Range Mgmt. & Agroforestry 39 (2) : 147-155, 2018
ISSN 0971-2070

Fertility status of mulberry (*Morus indica* L.) growing soils of upper Brahmaputra valley region of north eastern India

Prasenjit Ray[1]*, S. N. Gogoi[2], S. Bandyopadhyay[3], S. Padua[1], R. K. Jena[1], P. Deb Roy[1], S. Ramachandran[1], G. K. Sharma[1], K. D. Sah[3], K. Trivedy[4], S. K. Singh[5] and S. K. Ray[1]
[1]ICAR-National Bureau of Soil Survey and Land Use Planning, Regional Centre, Jorhat-785004, India
[2]Regional Sericultural Research Station, Central Silk Board, Jorhat-785005, India
[3]ICAR- National Bureau of Soil Survey and Land Use Planning, Regional Centre, Kolkata-700091, India
[4]Central Sericultural Research and Training Institute, Central Silk Board, Berhampore-742101, India
[5]ICAR-National Bureau of Soil Survey and Land Use Planning, Nagpur-440033, India
*Corresponding author e-mail: prasenjit.iari@gmail.com
Received: 16th January, 2018 Accepted: 31st October, 2018

Abstract
Mulberry (*Morus indica* L.) is an agroforestry species grown extensively in India as multipurpose tree. In north eastern India, it is cultivated as sole crop for rearing silkworm under low management practices without any chemical fertilizers and organic inputs. Besides, limited scope of incorporation of mulberry leaves in soil prevents the addition of organic matter into soil. Therefore, the quality of mulberry leaf as well as silk solely depends on the nutritional status of soil on which mulberry is grown. In the present investigation, an attempt was made to assess the fertility status of soil under mulberry cultivation as sole crop in six rural development blocks namely, Kakodonga, Dergaon, Kathalguri, Podumoni, Sarupathar and Bokakhat of Golaghat district in upper Brahmaputra valley of Assam in north eastern India. Results indicated that soils were extremely to strongly acidic (pH < 5.5) in 44% of the mulberry gardens. Organic carbon content was medium to high in 80% of the surface soil samples (0-20 cm.) and low to medium in 84% of sub-surface soil samples (20-50 cm.). About 51% of the sub-surface soil samples were low in N and 98% of the sub-surface soil samples were low in P status. Among micronutrients, B was deficient in more than 80% samples; whereas, Zn deficiency was found in 36% of the sub-surface samples. Nutrient index values indicated that mulberry growing soils of Kakodonga and Bokakhat were the least fertile as far as the availability of major nutrients are concerned due to the soil resources of recent origin (Entisols) with coarse texture occurring on active flood plains in these blocks. The study indicated the wide spread nutritional deficiency in soils of upper Brahmaputra valley of north eastern India.

Keywords: Mulberry, Nutrient index, Soil fertility status, Soil taxonomy

Introduction
Mulberry (*Morus spp.*) is one of the common tree species grown under agroforestry systems in different countries (Rama Kant *et al*., 2004; Neupane and Thapa, 2001). It is also reported as important tree species grown for animal fodder under silvipasture system (Sharma and Zote, 2010; Kumar *et al*., 2017). However, it is cultivated as sole crop under low management practices in the north eastern region (NER) of India for rearing silkworm (*Bombyx mori* L.). Farmers usually do not apply fertilizers in the mulberry field. Besides, limited scope of retention and incorporation of mulberry leaf in soil hinders the process of addition of organic matter and nutrient recycling in mulberry growing soils since the leaves are mostly fed to the silkworm. Under such conditions, nutrient depletion is a common phenomenon which needs proper attention. The importance of essential nutrient elements in soils on the quality of both the mulberry leaf and silkworm cocoon was studied earlier by various researchers (Shankar and Rangaswamy, 1999; Lu *et al*., 2004; Chen *et al*., 2009). However, systematic assessment of fertility status of mulberry growing soils is meager (Bongale and Lingaiah, 1998; Samanta *et al*., 2002).

Recent estimate indicates that total area under mulberry cultivation is 26,398 ha in the NER of the country (CSB, 2016). Among the traditional mulberry growing belts in India, upper Brahmaputra valley (UBV) region of Assam is one of them. Since mulberry is a deep-rooted tree crop, it draws a part of its required nutrients from sub-surface layers of soil. Hence, assessment of fertility parameters in sub-surface soil layer under mulberry cultivation is equally important. In view of these facts, the present study was undertaken to assess the fertility status of surface and sub-surface soil in relation to land resources under mulberry cultivation as sole crop.

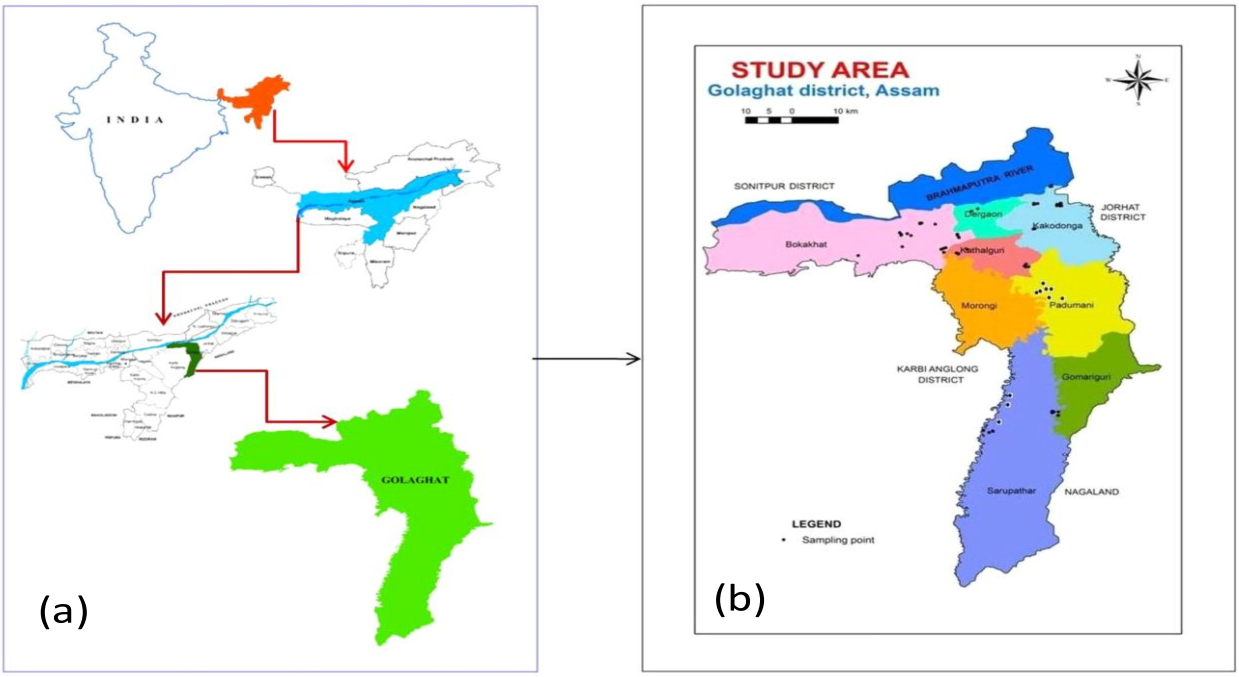

Fig 1. Maps of the study area showing (a) location and (b) soil sampling points

Materials and Methods

***Study area, collection of soil samples and yield data*:** The study area covers hundred sole mulberry gardens under six development blocks namely, Kakodonga, Dergaon, Kathalguri, Podumoni, Sarupathar and Bokakhat of Golaghat district in upper Brahmaputra valley of Assam. Composite soil samples were collected at two different depths *viz*., surface (0-20 cm) and sub-surface (20-50 cm) from hundred sampling points in these six blocks (Fig 1). Sampling was done during winter season in the year 2016. The age of plantations varied from one year to ten years. During soil sampling, leaf yield data of mulberry plantations under differential ages were also collected through interaction with the mulberry growers, wherever possible.

***Soil and land resources in the study area*:** In order to identify the soil and land resources in the study area, available database of Indian Council of Agricultural Research (ICAR)-National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) was utilized. The major soils/ soil associations and landforms were identified in the study area under different blocks of Golaghat district (Table 1). It was found that major soils of the study area belong to Fluvaquents, Udifluvents, Dystrudepts and Endoaquepts. Texture of soil varies from coarse-loamy to fine-silty in the study area. Two major landforms were identified namely, active flood plain and old alluvial plain.

***Processing and chemical analysis of soil samples*:** Soil samples were air-dried, ground, passed through 2-mm sieve and analyzed for important properties. For determination of organic carbon, soil samples were passed through 0.2 mm sieve. Soil pH and electrical conductivity (EC) were determined following standard procedure (Jackson, 1973). Soil organic carbon (OC) was

Table 1. Major soils/ soil associations and landforms under mulberry land use system in different blocks of Golaghat district of Assam in north eastern India

Block name	Land use system	Major soils/ soil associations	Major landforms
Kakodonga	Mulberry	Coarse-loamy Typic Fluvaquents	Active flood plain
Dergaon	Mulberry	Coarse-silty Typic Udifluvents	Active flood plain
Kathalguri	Mulberry	Fine-loamy Typic Dystrudepts	Old alluvial plain
Podumoni	Mulberry	Fine-loamy Typic Dystrudepts	Old alluvial plain
Sarupathar	Mulberry	Fine-silty Aeric Endoaquepts	Old alluvial plain
Bokakhat	Mulberry	Coarse-loamy Typic Fluvaquents Coarse-silty Aquic Udifluvents	Active flood plain

determined by chromic acid oxidation method (Walkley and Black, 1934). The available nitrogen (N) was determined by the alkaline potassium permanganate ($KMnO_4$) method (Subbiah and Asija, 1956). Standard procedures were followed for the determination of available phosphorus (Bray and Kurtz, 1945), ammonium acetate extractable potassium (Jackson, 1973) and sulphur (0.15% $CaCl_2$) (Chesnin and Yien, 1951). For determination of available zinc (Zn), copper (Cu), iron (Fe) and manganese (Mn), soil samples were extracted with DTPA (0.005 *M*) (Lindsay and Norvell, 1978) and the concentrations of these micronutrients in the extract were determined by atomic absorption spectrophotometer (AAS). For determination of available boron (B), soil samples were extracted with hot water and B in clear extract was determined by Azomethine-H (John *et al*., 1975).

***Assessment of soil fertility status using nutrient index*:** Nutrient index (NI) value for available N, P (as P_2O_5) and K (as K_2O) was calculated block wise for surface soil samples as described by Motsara *et al*. (1982).

$$\text{Nutrient index} = [(Nl \times 1) + (Nm \times 2) + (Nh \times 3)] / Nt$$

where, N*t* = total number of samples analyzed in given area; N*l* = number of samples falling in the low category of nutrient status; N*m* = number of samples falling in the medium category of nutrient status; and N*h* = number of samples falling in high category of nutrient status. On the basis of NI value, soil fertility level in respect of N, P and K was categorized as low (if NI < 1.67), medium (1.67 $\leq$ NI $\leq$ 2.33), or high (NI > 2.33).

***Statistical analysis*:** Descriptive statistical analysis and correlation analysis were done by data analysis function of SAS software. For correlation study between important soil properties and nutrient availability, pooled data for surface and sub-surface soil samples were used. For analysis of correlation between mulberry leaf yield and nutrient availability, the data for surface soil samples were considered. The mean values of soil properties in surface and sub-surface soil (pooled data) were statistically compared and evaluated by applying paired t-test.

Results and Discussion

***Soil reaction, electrical conductivity and organic carbon content*:** Data pooled over locations showed variation in surface soil pH (4.3 to 7.6), EC (0.01 to 0.13 dS m^{-1}) and OC content (0.05 to 1.90%). The pH, EC and OC content in sub-surface soils ranged from 4.4 to 7.6, 0.01 to 0.10 dS m^{-1} and 0.02 to 1.47%, respectively (Table 2). Paired t-test indicates significant difference in mean values of these properties between surface and sub-surface soil. In general, the pH of sub-surface soils was recorded higher than that of surface soils. Whereas, EC and OC content were recorded higher in surface soils as compared to those recorded in sub-surface soils. The observations on soil pH indicated that 6.0, 19, 20, 22 and 17% of the surface soil samples were extremely acidic (pH $\leq$ 4.5), very strongly acidic (4.5< pH $\leq$ 5.0), strongly acidic (5.0< pH $\leq$ 5.5), medium acidic (5.5<pH $\leq$ 6.0) and slightly acidic (6.0<pH $\leq$ 6.5), respectively. Neutral (6.5<pH $\leq$ 7.3) and mildly alkaline (7.3<pH $\leq$ 7.8) reaction were found in 15 and 1% of the surface samples, respectively. Similarly, 76% of the sub-surface soil samples were categorised under extremely acidic to slightly acidic reaction, whereas, 24% of samples were neutral to mildly alkaline. Acidic reaction of soils might be due to high annual rainfall (2000-2500 mm) in this region and consequent low base saturation of soil. Further, it was observed that soil pH was <5.5 within 50 cm depth in case of 44 mulberry gardens (44% of total gardens), which indicates aluminium toxicity for mulberry crop in these gardens (Evans and Kamprath, 1970). The EC values of the soils were normal, which might be attributed to leaching of salts below root zone due to high rainfall. Organic carbon content in surface soil was recorded as high in 46%, medium in 34% and low in 20% of the samples according to the OC rating as suggested by Muhr *et al*. (1965). Whereas, 57% of the sub-surface soil samples were rated as low, 27% as medium and only 16% as high in OC content. Higher OC content in surface soil may be ascribed to the possible accumulation of litters in the surface soil under mulberry land use system. Low to medium status of OC in sub-surface soil (84%) samples indicates the need of rejuvenating soil health in sub-surface strata, since the OC content in sub-surface soil is equally important as in the surface soil under deep-rooted mulberry cultivation.

***Available macronutrient status*:** Availability of major nutrients *viz*., N, P_2O_5, K_2O and S was higher in surface soils as compared to that in sub-surface soils. The mean values of N, P_2O_5 and K_2O in surface soil were 334, 26.9 and 276 kg ha^{-1}, respectively; corresponding values in sub-surface soil were 258, 21.1 and 226 kg ha^{-1}, respectively (Table 3-4). Sulphur content in surface soils varied from 10.4 to 23.0 mg kg^{-1} with the mean value of 16.8 mg kg^{-1}, whereas, S content varied from 9.20 to 20.4 mg kg^{-1} in the sub-surface soils with the corresponding

Table 2. Important properties of mulberry growing soils of Golaghat district of Assam

Mulberry growing area	pH		EC (dSm^{-1})		OC (%)	
	Depth (cm)		Depth (cm)		Depth (cm)	
	0-20	20-50	0-20	20-50	0-20	20-50
Kakodonga (16)++	5.2-7.6	5.8-7.6	0.02-0.13	0.01-0.06	0.05-1.90	0.04-1.47
	(6.5±0.67)#	(6.9±0.70)	(0.04±0.03)	(0.02±0.01)	(0.67±0.49)	(0.37±0.38)
Dergaon (10)	4.3-5.8	4.4-6.3	0.01-0.05	0.01-0.03	0.14-1.79	0.02-0.73
	(5.0±0.57)	(5.4±0.69)	(0.02±0.01)	(0.01±0.08)	(0.88±0.44)	(0.39±0.25)
Kathalguri (18)	4.4-6.4	4.5-6.6	0.01-0.10	0.01-0.06	0.35-1.20	0.20-0.80
	(5.0±0.54)	(5.3±0.55)	(0.04±0.03)	(0.02±0.01)	(0.77±0.23)	(0.49±0.17)
Podumoni (9)	5.1-7.0	5.6-7.3	0.02-0.10	0.01-0.04	0.26-1.29	0.18-1.06
	(5.9±0.62)	(6.3±0.57)	(0.04±0.03)	(0.03±0.01)	(0.78±0.36)	(0.57±0.30)
Sarupathar (17)	5.0-6.8	5.2-7.1	0.02-0.12	0.01-0.07	0.35-1.60	0.24-1.10
	(5.9±0.55)	(6.1±0.57)	(0.06±0.04)	(0.03±0.01)	(0.79±0.36)	(0.54±0.25)
Bokakhat (30)	4.8-7.3	4.9-7.4	0.01-0.12	0.02-0.10	0.26-1.56	0.15-1.06
	(5.6±0.80)	(5.8±0.81)	(0.06±0.04)	(0.05±0.03)	(0.79±0.34)	(0.50±0.26)
Pooled soil samples	4.3-7.6	4.4-7.6	0.01-0.13	0.01-0.10	0.05-1.90	0.02-1.47
	(5.7±0.80)**	(5.9±0.84)	(0.05±0.03)**	(0.03±0.02)	(0.77±0.36)**	(0.48±0.27)

++Figures in parenthesis indicate number of soil sampling points; #Figures in parenthesis indicate (mean ± standard deviation); **Indicates that the differences between means at two different depths are significant at 1% probability level

Table 3. Status of available macronutrients in mulberry growing soils of Golaghat district of Assam

Mulberry growing area	N (kg ha^{-1})		P_2O_5 (kg ha^{-1})		K_2O (kg ha^{-1})	
	Depth (cm)		Depth (cm)		Depth (cm)	
	0-20	20-50	0-20	20-50	0-20	20-50
Kakodonga (16)++	47.5-398	47.5-379	14.7-54.8	12.5-35.3	100-357	67.2-315
	(291±90)#	(202±110)	(26.9±10.1)	(21.4±6.21)	(265±77)	(204±68)
Dergaon (10)	180-480	66.5-389	17.6-51.4	14.5-30.7	141-479	114-347
	(370±87)	(239±98)	(28.5±8.77)	(21.4±4.28)	(317±96)	(234±77)
Kathalguri (18)	175-486	106-401	18.0-31.5	14.5-27.4	100-420	60.5-377
	(343±90)	(278±82)	(25.5±4.31)	(20.6±3.79)	(292±85)	(250±81)
Podumoni (9)	341-490	287-387	17.7-37.7	14.6-29.6	161-389	114-301
	(428±52)	(346±38)	(27.2±5.92)	(22.4±5.13)	(332±70)	(256±68)
Sarupathar (17)	250-495	165-390	17.2-38.3	13.6-29.5	114-416	89.0-396
	(359±60)	(283±72)	(24.6±6.00)	(19.5±4.25)	(301±109)	(275±103)
Bokakhat (30)	123-469	104-359	19.8-38.2	14.1-29.8	125-356	98.5-333
	(299±88)	(241±62)	(28.3±5.48)	(21.6±4.28)	(229±72)	(184±63)
Pooled soil samples	47.5-495	47.5-401	14.7-54.8	12.5-35.3	100-479	60.5-396
	(334±90)**	(258±86)	(26.9±6.74)**	(21.1±4.59)	(276±90)**	(226±83)

++Figures in parenthesis indicate number of soil sampling points; #Figures in parenthesis indicate (mean ± standard deviation); **Indicates that the differences between means at two different depths are significant at 1% probability level

mean value of 14.4 mg kg^{-1}. According to the ratings suggested by Muhr *et al*. (1965), the surface soil samples for available N could be categorised into medium (72% soil samples; 280 to 560 kg N ha^{-1}) and low (28% soil samples; <280 kg N ha^{-1}). Similarly, sub-surface soil samples were also reported to have medium (49% soil samples) and low (51% soil samples) available N status. The magnitude of soil samples having low available N status was higher in sub-surface soil in comparison to surface soil. This might be attributed to the higher OC content in surface soil with respect to sub-surface soil. Such low N status (up to 51% of samples) of mulberry growing soils might have large scale implication on the quality (N content) of leaf. The positive effect of N fertilization on mulberry leaf yield and quality in relation to silkworm cocoon characters was reported by Shankar and Rangaswamy (1999). On the basis of the limit in relation to available P (as P_2O_5) in soil as suggested by Baruah and Barthakur (1997), 88% of the surface soil samples were in low (<34 kg P_2O_5 ha^{-1}) and 12% of the samples were in medium (34-68 kg P_2O_5 ha^{-1}) category. Similarly in case of sub-surface soil, low P status (98%

samples) dominated over medium (2% samples) category. Low P status in these soils might be ascribed to the precipitation of P as iron and aluminium complexes due to acidic reaction of soil. The status of available K (as K_2O) in surface soil was rated as medium (62% soil samples; 135 to 335 kg K_2O ha^{-1}), high (32% samples; >335 kg K_2O ha^{-1}) and low (6% samples; <135 kg K_2O ha^{-1}) category as per the ratings suggested by Muhr *et al.* (1965). Whereas, available K was medium in 75%, low in 16% and high in 9% of the soil samples in sub-surface layer. Perusal of data indicated that S content was sufficient in all the surface soil samples, whereas, only 6% of the sub-surface soil samples were deficient in available S as per the critical limit of 10 mg kg^{-1} (0.15% $CaCl_2$ extractable S). In order to harness the benefit of high available S, proper N management is needed for maintaining appropriate N:S ratio in mulberry growing soils as well as mulberry leaves. Since both the elements are the constituents of protein, S metabolism in plants is closely linked with N. In view of the quality of mulberry leaf, proper N fertilization should be adopted since 51% of the soil samples in sub-surface layer were found low in available N status.

Table 4. Status of available sulphur and micronutrients in mulberry growing soils of Golaghat district of Assam

Mulberry growing area	S (mg kg^{-1})		Zn (mg kg^{-1})		Cu (mg kg^{-1})	
	Depth (cm)		Depth (cm)		Depth (cm)	
	0-20	20-50	0-20	20-50	0-20	20-50
Kakodonga (16)$^{++}$	10.4-17.0 (13.8±1.81)	9.20-13.2 (11.2±1.27)	0.23-3.00 (1.13±0.92)$^{\#}$	0.16-1.70 (0.56±0.48)	1.81-4.80 (3.49±0.81)	0.72-3.34 (2.34±0.62)
Dergaon (10)	12.6-17.2 (15.1±1.32)	10.7-16.9 (13.2±1.93)	0.21-3.70 (2.24±1.14)	0.14-2.50 (1.15±0.79)	1.53-3.78 (2.67±0.82)	0.79-2.20 (1.59±0.57)
Kathalguri (18)	13.2-21.0 (17.4±2.34)	10.9-18.3 (15.5±1.84)	0.98-3.47 (1.90±0.68)	0.49-2.76 (1.20±0.57)	0.90-3.10 (1.93±0.56)	0.40-2.30 (1.38±0.44)
Podumoni (9)	17.2-23.0 (20.5±2.08)	12.2-19.8 (16.5±2.33)	0.75-3.70 (2.54±0.99)	0.59-2.70 (1.52±0.69)	1.65-3.00 (2.42±0.47)	0.90-2.36 (1.90±0.46)
Sarupathar (17)	16.3-22.2 (18.7±1.72)	14.8-19.0 (16.5±1.24)	0.80-2.04 (1.14±0.31)	0.41-1.30 (0.65±0.21)	1.30-3.20 (2.15±0.56)	0.90-2.40 (1.54±0.48)
Bokakhat (30)	12.0-22.0 (16.5±2.58)	9.56-20.4 (14.1±2.83)	0.40-3.44 (1.49±0.84)	0.20-2.58 (0.90±0.61)	0.83-4.56 (2.20±0.99)	0.35-2.90 (1.62±0.83)
Pooled soil samples	10.4-23.0 (16.8±2.83)**	9.20-20.4 (14.4±2.73)	0.21-3.70 (1.62±0.91)**	0.14-2.76 (0.94±0.62)	0.83-4.80 (2.42±0.91)**	0.35-3.34 (1.70±0.68)

Mulberry growing area	Fe (mg kg^{-1})		Mn (mg kg^{-1})		B (mg kg^{-1})	
	Depth (cm)		Depth (cm)		Depth (cm)	
	0-20	20-50	0-20	20-50	0-20	20-50
Kakodonga (16)$^{++}$	17.8-126 (72.7±37.2)	11.8-80.0 (37.1±20.2)	2.57-35.4 (12.4±9.64)	2.10-19.4 (8.27±6.23)	0.48-0.75 (0.58± 0.09)	0.42-0.65 (0.54±0.08)
Dergaon (10)	38.5-163 (104±40.5)	17.6-126 (61.3±37.2)	2.10-41.0 (20.0±13.6)	1.44-29.7 (12.1±8.97)	0.41-0.83 (0.55± 0.14)	0.32-0.65 (0.49±0.12)
Kathalguri (18)	63.2-120 (97.6±14.9)	32.5-115 (77.9±24.3)	5.70-41.5 (21.6±9.02)	4.30-33.6 (14.5±6.46)	0.32-0.48 (0.37± 0.05)	0.29-0.39 (0.34±0.03)
Podumoni (9)	58.5-155 (110±35.3)	45.5-121 (83.1±25.6)	16.4-66.5 (35.7±14.1)	10.8-56.3 (26.8±12.9)	0.36-0.50 (0.42± 0.05)	0.25-0.45 (0.39±0.07)
Sarupathar (17)	41.6-98.3 (63.4±16.5)	30.9-75.3 (49.4±13.8)	12.2-26.1 (22.3±3.53)	9.80-20.9 (17.6±2.70)	0.33-0.47 (0.37± 0.04)	0.29-0.39 (0.33±0.03)
Bokakhat (30)	10.2-138 (87.1±36.6)	9.20-137 (64.0±34.3)	3.60-51.2 (17.7±13.3)	2.40-37.2 (12.3±10.0)	0.36-0.69 (0.46± 0.08)	0.31-0.64 (0.42±0.09)
Pooled soil samples	10.2-163 (86.5±34.1)**	9.20-137 (61.2±30.5)	2.10-66.5 (20.2±12.2)**	1.44-56.3 (14.2±9.40)	0.32-0.83 (0.45± 0.10)*	0.25-0.65 (0.41±0.10)

$^{++}$Figures in parenthesis indicate number of soil sampling points; $^{\#}$Figures in parenthesis indicate (mean ± standard deviation); *Indicates that the differences between means at two different depths are significant at 1% probability level

***Available micronutrient status*:** Micronutrient status in the mulberry growing soils indicated that DTPA extractable Zn, Cu, Fe and Mn in surface layer varied from 0.21 to 3.70, 0.83 to 4.80, 10.2 to 163 and 2.10 to 66.5 mg kg^{-1}, respectively (Table 4). Soils collected from Podumoni block recorded the highest Zn content (2.54 mg kg^{-1}), which was followed by the samples from Dergaon (2.24 mg kg^{-1}), Kathalguri (1.90 mg kg^{-1}), Bokakhat (1.49 mg kg^{-1}), Sarupathar (1.14 mg kg^{-1}) and Kakodonga (1.13 mg kg^{-1}) block. Almost similar trend was also recorded for Fe content in the soils from different blocks under mulberry cultivation. Similarly soil samples from Podumoni block recorded the highest Mn content (35.7 mg kg^{-1}) and the lowest Mn content was recorded in soils of Kakodonga block (12.4 mg kg^{-1}). However, Cu content was recorded to be the highest in soils of Kakodonga (3.49 mg kg^{-1}), which was followed by Dergaon (2.67 mg kg^{-1}), Podumoni (2.42 mg kg^{-1}), Bokakhat (2.20 mg kg^{-1}), Sarupathar (2.15 mg kg^{-1}) and Kathalguri (1.93 mg kg^{-1}) blocks. Relatively lower content of Zn, Fe and Mn in soils of Kakodonga block might be attributed to the higher pH (6.5) and lower OC content (0.67%). Relative abundance of Cu in soils of Kakodonga block could not be explained by these properties, which indicates that there might be other dominating factors governing the solubility of Cu in these soils. According to the critical limits suggested by Bansal and Takkar (1986) for Zn (0.6 mg kg^{-1}), Nayyar *et al*. (1985) for Mn (3.5 mg kg^{-1}) and Lindsay and Norvell (1978) for Cu (0.2 mg kg^{-1}) and Fe (4.5 mg kg^{-1}), only 9% of the surface soil samples were found to be deficient in available Zn, whereas Mn deficiency was found in 4% of the surface samples. Contents of Fe and Cu in surface layer were well above the critical limits. The DTPA extractable Fe and Cu in sub-surface soils were also found to be above the critical limits, whereas Zn and Mn deficiency were reported in 36 and 10% of the samples, respectively. Higher magnitude of deficiency of Zn and Mn in sub-surface soil might be attributed to the higher pH and lesser OC content of sub-surface layer as compared to surface layer. Similar extent of Zn deficiency (35%) was reported by Samanta *et al*. (2002) in soils of West Bengal under continuous cultivation of mulberry. On an average, the DTPA-extractable micronutrients in sub-surface soils were recorded to be lower compared to that of surface soils. Boron content in surface soil was reported to vary from 0.32 to 0.83 mg kg^{-1} with the mean value of 0.45 mg kg^{-1}, whereas it varied from 0.25 to 0.65 mg kg^{-1} in sub-surface soil with the mean value of 0.41 mg kg^{-1}. Comparison of B content (mean) between surface and sub-surface soil indicated that surface soil had significantly higher boron content in comparison to sub-surface soil. Considering 0.5 mg kg^{-1} as critical limit of deficiency in soil for hot water extractable B, 81% of surface soil samples and 83% of sub-surface soil samples were found to be deficient in available B in the study area under mulberry cultivation. Boron deficiency in soils of Assam was also reported earlier by Takkar (1996).

Table 5. Nutrient index values of N, P (as P_2O_5) and K (as K_2O) in soil samples collected from different mulberry growing blocks of Golaghat district of Assam in north eastern India.

Mulberry growing blocks	Nutrient index/ nutrient status		
	N	P_2O_5	K_2O
Kakodonga	1.50; L	1.12; L	2.12; M
Dergaon	1.90; M	1.10; L	2.50; H
Kathalguri	1.72; M	1.00; L	2.27; M
Podumoni	2.00; M	1.11; L	2.77; H
Sarupathar	1.88; M	1.11; L	2.17; M
Bokakhat	1.60; L	1.20; L	2.13; M
Pooled soil samples	1.72; M	1.12; L	2.26; M

L: low; M: medium; H: high

***Nutrient index value*:** Nutrient index value (NIV) was calculated to assess the overall nutritional status of N, P and K under mulberry cultivation in the study area. The NIV for available N in surface soils varied from 1.5 to 2.0 with an overall average of 1.72 indicating a medium N fertility status in the study area (Table 5). Perusal of data on NIVs for N across different blocks indicated low to medium fertility status of N in the surface layer. This might be due to non-application of nitrogenous fertilizers or organic inputs and limitation of retention and recycling of mulberry leaf unlike other agricultural crops in the mulberry gardens. The NIV for available P_2O_5 varied from 1.0 to 1.2 with an overall average value of 1.12 indicating low P availability in these soils. The NIV for available K_2O varied from 2.12 to 2.77 with the mean value of 2.26 indicating medium fertility status of K in these soils. Perusal of data on NIVs for available N, P_2O_5 and K_2O in different blocks revealed that the mulberry growing soils of Kakodonga and Bokakhat are the least fertile in the study area. This might be attributed to the soil resources of recent origin (Entisols) with coarse texture in these blocks. The Entisols are very recently developed mineral soils with no diagnostic horizonation other than an ochric or anthropic epipedon (Soil Survey Staff, 2014). Due to very slight degree of soil formation, Entisols are in general less fertile than Inceptisols. The fluviatile Entisols (Fluvaquents / Fluvents) were found in these blocks, which study area across the blocks ranged from 6.50 to 13.5 t/ ha / yr with the mean value of 9.50 t/ha/yr. Generally, are common in the active flood plain areas of Brahmaputra valley in Assam. Further, unlike P_2O_5, wide variation in NIVs was observed in case of N and K_2O in soils across the study area. This might be due to the dependence of N and K availability in the present study on both the pH and OC and their wide variation (OC from 0.05 to 1.90%, pH from 4.3 to 7.6) in soil. Variation in the age of mulberry plantation (1 to 10 years) might be a possible reason for wide variation in OC content in mulberry growing soils across the study area.

***Deficiency status of micronutrients in mulberry growing soils*:** Perusal of database on available micronutrients in surface soils under mulberry land use system in different blocks indicated that severity of deficiency of B and Zn was much higher among the micronutrients (Table 6). The limits of deficiency of micronutrients in soil were applied to assess the overall deficiency status in respect of micronutrients in different blocks. Results indicated that deficiency of B was observed in all the blocks. Boron deficiency was recorded in 37.5 to 100% of the soil samples collected across different blocks. Zinc deficiency was recorded in 6.70 to 37.5% of the samples collected across different blocks in the study area. Zinc deficiency was observed only in Kakodonga, Dergaon and Bokakhat blocks in the study area. Similarly Mn deficiency was observed only in Kakodonga and Dergaon blocks in the study area. The results indicated the prevalence of the deficiency of B, Zn and Mn in the soils of these three blocks. This might be attributed to the existing soil resources (Entisols) in the blocks. Further, coarse soil texture in these blocks (Table 1) aggravated the nutritional deficiency. Presence of common fluviatile Entisols on active flood plains in these blocks might be due to the occurrence of flood as a result of the proximity of these blocks to the Brahmaputra river (Fig 1).

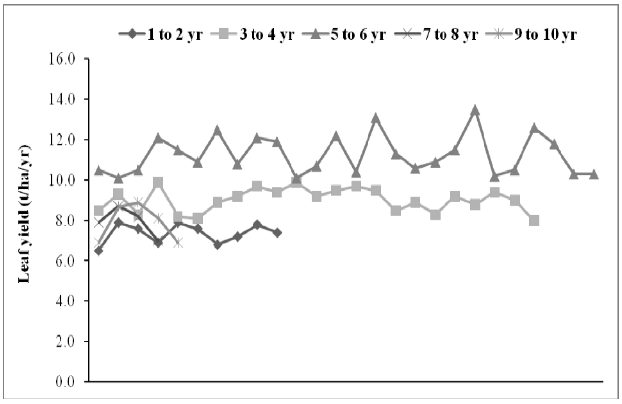

Fig 2. Leaf yield of mulberry as influenced by the age of the plantation

***Correlation between important soil properties and nutrient availability*:** Soil pH and OC are widely discussed in literature for their important role in governing the availability of essential nutrient elements in soil and plants. In the present investigation, correlation analysis between these properties and nutrient elements in soil indicated that soil pH had significant negative correlation with N (r = –0.39), K_2O (r = –0.13), S (r = –0.32), Zn (r = –0.34), Cu (r = –0.35), Fe (r = –0.50) and Mn (r = –0.25), whereas pH had no significant correlation with P_2O_5 and B (Table 7). The negative correlation between pH and cationic micronutrients was due to the fact that the solubility of these nutrients decreased with increase in pH. Reduced volatilization loss of N at low pH might be the reason for negative correlation between pH and available N. Negative relationship between pH and K might be due to the fact that with the increase in pH the increase in K-selective exchange sites (blocked by Al at low pH) makes K susceptible to fixation (Nemeth and Grimme, 1972). Similarly, negative correlation between pH and S might be ascribed to the adsorption of SO_4-S ($CaCl_2$ extractable) on Fe/Al oxides in acid soil and retention of sulphate against leaching. On the contrary, OC had significant positive correlation with all the nutrients under study, except B (Table 7). This indicated the importance of OC on the availability of these nutrients in soil. No significant relation of B with pH and OC in the present investigation indicated that B availability did not vary with the variation in pH or OC in soil. Such information might have important implication on designing appropriate management intervention in tackling B deficiency in soil-plant system.

***Mulberry leaf yield and age of plantation*:** Mulberry leaf yields as obtained for the plantations of differential ages in the study area were also recorded (Fig 2). Results indicated that mulberry leaf yield varied from 6.5 to 7.9, 8.0 to 9.9, 10.1 to 13.5, 7.0 to 8.7 and 6.9 to 8.9 t/ha/yr for the plantations of 1-2, 3-4, 5-6, 7-8 and 9-10 years old, respectively; the corresponding mean values of leaf yield were 7.3, 9.0, 11.2, 8.0 and 7.9 t/ha/yr, respectively (data not shown). Perusal of data indicated that leaf yield of mulberry plantations increased up to the age of 5-6 years and decreased thereafter. The maximum leaf yield of mulberry was recorded in the plantations of 5-6 years of age group. Such results might be attributed to the poor management practices (e.g. improper pruning) in case of aged plantations. Besides, nutrient mining due to non application of fertilizers in mulberry in this region might have resulted poor leaf yield in case of aged plantations. Further, analysis of data indicated that leaf yield in the

Table 6. Deficiency status of micronutrients in mulberry growing soils of different blocks of Golaghat district of Assam

Mulberry growing blocks	Zinc	Copper	Iron	Manganese	Boron
Kakodonga	37.5	Nil	Nil	18.7	37.5
Dergaon	10.0	Nil	Nil	10.0	60.0
Kathalguri	Nil	Nil	Nil	Nil	100
Podumoni	Nil	Nil	Nil	Nil	100
Sarupathar	Nil	Nil	Nil	Nil	100
Bokakhat	6.70	Nil	Nil	Nil	83.3

Deficiency status is expressed in % of the total samples analyzed

Table 7. Simple correlation coefficients (r) between important soil properties and available nutrients in mulberry growing soils of Assam

Important soil properties	Available nutrient in soil								
	N	P_2O_5	K_2O	S	Zn	Cu	Fe	Mn	B
pH	-0.39**	0.10	-0.13*	-0.32**	-0.34**	-0.35**	-0.50**	-0.25**	0.03
OC	0.50**	0.84**	0.29**	0.32**	0.37**	0.21**	0.56**	0.36**	0.004

**Values of r are significant at 1% probability level; *Values of r are significant at 5% probability level (N=200)

Table 8. Simple correlation coefficients (r) of mulberry leaf yield with age of plantation and available nutrients in mulberry growing soils of Assam

Correlation coefficient (r)	Age of mulberry plantation	Available nutrient in soil								
		N	P_2O_5	K_2O	S	Zn	Cu	Fe	Mn	B
Mulberry leaf yield	0.34**	0.30**	-0.11	0.19	0.51**	0.12	0.30**	0.15	0.39**	-0.15

** Values of r are significant at 1% probability level (N=68)

mulberry (*Morus indica* var. S_{1635}) is cultivated under rainfed condition in this region. Literature survey indicated that the potential leaf yield of the variety S_{1635} under rainfed condition is 18 t/ha/yr (Bose and Kar, 2010). Comparison of data between potential and actual yield reveals that there is enough scope of enhancing mulberry leaf yield, if proper management strategies are followed.

Correlation analysis indicated significant positive relationship between mulberry leaf yield and age of plantation (r=0.34) (Table 8). Similarly mulberry leaf yield was found to be positively correlated with available N (r=0.30), S (r=0.51), Cu (r=0.30) and Mn (r=0.39) content in soil.

***Fertility paradigm of mulberry growing soils*:** Existing soil and land resources are the important factors governing the nutritional status of mulberry land use system in the study area. Soils occurring on active flood plains are less fertile than that on old alluvial plains. Emerging nutritional deficiency, particularly of N, P, Zn and B in soil is not desirable for the production of high quality silk in this traditional mulberry growing belt of north eastern India; since these elements are very much essential for protein synthesis and important enzymatic reactions in mulberry (Bose and Kar, 2010). Nutrient deficiency problem was further aggravated due to non-application of fertilizers, limited scope of incorporation of mulberry leaves in soil and cultivation of mulberry as sole crop in the study area.

Conclusion

Findings of the study suggest that growing mulberry as sole crop under low management practice may not be favourable for soil health as well as the farming community associated with sericulture and livestock production in the years to come. Hence, there is a need to develop appropriate nutrient management strategies and suitable farming systems to alleviate the limitations imposed by acidity, nutritional status of N and P, and deficiency of micronutrients, particularly Zn and B, in mulberry growing soils of north eastern India. Priority has to be given to improve the nutritional status of mulberry growing soils occurring on active flood plains of the Brahmaputra valley region of north eastern India.

Acknowledgement

The authors thank to the Central Silk Board (CSB), Government of India and Indian Council of Agricultural Research (ICAR), New Delhi, India for funding and providing laboratory facilities, respectively to carry out the study.

References

Bansal, R. L. and P. N. Takkar. 1986. Micronutrient status of soils in Amritsar district. *Indian Journal of Ecology* 13: 158–160.

Baruah, T. C. and H. P. Barthakur. 1997. *Text Book of Soil Analysis.* Vikas Publishing House Pvt. Ltd., New Delhi.

Bongale, U. D. and Lingaiah. 1998. Vertical distribution of nitrogen fractions in mulberry garden soils. *Indian Journal of Sericulture* 37: 48-51.

Borkakoti, K. and P. N. Takkar. 2001. Forms of boron in acid alluvial and lateritic soils in relation to ecosystem and rainfall distribution. In: Proc. *International Conference on Managing Resources for Sustainable Agricultural Production in the 21st century*.

Bose, P. C. and R. Kar. 2010. *Soil Characteristics and Nutritional Management of Mulberry in Eastern & North-Eastern India*. Central Sericultural Research and Training Institute, Central Silk Board, Govt. of India, Berhampore, West Bengal, India.

Bray, H. R. and L. T. Kurtz. 1945. Determination of total organic and available forms of phosphorus in soil. *Soil Science* 59: 39–45.

Chen, F., J. Lu., M. Zhang, K. Wan and D. Liu. 2009. Mulberry nutrient management for silk production in Hubei Province of China. *Journal of Plant Nutrition and Soil Science* 172: 245–253.

Chesnin, L. and C. H. Yien. 1951. Turbidometric determination of available sulphate. *Soil Science Society of America Proceedings* 15: 149–151.

CSB. 2016. Annual Report 2015-16. Central Silk Board, Ministry of Textiles, Govt. of India.

Evans, C. E. and E. J. Kamprath. 1970. Lime response as related to percent aluminum saturation, soil solution aluminum and organic matter content. *Soil Science Society of America Proceedings* 34: 893–896.

Jackson, M. L. 1973. *Soil Chemical Analysis*. Prentice Hall of Indian (Pvt.) Limited, New Delhi.

John, M. K., H. H. Chuah and J. H. Neufeld. 1975. Application of improved azomethine-H method to the determination of boron in soils and plants. *Analytical Letters* 8: 559–568.

Kumar, R. V., H. V. Singh., S. Kumar., A. K. Roy and K. A. Singh. 2017. Growth and biomass production of fodder trees and grasses in a silvipasture system on non-arable land of semi-arid India. *Range Management and Agroforestry* 38: 43-47.

Lindsay, W. L. and W. A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of America Journal* 42: 421–428.

Lu, J. W., J. P. Xiong., F. Chen., Y. H. Xu., Y. F. Wan., D. B Liu., Z. Q. Zhang and C. B. Yu. 2004. Study on the nutrition status of mulberry gardens in Hubei. II. Mulberry leaf nutrition content. *Hubei Agricultural Science* 1: 59–62.

Motsara, M. R., J. Singh and K. P. S. Verma. 1982. Nutrients indexing system in soil fertility evaluation and fertilizer use in India. *Fertiliser News* 27: 92–99.

Muhr, G. R., N. P. Datta., H. Subramoney., V. K. Liley and R. R. Donahue. 1965. *Soil Testing in India*. U.S. Agency for International Development, New Delhi.

Nayyar, V. K., U. S. Sadana and T. N. Takkar. 1985. Methods and rates of application of Mn and its critical levels for wheat following rice on coarse textured soils. *Fertiliser Research* 8: 173–178.

Nemeth, K. and H. Grimme. 1972. Effect of soil pH on the relationship between K concentration in the saturation extract and K saturation of soils. *Soil Science* 114: 349–354.

Neupane, R. P. and G. B. Thapa. 2001. Impact of Agroforestry intervention on soil fertility and farm income under the subsistence farming system of the middle hills, Nepal. *Agriculture, Ecosystems and Environment* 84: 157–167.

Rama Kant., S. Chakrabarty., S. K. Dhyani and R. K. Upadhyay. 2004. Mulberry (*Morus alba* L.) as an agroforestry plant in Uttaranchal. *Indian Forester* 130: 939–944.

Samanta, A., A. K. Chatterjee., P. K. Mete and B. Mandal. 2002. Status of total and available iron and zinc in soils of West Bengal under continuous cultivation of mulberry. *Journal of the Indian Society of Soil Science* 50: 35–42.

Shankar, M. A. and B. T. Rangaswamy. 1999. Effect of applied nitrogen and potassium on mulberry leaf yield and quality in relation to silkworm cocoon characters. *Better Crops International* 13: 20–21.

Sharma, S. K. and K. K. Zote. 2010. Mulberry-a multipurpose tree species for varied climate. *Range Management and Agroforestry* 31: 97–101.

Soil Survey Staff. 2014. *Keys to Soil Taxonomy*. 12th Edition. United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC.

Subbiah, B. V. and G. L. Asija. 1956. A rapid procedure for the determination of available nitrogen in soils. *Current Science* 25: 259–260.

Takkar, P. N. 1996. Micronutrient research and sustainable agricultural productivity in India. *Journal of the Indian Society of Soil Science* 44: 562–581.

Walkley, A. and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* 37: 29–38.