Changes of Soil Physical and Chemical Properties in Aonla (Phyllanthus emblica L.) based Multistoried Agroforestry System

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Changes of Soil Physical and Chemical Properties in Aonla (*Phyllanthus emblica* L.) based Multistoried Agroforestry System

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A field experiment was conducted in single factor randomized complete block design, where treatments were open field (T_1), aonla (T_2), carambola (T_3), lemon (T_4), aonla + carambola (T_5), aonla + lemon (T_6) and aonla + carambola + lemon (T_7) to assess the soil physical and chemical properties in aonla based multistoried agroforestry system. From this study, it was observed that aonla + carambola + lemon combined treatment showed highest improvement in physical properties of soil i.e., soil moisture content, bulk density, particle density, and porosity which was followed by aonla + carambola and aonla + lemon combined treatment. On the other hand, T_7 showed concentrations of nitrogen, organic carbon, phosphorus, magnesium, potassium, calcium, boron, sulphur, iron, manganese, zinc and copper followed by other treatments except soil pH and decreased with the soil depths. Due to the presence of highest amount of organic matter with the carbonic acid production during root respiration the pH becomes lower in T_7 treatment. The soil physico–chemical properties of single strata treatment i.e., aonla, carambola and lemon–based treatments did not show much improvement as triple and double strata agroforestry system. Multistoried agroforestry system provides more biomass by harvesting maximum photosynthetically active radiation from different strata. Here, T_7 treatment utilize maximum above and below ground resources for maximum biomass production which also helps to incorporate organic carbon content in soil. As a result, aonla + carambola + lemon based multistoried agroforestry system can provide improve and healthy soil environment for better production.

Key words: Aonla, carambola, lemon, soil properties, multistoried agroforestry system

INTRODUCTION

Bangladesh is so much vulnerable to climate related extreme events viz. increasing temperature and variable rainfall levels along with severe and frequent floods, droughts and cyclones which adversely affect agricultural sector with the risk of food security (GoB, 2011). Rapid human population increasing and decreasing of agricultural productivity along with shrinking of cultivated land owing to drought and salinity makes the situation more worsen. As climate variability increases and related extreme weather events become more frequent and severe, there is a need to identify adaptation options to assist those most vulnerable to their impacts. Agroforestry is increasingly recognized as a sustainable land use in multi–functional landscapes which enhances farmers' ability to adapt to climate change because of the multiple benefits it delivers including food provision, supplementary income and environmental services (Lasco *et al.*, 2011).

Among divergence agroforestry systems, multistoried agroforestry system is considered one of the best systems which integrate different trees and agricultural crops in layer by layer that facilitate to enhance soil fertility, reduce erosion, improve water quality, enhance biodiversity, increase aesthetics and sequester carbon to alleviate global warming (Garrett *et al.*, 2009; Williams-Guillén *et al.*, 2008; Nair *et al.*, 2009). Trees and crops in multistoried agroforestry systems, produce organic matter (OM) inputs to the soil (Jordan, 2004; Peichl *et al.*, 2006), and could thus enhance soil organic carbon (SOC) stocks. Leaf litter and pruning residues are left on the soil, whereas OM originating from root mortality and root exudates can be incorporated much deeper into the soil as agroforestry trees may have a very deep rooting to minimize the competition with the annual crop (Cardinael *et al.*, 2015; Mulia and Dupraz, 2006). Moreover, several studies showed that root-derived C was preferentially stabilized in soil compared to above ground derived C (Rasse *et al.*, 2005), mainly due to physical protection of root hairs within soil aggregates (Gale *et al.*, 2000), to chemical recalcitrance of root components (Bird and Torn, 2006), or to adsorption of root exudates or decomposition products on clay particles (Chenu and Plante, 2006). Compared to an agricultural field, additional inputs of C from tree roots could therefore be stored deep into the soil, but could also enhance decomposition of SOM (Fontaine *et al.*, 2007).

Further, the integration of trees into agricultural systems as agroforestry may dramatically affect soil nutrient cycling by altering soil structure, microbial biomass and microclimate, and by increasing the quantity and diversity of plant residues and rhizodeposition products (Araujo *et al.*, 2012). For example, higher microbial biomass and N mineralization potential have been observed in soils within temperate wind breaks and in

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tree–based intercropping systems compared to conventional agricultural systems (Kaur *et al*., 2000; Wojewoda and Russel, 2003). Also, agroforestry systems may strongly alter the composition of soil microbial communities as the latter have been strongly linked to physicochemical properties of the soil (Bainard *et al*., 2011). For instance, more diverse soil microbial and arbuscular mycorrhizal (AM) communities have been observed in tree-based intercropping systems than in conventional agricultural systems (Bainard and Klironomos, 2011; Lacombe *et al*., 2009).

Aonla based multistoried agroforestry systems (aonla + carambola + lemon) in Bangladesh not only act as a nutritional hotspot but also sequestrate carbon and modify microclimate through its canopy to boost agricultural yield to provide year–round economic returns to the farmers. Nonetheless, *Phyllanthus emblica* L., aonla is one of the valuable medicinal herbs (Mehmood *et al*., 2011); widely distributed in subtropical and tropical areas of China, India, Indonesia and Malay Peninsula (Luo *et al*., 2011; Liu *et al*., 2012). It is also naturally grown in the terrace ecosystem of Bangladesh. Aonla fruit is reported to have antioxidant (Anila and Vijayalakshmi, 2003; Sreeramulu and Raghunath, 2010), hypolipidemic (Anila and Vijayalakshmi, 2000) and hypoglycemic activities (Abesundara *et al*., 2004). It is also used as antimicrobial (Buzzini *et al*., 2008), antiviral (Ryu *et al*., 2010), anti–tumour (Adams *et al*., 2006), antibacterial (Matito *et al*., 2003) and anti-inflammatory agent (Perianayagam *et al*., 2004). Carambola or star fruit (*Averrhoa carambola*) is a tropical fruit widely grown in South East Asia and many other countries. Carambola has remarkable nutritional value due to its antioxidant potential (Shofian *et al*., 2011). *Citrus limon* commonly known as lemon; is also a rich source of nutrients, including flavonoids, citric acid, vitamin C and minerals (e.g., potassium) (Tag *et al*., 2014), which provide numerous health promoting properties (González–Molina *et al*., 2009). Multistoried agroforestry practices can play a crucial role to supply diversified food round the year and to change the soil physical, chemical properties, and microclimates for more favorable conditions of crop, forage, and livestock production. The study about multistoried agroforestry practices is very rare in Bangladesh. Therefore, the present study was targeted to know the situation of soil physico–chemical properties at different depth in aonla based multistoried agroforestry system.

MATERIALS AND METHODS

Location of the study

A field experiment was conducted in the aonla based agroforestry research field of the department of agroforestry and environment, Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) from November 2013 to October 2014. The study area belongs to the agro–ecological zone 28 i.e., the Madhupur tract which lies between 24.09° N latitude and 90.26° E longitude with a mean elevation of 8.5 m above sea level. The soil of the experimental field was terrace soil, which is nearly equivalent to Ustocharepts suborder under the order Inceptisol of USDA Soil Taxonomy and belongs to the locally termed Salna Series of Shallow Red–Brown Terrace Soil (Brammer, 1971). The soil at the study site is silty clay loam in texture being acidic in nature, poor in fertility status, and impeded internal drainage. The climate of the area is sub–tropical, characterized by a heavy rainfall during the period from July to September and scanty rainfall during the period of October to March. The pre–monsoon or hot season with scanty rainfall was observed from March to June. The weather data were collected from the weather station located at BSMRAU.

Experimental field

The aonla orchard was established in 2000 maintaining 8 m×8 m distance at the research farm of the Department of Agroforestry and Environment, which was used for the experimentation. Aonla trees were planted in North–South direction. There were six rows of aonla trees and each row contains eleven trees. One year old seedlings of carambola and lemon planted on November 2008 under aonla trees as well as open field condition forming a systematic design. Carambola plant was planted just in the middle of two aonla trees and lemon plant was planted just in the middle of aonla and carambola plant. The aonla orchard was divided into seven parts. (a) the open field was stand in the extreme southern side (b) Middle–Eastern block was stand for aonla trees (c) South–Western block of aonla orchard was transformed into triple storied(d) Aonla and lemon plants were planted North–Eastern part of the orchard (e) Aonla and carambola plants were planted North-western side of the orchard (g) Only carambola plants were planted in south-western side (h) Only lemon plants were planted in south-eastern side. The variety of aonla was local race, carambola was BARI Kamranga–1 and lemon was BARI lebu–1.

Selected tree species (Aonla, carambola and lemon)

Aonla (*Phyllenthus emblica* L.) is a medium sized much–branched deciduous tree having the height of 5–10 m. The fruit is rich in vitamin C. Stem is smooth, greenish grey to brown, exfoliating bark, which peels off in thin flakes. Aonla tree is characterized by phyllanthoid branching habit. On the basis of growth characteristics, these have been characterized as long indeterminate and short determinate shoots. These are also referred to as branch and branchlet. The aonla trees in the experiment had the following features i.e., the average tree height was 8.89 m, base diameter was 55.78 cm, diameter at breast height was 44.53 cm and canopy area was 31.73 m^2.

Carambola (*Averrhoa carambol*a L.) tree is slow-growing, short–trunked with a much–branched, bushy, broad, rounded crown. The showy, oblong, longitudinally 5– to 6–angled fruits, are yellow flesh when fully ripe and sliced cut in cross-section showed the form of a star. The fruit has a more or less pronounced oxalic acid

Table 1. Method of analysis of soil sample

Properties	Methods of analysis	References
Soil Moisture	Gravimetric Method	Black, 1965
Bulk Density	Core Sampling Method	Blake and Hartge, 1965
Particle Density	Pycnometer Method	Blake and Hartge, 1965
Soil Texture	Hydrometer Method	Bouyoucos, 1962
Soil pH	Potentiometric Method	Jackson, 1962
Organic carbon	Wet oxidation Method	Allison, 1965
Total Nitrogen	Kjeldahl Method	Bremner, 1965
Available P	Bray Method	Bray and Kurtz, 1945
Exchangeable K	Ammonium Acetate Extraction	Ilkovskaya and Konovalova, 1975
Available Sulfur	Turbidimetric Method	Bardsley and Lancaster, 1965
Available Boron	Turbidimetric Method	Bardsley and Lancaster, 1965
Exchangeable Ca	Ammonium Acetate Extraction	Ilkovskaya and Konovalova, 1975
Exchangeable Mg	Ammonium Acetate Extraction	Ilkovskaya and Konovalova, 1975
Available Mn	DTPA Extraction Method	Lindsay and Norvell, 1978
Available Iron	DTPA Extraction Method	Lindsay and Norvell, 1978
Available Copper	DTPA Extraction Method	Lindsay and Norvell, 1978
Available Zinc	DTPA Extraction Method	Lindsay and Norvell, 1978

odor and the flavor ranges from very sour to mildly sweetish. The so-called "sweet" types rarely contain more than 7.5% sugar. BARI Kamranga 1 was used in the experimental field. The carambola trees in the experiment had the following features i.e., the average tree height was 4.8 m in, base diameter was 27.10 cm, diameter at breast height was 25.07 cm and canopy area was 15.66 m^2.

Lemon (*Citrus limon*) is weakly poly–embryonic species with medium–sized spreading trees. Fruits are oval to elliptic with pointed nipple. Fruit surface is smooth, light yellow and core solid, juice abundant and acidic with vitamin C. Seed cotyledons are white. The species, BARI Lebu 1 was used in the experimental field. The lemon plants in the experiment had the following features i.e., the average tree height was 2.56 m in, base diameter was 8.53 cm, diameter at breast height was 14.48 cm and canopy area was 9.85 m^2.

Experimental design

The research was done for the sustainable and productive aonla based multistoried agroforestry systems where aonla was used as the upper storied tree species, carambola was used as middle storied species and lemon was the lower storied species, with sole production of each species. The experiment was laid out following single factor Randomized Complete Block Design (RCBD) with three replications. The plot size for each treatment was 18 m×24 m. Adjacent plots were separated by 8 m distance and neighboring blocks were separated by aonla and middle storied trees. Open field was adjacent to the south of aonla orchard. The treatments were as follows; T_1=Open field, T_2=Aonla, T_3=Carambola, T_4=Lemon, T_5=Aonla+Carambola, T_6=Aonla+Lemon, and T_7=Aonla +Carambola+Lemon.

Soil temperature measurement

Soil temperature was measured by soil thermometer (°C). Soil temperature was measured at 0–10 cm depth soil from 4 points of respective aonla to aonla, carambola to carambola, lemon to lemon at east to west direction in case of every replication once in week over the year and the collected data were averaged.

Collection and analyses of soil samples

For each replication a pit (1 m*1 m*1.2 m) was dug. Soil samples were collected from 0–15 cm, 15–30 cm, 30–45 cm, 45–60 cm, 60–90 cm and 90–120 cm depths with core sampler and hand spade. Collected soil sample's soil moisture content (%) and soil bulk density (g/cc) were determined. Collected soil samples were air dried, ground and sieved through a 2 mm (10 mesh) sieve. The composite samples were stored in clean plastic bag for physical and chemical analyses. Soil samples were analysed for different parameters following standard protocols (Table 1).

Statistical analysis

All statistical analysis in this study were performed using Excel software, SPSS statistics software and Statistix10. The mean differences among the treatments were evaluated by Least Significant Difference (LSD) at 5% levels of significance.

RESULTS AND DISCUSSION

Soil physical properties at different depth

Soil moisture content and bulk density

Soil moisture is the most important soil physical parameter for the growth and development of plants. In this experiment, it was found that, with the increase of

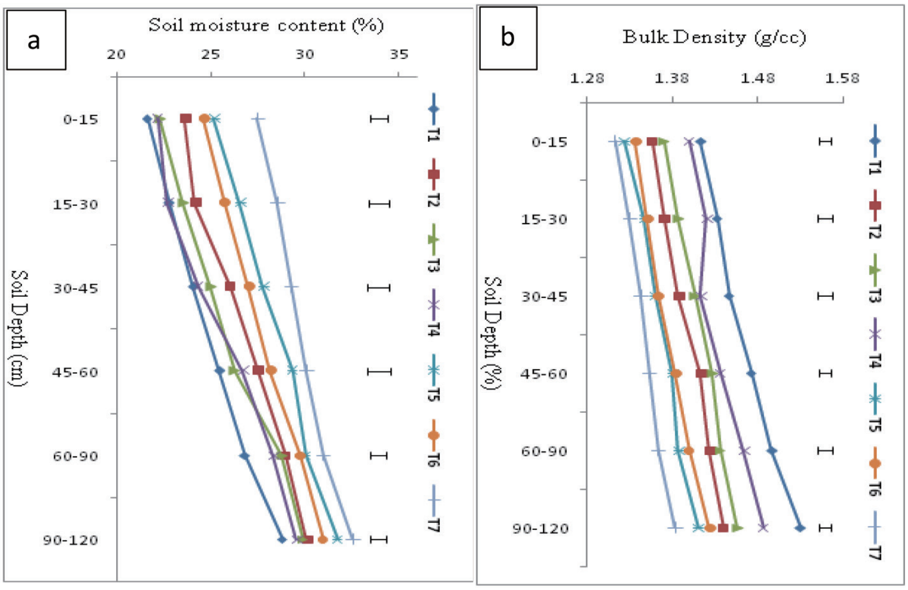

Fig. 1. a) Soil moisture content and b) soil bulk density at different soil depth under different treatments.

soil depth, the soil moisture content increased progressively. However, significantly the highest moisture content was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 90–120 cm soil depth (Fig. 1a). In contrast, significantly the lowest moisture content was recorded in T_1 (open field) at 0–15 cm soil depth. Moisture content in upper depth (0–15 cm) was lower due to high evaporation rate where soil surface received sunlight directly. The evaporation rate was reduced in T_7 remarkably due to its large canopy area and shade effect. More litter fall was incorporated to soil resulting increased water holding capacity of soil. Therefore, moisture content was found higher in T_7 compared to other treatments. On the other hand, T_1 contained no plants, so direct sunlight strikes the soil surface which enhances evaporation, resulting low moisture content. Similar result was reported that the measured soil moisture in most stations over northeast China was larger than that at 0–10 cm depth. This result implied that soil moisture in most stations over northeast China increased from shallow depth (0–10 cm) to deep depth (0–50 cm) (Lai *et al.*, 2016). Qiu *et al.* (2001) made a measurement that were performed biweekly at five depths in the soil profile (0–5 cm, 10–15 cm, 20–25 cm, 40–45 cm and 70–75 cm) from May to October 1998 and from May to September 1999 using Delta–T theta probe. Results indicated that with increasing soil depth, the mean soil moisture content increases significantly for five layers.

Soil bulk density is an important soil physical property that influences the biomass productivity and environmental quality. It is expressed as weight per unit volume (g/cc). Degree and stability of aggregation strongly influence bulk density. With the increasing of soil depth, bulk density increased prominently and progressively. Significantly the highest bulk density was found in T_1 (open field) followed by T_4 (lemon) and T_3 (carambola) at 90–120 cm soil depth. In contrast, significantly the lowest bulk density was recorded in T_7 (aonla+carambola+lemon) at 0–15 cm soil depth (Fig. 1b). This might be due to presence of higher organic matter in top soil than lower depths. Maximum organic matter to soil added from T_7 which loose the top soil through altering the soil structure, therefore, bulk density was lower at top soil. Similar result was also observed by Missanjo and Kamanga–Thole (2014) suggesting that soil bulk density at 0–20 cm depth increased from 0.45 to 0.66 $Mg\,m^{-3}$ in the most compacted portions of traffic lanes. According to Froese (2004), in the upper soil, biological activity can act to reduce resistance and soil bulk density while at lower depths soil texture, gravel content, and structure may increase soil resistance and soil bulk density; hence soil bulky density increases with depth (Froese, 2004). Increase of bulk density is the indication of more compaction and less porosity with the increase of soil depth.

Particle density

Soil particle density expressed as weight per unit volume without pore space (g/cc). Degree and stability of aggregation strongly influence the particle density. We found that, with the increasing soil depth, the soil particle density was also increased progressively. The highest particle density was found in T_1 (open field) followed by T_4 (lemon) and T_3 (carambola) at 90–120 cm soil depth (Table 2). In contrast, lowest Particle Density was recorded in T_7 (aonla+carambola+lemon) at 0–15 cm soil depth. The result what we found may be due to higher organic matter presence in top soil than lower levels. Treatment T_7 add more litter fall (cumulative accumulation of leaf litter of aonla by 20 years) that convert into organic matter which change the soil structure; therefore, particle density was lower.

Soil porosity

Porosity of surface soil typically decreases as particle size increases. This is due to soil aggregate forma-

Table 2. Depth wise particle density in soil under different treatments

Treatment	Soil depth (cm)					
	0–15	15–30	30–45	45–60	60–90	90–120
T_1	2.69 a	2.71 a	2.73 a	2.73 a	2.74 a	2.77 a
T_2	2.66 b	2.68 b	2.68 c	2.70 b	2.72 b	2.74 b
T_3	2.67 b	2.68 b	2.70 b	2.72 a	2.74 a	2.76 a
T_4	2.68 a	2.70 a	2.72 a	2.73 a	2.74 a	2.76 a
T_5	2.63 d	2.65 c	2.66 d	2.68 c	2.70 d	2.72 c
T_6	2.65 c	2.67 b	2.68 c	2.70 b	2.71 c	2.74 b
T_7	2.62 e	2.64 c	2.66 d	2.67 c	2.68 e	2.70 d
LSD	0.01	0.02	0.02	0.01	0.01	0.01
CV (%)	0.27	0.40	0.32	0.29	0.20	0.25

In a column, means followed by same letter (s) are not statistically different by LSD.

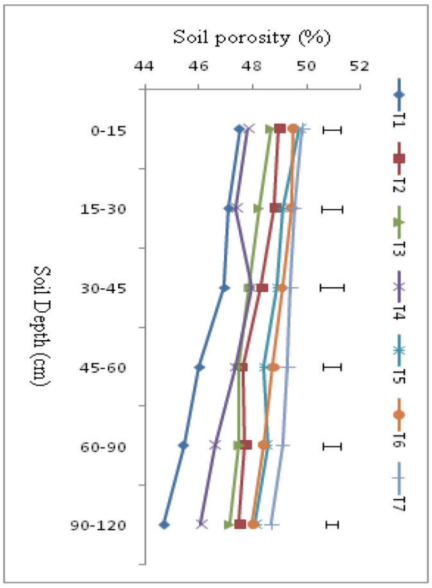

Fig. 2. Soil porosity at different soil depth under different treatments.

tion in finer textured surface soils when subject to soil biological processes. Aggregation involves particulate adhesion and higher resistance to compaction. The porosity of a soil can be reduced by compaction or be increased by the addition of organic matter to improve a soil's aggregation (structure). It was found that with the increasing soil depth, the soil porosity clearly decreased progressively. Nevertheless, significantly the highest soil porosity was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Fig. 2). In contrast, significantly the lowest soil porosity was recorded in T_1 at 90–120 cm depth. The result what we found may be due to higher organic matter presence in top soil than lower levels. Treatment T_7 add more litter fall convert into organic matter which loose the top soil, therefore porosity was higher. Increased development of roots of different trees and frequent litter fall kept the soil in aonla based system constantly protected thereby resulting in improved soil physical properties.

Soil chemical properties at different depth

Soil pH and total nitrogen (N) content

Soil pH is a measurement of the acidity or alkalinity of a soil. On the pH scale, 7.0 is neutral. Below 7.0 acidic and above 7.0 is basic or alkaline. A pH range of 6.8 to 7.2 is termed near neutral. It is the most important criteria of soil chemical properties that determine the availability of all nutrients in soil. It was found that, with the increasing of soil depth, soil pH increased gradually in Table 3. However, significantly the highest soil pH was found in T_1 treatment (open field) followed by T_3 (carambola) and T_4 (lemon) at all respective soil depth. In contrast, significantly the lowest pH was recorded in T_7 (aonla+carambola+lemon) at 0–15 cm soil depth. The top soil of T_1 treatment having less amount of organic matter, less organic acid resulting soil pH higher compared to other treatments. In case of Treatment T_7 the highest amount of organic matter allowed maximum mineralization, nitrification processes with the release of H^+ in soil along with carbonic acid production during root respiration. Similar result was found that analysis of soil pH increased with increasing soil depth of profiles (Kumar *et al.*, 2012).

Although nitrogen is an essential element for tissue development both in plants and animals, nitrogen in its elemental form, nitrogen gas (N_2) is very inert. All organisms need nutrients, such as nitrogen and phosphorus, for growth and reproduction. It was found that with the increasing of soil depth, the total nitrogen content decreased progressively. Significantly the highest total nitrogen content was found in T_7 (aonla+carambola +lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Table 3). In contrast, significantly the lowest total nitrogen content was recorded in T_1 treatment at the depth of 90–120 cm. As treatment T_7 contains three tree components those accumulates higher organic matter on top soil and this organic matter is a good source of soil nitrogen. Similar result was also observed by Eghball *et al.* (1994) where the mean percentages of NH_4^+N, NO_3^-N and other nitrogen forms range from 0.99–3.94%, 2.32–4.55% and 91.51–96.69%, respectively based on analysis of 296 soil samples. The percentages of NH_4^+ N and NO_3^- N are gen-

Table 3. Depth wise soil pH and total N content in soil under different treatments

Treat-ment	Soil depth (cm)											
	0–15		15–30		30–45		45–60		60–90		90–120	
	pH	N	pH	N	pH	N	pH	N	pH	N	pH	N
T_1	5.11a	0.10 d	5.15 a	0.09 bc	5.18 a	0.07 e	5.21 a	0.06 c	5.23 a	0.04 c	5.26 a	0.02 c
T_2	5.04 c	0.11 b	5.08 cd	0.10 b	5.11 cd	0.09 bc	5.15 bc	0.07 bc	5.18 c	0.05 bc	5.20 c	0.03 abc
T_3	5.08 ab	0.10 c	5.12 b	0.10 bc	5.15 b	0.08 cd	5.17 b	0.07 bc	5.21 b	0.05 bc	5.24 ab	0.03 ab
T_4	5.08 b	0.11 bc	5.09 bc	0.09 c	5.13 bc	0.07 de	5.16 b	0.06 c	5.20 b	0.04 c	5.23 b	0.03 bc
T_5	5.02 c	0.12 a	5.05 d	0.12 a	5.08 d	0.10 ab	5.12cd	0.08 a	5.15 d	0.05 ab	5.18 de	0.04 a
T_6	5.03 c	0.11 b	5.06 d	0.10 b	5.11 cd	0.09 abc	5.14bc	0.08 ab	5.17 e	0.05 abc	5.19 cd	0.03 ab
T_7	4.98 d	0.12 a	5.01 e	0.12 a	5.05 e	0.10 a	5.09 d	0.09 a	5.13 e	0.06 a	5.17 e	0.04 a
LSD	0.03	0.01	0.03	0.01	0.03	0.01	0.03	0.01	0.02	0.01	0.02	0.01
CV (%)	0.33	3.04	0.30	6.36	0.33	7.27	0.38	6.72	0.18	7.45	0.22	8.28

In a column, means followed by same letter (s) are not statistically different by LSD.

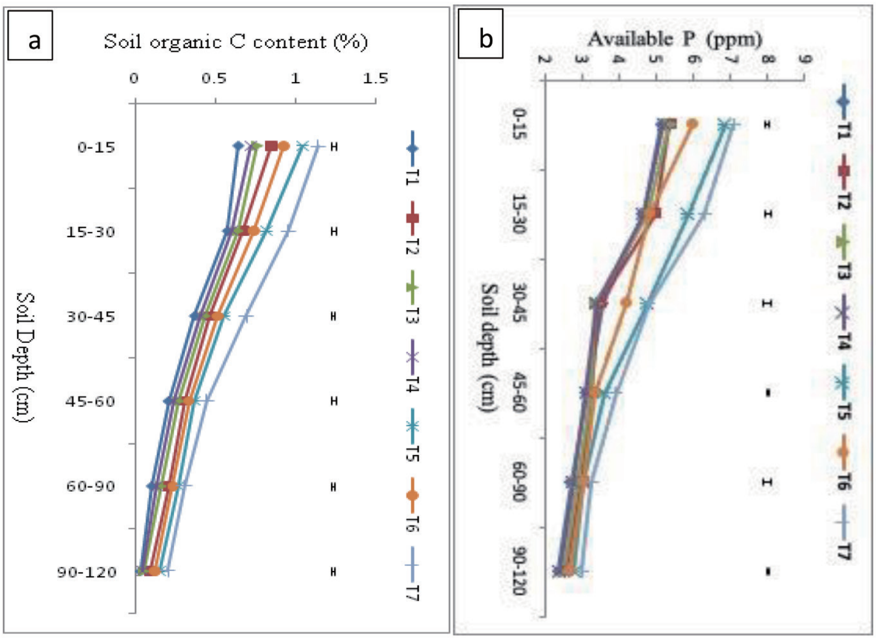

Fig. 3. a) Soil organic carbon content and b) available phosphorus content at different soil depth under different treatments.

erally less than the deeper soil layer and the NH_4^+ N percentage is less than that of NO_3^- N in the same soil layer. The minimum and maximum values of NH_4^+ N and NO_3^- N in each soil layer also indicate the same result. Lower percentages of NH_4^+ N and NO_3^- N imply that nitrogen content is dominated by the other nitrogen forms. The percentages of the other forms of nitrogen decreased as depth increases and range from 96.69 to 91.51%. These findings indicate that organic nitrogen is the main source of soil nitrogen.

Organic carbon (C) and available phosphorus (P) content

Organic carbon i.e., organic matter is the store house of all nutrients. Soil carbon is the major pool of the carbon cycle. The carbon that is fixed by plants is transferred to the soil via dead plant matter, i.e., dead roots, twigs, leaves, fruiting bodies and dead microbes. It was observed that with the increasing of soil depth, the organic carbon content also decreased relatively. Significantly the highest organic carbon content was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Fig. 3a). In contrast, significantly the lowest organic carbon content was recorded in T_1 at the depth of 90–120 cm. As because treatment T_7 comprises of three components combination those utilize maximum above and below ground resources resulting maximum biomass production. As a result, above ground biomass incorporation is higher in top soil than below ground biomass incorporation in all soil depths, so organic carbon content is higher in top soil. Similar result reported by Sheikh *et al.*, 2009 where decreasing trend in soil organic carbon was observed with increased soil depths

Table 4. Depth wise exchangeable Mg and K content in soil under different treatments

	Soil depth(cm)											
	0–15		15–30		30–45		45–60		60–90		90–120	
	Mg	K	Mg	K	Mg	K	Mg	K	Mg	K	Mg	K
T_1	1.86 g	0.18 e	1.71g	0.18 e	1.32 g	0.14 e	1.12 g	0.11 e	1.01 g	0.07 d	0.88 g	0.02 d
T_2	2.04 d	0.21 d	1.92d	0.21 d	1.65 d	0.15 cd	1.33 d	0.14 cd	1.18 d	0.09 c	1.12 d	0.03bcd
T_3	1.96 e	0.21 cd	1.86 e	0.21 cd	1.53 e	0.16 bc	1.26 e	0.14 bc	1.11 e	0.10 bc	1.02 e	0.04abc
T_4	1.90 f	0.19 e	1.76 f	0.19 e	1.42 f	0.15 de	1.20 f	0.13 d	1.08 f	0.08 d	0.98 f	0.03 cd
T_5	2.15 b	0.23 b	2.05b	0.23 b	1.79 b	0.17 ab	1.49 b	0.15 ab	1.33 b	0.10 ab	1.20 b	0.04 ab
T_6	2.11 c	0.22 bc	1.99 c	0.22 bc	1.72 c	0.17 b	1.41 c	0.15abc	1.28 c	0.10 ab	1.15 c	0.04abc
T_7	2.24 a	0.25 a	2.12 a	0.25 a	1.84 a	0.18 a	1.57 a	0.16 a	1.37 a	0.11 a	1.26 a	0.05 a
LSD	0.04	0.01	0.03	0.01	0.04	0.01	0.03	0.01	0.03	0.01	0.03	0.01
CV (%)	1.01	3.40	0.92	3.40	1.27	4.44	1.19	4.68	1.24	5.08	1.48	1.31

In a column, means followed by same letter (s) are not statistically different by LSD.

in all the sites except site–II of the *Pinus roxburghii* forest, where organic carbon was highest in the top layer (0–20 cm) and lowest in middle depth (20–40 cm). The same author reported that in the site–I of *Quercus leucotrichophora* forest, the level of soil organic carbon ranged from 24.3±1.9 g kg^{-1} to 21.9±3.1 g kg^{-1} and was higher in the upper layer, dropping with an increase in depth. The trend was same for site–II and site–III where the SOC values also decreased with increasing depths. In another report Eghball *et al.* (1994) showed the highest organic C concentration at 0–10 mm soil depth and decreased with increasing soil depth. The organic matter positively influences nearly all–important properties that contribute to the quality of soil (Bot and Benites, 2005). Thus, it is crucial to understand and emphasize the key importance of crops and soil management to maintain and increase the organic matter content of the soil in order to develop good soil quality (Magdoff *et al.*, 1999).

Available P is very important for the growth and development of plant. Phosphorus is limiting macro nutrient in soil. From this experiment it was observed that, with the increasing of soil depth, the available phosphorus content decreased progressively. Significantly the highest phosphorus content was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Fig. 3b). In contrast, significantly the lowest phosphorus content was recorded in T_1 treatment at the depth of 90–120 cm. Treatment T_7 contains three tree components those accumulates higher organic matter on top soil and this organic matter is a good source of soil P. Jobbágy and Jackson (2001) said the globally, the ranking of nutrients through vertical distributions were in the following order: P>K>Ca>Mg>Na=Cl=SO_4. Nutrients strongly cycled by plants, such as P and K were strongly cycled by plants and concentrated in the topsoil (upper 20 cm) as compared to less limiting for plants such as Na and Cl. The authors also recommended that the topsoil concentrations of all nutrients except Na were higher in the soil profiles where the elements were more scarce.

Exchangeable magnesium (Mg) and potassium (K) content

With increasing soil depth, magnesium content decreased progressively. Nevertheless, significantly highest magnesium content was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 90–120 cm soil depth. In contrast, significantly the lowest magnesium content was recorded in T_1 treatment at the depth of 90–120 cm (Table 4). The top soil having more organic matter and more total nitrogen content along with high temperature accelerates higher decomposition rate resulting more availability of macro nutrients. So that T_7 treatment provided maximum exchangeable Mg content in soil. Similar result suggests that the pattern of distribution of the various forms of magnesium in the respective parent materials have been categorized into water soluble Mg and exchangeable Mg which constitute the available magnesium and appears to be concentrated in the surface of soil (Okpamen *et al.*, 2013). This surface soil is the prevalence of organic matter where many bio–physical and chemical weathering activities in the environments seem to be occurring.

It was observed that, with the increasing of soil depth, potassium content decreased progressively. Significantly highest available P content was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Table 4). In contrast, significantly lowest potassium content was recorded in T_1 treatment at the depth of 90 –120 cm. The top soil having more organic matter along with high temperature accelerates higher decomposition rate resulting more availability of macro nutrients. The result was more or less similar with the published article of Jobbágy and Jackson (2001).

Exchangeable calcium (Ca) and available boron (B) content

It was observed that, with increasing soil depth, calcium content decreased progressively. Nevertheless, significantly the highest calcium content was found in T_7

(aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Fig. 4a). In contrast, significantly the lowest Ca content was recorded in T_1 treatment at the depth of 90–120 cm. The result what we found may be due to having more organic matter in top soil as in treatment T_7. Similar result was also observed by Jobbágy and Jackson (2001).

It was observed that, with increasing soil depth, boron content decreased progressively. Significantly the highest boron content was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Fig. 4b). In contrast, significantly the lowest boron content was recorded in T_1 treatment at the depth of 90–120 cm. The increases of available macronutrient in soil enhance the availability of micronutrient. On the other hand, organic matter is the store house of all nutrients. That's why the treatment T_7 contains more Boron in all cases. in some typical B–deficient Inceptisols, Entisols, and Alfisols in relation to soil properties showed that depth distribution of boron (B) extractable by hot calcium chloride (HCC), potassium dihydrogen phosphate (PDP), and tartaric acid (TA) (Sarkar *et al.*, 2008). The magnitude of B extraction followed the order HCC>PDP>TA for Inceptisols, TA>HCC>PDP for Entisols, and PDP>HCC>TA for Alfisols showed a decrease along with soil depth.

Available sulfur (S) and available iron (Fe) content

It was observed that, with the increasing of soil depth, the available sulfur content decreased progressively. Significantly the highest available Sulfur content was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Table 5). In contrast, the lowest sulfur content was recorded in T1 treatment at the depth of 90

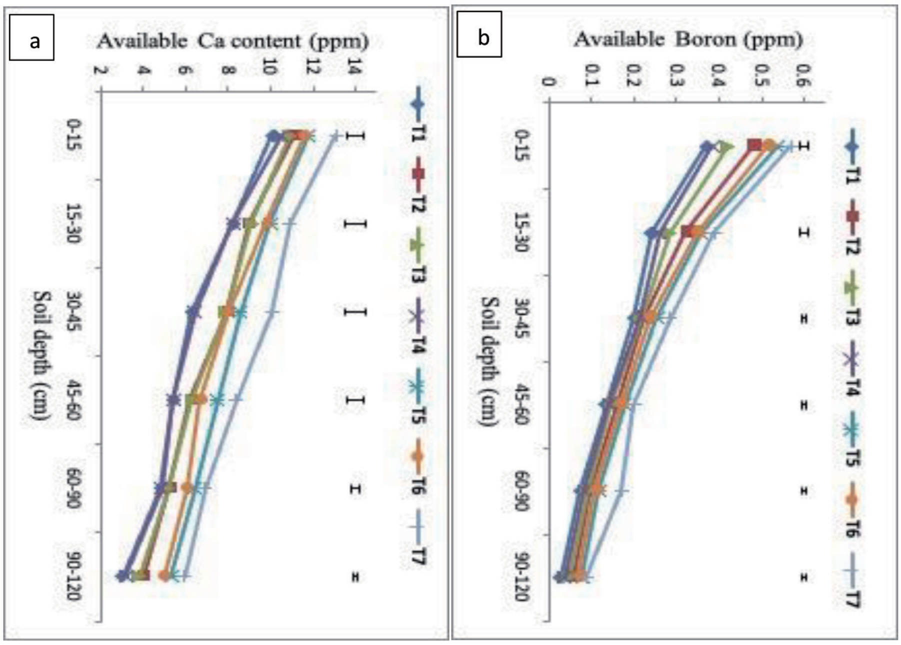

Fig. 4. a) Exchangeable Calcium content and b) available boron at different soil depth under different treatments.

Table 5. Depth wise available S and Fe content in soil under different treatments

Treatment	Soil depth (cm)											
	0–15		15–30		30–45		45–60		60–90		90–120	
	S	Fe	S	Fe	S	Fe	S	Fe	S	Fe	S	Fe
T_1	26.44 f	71.80 f	22.64 e	40.32 e	15.26 e	30.29 e	8.61 a	15.12 f	6.19 e	9.69 e	4.25 e	4.75 d
T_2	27.18 d	75.69 cd	22.98 c	45.79 c	16.14 c	35.28 bc	10.03 a	18.37 cd	7.02 c	12.48 c	4.51 c	7.76 b
T_3	27.10 de	74.62 de	22.81d	45.45 c	16.05 cd	34.62 cd	9.38 a	17.64 de	6.96 c	11.71 d	4.45 cd	7.25 bc
T_4	26.99 e	73.27 ef	22.75 de	43.42 d	15.9 d	33.36 d	9.01 a	16.71 e	6.47 d	11.04 d	4.37 d	6.26 c
T_5	29.03 b	78.49 b	23.86 b	48.52 b	17.12 b	36.54 b	12.42 a	20.36 ab	7.65 b	13.43 ab	6.00 ab	9.48 a
T_6	28.01 c	76.63 c	23.52 b	47.23 bc	17.06 b	36.28 b	12.02 a	19.30 bc	7.60 b	12.84 bc	5.94 b	8.95 a
T_7	32.08 a	80.48 a	25.06 a	51.01 a	18.81 a	38.46 a	14.08 a	20.99 a	8.36 a	13.87 a	6.08 a	9.83 a
LSD	0.13	1.76	0.15	1.94	0.14	1.60	0.08	1.38	0.10	0.70	0.12	1.10
CV (%)	0.26	1.30	0.36	2.38	0.47	2.58	0.44	4.24	0.82	3.25	1.31	7.95

In a column, means followed by same letter (s) are not statistically different by LSD.

–120 cm. High temperature on the top soil accelerates higher decomposition rate of organic matter resulting more availability of different nutrients. As a result, treatment T_7 contained three tree components those accumulated higher organic matter on top soil which was a good source of sulfur. Similar result was also observed by Parvin (2012) where the total S content varied in different aged tea soils ranging from 506.53 to 661.20 ppm at 0–15 cm depth but at 15–30 cm depth it was varied from 404.07 to 624.60 ppm in different tea cultivated soil. Analysis of sixty–seven each of surface and subsurface soil samples from four districts viz. Birbhum, Bankura, Burdwan, and Purulia under red and lateritic soils of West Bengal indicated the intensity of sulphur deficiency as per Sulphur Availability Index (SAI) which ranged from 13 to 73% with an average of 45.2% in surface soils and 40 to 66% with an average of 56.5% in subsurface soils (Patrac *et al*., 2012).

With the increasing of soil depth, iron content decreased progressively. Significantly the highest iron content was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Table 5). In contrast, significantly the lowest iron content was recorded in T_1 treatment at the depth of 90–120 cm. Soil pH and organic carbon content are responsible for available Fe in soil. Low pH favors the Fe availability along with higher organic matter. The result what we found may be due to having more organic matter in top soil. Similar result was also observed by Ghosh *et al*. (2009).

Available manganese (Mn) and available zinc (Zn) content

It was found that, with increasing soil depth, manganese content decreased progressively. Significantly the highest manganese content was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Fig. 5a). In contrast, significantly the lowest manganese content was recorded in T_1 treatment at the depth of 90–120 cm. Mn availability mainly depends on soil pH and organic carbon content. Low pH also favors the Mn availability like Fe content along with higher organic matter. More organic matter on top soil may be responsible for available Mn in treatment T_7. Similar result was also observed by Ghosh *et al*. (2009).

It was manifested from the data presented in Fig. 5b that, with increasing soil depth, soil zinc content decreased like other nutrients. The highest zinc content was found in T_7 (aonla+carambola+lemon) treatment followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) treatment at 0–15 cm soil depth. The lowest zinc content was recorded in T_1 treatment at the depth of 90–120 cm. The available macronutrient in soil increases the availability of micronutrient. Moreover, organic matter is the store house of all nutrients which may increase the availability of Zn in treatment T_7. Similar results were observed by Bassiranil *et al*. (2011) and Ghosh *et al*. (2009) where in general, in most of the profiles the available Zn decreased with depth.

Copper (Cu) content

It was found that, with increasing soil depth, copper content decreased progressively. Significantly the highest copper content was found in T_7 (aonla+carambola+lemon) followed by T_5 (aonla+carambola) and T_6 (aonla+lemon) at 0–15 cm soil depth (Table 6). In contrast, significantly the lowest copper content was recorded in T_1 treatment at the depth of 90–120 cm. The increases of available macronutrient in soil enhance the availability of micronutrient. On the other hand, organic matter is the store house of all nutrients. This might be possible reason for highest copper content in treatment T_7. Manea *et al*. (2011) observed more or less similar result

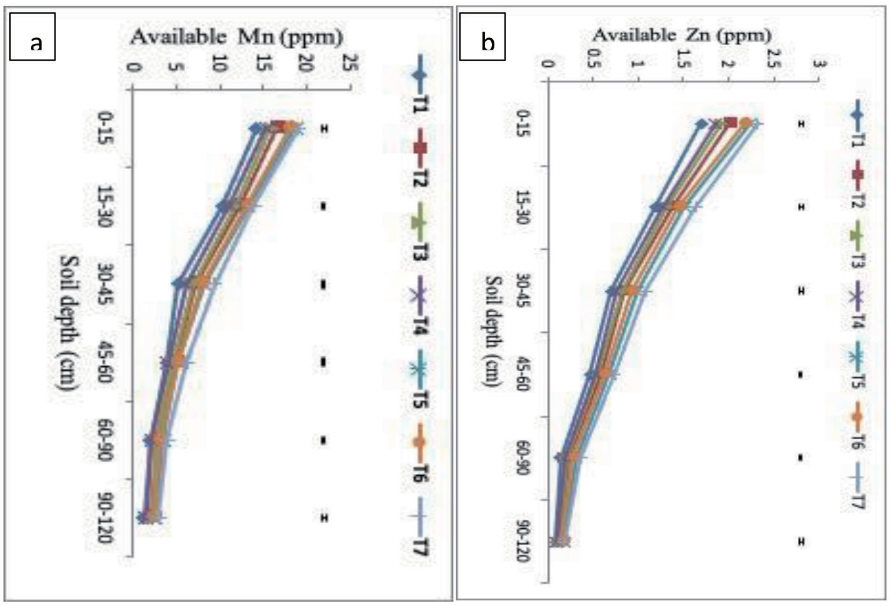

Fig. 5. a) Available Manganese content and b) available zinc at different soil depth under different treatments.

Table 6. Depth wise available Cu content in soil under different treatments

Treatment	Soil depth (cm)					
	0–15	15–30	30–45	45–60	60–90	90–120
T_1	1.92 g	1.08 g	0.65 f	0.45 e	0.29 f	0.17 e
T_2	2.22 d	1.17 d	0.75 d	0.76 a	0.36 cd	0.23 c
T_3	2.16 e	1.15 e	0.72 e	0.55 d	0.34 de	0.22 c
T_4	2.08 f	1.12 f	0.70 e	0.52 d	0.32 e	0.20 d
T_5	2.34 b	1.25 b	0.85 b	0.79 a	0.40 b	0.27 b
T_6	2.29 c	1.21 c	0.79 c	0.69 b	0.37 c	0.25 b
T_7	2.41 a	1.29 a	0.89 a	0.62 c	0.42 a	0.30 a
LSD	0.04	0.02	0.03	0.07	0.02	0.02
CV (%)	1.09	1.04	1.84	5.95	3.64	4.23

In a column, means followed by same letter (s) are not statistically different by LSD.

i.e., top soil contains more copper and decrease with the soil depth.

Pearson correlation between soil physical and chemical parameters

The distribution of available soil nutrients depends on some important soil physical characteristics which are exhibited by significant coefficient of correlation between them (Table 7). All the chemical parameters are highly positively correlated with soil moisture and soil porosity. Silt (%) and Clay (%) has significantly strong relationship with both available phosphorus and available sulphur but it was positive in case of clay (%) and negative in case of silt (%). Bulk density and particle density are highly negatively correlated with all the chemical parameters. Silt (%) showed significant negative relationship and Clay (%) showed significant positive relationship with all the chemical parameters except total nitrogen and available copper. It can be concluded that amount and availability of soil nutrients are highly depend on soil moisture, bulk density, particle density and soil porosity. Soil texture also determines the nutrient status of soil except nitrogen and copper. Especially, phosphorus and sulphur availability are largely depended on it. But sand (%) has no significant impact on nutrient status. Soil Organic Carbon (%), total nitrogen (%) and soil temperature has showed strong significant and positive correlation with all the soil nutrients.

Overall, tree species had an impact on the chemical characteristics of the soil. Under diverse tree species, differences in soil chemical characteristics such as pH, organic–C, and rate of N mineralization have been observed (Phillips *et al.*, 2008; Russell *et al.*, 2007). Exudation of organic acids, the quality or quantity of litter deposited and the rate of their decomposition, and pumping of nutrients from deeper soil to surface soil layers may have all contributed to variances in soil properties among tree species. (Russell *et al.*, 2007). In this study, organic matter (store house of all nutrients) has been released through the incorporation of different tree leaves might be the possible reason for the availability of nutrients. Differences in soil properties are also influenced by the composition of tree species and the environmental conditions within tree systems (Ayres *et al.*, 2009).

CONCLUSIONS

The long–term improved agroforestry system like aonla based agroforestry system have significant effects on soil physical and chemical properties. Aonla+ carambola+lemon combined treatment showed improve physical and chemical properties of soil i.e., soil moisture content, soil temperature, soil bulk density, particle density, soil porosity, soil texture, soil pH and nutrients, which was followed by aonla+carambola and aonla+ lemon combined treatment. The soil physico–chemical properties of single strata treatment i.e., aonla, carambola and lemon–based treatments did not show improvement as like as double and triple strata agroforestry system. By storing a large amount of organic carbon in the soil and retaining a significant amount of nutrients, the agroforestry system of perennial crop management can play an important role in improving soil fertility.

AUTHOR CONTRIBUTIONS

Md. Main Uddin Miah and Md. Helal Uddin contributed to the study conception, design, material and sample preparation, and analysis. The first draft of the manuscript was written by Minhaz Ahmed. Md. Main Uddin Miah, Md. Giashuddin Miah and Md. Mizanur Rahman designed and supervised the research work. Minhaz Ahmed and Md. Main Uddin Miah helped in subsequent revisions. Md. Main Uddin Miah helped in the data analysis and preparation of manuscript. Masaru Matsumoto critically reviewed the manuscript with valuable suggestions and comments. All authors read and approved the final manuscript.

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Table 7. Pearson correlation between soil physical and chemical parameters

Pearson Correlation	SM	BD	PD	SP	% Sand	% Silt	% Clay	% Soil Organic Carbon	% Total Nitrogen	Soil Temperature (°C)
% Soil Organic Carbon	.897**	–.963**	–.938**	.922**	.053	–.454*	.433*	1		.963**
% Total Nitrogen	.709**	–.726**	–.721**	.688**	–.198	–.193	.253	.697**	1	.702**
Available Phosphorus	.906**	–.865**	–.905**	.799**	–.109	–.575**	.605**	.882**	.681**	.941**
Exchangeable Calcium	.891**	–.849**	–.855**	.800**	.010	–.535*	.531*	.845**	.599**	.924**
Exchangeable Magnesium	.932**	–.946**	–.944**	.895**	.002	–.498*	.494*	.960**	.649**	.983**
Exchangeable Potassium	.875**	–.922**	–.903**	.881**	–.155	–.492*	.543*	.902**	.652**	.926**
Available Sulphur	.922**	–.797**	–.856**	.724**	–.147	–.569**	.616**	.793**	.628**	.916**
Available Boron	.919**	–.966**	–.945**	.923**	.089	–.468*	.434*	.982**	.665**	.970**
Available Zinc	.913**	–.957**	–.960**	.902**	–.023	–.504*	.507*	.974**	.710**	.980**
Available Iron	.873**	–.902**	–.931**	.837**	–.034	–.472*	.478*	.914**	.671**	.971**
Available Manganese	.892**	–.956**	–.959**	.901**	–.031	–.498*	.504*	.979**	.681**	.978**
Available Copper	.870**	–.951**	–.929**	.909**	–.062	–.394	.411	.949**	.683**	.954**

**. Correlation is significant at the 0.01 level (2–tailed).
*. Correlation is significant at the 0.05 level (2–tailed).
SM (% Soil Moisture), BD (Soil Bulk Density g/cc), PD (Soil Particle Density g/cc), SP (% Soil Porosity)

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