainy and post-rainy, a very low dehydrogenase activity was found in NB tea gardens. It was significantly highest for Dufflagarh for all seasons (0.06, 0.2 and 0.7 μg g^{-1} hr^{-1}) while the lowest was found at Gingia (0.03 μg g^{-1} hr^{-1}); Nayagogra (0.13 μg g^{-1} hr^{-1}) and Manmohinipur (0.25 μg g^{-1} hr^{-1}) in pre-rainy, rainy and post-rainy, respectively. For tea

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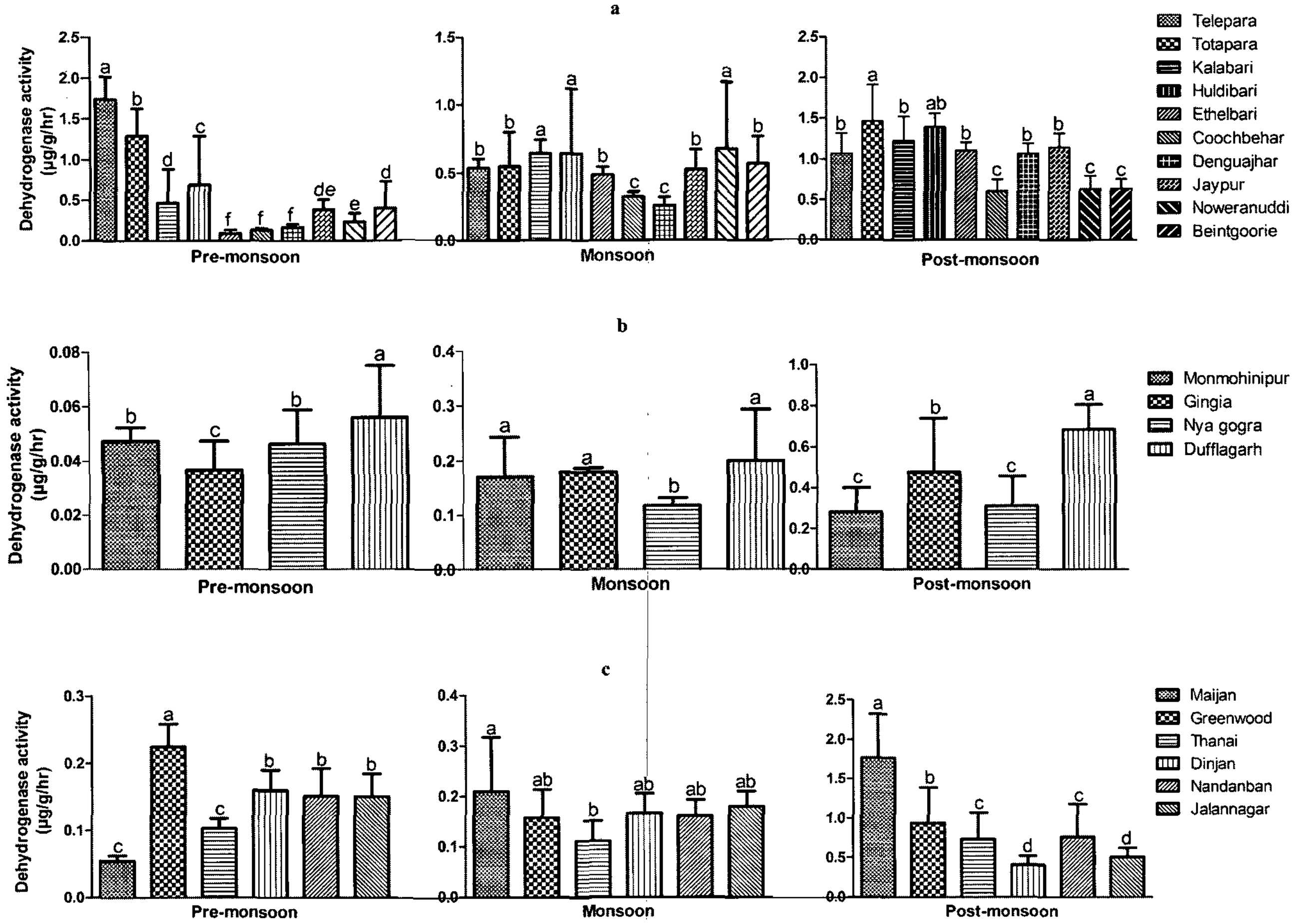

Figure 1. Dehydrogenase activity of different tea gardens in Assam and West Bengal in three different seasons.

Data are mean of 10 individual observations; error bars represent standard error means of observed values; error bars followed by similar letter within the group are not significantly different from one another according to DMRT at $P<0.05$; a. Dooars region of West Bengal (WB); b. North bank (NB) of Assam c. South bank (SB) of Assam.

gardens of Dooars region of WB, a significantly highest dehydrogenase activity was found for Telepara (1.6 mg g^{-1} hr^{-1}) and the lowest for Ethelbari (0.1 mg g^{-1} hr^{-1}) during pre-rainy. During rainy, the highest dehydrogenase activity was found for Nowernidhi (0.7 mg g^{-1} hr^{-1}) and was found insignificant compared to Kalabari and Haldibari. On the other hand, during post-rainy, a significantly highest dehydrogenase activity was found for Totapara (1.5 mg g^{-1} hr^{-1}) while the lowest was found for Coochbehar (0.6 mg g^{-1} hr^{-1}). Except Telepara and Totapara tea gardens, the highest dehydrogenase activity was found for post-rainy followed by rainy and pre-rainy seasons, respectively.

Phosphatase activity

Posphatase activity of soil collected from different tea gardens of Dooars, NB and SB regions is described in Figure 2. In NB tea gardens, during pre-rainy season, a beyond detectable limit of phosphatase activity was found for Manmohinipur while a significantly highest phosphatase activity was found for Gingia tea garden during pre-rainy (03 µg g^{-1} hr^{-1}) and post-rainy (0.7 µg g^{-1} hr^{-1}) seasons. However, it was the highest for Manmohinipur (0.75 µg g^{-1} hr^{-1}) during rainy seasons. In case of SB tea gardens, a significantly highest phophatase activity compared to Maijan and Greenwood tea gardens was found for Jalanagar (29 mg g^{-1} hr^{-1}) during pre-rainy. During rainy and post-rainy seasons, it was the highest for Maijan (150 µg g^{-1} hr^{-1}) and Thanai (2 µg g^{-1} hr^{-1}) tea gardens. Overall highest phosphatase activity was found during rainy followed by pre-rainy and post-rainy seasons for SB tea gardens. On the other hand, during pre-rainy, a significantly highest phosphatase activity was recorded for Noweranuddi (0.25 µg g^{-1} hr^{-1}) compared to Telepara, kalabari, Ethelbari, Coochbehar, Jaypur and Beintguri. Except Ethelbari and Beintgoorie, a significantly highest phosphatase activity was found for Huldibari (0.19 µg g^{-1} hr^{-1}) during rainy seasons and significantly highest for Ethelbari (0.11 μg g^{-1} hr^{-1}) compared to Telepara, Huldibari and Denguajhar during post-rainy seasons. Like NB tea gardens, overall highest phosphatase activity was recorded during rainy seasons followed by pre-rainy and post-rainy seasons.

Urease Activity

The urease activity during pre-rainy, rainy and post-rainy season for Dooars, SB and NB is described in Figure 3. During pre-rainy, no urease activity was detected for Nayagogra and Dufflagarh, and among the other two gardens a significantly highest urease activity was found for Gingia. Overall, the highest urease activity was found during pre-rainy followed by post-rainy and rainy seasons. On the other hand, in SB, a significantly highest urease activity was found in Maijan (15 μg g^{-1} hr^{-1}), Jalanagar (150 μg g^{-1} hr^{-1}) and Green wood (0.23 μg g^{-1} hr^{-1}) during pre-rainy, rainy and post-rainy seasons, respectively. Like Manmohinipur and Dufflagarh of NB, no detectable urease activity was found for Maijan and Thanai tea gardens during post-rainy seasons. For SB tea gardens, the highest urease activity was recorded during rainy followed by pre-rainy and post-rainy seasons. For Dooars regions, a significantly highest urease activity was found for Nowernuddi (110 μg g^{-1} hr^{-1}) and Huldibari (0.28 μg g^{-1} hr^{-1}) and was the lowest for Coochbehar (25 μg g^{-1} hr^{-1}) during pre-monsoon. During rainy and post-rainy seasons, urease activity was found significantly highest for Huldibari (0.39 μg g^{-1} hr^{-1}), and Telepara (0.11 μg g^{-1} hr^{-1}), respectively. Overall, the highest urease activity was found during pre-rainy while almost equal during rainy and post-rainy seasons.

Relationships among the Tea Gardens

Clusture Analysis

Cluster analysis on soil characters for the different tea gardens of including three seasons of Assam and West Bengal is described in Figure.4. During pre-monsoon, two distinct clusters were found for Assam and West Bengal tea gardens based on soil characteristics. Based on soil characters, Tea Garden No. 8 showed the highest dissimilarities amongst the Assam tea gardens while Tea Garden No. 1, 2, 9, 11 and 12 and the Tea Garden No. 4, 5, 6, 7 and 10 belong to other two groups. Similarly, Tea Garden No. 13 of Dooars region of West Bengal showed the highest dissimilarities while the second group comprises of the Tea Garden No. 17 and 21 and the third group 14, 15, 16, 18, 19 and 20. During monsoon seasons, the tea gardens were falling in two distinct clusters based on soil characteristics. The fist cluster comprised of all the tea gardens belongs to NB and the two

Table 3: Organic carbon content of soils from tea gardens in Assam and West Bengal

Region	Name of garden	Organic carbon (%) Pre-monsoon	Monsoon	Post-monsoon
South Bank (Assam)	Maijan	0.88 (0.54-1.26)ab	0.89 (0.75-1.05)a	0.60 (0.34-0.99)a
	Greenwood	0.99 (0.48-1.50)a	0.66 (0.15-0.96)b	0.62 (0.09-1.29) a
	Thanai	0.98 (0.57-1.35)a	0.77 (0.21-1.20)b	0.57 (0.09-1.72)a
	Dinjan	0.73 (0.54-1.05)b	0.58 (0.14-1.20)c	0.35 (0.20-0.60)c
	Nandanban	0.80 (0.36-1.15)ab	0.71 (0.30-0.93)b	0.41 (0.09-0.60)b
	Jalannagar	0.98 (0.45-1.17)a	0.76 (0.63-1.08)b	0.42 (0.13-0.43)b
North bank (Assam)	Monabag	0.23 (0.13-0.45)b	0.35 (0.12-0.60)c	1.80 (1.62-2.03)a
	Monmohinipur	0.35 (0.15-0.45)ab	0.43 (0.17-0.85)bc	1.79 (1.38-1.94)a
	Gingia	0.45 (0.26-0.95)a	0.56 (0.51-0.68)a	1.69 (1.56-1.94)b
	Nyagogra	0.41 (0.15-0.80)a	0.31 (0.17-0.85)c	1.66 (0.17-2.07)b
	Dufflagarh	0.19 (0.09-0.90)b	0.36 (0.17-0.72)bc	1.76 (1.17-2.07)ab
Dooars (West Bengal)	Telepara	0.65 (0.30-1.55)c	0.56 (0.51-0.68)d	0.89 (0.62-1.03)d
	Totapara	1.45 (1.20-1.95)a	0.95 (0.60-1.71)b	1.43 (1.30-1.94)b
	Kalabari	0.89 (0.60-1.50)b	0.52 (0.31-0.86)d	1.67 (1.56-1.94)a
	Huldibari	0.98 (0.90-1.86)b	0.89 (0.77-1.67)bc	0.87 (0.17-2.07)d
	Ethelbari	0.23 (0.06-1.17)d	0.67 (0.26-0.94)c	1.45 (1.17-2.07)b
	Cooch Behar	0.82 (0.60-1.56)b	0.98 (0.39-1.84)b	0.56 (0.51-0.69)e
	Danguajhar	1.12 (0.90-1.98)b	0.81 (0.77-1.71)bc	0.82 (0.60-1.01)de
	Joypur	0.94 (0.60-1.86)b	0.91 (0.43-1.50)bc	0.75 (0.41-0.98)de
	Noweranuddy	1.41 (0.78-2.10)ab	0.99 (0.43-1.46)b	0.99 (0.56-1.97)c
	Baintgoorie	1.67 (1.20-1.92)a	1.44 (1.28-1.58)a	1.24 (1.17-2.07)bc

Data are the means of ten observations at each garden; data in parenthesis are the minimum and maximum observed values; mean values within the column followed by similar letters are not significantly different from one another according to DMRT at $P<0.05$.

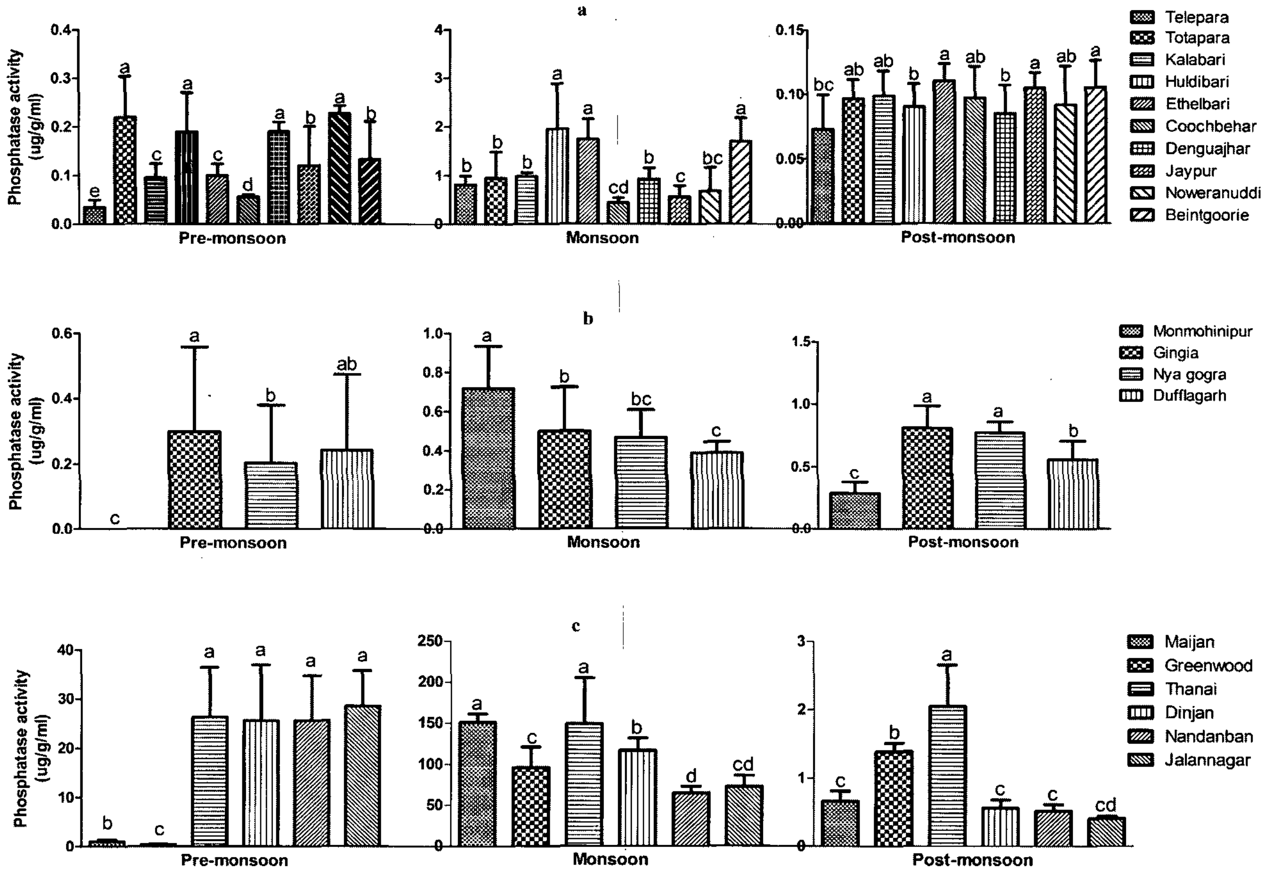

Figure 2. Phosphatase activity of different tea gardens in Assam and West Bengal in three different seasons.

Data are mean of 10 individual observations; error bars represent standard error means of observed values; error bars followed by similar letter within the group are not significantly different from one another according to DMRT at P<0.05; a. Dooars region of West Bengal (WB); b. North bank (NB) of Assam c. South bank (SB) of Assam.

tea gardens belong to SB of Assam. The second cluster comprised of the tea gardens belongs to south bank of Assam and the Dooars region of West Bengal. In contrast to pre monsoon, a mixture of three distinct clusters representing both Assam and Dooars region of West Bengal tea gardens was observed for the post-monsoon seasons based on soil characteristics. The first cluster comprising of Tea Garden No. 5, 7, 9, 10, 13 belongs to South bank of Assam and Tea Garden No. 19 and 20 belong to Dooars regions of West Bengal. On the other hand, the second group comprised of Tea Garden No. 1, 3 belongs to NB and 6, 8, 11 and 12 of SB of Assam and rest 16, 18 and 21 of Dooars region of west Bengal. While the two tea gardens numbered 2 and 4 representing only the NB of Assam comprised of the third group.

Correlation Analysis

The correlation analysis among the soil characters of different tea gardens is described in Table 5. During pre-rainy season, a significant correlation was observed for pH with other seven parameters at $P < 0.05$ and $P < 0.01$ level except phosphatase activities. In case of urease activities, a significant correlation at $P < 0.05$ and $P < 0.01$ level was found for all the other five factors except phosphatase and respiration. The other factors such as dehydrogenase showed significant correlation with urease and pH, moisture with pH, carbon with temperature and pH, while respiration with temperature and pH, respectively, at $P < 0.05$ and $P < 0.01$ levels. Like pre-monsoon, there was no significant correlation found for pH except dehydrogenase during monsoon among the tea gardens. In contrast, phosphatase has significant correlation with other soil parameters except pH and respiration at $P < 0.05$ and $P < 0.01$ level. On the other hand, like pre-monsoon during monsoon also the urease activity showed significant correlation to other four factors except pH and respiration. The other two soil characters carbon and temperature have significant correlation with phosphatase and urease, respectively. Like pre-monsoon and monsoon, there was no significant correlation observed among most of the soil parameters. During post monsoon except pH with urease carbon, and urease with moisture and temperature with respiration, no other soil characters showed significant correlation at $P < 0.05$

Table 4: Respiration and temperature of soils from tea gardens in Assam and West Bengal

Region	Name of Garden	Respiration (μ mol $m^{-2}s^{-2}$)			Temperature (C°)		
		Pre-Monsoon	Monsoon	Post-Monsoon	Pre-Monsoon	Monsoon	Post-Monsoon
North bank (Assam)	Monabag	4.7 (4.1-5.9)a	5.2 (4.5-6.0)a	4.0 (2.2-5.9)a	24.7 (20.3-26.9)a	26.1 (25.5-26.7)a	20.8 (20.3-21.7)bc
	Gingia	0.9 (0.7-6.2)c	3.6 (2.5-6.2)b	1.5 (0.6-2.7)bc	22.1 (19.9-25.5)b	25.5 (25.4-25.6)ab	21.4 (19.7-23.1)ab
	Noyagogra	2.5 (2.1-3.5)b	3.0 (2.7-3.5)b	1.7 (0.6-2.5)b	21.8 (20.8-24.8)b	25.6 (25.2-26.0)ab	22.4 (19.5-23.6)a
	Dufflagarh	1.5 (1.5-7.7)c	2.4 (1.5-9.7)c	1.4 (0.7-3.1)c	21.9 (21.1-22.5)b	24.9 (24.6-25.5)b	20.1 (21.1-22.0)c
	Manmohinpor	1.5 (1.5-6.8)c	2.4 (1.5-9.7)c	1.9 (1.0 3.2)b	22.1 (21.1 -22.5)b	25.6 (24.6–25.5)ab	22.4 (21.2- 23.0)a
South Bank (Assam)	Maijan	2.5 (2.2-2.7)b	2.6 (2.3-2.9)bc	2.0 (1.9-2.3)c	19.6 (18.2-20.2)bc	19.5 (18.4-20.4)b	18.6 (17.0-19.6)b
	Greenwood	3.6 (3.4-3.9)a	4.0 (3.2-4.0)a	4.0 (3.1-4.1)a	17.1 (16.6-19.4)d	18.0 (16.9-19.6)c	17.8 (16.7-19.0)c
	Thanai	3.5 (2.3-2.7)a	3.6 (3.2-4.2)ab	4.0 (3.4-4.1)a	20.5 (19.0-23.6)ab	20.3 (18.3-20.8)a	19.9 (17.7-21.0)a
	Dinjan	2.4 (2.1-2.7)b	2.3 (2.1-2.7)c	2.3 (2.1-2.6)bc	19.0 (17.0-18.6)cd	19.1 (18.5-21.3)b	18.3 (16.5-21.6)b
	Nandanban	2.8 (2.4-3.1)b	3.0 (2.6-3.1)b	2.7 (2.4-2.8)b	21.8 (20.7-22.8)a	22.2 (21.4-23.9)a	21.0 (19.4-21.5)a
	Jalannagar	1.9 (1.4-2.1)c	1.9 (1.6-2.2)d	1.0 (0.9-1.2)d	17.1 (17.0-18.6)d	18.1 (17.6-19.1)c	17.2 (16.2-19.2)c
Dooars (West Bengal)	Telepara	6.4 (4.7-6.8)b	8.7 (5.4-12.2)a	5.6 (2.5-12.5)a	24.8 (23.9-26.2)bc	28.90 (26.3-31.9)cd	22.7 (21.8-23.3)a
	Totapara	6.7 (6.0-8.0)b	8.3 (7.2-9.2)a	5.6 (4.3-7.1)a	24.7 (23.7-26.2)bc	26.81 (23.7-29.5)c	21.2 (20.8-21.7)bc
	Kalabari	13.1 (8.0-17.0)a	7.2 (6.2-8.0)b	3.1 (2.5-3.4)b	28.3 (27.7-28.9)ab	31.41 (30.8-32.4)b	22.5 (21.9-23.0)a
	Huldibari	4.0 (3.2-4.7)e	5.1 (2.8-6.8)c	2.7 (1.4-3.6)c	27.5 (25.4-30.5)bc	36.72 (35.8-38.1)a	22.6 (22.1-23.4)a
	Ethelbari	7.1 (6.2-8.1)b	4.8 (3.1-6.8)c	5.4 (2.7-8.8)a	26.5 (24.4-29.2)bc	21.24 (20.4-24.2)f	20.7 (20.1-21.3)c
	Coochbehar	3.3 (2.5-4.8)ef	1.6 (1.3-1.8)e	1.9 (1.1-2.5)d	31.3 (26.9-33.3)a	26.40 (21.7-24.2)d	19.7 (18.6-20.3)d
	Danguajhar	5.1 (3.1-8.1)de	3.5 (1.3-6.8)d	1.6 (1.2-2.5)d	24.9 (24.1-26.6)b	23.11 (21.0-28.2)ef	23.4 (22.5-24.6)ab
	Jaipur	0.4 (0.4-0.4)f	3.6 (2.7-5.2)d	2.2 (1.3-2.0)d	24.9 (24.0-26.1)bc	24.43 (21.0-28.2)e	20.8 (20.1-22.5)c
	Noweranuddy	5.4 (4.9-5.9)d	1.9 (1.0-2.3)e	2.3 (1.5-3.9)cd	24.8 (23.8-26.9)c	24.11 (20.1-23.1)e	21.9 (21.2-22.2)bc
	Baintgoorie	5.2 (2.9-7.8)d	1.2 (0.4-1.8)e	2.3 (1.8-2.6)cd	24.9 (24.6-25.3)c	23.60 (23.9-25.2)ef	24.0 (23.9-24.2)a

Data are the means of 10 observations at each garden; data in parenthesis are the minimum and maximum observed values; mean values within the column followed by similar letters are not significantly different from one another according to DMRT at $P<0.05$.

level. Interestingly, all the correlations during post-rainy were positively correlated.

Discussion

Soil Physicochemical Properties

The soil pH was found to be moderately acidic in Assam and West Bengal. During the pre-rainy season, the pH of the soils in these regions ranged 3.5–4.5 while they were approximately 5.0 and 7.0 during the rainy and post-rainy seasons, respectively. The variation in the soil pH in the Assam and WB tea gardens likely occurred due to variations in precipitation and the use of synthetic and agrochemicals. Effects of soil pH on soil enzyme activity and mineralization have been reported earlier by Tabatabai and Bremner[28] and Acosta-Marlinez and Tabatabai.[31] In addition, many studies have found that plant diversity and soil pH are related.[32,33] In the present study, we found that the soil pH varied among tea gardens. This may be due to different cultivation practices and the variety of plants used. The variation of soil pH was also due to the soil type of individual tea gardens which also determines the pH of the soil.

Soil respiration, which is a measure of the biological activity of a soil, and soil temperature play critical roles in supporting plant growth. Similarly, the moisture content of the soil is also important to plant's survival and the maintenance of soil health. The importance of soil respiration, temperature and moisture content in soil has been demonstrated in several studies.[34,35] It has been reported that the respiratory quotient[36,37] (RQ) values in aerobic soils range from 0.6 to 1.0 while these values are generally >1.0 in anaerobic soils.[38] These temporal variations are generally associated with abiotic factors such as the soil moisture–temperature relationship.[37,38] The results of the present study revealed that the respiration and temperature varied within an optimal range. This variation, in turn, supports the normal physiochemical characteristics of the soils in tea gardens of Assam and WB.

Soil organic C is referred to the amount of C stored in the soil and is a major factor in its overall health. Soil C maintains the physical properties of soil such as cation exchange capacity, water holding capacity as well as structural stability.[39,40] In Australian soil, an amount of 1.3–10.5% soil organic matter was reported by Leeper and Uren.[39] In the present investigation; NB tea gardens represent 0.19–1.80%, soil organic C, while SB was 0.35–1.0% and WB tea gardens were recorded 0.23–1.67%, respectively.

Soil Enzyme Activity

All soil physicochemical and biological properties are known to change in response to plants.[41] The negative correlation due to variations in plant diversity has also been described by Rodriguez-Loinaz *et al.*[42] In this study, a significant positive correlation ($P < 0.05$) was found between enzyme activity and the post-rainy season in the WB and Assam tea gardens, while a negative correlation was observed between enzyme activity and the other seasons (data not shown). These findings may have been due to the strong relationship between nitrogen application and enzyme activity. Therefore, a negative correlation between urease activity and pre-rainy and post-rainy season was observed. These results are similar to the results of other studies that have shown that the urease activity was greater in flooded soils than non-flooded soils.[43]

Urea is the primary source of N in many crops, including flooded or irrigated rice and maize in many parts of Africa and Asia.[44–46] Soil physiocochemical and soil enzyme activities are very sensitive to natural and anthropogenic activities and vary greatly in response to induced changes.[1,2] These physicochemical and soil enzyme activities play key biochemical roles in soils. Rainy seasons have been found to enhance the enzyme activity of dehydrogenase in soils in southeastern Spain.[13] In addition, increased microbial activity in forest[47] and grassland soils are often attributed to a higher soil characters.[48] In pre-rainy seasons, an increase in dehydrogenase activity has been found to occur in response to the amendment of soils with different synthetic and organic fertilizers, which may also contribute to observed seasonal increases in dehydrogenase activity. The amendment of synthetic and organic manure has also been found to increase the overall soil oxidase activity.[49] Differences in the soil enzyme activity and soil physiological properties can also occur due to differences in soil texture and the age and nature of cultivation.[50,51]

Relationships among the Tea Gardens

Cluster analysis showed no uniformity of clustering among the tea gardens. During rainy, two distinct clusters were found. The first group represents the tea gardens of north bank and Dooars region of Assam and WB while second group comprises SB alone. On the other hand, there was a mixed representation of tea gardens for the pre- and post-rainy seasons. The uniformity among the tea gardens during monsoon due to similarities in man-

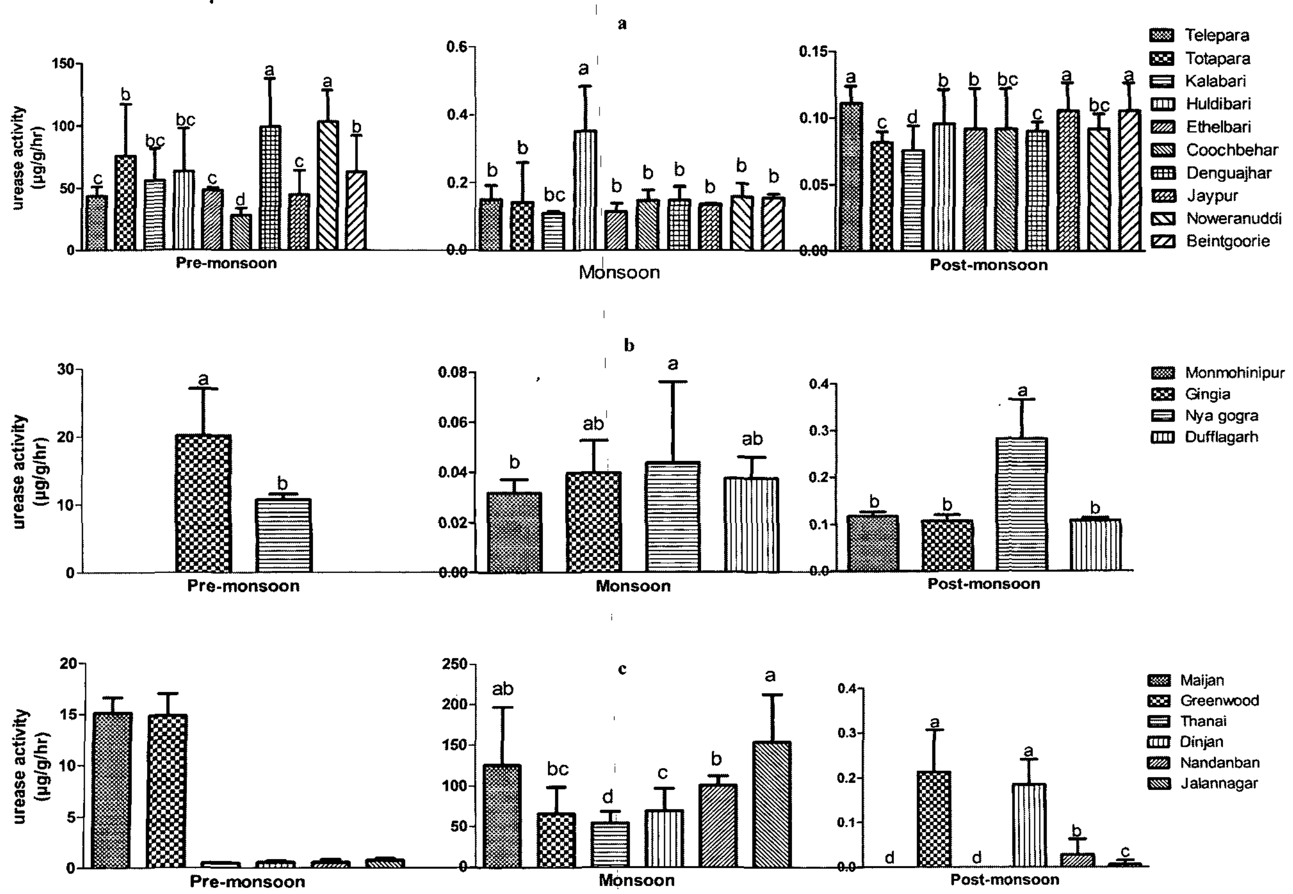

Figure 3. Urease activity of different tea gardens in Assam and West Bengal in three different seasons.

Data are mean of 10 individual observations; error bars represent standard error means of observed values; error bars followed by similar letter within the group are not significantly different from one another according to DMRT at $P<0.05$; a. Dooars region of West Bengal (WB); b. North bank (NB) of Assam c. South bank (SB) of Assam.

Table 5: Correlation analysis among soil physical and biochemical parameters for the different tea gardens of Assam and West Bengal

Seasons	Parameters	pH	Phosphatase	Dehydrogenase	Urease	Moisture	Carbon	Temperature	Respiration
Pre monsoon	pH	1							
	Phosphatase	-.005	1						
	Dehydrogenase	-.464*	-.229	1					
	Urease	-.729**	-.113	.654**	1				
	Moisture	-.464*	-.041	.314	.532*	1			
	Carbon	-.734**	-.056	.356	.742**	.370	1		
	Temperature	-.646**	-.465	.409	.613**	.167	.491*	1	
	Respiration	-.707**	-.047	.004	.323	.172	.350	.446*	1
Monsoon	pH	1							
	Phosphatase	-.201	1						
	Dehydrogenase	-.469*	-.435*	1					
	Urease	-.309	.787**	-.428	1				
	Moisture	.011	-.484*	.430	-.522*	1			
	Carbon	.126	-.502*	.076	-.500*	.197	1		
	Temperature	.250	-.541*	.247	-.550**	.514*	.322	1	
	Respiration	.086	-.177	.106	-.313	.251	-.136	.378	1
Post monsoon	pH	1							
	Phosphatase	-.213	1						
	Dehydrogenase	.173	-.403	1					
	Urease	.470*	-.034	-.294	1				
	Moisture	.362	-.088	-.200	.449*	1			
	Carbon	.454*	-.279	-.089	.044	-.067	1		
	Temperature	.099	-.115	.325	.146	.250	-.063	1	
	Respiration	-.131	-.033	.373	-.013	.046	-.055	.457*	1

*, correlation is significant at the 0.05 level (two-tailed); **, Correlation is significant at the 0.01 level (two-tailed)

agement practices was prevalent among the tea gardens and also the soil type. On the other hand, the maximum variation during pre-rainy and post-rainy may be due to early initiation of manure amendment while in post-rainy the variation may be due to the late plucking in some tea gardens and also the influence of climate. The relationships of tree size and soil respiration, and microbial nitrogen in relation to forest type were earlier studied by Brechet *et al.*,[52] and Zechmeistern-Boltenstern *et al.*[53] Correlation analysis found that pH showed a significant correlation among the other parameters during pre-monsoon followed by urease > dehydrogenase > organic carbon > temperature. It was observed that phosphatase showed no significant correlations among the other factors. However, in rainy phosphatase showed a significant correlation, except pH and respiration, followed by urease > moisture > temperature > carbon, respectively. The phosphorous and nitrogen fertilization during rainy seasons may be the reason for significant correlation. On the other hand, significant correlation during post-rainy was shown by pH followed by urease > carbon and temperature. The diverse correlation among post-rainy for different tea gardens was due to the cessation of green leaf production. The influence of soil biochemical characters due to fertilization intensity, tillage and pasture management, tree size were reported by several workers.[54–56] A positive correlation between organic carbon content and other soil parameters were reported by Bonanomic *et al.*[57] The variation in microbial enzyme activity in intensive cultivation, and corresponding less disturbed soil was earlier reported by several workers and is supporting the present findings.[31,58,59]

Conclusion

Variation in soil physiological and biological properties was observed among soils from tea gardens in Assam and WB. The SB tea gardens contained loamy soils with an average age of cultivation between 50 years and 70 years while the NB gardens contained sandy loam soils with an average age of cultivation between 43 years and 80 years. In addition, the tea gardens in WB contained sandy loam to heavy soil with an average age of cultivation more than 70 years. The pH of all soils evaluated in this study was moderately acidic and the moisture holding temperature capacities were 20%, 25% and 35% for the SB, NB and Dooars regions, respectively. Additionally, the temperature was 36°C for Dooars, 26°C for NB and 22°C for SB. Similarly, the respiration ranged from 0.87 to 4.00 μmol m^{-2} s^{-1}; 1.02 to 4.00 μmol m^{-2} s^{-1} and 0.42 to 5.6 μmol m^{-2} s^{-1} for NB, SB and WB, respectively. A nega-

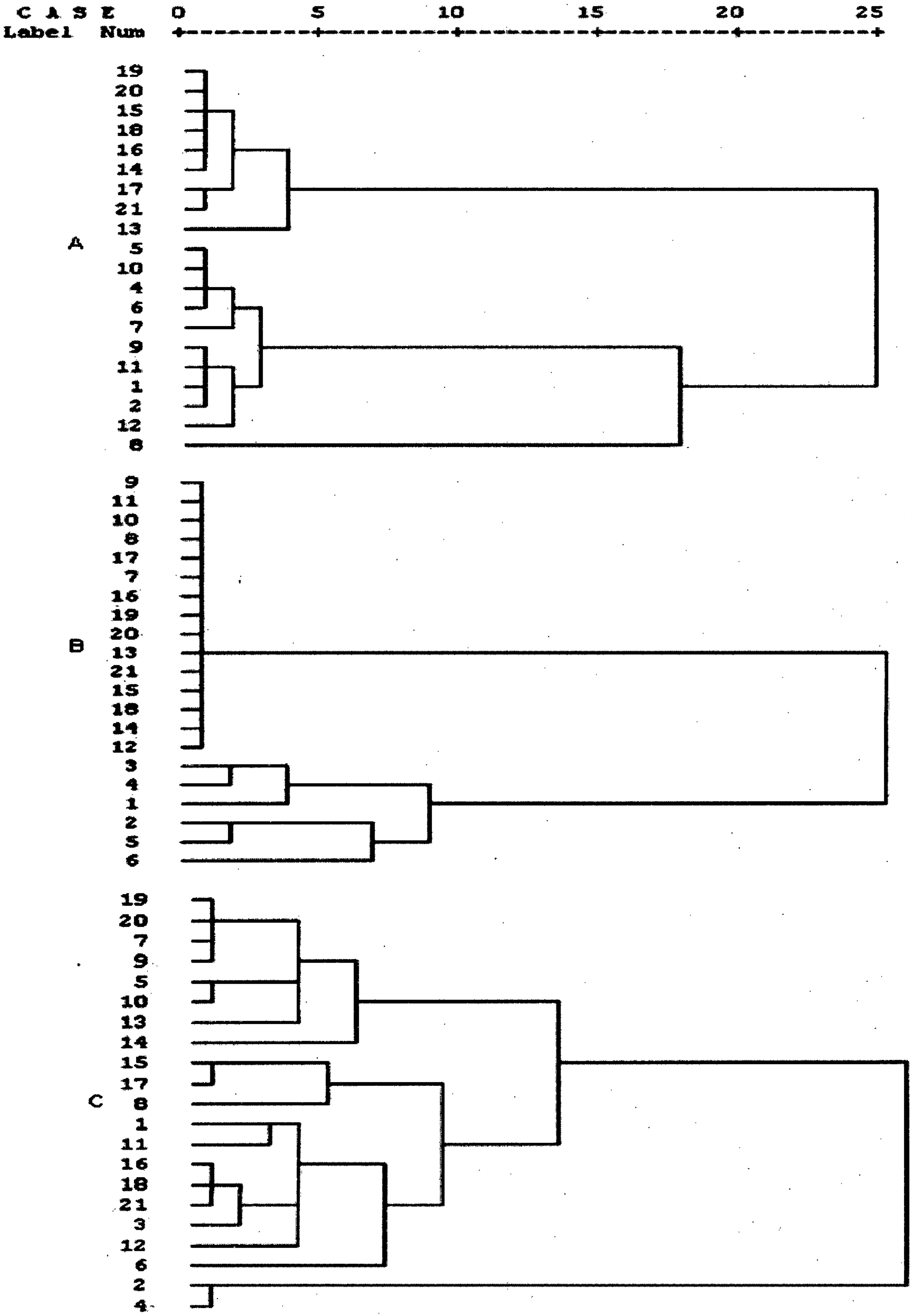

Figure 4. Cluster analysis among soil physical and biochemical parameters for the different tea gardens of Assam and West Bengal.

1. Maijan; 2. Greenwood; 3. Thanai; 4. Dinjan; 5. Nandanban; 6. Jalannagar; 7. Monabag; 8. Monmohinipur; 9. Gingia; 10. Nyagogra; 11. Dufflagarh; 12. Telepara; 13. Totapara; 14. Kalabari; 15. Huldibari; 16. Ethelbari; 17. Cooch Behar; 18. Danguajhar; 19. Joypur; 20. Noweranuddy and 21. Baintgoorie.

tive correlation with respect to seasons was observed for the enzyme activity of phosphatase, dehydrogenase and urease enzymes for all of the tea gardens.

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References

1. Dick RP, 1997, Soil enzyme activities as integrative indicators of soil health. In: CE Pankhurst, BM Doube, and VVSR Gupta (Eds.), *Biological Indicators of Soil Health*, CAB international: Wellingford, pp. 121–156.
2. Quilchano C & Maranon T, 2002, Dehydrogenase activity in Mediterranean forest soils. *Biol Fert Soils* 35: 102–107.
3 Burns RG, 1983, Extracellular enzyme–substrate interactions in soil. In: JH Slater, R Wittenbury, and JWT Wimpenny (Eds), *Microbes in Their Natural Environment*, Cambridge University Press: London, pp. 249–298.
4. Sinsabaugh RL, Antibus RK, & Linkins AE, 1991, An enzymatic approach to the analysis of microbial activity during plant litter decomposition. *Agr Eco Environ* 34: 43–54.
5. Dick RP, 1994, Soil enzyme activities as indicators of soil quality. In: JV Doran, DC Coleman, DF Bezdicek, and BA Stewart (Eds), *Defining Soil Quality for a Sustainable Environment, Soil Sci. Soc. of Ame.*, American Society of Agriculture: Madison, pp. 107–124.
6. Bergstrom DW, Monreal CM, & King DJ, 1998, Sensitivity of soil enzyme activity to conservation practices. *Soil Sci Soc Am J* 62: 1286–1295.
7. Beyer L, Wachendorf C, Balzer FM, & Balzer-Graf UR, 1992, The effect of soil texture and soil management on microbial biomass and soil enzyme activities in arable soils of Northwest Germany. *Agrobiol Res* 45: 2766–2836.
8. Dick RP, 1992, A review: Long-term effects of agricultural systems on soil biochemical and microbial parameters. *Agr Eco Environ* 40: 25–36.
9. Miller M & Dick RP, 1995, Thermal stability and activities of soil enzymes as influenced by crop rotations. *Soil Biol Biochem* 27: 1161–1166.
10. Tabatabai MA, 1994, Soil enzymes. In: RW Weaver, JS Angle, and PS Bottomley (Eds), *Methods of Soil Analysis*, part 2. *Microbiological and Biochemical Properties*. SSSA Book Series No. 5, Soil Science Society of America: Madison, WI, pp. 775–833.
11. Schimdt G & Laskowski Sr. M, 1961, Phosphate ester cleavage (Survey). In: PD Boyer, H Lardy, and K Myrback (Eds), *The Enzymes*, 2nd edn. Academic Press: New york, pp. 3–35.
12. Cookson P, 2002, Variation in phosphatase activity in soil: A case study. *Agricul Sci* 7: 65–72. Department of Soil and Water Sciences, College of Agricultural and Marine Sciences, Sultan Qaboos University, Sultanate of Oman.
14. Doelman P & Haanstra L, 1979, Effects of lead on soil respiration and dehydrogenase activity. *Soil Biol Biochem* 11: 475–479.
15. Glinski J & Stepniewski W, 1985, *Soil Aeration and its Role for Plants*. CRC Press: Boca Ralton, Florida.
16. Kandeler E, Kampichler C, & Horak O, 1996, Influence of heavy metals on the functional diversity of soil microbial communities. *Biol Fert Soils* 23: 299–306.
17. Andrew RK, Blakeley RL, & Zerner B, 1989, Ureases: A Ni(II) metalloenzyme. In: JR Lancaster (Ed), *The Bioinorganic Chemistry of Nickel*, VCH Publishers: New York, pp. 141–166, 221–231.
18. Byrnes BH & Amberger A, 1989, Fate of broadcast urea in a flooded soil when treated with N-(*n*-butyl) thiophospheric triamide, a urease inhibitor. *Fertil Res* p. 18.
19. Rotini OT, 1935, La transformazione enzimatica dell'urea nel terreno. *Ann Labor Ric Ferm Spallanrani* 3: 143–154.
20. Saikia N, Barthakur M, & Deka Boruah HP, 2000, Effect of siderophore on soil enzyme activities. *Ind J Agr Sci* 70: 697–699.
21. Bezbaruah B, Bora T, & Saikia N, 1996, A comparison of soil enzyme activities in forest and tea (*Camellia sinensis*) plantation soil samples. *Ind J Agr Sci* 68(9): 616–619.
23. Arshad MA & Coen GM, 1992, Characterization of soil quality: Physical and chemical criteria. *Am J Alt Agr* 7: 25–33.
24. Parr JF, Papendick RI, Hornick SB, & Meyer RE, 1992, Soil quality: Attributes and relationship to alternative and sustainable agriculture. *Am J Alt Agr* 7: 5–11.

25. Visser S & Parkinson D, 1992, Soil biological criteria as indicators of soil quality: Soil micro-organisms. *Am J Alt Agr* 7: 33–37.

26. Walkley A & Black A, 1934, An examination of the Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Sci* 37: 29–37.

27. Trivedy RK, Goel PK, & Trisal CL, 1998, *Practical Methods in Ecology and Enviro Media Series in Methodology 2*. Enviro Media Publication: Karad, India.

28. Tabatabai MA & Bremner JM, 1972, Assay of urease activity in soils. *Soil Biol Biochem* 4: 479–487.

29. Casida DE, 1964, Soil dehydrogenase activity. *Soil Sci* 98: 371–376.

30. Mc. Garity JW & Myers MC, 1967, A survey of urease activity in soils of Northern New South Wales. *Plant Soil* 27: 217–238.

31. Acosta-Martinez V, AcostaMercado D, Sotomajor-Ramierz D, & Cruz-Rodriguez L, 2008, Microbial community and enzymatic activities under different management in semi arid soil. *Appl Soil Ecol* 38: 249–260.

32. Liniere A & Houle G, 2006, Response of herbaceous plant diversity to reduced structural diversity in maple-dominated (*Acer saccharum* Marsh.) forests managed for sap extraction. *Forest Ecol Mgmt* 231: 94–104.

33. Partel M, 2006, Data availability for macroecology: How to get more out of regular ecological papers. *Acta Oeco* 30(1): 97–99.

34. Carl JM, Joshuua S, & Allen PD, 2002, Temperature controls microbial respiration in arctic tundra soils above and below freezing. *Soil Biol Biochem* 34: 1785–1795.

35. Hill H, Herlihy AT, & Kaufmann PR, 2002, Benthic microbial respiration in Appalachian mountain, Piedmont, and coastal plains streams of the eastern U.S.A. *Freshwater Biol* 47: 185–194.

36. Klein DA, 1977, Seasonal carbon flow and decomposer parameter relationships in a semiarid grassland soil. *Ecol* 58: 184–190.

37. Dilly O, 2001, Microbial respiratory quotient during basal metabolism and after glucose amendment in soils and litter. *Soil Biol Biochem* 33: 117–127.

38. Scagel CF & Andersen CP, 1977, Seasonal changes in root and soil respiration of ozone-exposed ponderosa pine (*Pinus ponderosa*) grown in different substrates. *New Phyt* 136: 627–643.

39. Leeper GW & Uren NC, 1993, *Soil Science: An Introduction* (5th edn). Melbourne University Press: Melbourne.

40. Bardgett RD, 2005, *The Biology of Soil: A Community and Ecosystem Approach*. Oxford University Press: New York.

41. Agnelli A, Ascher J, Corti G, Eecherini MT, Nannipieri P, & Pietramellara G, 2004, Distribution of microbial communities in a forest soil profile investigated by microbial biomass, soil respiration and DGGE of total and extracellular DNA, *Soil Biol Biochem* 36: 859–868.

42. Rodriguez-Loinaz G, Onaindia M, Amezaga I, Mijangos I, & Garbisu C, 2008, Relationship between vegetation diversity and soil functional diversity in native mixed-oak forests. *Soil Biol Biochem* 40: 49–60.

43. Dkhar MS & Mishra RR, 1983, Dehydrogenase and urease activities of maize (*Zea mays* L.) field soils. *Plant Soil* 70: 327–333.

44. Stangel PJ, 1984, World nitrogen situation-trends, out-look, and requirements. In: RD Hauck (Ed.), *Nitrogen in Crop Production*. American Society of Agronomy: Madison, WI, pp. 23–53.

45. Buresh RJ, De Datta SK, Padilla JL, & Samson MI, 1988, Effect of two urease inhibitors on floodwater ammonia following urea application to lowland rice. *Soil Sci Soc Am J* 52: 856–861.

46. Van Cleemput O & Wang Z, 1991, Urea transformations and urease inhibitors. *Trop Soil Sci* 1: 45–51.

47. Gorres JH, Dichiaro MJ, Lyons JB, & Amador JA, 1998, Spatial and temporal patterns of soil biological activity in a forest and old field. *Soil Biol Biochem* 30: 219–230.

48. Banerjee MR, Burton DL, McCaughery WPP, & Grant CA, 2000, Influence of pasture management on soil biological quality. *J Range Mgmt* 53: 127–133.

49. Herrick JE, 2000, Soil quality: An indicator of sustainable land management. *App Soil Eco* 15: 75–83.

50. Williamson WM & Wardle DA, 2007, The soil microbial community response when plants are subjected to water stress and defoliation disturbance. *App Soil Eco* 37: 139–149.

51. Harmer U, Makeschin F, Standler J, & Klotz S, 2008, Soil organic matter and microbial community structure in set-aside and intensely managed arable soils in NE-Saxony, Germany. *App Soil Eco* 40: 465–475.

53. Zechmeistern-Boltenstern S, Michel K, & Pfeffer M, 2011, Soil microbial community structure in European forests in relation to forest type and atmospheric nitrogen diposition. *Plant Soil* 343: 37–50.

54. de Vries, Hoffland E, van Eekeren N, Brusaard L, & Bloem J, 2006, Funagal/bacterial ratios in grassland with contrasting nitrogen management. *Soil Biol Biochem* 38: 2092–2103.

55. Frey SD, Elliot ET, & Paustian K, 1999, Bacterial and fungal abundance and biomass in conventional and no tillage agrosystems along two climate gradients. *Soil Biol Biochem* 31: 573–585.

56. Brechet L, Ponton S, Almeras T., Bonal D, & Epron D, 2011, Does spatial distribution of tree size account for spatial variation in soil respiration in a tropical forest? *Plant Soil*, DOI: 10.1007/s11104-011-0848-1.

57. Bonanomi G, D'Ascoli R, Antignani V., Capodilupo M., Cozzolino L, Marzaioli R, Puopolo G, Rutigliano FA, Scelza R, Scotti R, Rao MA, & Zoina A, 2011, Assessing soil quality under intensive cultivation and tree orchards in Souther Italy. *App Soil Ecol*, DOI: 10.1016/j.apsoil.2010.12.007.

58. Drinkwater LE, Letourneau DK, Workneh F, van Bruggen AHC, & Shennann C, 1995, Fundamental difference between conventioanl and organic tomato ecosystem in Calfornia. *Ecol Appl* 5: 1098–1112.

59. Gianfreda L, Rao MA, Pitrowska A, Palmobo G, & Colombo C, 2005, Soil enzyme activities as affected by anthropogenc alteration: Intensive agricultural practices and organic pollution. *Sci Total Environ* 341: 265–279.