

The Effects of Tea Plantation Upon the Soil Properties Based Upon the Comparative Study of India and China: A Meta – Analysis

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Abstract

The effects of tea plantations upon soil are of great concern in the context of monoculture crops due to their increasing demand resulting in the expansion of tea growing areas. Therefore, this study was conducted to understand the soil's Physico-chemical properties, soil nutrient concentrations, and stoichiometry in major tea-growing areas of India and China. For this study Meta-analysis approach was used to examine the difference between the two countries. Soil pH tends to be more acidic in Chinese soil (CS) than in Indian Soil (IS), soil Bulk Density (BD) was higher in CS with low soil Total Porosity (TP). Whereas the soil texture in CS was fine texture with Silt Clay while IS texture was coarse with sandy clay loam. Soil Carbon (C) showed no significant difference; while Nitrogen (N) concentration showed a significant difference only at the top layer with a higher concentration in IS. Soil Phosphorus (P) and Potassium (K) concentration were significantly higher CS than IS at all soil depths. The C: N ratio in both the countries was below 10 showing the accumulation of organic matter is low whilst the C: P ratio showed net mineralization of nutrients in both the countries. The N: P ratio represented N limitation in CS while P limitations in IS. The comparison of soil physico-chemical properties between India and China revealed the distinct differences between the tea plantation soils in both of these countries. Except for C concentration C: P, N: K, and P: K ratio all the properties are deemed to be different. Our results suggest that a balanced fertilizer application and these N and P limitations in tea growing soil of these two countries should be paid more attention to.

Keywords: Soil physico-chemical properties; Soil nutrient; stoichiometric ratio; India; China.

1. Introduction

Soil is a dynamic natural body consisting of mineral and organic compounds formed through various pedogenic and weathering processes and thus possessing definite physical, chemical as well as biological properties which provides medium for plant growth [1]. In fact, soil is the foundation of our own existence as it provides us with a wide range of food, fodder and timber. It forms the basis through which the entire system functions, thereby delivering other ecosystem services as well [2, 3]. However, the aptness of soil for its production largely depends upon its physical, chemical and biological properties [4]. A proper understanding of soil physico chemical properties is essential for proper implementation of any management practices which ultimately affects the soil productivity [5]. Therefore, in order to analyze the soil quality some of the key physical and chemical attributes has to be taken into account. Soil physical properties largely characterize the movement of air and water, dissolved chemical through soil that helps lay the foundation of several chemical processes which are further governed by land use, climate and landscape position [6], parent material, vegetation and human disturbances [7]. Among all these factors human decisions and actions are considered to be the ultimate factor in determining sustainable agricultural production system on a given soil [8]. Human impacts are largely related to the changing land use pattern and the most significant changes in the past few decades are in the form of agricultural intensification all around the world [9]. The tropical regions as well as huge areas have undergone drastic change in the form of forest clearance [10, 11] for the cultivation of mono crops like tea along with exotic crops like oil palms, rubber trees [12, 13]. The underlying reason for its expansion is due to the fact that plantation crops are mainly an export commodity and is in great demand in the global market [14]. Plantation crops are mostly mono cropped and have a distinct agricultural system associated with colonial expansion in tropics and subtropics [15].

Tea originated in China, which has a lengthy history of tea plantation [16] dating back over 3000 years [17], with South West China serving as the world's original tea producing zone [18]. The total area under tea plantation accounts for 2.41 million ha globally, with China alone covering an area of 1.3 million ha under tea plantations, [19] making China as the world largest producer of tea in the world. Followed by China, India is the second largest

producer of tea in the world with the area of 0.58 million ha and covering the total cultivated area of 14.72% in the world [20]. Tea (*Camellia sinensis* L.) is one of the widely consumed beverages in the world [21, 22] due to its aroma, medicinal values with health effects [23] derived from its rich organic and inorganic constituent elements, nutrients and pharmacodynamic composition [24, 25]. Moderately hot (13- 23°C) humid climate [26] with well drained fertile acidic deep and well-aerated soil (pH of 4.5 - 5.5) and more than 2% of organic matter [27] are the favorable climatic and soil condition required for tea plantations.

Tea being a perennial monoculture plant, its long-term cultivation induces variable amount of changes upon the soil properties [26] as well as on its nutrient concentration and distributions. These changes in soil can be accessed through examining the change in soil physico chemical (physico-chemical) properties under tea plantations [28]. Several research findings in the past reflected the impact of tea plantation upon soil quality and showed depletion of soil nutrient content in tea soil [29, 30]. Soil condition and agronomy management practices are detrimental in tea cultivation [31] as soil properties determine the availability of essential nutrients and their uptake by plants [32]. The soil physico-chemical properties in perennial monoculture crop like tea is the pH, soil Carbon (C) [26], Nitrogen (N) [33], Phosphorus (P) [34] Potassium (K), soil texture, Bulk Density (BD), Total Porosity (TP) are of utmost significance as they directly affect the soil quality. Soil C acts as the storehouse of nutrients and contributes in reducing soil compaction, contributes to soil aeration, infiltration ratio and water storage capacity increase [35]. N, P and K are possibly another important nutrient in the soil required by tea plantation [33, 34]. N plays a paramount role in establishing proteins and chlorophyll synthesis [36]. P availability in soil is always low in soil due to its low natural content and high P fixation capability of the soil [37]. Further, some of the earlier research shows that in more than 70% tea garden soil has P deficient [38]. Not only P, K deficient is also common in tea plantation soil due to imbalanced fertilization, which is characterized by increased N application with or without insufficient supply of other nutrients [39]. In tea plantation this nutrient deficiency is met through the use of chemical fertilizers but repeated and heavy application of fertilizers can deteriorate soil properties over time [40]. Proper nutrient management will help in maintaining soil quality while optimum N level in soil will help to uptake P and K in the soil [41]. The ideal nutrient in tea soil should consist of 1.7 – 2.3% of soil organic matter (SOM) [42], 11% of N, 1.65% of P and 3.1 % K [43] respectively. Soil pH is considered as the “master soil variable” [44]. Tea being an acid loving plant requires acidic soil and thus in turn acidifies the soil [45]. Generally, soil pH decreases with the time of tea plantation [46, 47]. Han [48] reported that 40 % of tea garden has a pH around 4. The soil under tea plantations is liable of having high BD over the years because of intensive leaching and trampling by Phukan and Baruah [49]. Soil texture also plays a key role in nutrient availability in tea soils, as evidence suggested by Mishra and Francaviglia [50] showed that soil organic carbon (SOC) is higher when soil texture was medium and fine [51]. Therefore, soil characteristics along with the proper nutrient management parameters play a good role in better tea production and maintenance of good soil health.

The studies mentioned above shows the effects of tea plantations upon the soil quality and most of the study showed the depleted soil properties in mono cropped tea plantations. However, the previous study indicates a gap in quantification of these effects of plantation over long run. With regard to the current observation, this study was taken to provide the first ever quantitative review of tea plantation effects on soils physico-chemical properties along with nutrient concentration, its dynamics and stoichiometry in India and China using a meta-analysis approach. The rationale for choosing these two countries as the study site is due to the fact that these two giants act as the axis of main tea producers in the world as they are reported to be the first and second largest tea producer in the world. These two countries have very long history of tea plantation of over 100 years of plantations and their considerable long-term effects upon soil properties have been neglected by previous studies. The geographical location, soil structure, parent material, soil properties (physical and chemical properties) and soil management strategies in these two countries is diverse which leads us to hypothesize that the extent and degree of change upon soil quality parameters can also be different. Therefore, it is desirable to examine the changes that have occurred in soil that results in degradation of soil quality. This information will help these two countries to provide effective information on soil quality deterioration along with nutrient limitation in soil so that effective strategies on nutrient management, fertilizer use can be adopted as long as the question of sustainable agriculture remains the prime focus. We hypothesized that there exists a significant difference between the tea plantation soil of India and China due to the influence of soil inherent properties, parent material, soil structure and management strategies (fertilizer use). Hence, the main objectives of this study are as follows (1) to optically compare the soil nutrient concentrations and stoichiometry under tea growing areas in India and China. (2) To check the potential limiting nutrient in tea soil between India and China.

2. Materials and Methods

2.1. Data Collection/ Meta-Analysis

For this Meta-analysis, the relevant articles were collected from wide range of published in English and Chinese literature upon soil physical chemical properties in tea growing areas of India and China. The relevant articles were collected from Science Direct and Google scholars with the search terms tea garden, soil physical and chemical properties in tea plantations, Tea plantation in India and China. Our final database included 270 observations (different soil profiles) from 110 published sources. The various soil profiles were then classified into 3 horizons (0 - 20cm, 20 - 50cm and > 50cm) of top, middle and deep soil layers. For all of these given parameters, the average values were taken.

China: Tea in China is mostly grown in the southern and southwest, southeast part of China (Figure 1, Table 1 b). In China tea is grown upon the elevation ranging from 212 - 1450 m above sea level [52, 53]. The tea growing

area in China experiences a subtropical monsoon climate with the mean average annual temperature 15.4°C - 33°C with mean annual average rainfall in between 1500 - 2023 mm with 72.6% of precipitation between June to September [16, 54-56]. The average humidity is around 78% [54] in tea growing areas of China. Tea in China is grown in the wide variety of soil that includes bleached paddy soil, acid purple [53, 57], red soil [57, 58], bleached yellow earth [59], yellow earth [53, 57, 60], moisture sandy soil, alpine meadow soil, purple soil [61], yellow brown earth, purplish soil, mountain meadow soil [55].

India: The main tea growing areas in India are Assam, Darjeeling, Kangra, Nilgiris, Anamallais, Wayanad, Karnataka, Munnar, Travancore, Doars and Terai (Figure 1). In India, tea is grown upon the elevation ranging from 300 - 2500 m above sea level [62]. The tea growing areas in India experiences subtropical monsoon climate with mild winter, warm and humid summer [63] (Table 1a) with the average rainfall ranging from 900 and 7500mm occurring mostly in rainy season from June to September [64]. The temperature ranges from 28°C - 30°C in summer and 14°C - 16°C in winter [65] with relative humidity ranging from 53.67% - 94.59% in winter and 64.04% - 94.60% in summer [66]. Soils in Indian tea plantation areas are alluvial [67], red loam and lateritic soil. The main soil type in tea growing areas of India is classified as Oxisols according to USDA classification [26].

2.2. Statistical Analysis

All the statistical analysis was performed by using IBM SPSS 22.0. T-test was adopted to discern the differences of soil properties at different soil depth. Pearson correlation coefficient was used to represent the relationships between the C, N and P concentration and stoichiometry and selected soil physical properties. A *p* value < 0.05 was accepted as statistically significant difference for those analyses. All the figures were prepared using Sigma Plot 12.5. The map was produced using Arc GIS 10.1.

3. Results

3.1. Tea Plantations Impacts Upon the Soil C, N, P and K Concentrations

Soil C concentration did not show any significant difference at all depths (Table 3, Figure 3a and 3b). Soil N exhibited significant difference only in top layer (0 - 20cm) (Figure 3c and 3d, Table 3) with higher concentration in IS than CS. Soil P showed significant differences at all depths with much lower concentration in IS (Figure 3e and 3f, Table 3). Soil K also presented significant difference at the top (0 - 20cm) and middle layer (20 - 50 cm) except lower layer (> 50 cm) (Figure 3g and 3h, Table 3). Soil K in IS were much lower than CS.

3.1.1. Tea Plantations Impacts Upon C, N, P and K Stoichiometry

Soil C : N ratio showed significant difference only at lowest layer (> 50 cm) (Figure 4a and 4b, Table 3) with highest in CS. Soil N : P ratio showed significant difference only at the middle layer(20 - 50cm) (Figure 4g and 4h) and it was higher in IS. Similar to C : N, soil C : K ratio also differed significantly but only at the lower layer (> 50 cm) with significantly higher in CS. Soil C : P, N : K, P : K ratio did not show any such significant difference at any soil depths (Figure 4 c, d, i, j, k, l)

3.1.2. Tea Plantations Impacts Upon the Soil Physicochemical Properties

Soil pH tends to be more acidic in CS than in IS with significant difference at the top soil layer (0 - 20 cm) (Table 3, Figure 2a and 2b). BD also differed in these two countries but only in middle (20 - 50cm) and lower layer (> 50cm) with high BD in Chinese soil (Table 3, Figure 2c and 2d). TP also showed significant difference only in the middle and lower layer with low TP in CS (Table 3, Figure 3e and 3f). Soil texture showed significant difference in both the countries. The IS texture was coarse with sandy clay loam which contain more sand as apparent from the Figure 2g and 2h where sand content was much higher in IS than CS. Whereas the soil texture in CS was fine texture with Silt Clay as shown in Figure 2i and 2j where the Silt content was higher than IS and thus significant difference was found (Table 3).

3.1.3. Soil Nutrient and its Stoichiometric Relationship with Selected Soil Physicochemical Properties

Soil pH showed significantly negative correlation with C, C : N, C : P ratio in CS but no such significant relationship was found with pH in IS (Table 2). Soil BD was positively correlated with P and K concentration with negatively correlated with C : P, C : K and N : K in IS while it was negatively correlated with C, N, C : N, C : P and N : P in CS (Table 2). In IS TP showed negative relationship with P and K while positive with C : P, C : K and N : K (Table 2). In CS TP was positively correlated with C, N, C : N, C : P and N : P. Sand represented a negative relation with C, N, K, N : P and N : K while silt have a perfect positive correlation with N, N : P and N : K in IS, whereas sand and silt in CS did not showed any relationship with any other nutrient variables (Table 2). Clay showed significantly positive correlation with N : K, K while negative with C in IS. On the other hand, Soil K was negatively correlated with clay in CS (Table 2).

4. Discussion

4.1. Contents of C, N, P and K in Response to IS and CS

In this present study. there was higher concentration of C, N and P in the top soil, which is associated with littering by tea leaves, shade tree leaf littering [21], decayed grass, pruned braches [65] and root debris. The C

content in the soil defines the fertility of the soil, which is defined to be low or unsuitable, moderate and satisfactory depending upon the availability of C in the soil (< 0.60 , $>0.60-1$, $> 1.00\text{gkg}^{-1}$) [26]. The average C concentration in soil was 9.55 (IS) and 7.93 gkg^{-1} (CS) showing the satisfactory level of C in the soil but didn't showed any significant differences. This result is consistent with that of the finding of De la Paix Mupenzi, *et al.* [68] where the C concentration in the 11 zones of Rwanda tea growing in East Africa areas ranged in between 3 - 16.9gkg^{-1} . In fact, tea plantation produces immense amount of litter in the fallen leaves that helps to maintain the high calibre of organic matter.

Soil N concentration in both the countries differed only at the top layer with the average of 1.56 (IS) and 1.2 (CS) respectively. This finding is in a good line with that of the Sultana, *et al.* [69], Adiloglu and Adiloglu [70] where the N concentration were 1.2 - 3.7gkg^{-1} and 1.09gkg^{-1} respectively. The differences in the top layer could be explained by different rate of fertilization process followed by the decomposition rate driven by microorganisms. Another possible reason is the slope factor where N concentration increases in lower slopes than in the higher slopes [71]. As the matter of fact that in order to meet the massive demand of tea in domestic and overseas market, large number of new tea plantation were established in Subtropical China [72] in erosion prone hilly country area. After that huge N fertilization application coupled with heavy precipitation and topographical factors lead to the low N use efficiency condition and loss of N through leaching, soil erosion and surface runoff [73]. This result is consistent with the findings of Yuan, *et al.* [57], which shows that low N in the soil is due to more intensive soil leaching and soil erosion. Another reason may be rapid growth of tea plants, which consumes huge N form soil [66].

Soil P and K were significantly higher in CS then IS. P deficiency is widespread in IS because adequate reserve of rock Phosphate is low in India [74]. Another reason is due to the reduction in top dressing with inorganic fertilizers and absorption of these fertilizers by tea plants coupled by soil erosion [75] or unavailability of P in the soil. This result is in consistent with the findings of Bhuyan, *et al.* [76] which shows low P in tea soil and it is due to the fact that when large amount of P is added as fertilizers in the form of super Phosphate, they are fixed by Al_{3+} and Fe_3 rendering it unavailable in the soil. There is High K content in the soil of Southern China due to the fact that Chinese soil contains more Hydrous mica, which sustain the soil with high availability of K in the soil [74]. In one of the study soil fertility can be restored through organic management practice, as reported in one study that the use of Laredo soybeans green manure and goat manure was proven to be beneficial for enhancing nutrient status under tea plantation [77]. When there is existence of variation in soil C, N and P along with their stoichiometric ratios, they are considered to be critical in agricultural nutrient management system [78].

4.2. Tea Plantation Effects on Soil C, N, P and K Stoichiometric Ratios in Response to IS and CS

Soil stoichiometric ratio (C : N, C : P, N : P) not only represents the equilibrium features of Soil C, N and P but also takes into account the fertility characteristics, [79] reflecting nutrient cycle characteristics in micro soil environments [78] in the soil formation processes. Our result showed significant differences only in C : N, N : P and C : K. The average C : N in Indian soil was 11.20 whereas in China it was 10.52. This result is in the good agreement with the findings of Wang, *et al.* [60]; Haorongbam, *et al.* [66] where the C : N ratio is lower than 10 in conventional tea plantations. The deeper layer showed significant difference in C : N showing that the deeper layer do not provide enough nutrient for plant growth. The higher average C : N in this study implies higher organic matter accumulation representing net mineralization of nutrient in both the countries as the mean value in both the countries is below is < 200 .

The N : P ratio is reflected to be one of the reliable indicators of nutrient constraint, where if the ratio is > 16 betokens P constraint, < 14 is indicative of N inhibition and in between 14 and 16, either N or P can be inhibiting or plant growth is co-circumscribed by N and P together [61]. In this study the average N : P ration in IS and CS were 16.09 and 7.64 respectively which was higher than the global average (13.1) [80] in IS but lower in CS, but the N : P ratio in CS falls within the Chinese average of 9.30. [81]. This study showcased widespread P limitation in IS whilst N limitation in CS. The potent factor may be acidic nature of soil along with high precipitation that ultimately lead to the substantial loss of N from soil through runoff and leaching or it may be attributed that N is more soluble than P and there is consequent loss of N than P [82] in CS. In IS there is widespread P limitation. This finding is in line of the previous findings of Dey, *et al.* [74] where it is stated that most of IS are deficient in P content as the adequate reserve of rock phosphate is low thus posing a threat. Their showed no significant difference in the N : K, P : K due to relatively stable P and K content and significant increase in total N and high amount of litter and fixed N in soil [30].

4.3. Effects of Tea Plantation on Selected Physicochemical Properties and Their Connection with C, N, P and K Concentration and Stoichiometry

There are many factors that effects the soil physicochemical properties like elevation, parent material or geological formation, human activities or interferences and climatic characteristics [83]. In these study the prime factors affecting the soil properties are parent material, heavy rainfall, weathering processes, high aluminum (Al), iron and manganese contents [21] and the large number of base cations leaching from soil [57]. Selected physicochemical properties in this study presented distinct differences in pH, BD, TP and Texture (Figure 2). In this study CS tend to be more acidic than IS and the possible reason is related to the age of tea bushes, as the pH decreases with age [84] and secondly is the huge addition of ammonium ($\text{NH}_4\text{-N}$) fertilizer [85] and the last factor is the pruning of tea bushes which also contribute to low pH [65]. The acid soil in IS provides another additional

problem of low base saturation (<75%) along with low exchangeable cations concentrations [86]. Soil pH is significant in shaping soil nutrient concentration that ultimately affects their Stoichiometric ratios [5].

Soil BD is the display of tightness and looseness. If the value is high, it refers that the soil is compact and it will significantly reduce soil infiltration rate [16]. An appropriate BD for tea growing soil should be 1.00 - 1.20 gcm⁻³ at the surface and 1.20 - 1.45gcm⁻³ at the heart [31]. BD in CS was higher than IS displaying higher degree of tightness which was supported by our result that showed significant negative relationship with C and N (Table 2). This may be due to use of machinery, human traffic and reduction of organic matter content or availability of heavier inorganic fractions in soil [63, 87] and altitudinal variation as tea may be grown at different elevation or an inverse relationship with soil C and vice versa [88, 89]. BD in IS showed declining trend towards depths thus showing good soil structure with high organic matter content in soil [90]. In the CS, BD increased towards its depths showing significant difference at lower depths. Thus, it will affect plant roots, which are often physically impeded by compact subsoil layers. This also implies that the subsoil of the area cannot hold sufficient amount of available nutrients and water [91].

Soil TP is related to water and air permeability, thermal conductivity and density [16]. It is an important indicator for crop growth. TP in IS was higher than CS and this was supported by our result that C and N was positively correlated with C and N (Table 2). In the study TP showed the exact opposite relationship with BD. This is due to the fact that soil BD is inversely related to TP of the same soil [92]. Soil texture showed varied difference in Indian and Chinese soil. This variation can be due to weathering, soil erosion, deposition, different soil forming process [93], variable rainfall and temperature patterns [50], anthropogenic factors like cultivation management [94].

5. Conclusion

In this study we investigated soil physical chemical properties, soil nutrients and its stoichiometric ratios between India and China. The result revealed that except for soil C, C :P, N : K, P : K ratio all the properties deemed to be different. IS was deficient in P and K concentration while CS has low C and N concentration. IS represented widespread P limitation whereas CS had N limitation. Soil physical properties in CS showed increasing BD and more acidic nature of soil. Soil texture was coarse with sandy clay loam in IS while in CS was fine texture with Silt Clay. Our findings were providing a basis for effective nutrient management for sustainable tea plantations. Models for soil nutrient managements can be used in tea plantation also, for example Nutrient Expert is one of the fertilization recommendation system which was successful in Maize and wheat so the same can be applied in tea plantation also. Apart from that this study also provides basis for Integrated Nutrient Management (INM) models that can be applied in future. Overall this study can help in understanding nutrient dynamics in tea plantation soil and also provide an ecological stoichiometry in tea plantation soil.

Disclosure Statement

The authors declare no conflict of interest.

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Table-1. A and B: Distribution of Tea plantation areas in India and China based upon the literature survey

INDIA (I A)			
latitude	longitude	soil type	climate zone
27°05.38'-27°42.30'N	94°33.46'-95°29.80'E	Oxisols (Histic Haplaquox)	na
27°23'-27°48'N	94°22'-95°38'E	Oxisols (Histic Haplaquox)	na
8°- 13°N		Latosols (Oxisols and Ultisols)	na
26°45'N	96°16'E	Alluvial soil	na
26°25'-26°55'N	91°45'-91°20'E	na	Sub tropical climatic zone
26°44'N	94°12'E	na	Humid sub tropical climatic zone
25°45'N	93°30'E	na	Humid sub tropical climatic zone
24°22'-25°8'N	92°24'-93°15'E	na	Humid sub tropical climatic zone
26°35'0.50"N	93°21'12.49"E	na	na
26°36'33"N	93°35'14"E	na	na
26°39'19.3"N	94°39'22.7"E	na	na
26°17'30.6"N	94°28'29.2"E	na	na
27°05.38'-27°42.30'N	94°33.46'-95°29.80'E	na	subtropical monsoon climatic zone
26°44'29"N	88°38'41"E	na	na
26°68'N	88°22'E	na	na
-			-
CHINA 1(B)			
latitude	longitude	soil type	climate zone
30°12'04"-30°12'43"N	103°11'42"-103°12'02"E	yellow soil was formed in the older alluvium	subtropical monsoon climatic zone
28°56'-29°34'N	105°38'-106°05'E	purple soil	subtropical monsoon humid climatic zone
24°50'-25°26'N	117°36'-118°17'E	Yellow soil, Latosolic read soil, yellow red soil, red soil	tropical and subtropical monsoon climate zone
29°20'N	119°54'E	typic Hapludults	na
21°08'-22°36'N	99°56'-101°50'E	lateritic soil (Oxisol)	na
31°14'N	120°09'E	Ultisols	na
30°12'04"-30°12'43"N	103°11'42"-103°12'02"E	Luvisols	subtropical monsoon climate
25°15'-26°29'N	118°08'-120°31'E	red soil	Sub tropical climate
30°11'N	120°05'E	red soil	subtropical wet monsoon climate
27°13'S	119°34'E	Typic Alliti-Udic Ferrosols	na
28°15'N	116°55'E	Ultisols	na
29°58'N	102°59'E	na	na
29°53'N	105°56'E	na	na
25°08'N	102°45'E	na	na
28°11'N	113°13'E	na	na
30°36'N	114°18'E	na	na
18°20'N	116°01'E	na	
na	na	bleached paddy soil,	subtropical humid monsoon climate
na	na	yellow earth	subtropical humid monsoon climate
na	na	acid purple soil	subtropical humid monsoon climate
34°22'-38°23'N	114°19'-122°43'E	Brown soil (Albic Luvisol)	temperate, continental monsoon climate zone
na	na	Yellow Brown Earth(Alfisol)	transitional region between subtropical and temperate regions
na	na	yellow earth and purple earth(acid)	subtropical monsoon climate

Table-2. Pearson correlations between selected soil physical properties and soil nutrient stoichiometry* Correlation is significant at the 0.05 level(2 tailed) ** Correlation is significant at the 0.01 level(2-tailed) c. Cannot be computed because at least one of the variable is constant

		pH	BD	TP	Sand	Silt	Clay
INDIA	C	-0.08	-0.22	0.23	.387**	0.17	-.411**
	N	-0.18	-0.15	0.2	-.728**	1.000**	0.53
	P	0.13	.704**	-.684**	-0.29	0.26	.515*
	K	-0.36	.595**	-.554**	-.893**	.708*	.938**
	CN	0.22	0.05	0	0.53	-1.000**	-0.31
	CP	0.06	-.528*	.532*	0.09	0.24	-0.26
	CK	-0.03	-.588*	.585*	0.09	0.05	-0.33
	NP	-0.3	-0.49	0.47	-.635*	1.000**	0.44
	NK	-0.45	-.996**	.975*	-.998*	1.000**	.999*
	PK	-0.08	-0.29	0.26	0.5	-0.59	-0.66
CHINA		pH	BD	TP	Sand	Silt	Clay
	C	-.268**	-.649**	.654**	0.059	-0.108	0.092
	N	0.112	-.604**	.589**	-0.065	0.147	-0.089
	P	0.258	0.148	-0.15	-0.316	0.227	-0.168
	K	0.196	0.035	-0.039	-0.479	.617*	-.618*
	CN	-.489**	-.375*	.384*	0.405	-0.352	-0.004
	CP	-.489**	-.480*	.481*	0.095	-0.295	0.349
	CK	-0.002	-0.241	0.244	0.138	-0.424	0.5
	NP	-0.172	-.657**	.651**	. ^c	. ^c	. ^c
	NK	-0.099	-0.433	0.436	. ^c	. ^c	. ^c
PK	0.151	-0.178	0.178	0.072	-0.182	0.212	

Table-3. Statistical significant difference between India and China with each soil depths

Ph	BD	TP	Sand	Silt	Clay	C	N	P	K	CN	CP	NP	CK	NK	PK
***	ns	ns	***	***	*	ns	***	***	**	ns	ns	ns	ns	ns	ns
ns	**	*	**	ns	ns	ns	ns	*	***	ns	ns	**	ns	ns	ns
ns	**	**	*	***	ns	ns	ns	**	ns	*	ns	ns	*	ns	ns

* Correlation is significant at the 0.05 level
 ** Correlation is significant at the 0.01 level
 *** Correlation is significant at the 0.0001 level

Figure-1. Location map of showing some of the study site along with the sample points in the main tea growing areas of India and China derived from the literature survey

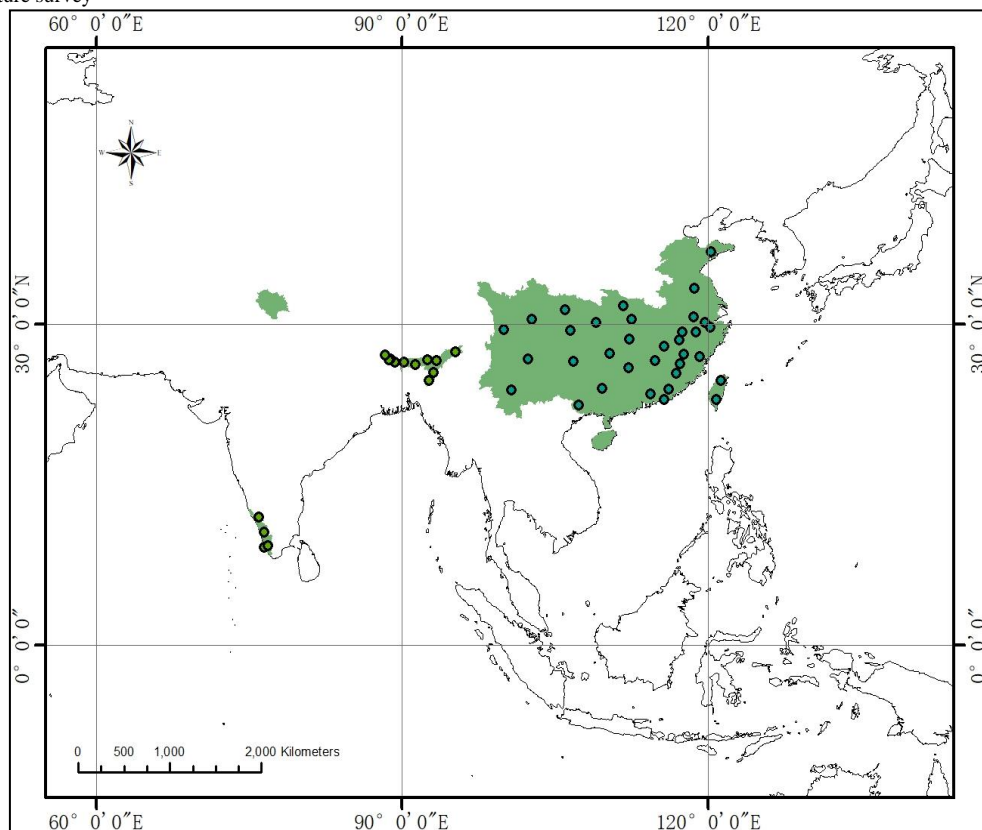


Figure-2. One-way ANOVA showing the soil physical chemical properties across three soil depths. Error bars indicate standard deviations. Symbols above the bars represent the significant differences at $p < 0.05$

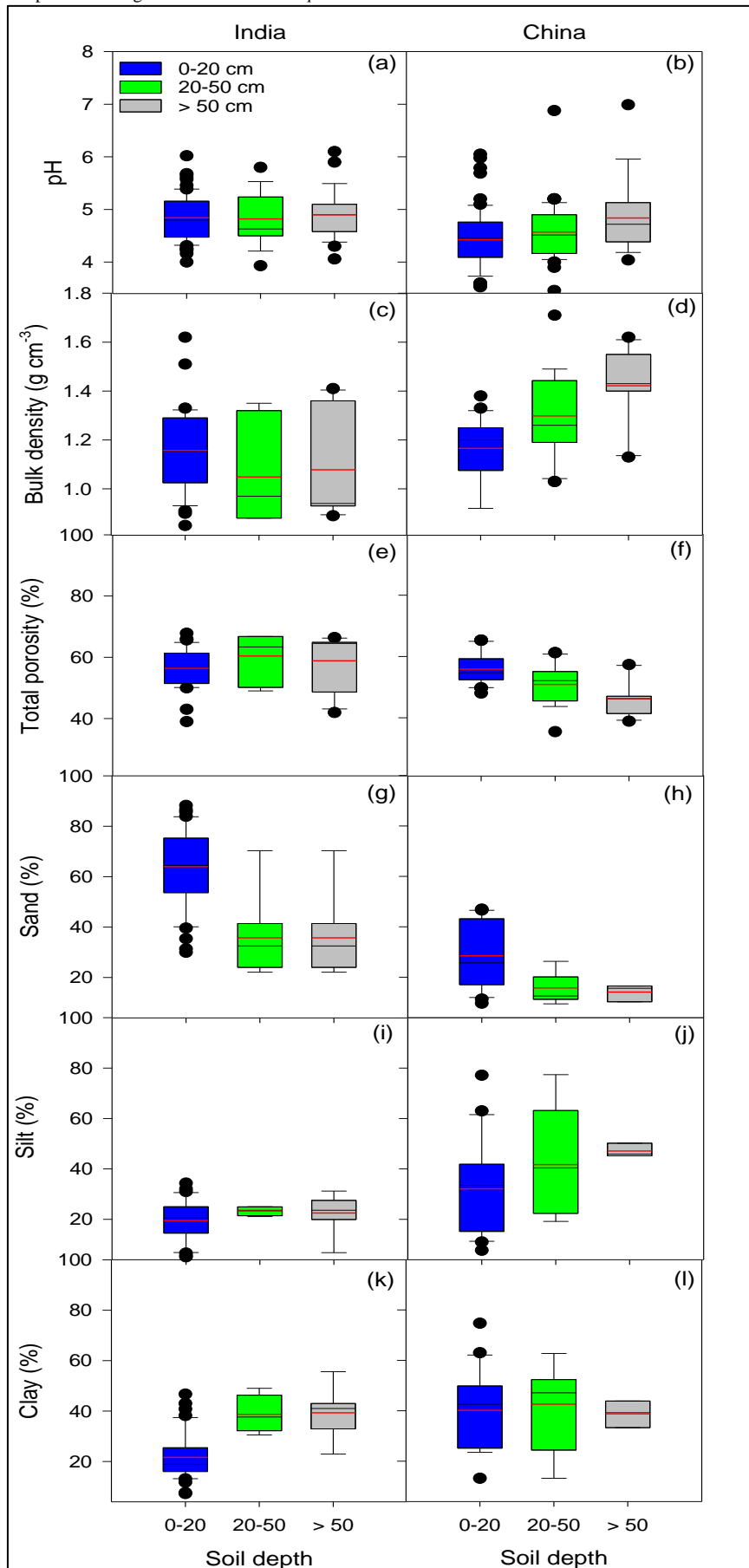


Figure-3. One-way ANOVA showing the C, N, P and K concentrations across three soil depths. Error bars indicate standard deviations. Symbols above the bars represent the significant differences at $p < 0.05$

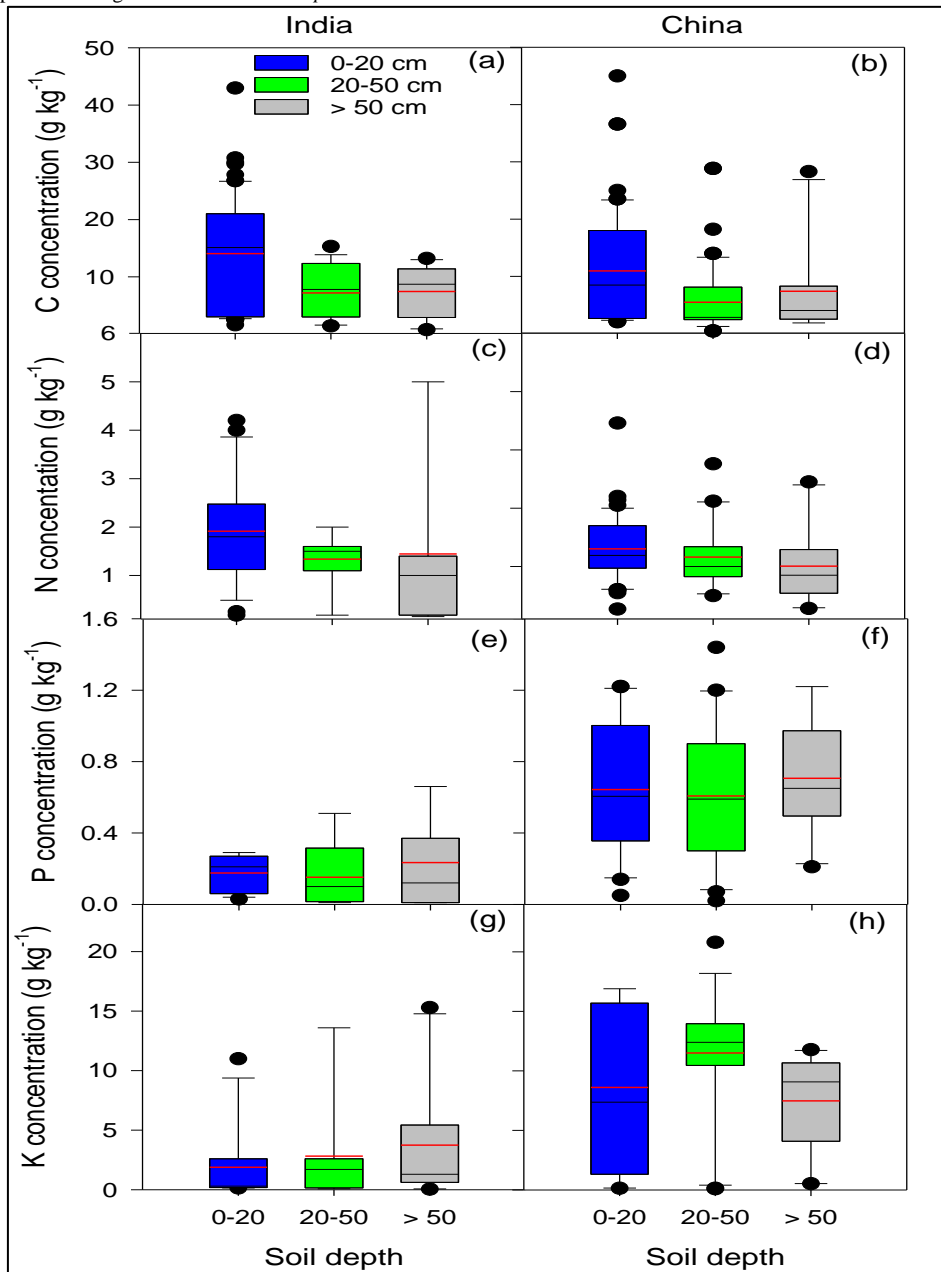


Figure-4. One-way ANOVA showing the C, N, P and K stoichiometry across three soil depths. Error bars indicate standard deviations. symbols above the bars represent the significant differences at $p < 0.05$

