



Fertility capability classification (FCC) of soils of a lower Brahmaputra valley area of Assam, India

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ABSTRACT

Fertility capability classification (FCC) is a system of classification which uses pedological data of soils and converts it into capability classes based on major fertility constraints portrayed by the soils. The present study was aimed to classify the soils major landforms of a lower Brahmaputra valley region of Assam, India in to FCC classes, to suggest specific management practices in order to overcome the fertility constraints and improve the crop productivity. The major strata types used were found to be loamy top soil, 'L' and clayey top soil 'C'. The sub-strata type found were loamy sub soil, 'L' and clayey sub soils, 'C'. The major condition modifiers or the major fertility constraints were found to be Al toxicity 'a' and 'a-', high leaching potential, 'e', low nutrient reserves 'k' and 'g' waterlogging. The paddy soils of alluvial plains were classified into La^{eg} and Lg^ae. The tea growing soils of younger alluvial plains were classified into Car^e. The non-paddy soils of alluvial plains were categorized as Ca^gke. The soils of uplands and inselberg were categorized into LCae class. The study revealed that FCC classification can successfully bring out the soil fertility constraints and can be very much helpful in soil fertility management for sustainable crop productions.

Introduction

Soil properties are the outcome of several soil-forming processes as influenced by basic soil-forming factors as outlined by Jenny (1942). Climate and geology are the two important factors affecting the soil development process through the type and quantity of material deposited at a place and these are reflected in the soil horizons and soil properties (Glinaet *al.*, 2013; Waroszewskiet *al.*, 2015). Geological history and climate affect the soils at a regional or continental scale whereas land use plays an important role at small catchment scale (Wang *et al.*, 2001). The soil properties of a landscape are continuously influenced by land use, soil management practices, soil erosion,

mineralization, and leaching of organic carbon and other nutrient elements (Xiao *et al.*, 2010; Vasu *et al.*, 2016). For sustainable agricultural production and environmental health, it is important to measure specific soil properties to monitor soil quality (Karlenet *al.*, 1997; Mukherjee and Lal, 2014; Choudhury and Mandal, 2021). Soil fertility is the inherent capacity of soil to supply plant nutrients in balanced proportion and adequate quantity for optimum plant growth (Bharti *et al.*, 2017). Soil fertility is affected by natural as well as anthropogenic factors (Kavitha and Sujatha, 2015). The detailed knowledge about soil fertility is a prerequisite for the adoption of improved soil and

crop management practices to get an optimum level of crop productivity (Delsouzet *et al.*, 2017). Soil taxonomic information generated at different scales has limited direct applicability in assessing soil fertility as they focus to quantify subsurface soil properties that are permanent (Sanchez *et al.*, 2003) and they do not include the dynamic properties of topsoil which are more important for fertility assessment (Chandrakala *et al.*, 2020; Vasu *et al.*, 2016). To overcome this limitation fertility capability classification (FCC) was first introduced by Buol *et al.*, (1975) with an intent to bring together soil classification and soil fertility into a single frame. Soil fertility capability classification (FCC) is a technical system to group the soils according to the kind of physical and chemical constraints they present under agronomic management (Sanchez *et al.*, 1982; Chandrakala *et al.*, 2020). The system comprises of three gradations viz., type (texture of surface soil), sub strata type (texture of sub-surface soil) and modifiers with respect to their characteristics in the 50 cm depth of soil. The term "topsoil" refers to the plough layer or the top 20 cm of the soil, whichever is shallower. The term "subsoil" includes the depth interval between the topsoil and 50 cm depth. The modifiers are the various physical and chemical constraints portrayed by the soils (Sanchez *et al.*, 1982). After several revisions (Sanchez *et al.*, 1982; Sanchez *et al.*, 2003), the FCC system is now widely accepted and has been used by many researchers in the different parts of the world (Babalola *et al.*, 2019; Prasad, 2000; Das, 2015; Vasu *et al.*, 2016; Kalaiselviet *et al.*, 2019; Hota *et al.*, 2021). Sanchez *et al.*, (2003) in their fourth approximation also introduced modifiers related to biological properties of soil to relate importance of biological processes and soil organic matter in maintaining crop productivity (Bhutiani and Ahamad, 2019). Prasad (2000) used the FCC system to convert the taxonomic units into fertility classes for soils of Konheri watershed in semi-arid tropics of India and concluded that FCC can give a basic idea of soil fertility without analysing routine fertility parameters for N, P and K fertilizer recommendation. Kalaiselviet *et al.*, (2019) have used FCC to classify soils of Palani block in a semi-arid tropical region of Tamil Nadu. They concluded that the FCC was beneficial in identifying the potential

constraints of fertility and for suggesting better management options. Hota *et al.*, (2021) successfully identified the major fertility constraints of soils under major land uses of north-eastern India to as low K reserves, highly acidic soil and low cation exchange capacity (CEC), and suggested management practices. Even though FCC does not include routine soil tests of fertility measurement it can be a useful approach to assess the capability of soils to sustain crop production and soil quality in the rainfed systems with low fertilizer input (Smithson and Sanchez, 2001; Vasu *et al.*, 2016). Assam is a state with 90% of area under rainfed agriculture which contributes around 34% of food production of the state (Indiastat, 2017). Agriculture is the dominant land use practiced in the state of Assam and it accounts for about 54.11 per cent of the total geographical area of the state (Environmental Information System network, Assam, 2015). Though 80 per cent of the total population in Assam is involved in agriculture, the state is quite backward in the national list of agricultural productivity i.e., the total food grain productivity of Assam is 2.08 MT/ha which is less than that of the national average of 2.29 MT/ha. Similarly, in case of horticulture, the total productivity is 9.92 MT/ha, which is quite low compared to the national average of 12.26 MT/ha (Indiastat, 2018). However, the agriculture productivity of the state of Assam is quite below the national average due to many constraints including low agricultural inputs (Saud, 2018). The poor soil fertility management is common in the Brahmaputra valley in general and in the lower Brahmaputra valley in particular, due to smaller sizes of land holding and subsistent agricultural practices (Sharma, 2011). Hence, the present study was undertaken with the aim to classify the soils of the study area into fertility capability classes to identify specific fertility constraints for adoption of best soil and crop management practices for sustaining higher level of productivity.

Material and Methods

The study was conducted in the Rangjuli block of Goalpara district in the lower Brahmaputra Valley region of Assam. Goalpara district is one of the aspirational districts selected by NITI ayog Government of India for faster socio-economic

development of the district. The block extends its boundary between $25^{\circ} 53.3' 3.637''$ to $26^{\circ} 6' 4.73''$ N latitude and $90^{\circ} 53.3' 8.231''$ to $90^{\circ} 5' 59.075''$ E Longitude and comes under Hot humid eco subregion (15.2) of agroecological regions of India (Velayutham *et al.*, 1999), having udic moisture regime and hyperthermic temperature regime (Soil Survey Staff, 2014) with a mean annual precipitation of 2000 to 2500 mm. The block is dominantly of agrarian economy and more than 90% of population is dependent on agriculture. The major crops grown in the block are paddy (as kharif crop followed by fallow), arecanut and banana. Other than that, rubber and vegetables crops are also grown by the farmers. A detailed soil survey of the study area was conducted in the year 2020. Different landform classes were delineated based on slope, aspect, and drainage etc using SRTM DEM and Sentinel-2 satellite data using ArcGIS 10.2 software. From each of the landform class soil profiles were studied for important morphological features in the field and layer wise soil samples were collected from entire profile depth (up to 150 cm) and brought to laboratory for analysis of various physical and chemical properties of soils. Soils were classified into taxonomic classes following USDA Soil Taxonomy (Soil Survey Staff, 2014). To classify the profiles in to FCC, representative profiles from each landform were selected. The collected soil samples were air-dried and grounded to pass through 2 mm sieve for analysis of soil physical and chemical parameters and part of the 2mm sieved soil samples were finely grounded and passed through 0.5 mm sieve and used for soil organic carbon (SOC) analysis. The soil samples were analysed for particle size distribution using international pipette method (Robinson, 1922). Soil organic carbon (SOC) was determined by Walkley and Black (1934) method. Cation exchange capacity (CEC) and exchangeable cations were determined following standard procedures (Schollenberger and Simon, 1945; Sumner and Miller, 1996). FCC was carried out using fourth approximation by Sanchez *et al.*, (2003) and FCC designations were allotted accordingly. FCC designations were allotted as per the three gradations, first, type (surface texture) and substrata type (subsurface texture). Second, the condition modifiers, which includes fertility constraints or limitations (physical and chemical

properties) and third, superscripts + or – which indicates the magnitude of modifiers. FCC considers the properties of 0-50 cm soil depth only, where 0-20 cm is considered surface soil, and 20-50 cm is considered as subsurface soil. Hence, the values of chemical properties were weighed to calculate the values for 0-20 cm and 20-50 cm for each profile. Descriptive statistics of soil parameters were worked out using data analysis tool of Microsoft excel 2019.

Results and Discussion

The major landforms of Rangjuli blocks were delineated in to active flood plain, younger alluvial plain, older alluvial plain, upland and inselbergs. From each landform 1 or 2 representative profiles have been selected and named as P1 to P8. The detailed taxonomic classifications of the soils are given in Table 1. The descriptive statistics of the soil parameters that were used to carryout FCC classification are presented in the Table 2 and 3 for surface and subsurface soils respectively. The weighted mean values of considered soil properties for each pedons from each landform is given in Table 4. The strata type used were (i) loamy top soil, 'L'; (ii) clayey top soil 'C' and sub-strata type used (i) loamy sub soil, 'L'; (ii) clayey sub soils, 'C'. The condition modifiers appropriate for the soils under study were (i) Al toxicity for most common crops in terms of base saturation < 33% of sum of cations at pH 7 'a'; (ii) Al toxicity for very sensitive crops like cotton in terms of Al saturation of 10-60% 'a'; (iii) high leaching potential, 'e' with low activity clay minerals; (iv) low nutrient reserves 'k'; (v) gravel 10-35 % 'r⁺'; (vi) 'g' waterlogging. P1 of active flood plain was categorized into fine loamy, mixed, hyperthermic Fluvaqueptic Endoaquepts. These soils are mostly cultivated with paddy double cropping in *kharif* and *rabi*. They had loamy topsoil and subsoil. The loamy texture of these soils is due to the close proximity to river channel. For the very same reason, these soils remain saturated with water for more than 60 days in normal years. Due to continuous submergence in most of the time in a year, paddy cultivated soils show glei condition leading to a chroma of <2 (Gangopadhyay *et al.*, 2015) in the top 50 cm soils indicating aquic moisture regime. The soils also showed high leaching potential and low activity clays and these soils were categorized in to La^{eg} FCC class (Table 5)

Table 1: Pedons and their respective landforms

Pedon number	Taxonomic classification	Landform
P1	Fine loamy, mixed, hyperthermic Fluvaquentic Endoaquepts	Active flood plain
P2	Fine, mixed, hyperthermic Inceptic Hapludalfs	Mounds of Younger alluvial plain
P3	Fine, mixed, hyperthermic Typic Endoaqualfs	Younger alluvial plain
P4	Fine, mixed, hyperthermic Fluvaquentic Endoaquepts	Older alluvial plain
P5	Fine loamy, mixed, hyperthermic Fluventic Eutrudepts	Older alluvial plain
P6	Fine loamy, mixed, hyperthermic Typic Kanhapludults	Upland
P7	Fine loamy, mixed, hyperthermic Typic Kandihumults	Upland
P8	Fine, mixed, hyperthermic Inceptic Hapludalfs	Inselberg

Table 2: Descriptive statistics of soil parameters at 0-20 cm depth

Parameters	Mean	Minimum	Maximum	Std. Dev.	SE(m)±
Sand (%)	20.40	3.62	61.15	18.24	6.45
Silt (%)	42.93	9.74	63.64	17.65	6.24
Clay (%)	36.68	29.11	47.49	6.98	2.47
pH	4.70	4.24	5.01	0.25	0.09
SOC (%)	1.09	0.87	1.40	0.17	0.06
CEC [c mol (p ⁺) kg ⁻¹]	8.00	6.47	8.96	0.80	0.28
Ca ²⁺ [c mol (p ⁺) kg ⁻¹]	1.53	0.80	3.03	0.79	0.28
Mg ²⁺ [c mol (p ⁺) kg ⁻¹]	1.87	0.98	3.88	0.95	0.34
Na ⁺ [c mol (p ⁺) kg ⁻¹]	0.32	0.23	0.43	0.06	0.02
K ⁺ [c mol (p ⁺) kg ⁻¹]	0.15	0.11	0.19	0.02	0.01
Sum of Bases [c mol (p ⁺) kg ⁻¹]	3.88	2.20	6.28	1.51	0.53
BS (%)	49.38	25.72	79.91	21.60	7.64
Al ³⁺ [c mol (p ⁺) kg ⁻¹]	2.19	0.93	4.49	1.33	0.47
H ⁺ [c mol (p ⁺) kg ⁻¹]	1.43	0.32	3.45	1.07	0.38
ECEC [c mol (p ⁺) kg ⁻¹]	7.50	5.37	10.14	1.56	0.55
Al saturation (%) of CEC	19.36	7.04	52.41	14.82	5.24
K saturation (%) of sum of bases	4.62	2.10	8.16	2.26	0.80

Table 3: Descriptive statistics of soil parameters at 20-50 cm depth

Parameters	Mean	Minimum	Maximum	Std. Dev.	SE(m)±
Sand (%)	18.53	2.95	45.23	14.60	5.16
Silt (%)	39.79	24.01	65.56	14.01	4.95
Clay (%)	41.68	25.58	54.70	10.05	3.55
pH	4.94	4.55	5.33	0.27	0.09
SOC (%)	0.90	0.58	1.27	0.26	0.09
CEC [c mol (p ⁺) kg ⁻¹]	8.15	6.63	9.35	1.05	0.37
Ca ²⁺ [c mol (p ⁺) kg ⁻¹]	1.69	0.63	3.63	1.19	0.42
Mg ²⁺ [c mol (p ⁺) kg ⁻¹]	2.19	0.99	4.63	1.33	0.47
Na ⁺ [c mol (p ⁺) kg ⁻¹]	0.28	0.14	0.35	0.07	0.02
K ⁺ [c mol (p ⁺) kg ⁻¹]	0.14	0.07	0.35	0.09	0.03
Sum of Bases [c mol (p ⁺) kg ⁻¹]	4.30	2.04	8.66	2.50	0.89
BS (%)	52.95	22.56	92.66	29.24	10.34
Al ³⁺ [c mol (p ⁺) kg ⁻¹]	1.52	0.37	4.08	1.50	0.53
H ⁺ [c mol (p ⁺) kg ⁻¹]	0.88	0.01	2.90	1.27	0.45
ECEC [c mol (p ⁺) kg ⁻¹]	6.70	3.00	9.16	2.36	0.83
Al saturation (%) of CEC	14.03	0.01	39.63	13.46	4.76
K saturation (%) of sum of bases	4.88	0.84	14.30	4.43	1.57

The soil reaction was found to be highly acidic (4.65 to 5.02). The management of soil acidity is crucial in these soils. Similar results have been reported by Tabi *et al.*, (2013), where the paddy growing soils showed modifiers of Al-toxicities (a), low nutrient capital reserves (k) and high leaching potential (e). Usually, paddy tolerates acidic soil conditions but if a second crop is to be recommended, like rabi pulses, the management of soil acidity with regular liming has to be undertaken. The soils with 'g' modifiers or glei conditions are usually prone to denitrification (Sanchez *et al.*, 2003). Hence, the split doses of N fertilizer and nitrification inhibitors are recommended.

Similarly, the paddy growing soils of the younger alluvial plain (P3) were loamy in texture. The major constraints are prolonged waterlogging, high leaching potential and Al toxicity for sensitive crops like cotton. These soils were categorized into Lg⁺a⁺e (Table 5). The glei condition of these soils are due to high-water table. However, these soils are dominantly cultivated with paddy and water saturation in most part of the year is advantageous for growing paddy. But it also makes these soils unsuitable for taking a non-paddy second crop, unless artificially drained. Hence, instead of monocropping of paddy, a second paddy crop can be taken in these soils. Only, the denitrification and leaching losses have to be addressed using nitrification inhibitors and slow-release fertilizers. P2 is the representative Pedon of younger alluvial plains, which are found in the mounds within the alluvial plains, and was categorized into fine, mixed, hyperthermic Inceptic Hapludalfs. Due to shifting course of braided rivers like Brahmaputra, small mounds are left in places between two river channels, and in the long-run these lands become isolated uplands between two narrow valleys of alluvial plains (Hazarika *et al.*, 2015). These lands are called as char land. These mounds of younger alluvial plain of our study area, are cultivated with tea. These soils have clayey topsoil and subsoils. The major constraints found in these soils are, Al toxicity for most of the crops and low buffering capacity with gravelly subsoil.

The Al toxicity of these soils arise due to prolonged leaching and washing away of bases down the profile (Reza *et al.*, 2018) due to prevalent heavy rainfall of the area. The low buffering capacity of

the soils arise due to the presence of low activity clays (Bhattacharyya *et al.*, 2010). Similar results have been reported by Bandyopadhyay *et al.*, (2014) for tea cultivated soils of upper Brahmaputra valley. These soils also showed highly acidic soil reaction (4.7 to 4.9), which falls within the ideal pH range for tea (Kacar, 1984). P2 was hence, categorized into Car⁺e FCC class (Table 5). These soils are suitable for tea and rubber (Naidu *et al.*, 2006). However, integrated nutrient management and liming is crucial for realizing optimum yields from these soils. Because inappropriate nutrient application may aggravate soil acidity, which will be detrimental for tea growth and productivity (Ozyazici *et al.*, 2010). The land use of older alluvial plains is paddy in the level slopes (0-1 %) whereas at 1-3 % slopes vegetables like potato and banana orchards are common. Two representative profiles one from paddy cultivation (P4) and another from homestead plantation (P5) were selected from older alluvial plains for categorising soils into FCC. Soils of the pedon P4 were categorized into fine, mixed, hyperthermic Fluvaquentic Endoaquepts. These soils were found to be extremely acidic in reaction (pH 4.61-4.78), clayey in texture, with low permeability and high water holding capacity. Low nutrient reserves, heavy leaching potential, and Al toxicity for very sensitive crops like cotton are the major constraints of these soils. Hence, these soils were designated as Ca⁺gk⁺e. The high leaching potential is indicated by low CEC (7.96- 9.35 c mol (p⁺) kg⁻¹ soil). The reasons of low CEC are usually low clay content, low organic matter content in the surface soils, or clay minerals with low activity (Minh, 2011).

The first two reasons are not applicable in this case because the soils showed high SOC (0.87 to 1.02 %) and high clay content (47-48 %). Hence, the reason must be presence of low activity clays similar to the other pedons P1, P2 and P3. These soils are suitable for paddy cultivation and presence of high residual moisture after paddy harvesting provide an opportunity to grow short duration second crop such as mustard, pea, gram etc in the Rabi season. However, application of lime and residue management is important for neutralizing extreme acidity of soils for optimum productivity. It is desirable to apply nitrogen fertilizers in split

Table 4: Soil properties relevant for FCC of each pedon

Pedon	Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	SOC (%)	CEC [c mol (p ⁺) kg ⁻¹]	Exchangeable bases [c mol (p ⁺) kg ⁻¹]				Sum of bases [c mol (p ⁺) kg ⁻¹]	BS (%)	Exchangeable Acid cations [c mol (p ⁺) kg ⁻¹]		ECEC [c mol (p ⁺) kg ⁻¹]	Al saturation (%)	K saturation (%)
								Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺			Al ³⁺	H ⁺			
P1	0-20	7.0	29.3	29.3	4.65	1.00	7.81	1.80	2.01	0.36	0.15	4.32	55.1	1.38	1.10	6.80	17.8	17.8
	20-50	2.9	31.5	31.5	5.01	1.23	6.63	1.66	1.96	0.32	0.15	4.09	60.9	1.40	1.07	6.55	22.1	22.1
P2	0-20	3.6	44.9	44.9	4.7	1.18	7.42	0.97	1.14	0.30	0.18	2.58	34.7	1.15	1.64	5.37	7.0	7.0
	20-50	4.2	54.7	54.7	4.9	0.59	7.75	0.79	1.11	0.28	0.35	2.53	32.6	0.47	0.00	3.00	3.3	3.3
P3	0-20	11.1	32.8	32.8	5.01	1.09	8.66	2.06	2.27	0.36	0.15	4.83	55.7	1.64	0.70	7.17	8.2	8.2
	20-50	15.1	34.1	34.1	5.06	0.58	9.14	2.69	3.20	0.28	0.13	6.29	68.6	0.37	0.00	6.66	0.01	0.0
P4	0-20	24.1	47.5	47.5	4.61	0.87	7.96	1.84	3.88	0.43	0.13	6.28	79.0	1.63	0.70	8.60	9.6	9.6
	20-50	26.1	48.3	48.3	4.78	1.02	9.35	3.63	4.63	0.33	0.07	8.66	92.7	0.49	0.00	9.16	2.6	2.6
P5	0-20	61.1	29.1	29.1	4.98	0.91	6.47	3.03	1.72	0.30	0.16	5.21	79.9	0.93	0.32	6.46	14.3	14.3
	20-50	45.2	25.6	25.6	5.23	0.79	6.91	2.77	3.12	0.35	0.08	6.33	91.2	0.68	0.10	7.11	9.8	9.8
P6	0-20	18.2	32.5	32.5	4.86	1.05	8.96	0.90	2.01	0.23	0.11	3.25	36.3	2.34	0.99	6.6	26.1	26.1
	20-50	14.2	48.1	48.1	5.33	0.83	8.19	0.68	1.51	0.14	0.07	2.40	29.2	0.96	0.17	3.5	11.7	11.7
P7	0-20	12.0	37.0	37.0	4.24	1.40	8.57	0.80	0.98	0.28	0.15	2.20	25.7	4.49	3.45	10.1	52.4	52.4
	20-50	9.4	46.4	46.4	4.70	1.27	9.28	0.67	0.99	0.28	0.15	2.09	22.6	3.68	2.81	8.6	39.6	39.6
P8	0-20	26.0	40.3	40.3	4.57	1.12	8.17	0.84	0.98	0.32	0.19	2.33	28.5	3.95	2.59	8.86	19.4	19.4
	20-50	31.1	44.9	44.9	4.55	0.91	7.92	0.63	0.99	0.29	0.13	2.04	25.9	4.08	2.90	9.02	23.1	23.1

Table 5: FCC of pedons and interpretations

Pedon	FCC designation	Description	Interpretations
P1	La ⁻ eg	Loamy top soil and subsoil, aquic condition and saturated with water for >60 days in a year. High leaching potential with Al toxicity for sensitive crops like cotton.	Glei condition indicates low water infiltration. These soils are suitable for paddy cultivation. However, anaerobic conditions in the subsoils lead to denitrification. Hence, nitrification inhibitors are recommended. Split application of nitrogen fertilizers should be practiced to prevent leaching losses. Prone to the deficiency of Zn micronutrient due to heavy leaching. Hence, micronutrient management is crucial. To take a second crop (rabi pulses) the acidic soil conditions are to be managed by regular liming.
P2	Ca ⁺ e	Clayey topsoil and subsoil. Low base saturation and Al toxicity for most of the crops and low buffering capacity. Gravelly subsoil.	High water holding capacity. Highly acidic soils. Suitable for tea and rubber cultivation. Integrated nutrient management is necessary for optimum yield and maintain fertility levels.
P3	Lg ⁺ a ⁻ e	Loamy topsoil and subsoil, prolonged waterlogging, High leaching potential with Al toxicity for sensitive crops like cotton.	Similar to P1. But due to prolonged waterlogging in most of the time in the year and high-water table, paddy can be taken in rotation with another crop of paddy only.
P4	Ca ⁻ gke	Clayey topsoil and subsoil, aquic condition and saturated with water for >60 days in a year. High leaching potential with Al toxicity for sensitive crops like cotton, low nutrient reserves.	Glei condition and clayey texture indicate low water infiltration. These soils are suitable for paddy cultivation. However, anaerobic conditions in the subsoils lead to denitrification. Hence, nitrification inhibitors are recommended. Split application of nitrogen fertilizers should be practiced to prevent leaching losses. Prone to the deficiency of Zn micronutrient due to heavy leaching. Hence, micronutrient management is crucial. To take a second crop (rabi pulses) the acidic soil conditions are to be managed by regular liming. Heavy K fertilizers and band application of K fertilizers is highly recommended.
P5	La ⁻ ek	Loamy top soil and subsoil, High leaching potential with Al toxicity for sensitive crops like cotton, low nutrient reserves.	Moderate water holding capacity. Soils are suitable for wide range of vegetable and pulse crops. Well drained. But the leaching loss of bases are to be addressed by band placement of K and P nutrients. N, P and K should be applied in split. Foliar spray of Zn and other micronutrients are recommended. Soil acidity should be addressed with regular liming.
P6	LCae	Loamy top soil and clayey subsoil, high erosion risk, Al toxicity and low base saturation for all crops, low buffering capacity.	Top soil management is crucial. These soils are suitable for cultivation of rubber, tea and arecanut, which are among the major crops of Assam. Major management practices should involve covering the top soil with cover crops and application of organic matter over the soil surface.

doses, application of slow-release fertilizers, use of nitrification inhibitors to increase the use efficiency of nitrogen fertilizers by minimizing the leaching and volatilization losses (Minh, 2011). Application of K fertilizers as band application in split doses is highly recommended to minimize nutrient losses. Due to prolonged submergence, these soils are prone to the deficiency of Zn micronutrient (Minh, 2011). Hence, integrated nutrient management including micronutrients is highly recommended.

The non-paddy soils of older alluvial plains (P5) were classified into Fine loamy, mixed, hyperthermic Fluventic Eutrochrepts categorized into FCC class La^{ek} (Table 5). They have loamy top soil with major constraints of high leaching potential, Al toxicity for sensitive crops like cotton and low nutrient reserves. The soils are lighter in texture compared to the paddy cultivated soils of older alluvial plains, because these soils were confined to the river banks of Deosila river, a main tributary of Brahmaputra in Goalpara district. Due to the lighter texture of these soils, and higher sand content (45 - 60 %), the leaching of K might have occurred leading to the low nutrient reserve status. Similar results have been reported by Orimoloye, (2016) for flood plain soils of Nigeria. Also, because of the very same reasons of low CEC due to low activity clays, the nutrient holding capacity reduce and nutrients leach down the profile. These soils are suitable for wide range of vegetable and pulse crops. But nutrient leaching has to be controlled by band placement of K and P nutrients. N, P and K should be applied in split to minimize these losses. These soils are also highly acidic in reaction (4.98 to 5.23) which might be due to the same reason of heavy rainfall in the area. Hence, regular liming is necessary for obtaining higher productivity.

The soils of upland (P6 and P7) were categorized into LCae FCC class (Table 5). The lighter textured soils (loamy) in the surface and heavier textured soils (clayey) in the subsurface indicate susceptibility to top soil erosion (Vasu *et al.*, 2016). Low base saturation and low buffering potential are the major constraints of these soils. Due to slope gradient of 3-8 % in combination with the prevalent heavy rainfall, the water erosion of top soil is a major risk of these soils. Also, low buffering potential and low base saturation can potentially

cause nutrient deficiencies to all the crops. These soils are suitable for tea and rubber. Tea cultivation can provide sufficient cover to prevent erosion but cultivation of rubber and arecanut should be taken along with covers crops as intercrops. Low buffering capacity of soils can be managed with regular incorporation of organic matters in the top soil to increase the CEC. If rubber cultivation is to be taken, organic matter incorporation in the first 4-5 years is necessary. Afterwards, the leaf litters from rubber can be incorporated or left on the soil surface. Integrated nutrient management including micronutrients is very much essential.

The soils of inselberg (P8) were also categorized into LCae FCC class (Table 5). Hence, the risks and limitations remain same as that of P6 and P7. However, the inselbergs are mostly covered by mixed forest and not cultivated. A very few inselbergs are cultivated with arecanut and rubber. For these cultivated soils, management practices recommended for P6 and P7 can be followed.

All the soils under study showed highly acidic soil reaction which might be due to the leaching of bases down the profile due to heavy rainfall. Similar results have been reported by Reza *et al.*, (2018) for soils of upper Brahmaputra valley. The common constraints in each soil under study were Al toxicity and high leaching potential or low buffering capacity. The Al toxicity could be attributed to the low base saturation. The low base saturation and low buffering capacity of soils might be due to the low CEC of the soils, which is due to presence of low activity clays in the Brahmaputra valley (Bandyopadhyay *et al.*, 2017). The low nutrient reserves in the soils of older alluvial plains might have aroused due to the soluble nature of K nutrient which is easily leached by the excess soil moisture in the lowlands (Ojanuga, 2006). Other reasons might be the geology of the alluvial plains of the study area, which is derived by quaternary alluvial sediments (Dasgupta and Biswas, 2000) which are inherently low in K reserves.

Conclusion

The soils of the lower Brahmaputra valley were grouped by similar set of characteristics that put them into single class in terms of fertility management. The major FCC classes found were La^{eg}, Lg^ae, Ca^re, Ca^gke and LCae. High soil

acidity, Al toxicity, high leaching potential and low CEC are the major problems of the soils of the block. Apart from these constraints, moisture saturation is the common problem in active flood plain, younger alluvial plains and paddy growing soils of older alluvial plains. This moisture saturation condition can be made beneficial by taking proper soil management practices of regular liming and proper nutrient management strategies. The problem of top soil erosion risk can be managed by cover crops and surface residue management with organic matter application. Our study revealed that converting the pedological parameter data into FCC for the lower Brahmaputra

valley could successfully bring out the fertility constraints of soils and has provided insight into proper management of these soils for sustainable crop productions.

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Conflict of interest

The authors declare that they have no conflict of interest.

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