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Assessing horticulture-based land management impacts on carbon dynamics and soil quality

JURISANDHYA BORDOLOI[1], LAHAR JYOTI BORDOLOI[2], KALU RAM YADAV[1] and LOHIT KUMAR BAISHYA[3]*

School of Agricultural Sciences and Rural Development (Nagaland University), Medziphema, Nagaland 797 106, India

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ABSTRACT

The present study was carried during 2020 and 2021 at School of Agricultural Sciences and Rural Development (Nagaland University), Medziphema, Nagaland to study the effects of different horticulture-based land use systems on carbon stock, soil fertility and soil biological health in acidic hill soils of Nagaland. Average values of bulk density of the soils were 1.20 and 1.21 g/cm^3 in surface and sub-surface soils, respectively irrespective of type of orchards. The maximum and minimum carbon stock was recorded in pineapple [*Ananas comosus* (L.) Merr.] (46.77 and 43.38 mg/ha) and citrus (*Citrus* spp.) (33.07 and 32.42 mg/ha) orchard soils. Soil microbial biomass carbon in pineapple (270.13 and 244.23 µg/g) and citrus orchard soils (165.64 and 152.49 µg/g) was recorded in surface and sub-surface layers, respectively. Banana (*Musa* spp.) orchard soils had greater values of dehydrogenase activity (15.26 and 9.83 µg TPF/g/h). Soils of banana orchard also recorded highest acid phosphatase activity (176.0 and 165.5 µg PNP/g/h), which was at par with mango (*Mangifera indica* L.) orchard soils (175 and 166 µg PNP/g/h). Minimum acid phosphatase activity (162.0 and 150.0 µg PNP/g/h) was recorded in citrus orchard soils. Maximum earthworm population density was recorded in banana orchard (12–20 number/m^2) and minimum (4–12 number/m^2) in citrus orchards.

Keywords: Biological properties, Carbon stock, Nagaland, Orchard, Physico-chemical properties

The importance of soil is a source and sinks for atmospheric carbon. Horticultural-based integrated farming system plays a vital role to sequester soil organic besides sustainable production of food feed, fiber as well as other ecosystem services. Soil organic carbon (SOC) is a vital indicator of soil quality; maintaining quality and quantity is important for safeguarding long-term soil fertility (Ramesh *et al*. 2013). Tree plantations had effects on soil physical, chemical and biological properties and thus influences on productive capacity of soil (Adak *et al*. 2016). SOC is greatly influenced by land use changes and thus SOC stock build up also (Kenye *et al*. 2019). Cultivation of perennial horticulture crops helps in sequestering more organic carbon compared to annual crops, and the perennials could provide a low cost method for net reduction in emission of CO_2 (Ramesh *et al*. 2019).

It is imperative to define soil quality threshold, soil fertility along with delineation of critical levels under different land use management practices. It has become even more important in regard to high value horticultural crops (Singh and Bordoloi 2014). Soil fertility and its productivity are mainly affected by soil physico-chemical, biological properties and nutrient status. Plantation crop land recorded high total nitrogen, available phosphorus, available potassium content compared to grasslands (Salim *et al.* 2015). Adak *et al.* (2018) assessed the soil conditions and SOC stock in guava orchards of subtropical condition having low organic carbon. Earthworms besides influencing nutrient cycling, creates holes that increase porosity and infiltration. By these actions, earthworms significantly increase the water holding capacity of soils. Earthworm population, along with microbial biomass carbon, total microbial count and the enzymatic activities are the good indicators to judge the biological health of a soil under different land use systems. Microbial biomass carbon, dehydrogenase activity, and glomalin protein are the sensitive indicators for the soil quality under horticultural land use in north-western Himalayan region (Bhattacharyya *et al*. 2017). Since, limited information is available under orchard soils, the present investigation was undertaken to study the impacts of different horticulture-based land use systems on soil health and carbon stock in acidic soils of Nagaland.

[1]School of Agricultural Sciences and Rural Development, Medziphema, Nagaland; [2]Krishi Vigyan Kendra (ICAR-Research Complex for NEH Region, Umiam, Meghalaya), Nagaland Centre, Kipire, Nagaland; [3]ICAR-Indian Agricultural Research Institute, Assam. *Corresponding author email: lkbicar@gmail.com

MATERIALS AND METHODS

Present study was carried out during 2020 and 2021 at School of Agricultural Sciences and Rural Development (Nagaland University), Medziphema (at 25.43923° to 25.50569° N latitude and 93.37645° to 93.5502° E longitude), Nagaland. The representative soil samples were collected from 5 different orchards from the experimental farm located. The major orchard, viz. banana (*Musa* spp.), citrus (*Citrus* spp.), litchi (*Litchi chinensis* Sonner.), mango (*Mangifera indica* L.) and pineapple [*Ananas comosus* (L.) Merr.] were considered under the study as these crops are most widely grown in the entire north-east hill (NEH) region. The soil sample of surface and sub-surface soils from two depths i.e. 0–0.20 m and 0.20–0.40 m were collected from each orchard as per standard procedure. A total of 40 soil samples were collected for the purpose of investigation under this study. Soil physical, chemical and biological parameters were determined following standard procedures. Earthworm population was counted by extraction and enumeration method (Kalu *et al.* 2015) using a standard quadrate. The size of the wooden quadrate was 0.5 m × 0.5 m. Eventually, earthworm population was counted in 0.25 m^2 area. The procedure use for the extraction of earthworm, sufficient amount of dry mustard powder was mixed with appropriate volume of water and the mixture was sprinkled in 0.25 m^2 area after loosening the soil inside the quadrate. Approximately, 15–20 min after sprinkling of mustard powder mixed water earthworms appeared on the surface of loosened soil the number of which counted after visual observation for experimental data. Earthworm population density (EPD) was calculated as:

$$\text{EPD (number/m}^2\text{)} = \frac{\text{Total number of earthworm population in sampling area}}{\text{Sampling area}}$$

Carbon stock (mg/ha) was calculated as:

$$\text{Carbon stock (mg/ha)} = \text{BD (mg/m}^3\text{)} \times \text{C content (g/kg)} \times \text{D (m)} \times 10$$

where BD, Bulk density; C, Organic carbon content; D, Sampling depth.

Nutrient index (NI) was calculated as:

$$\text{Nutrient index} = \frac{\text{Nl} + 2\text{Nm} + 3\text{Nh}}{\text{Nl} + \text{Nm} + \text{Nh}}$$

where Nl, Nm and Nh, Number of samples in low, medium and high category of available nutrients, respectively. The nutrient index classes were categorized into low, medium and high class of soil fertility using the values of nutrient index as: Low = < 1.5; Medium = 1.5–2.5; and High = > 2.5.

RESULTS AND DISCUSSION

The experimental results on soil physico-chemical properties and carbon stock of orchard soils (SOC) at different depths (Table 1) reveals that highest average bulk density (BD) at the surface soil was recorded in soil under litchi orchard (1.25 g/cm^3) and the lowest average

Table 1 Physico-chemical properties and carbon stock of orchard soils at different depths

Orchard	Bulk density (g/cm^3)		*p*H		Organic content (g/kg)		Soil organic carbon-stock (mg/ha)		Average nitrogen (kg/ha)		Average phosphorus (kg/ha)		Average potassium (kg/ha)	
	0–0.20 m	0.20–0.40 m	0–0.20 m	0.20–0.40 m	0–0.20 m	0.20–0.40 m	0–0.20 m	0.20–0.40 m	0–0.20 m	0.20–0.40 m	0–0.20 m	0.20–0.40 m	0–0.20 m	0.20–0.40 m
Banana	1.15	1.19	4.95	5.08	15.85	14.25	36.63	34.00	242.85	223.14	26.24	23.24	116.53	112.13
Citrus	1.18	1.21	4.83	4.90	14.05	13.20	33.07	32.42	241.99	225.10	24.49	21.51	134.88	116.88
Litchi	1.25	1.29	4.63	4.83	17.56	16.55	44.08	42.53	250.88	232.09	28.10	23.96	137.45	129.03
Mango	1.08	1.20	4.53	4.75	18.88	16.55	40.67	42.56	279.02	241.68	38.02	31.87	127.18	116.40
Pineapple	1.08	1.17	4.80	4.95	21.75	18.88	46.77	43.38	350.63	308.72	44.75	37.59	114.03	105.65
SD	0.073	0.044	0.169	0.123	2.94	2.22	5.52	5.18	46.05	35.72	8.70	6.84	10.54	8.55
CV (%)	6.41	3.69	3.56	2.53	16.67	13.97	13.73	13.35	16.87	14.51	26.93	24.76	8.36	7.37

bulk density was found in mango (1.08 g/cm^3) followed by pineapple orchards (1.08 g/cm^3). The soil analyzed data on the sub-surface soils reveals that the highest and the lowest average bulk density (BD) was found in litchi (1.29 g/cm^3) and pineapple orchard (1.17 g/cm^3). This might be owing to foliage coverage and less exposure of soil as well as better decomposition of plant foliage and accumulation of higher organic matter to the soil in case of mango and pineapple as compare to litchi (Rajan *et al.* 2014). Further, the soil organic carbon (SOC) stock at a point of time is generally determine by long term balance between addition of organic carbon from plant and other soil biota and its losses through environmental process like decomposition, erosion and leaching and these factors are controlled by land use system, soil type and climatic conditions specially rain fall (Sarkar *et al.* 2018). The orchard soils of study site were found to be strongly acidic to moderately acidic in nature as the soils of the north-eastern hill region are acidic in nature due to average rainfall in this region varies from 1600–2000 mm and the bases from the soils are leached down by the heavy rainfall and soil erosion and the soils become acidic. The average maximum *p*H at the depth of 0–0.20 m was recorded in orchard of banana (4.95) followed by citrus orchard (4.83). Low acidity in the sub-surface soils may be attributed to leaching and deposition of soluble bases at higher depth (Odyuo *et al*. 2015). The maximum organic content (OC) was recorded at the surface (21.75 g/kg) and sub-surface (18.88 g/kg) soil for pineapple orchard (Table 1) this may be due to higher accumulation of organic manure in the soil and less exposure of the soil due to smothering effect of pineapple plant which is confirmed with the findings of by Bordoloi *et al*. (2022). Soils of citrus orchard recorded minimum content of Soil Organic carbon (OC) in surface and sub-surface soils this may be due to slow in decomposition of citrus leaf foliage in the soil. Baishya *et al.* (2016) also reported that the increase in organic matter in the soil may be consider for good carbon budget as well as it increases availability OC, N, P and K content of soil. High nutrient index class (with NI value 3) was calculated for OC of different orchards and the result reveals that the maximum average available N content was found in pineapple orchard in surface (350.63 kg/ha) and sub-surface (308.72 kg/ha). The data showed the minimum values of record in banana (Table 1). Soils of different orchards exhibited low nutrient index class with NI value 1.3 in surface soil and 1.2 in sub-surface soils (Table 2). Sharma (2013) and Odyuo *et al*. (2015) revealed the highest values of available nitrogen in surface soils due to high organic matter as nitrogen is the major constituents of organic matter as compare to other P and K. It was also reported by William and Yakoov (2018) that increasing SOC requires a concomitant increase in soil N. Maximum available phosphorus was recorded in pineapple cultivation with 44.75 kg/ha at the surface soil and 37.59 kg/ha in sub-surface soil (Table 1). This might be due to increase in organic matter and buffering capacity of the organic matters towards making the soils more acidic which would have resulted in less availability of phosphorus in the soil. This is in conformity with the findings of Baishya *et al.* (2015). Nutrient index class for available P_2O_5 was medium with NI value1.95 and 1.7 for surface and sub-surface soil various orchards (Table 2). High amount of organic carbon in the surface soils can be attributed to formation of organophosphate complex and subsequent availability of phosphorus. Similar findings were reported by Sharma *et al*. (2012). The highest content of potassium was observed in soil samples from litchi orchard (137.45 kg/ha) and (129.03 kg/ha) in surface and sub-surface soils, respectively. Nutrient index (NI) class for potassium was calculated as medium with NI value 1.95 and 1.75 for surface and sub-surface soils (Table 2). Potassium content in the soil decreased with increasing depth as also recorded by Sharma (2013). In order to attain the sustainability in fruit orchards, micronutrient management is essentially required (Adak *et al.* 2023) and fruit growers of Nagaland should follow the soil and tree health management.

During the investigation, the highest earthworm population density (EPD) at the surface was observed in soils of banana (15.0 number/m^2), followed by mango (12.0 number/m^2) and lowest in citrus orchards (7.0 number/m^2) (Table 3). Difference in population under different orchards may be due to variations of soils macro and micro environment, prevailing temperature of the soil, rain fall pattern of a location and moisture availability in the soil. The variations on the taste and flavour of semi decomposed

Table 2 Nutrient index values and nutrient index classes of available nutrients and organic carbon of orchard soils at different depths

Parameter	Surface (0–0.20 m)				Sub-surface (0.20–0.40 m)			
	Class	Number of samples	Nutrient index value	Nutrient index classes	Class	Number of samples	Nutrient index value	Nutrient index classes
Organic content	High	20	3.0	High	High	20	3.0	High
Nitrogen	Low	14	1.3	Low	Low	16	1.2	Low
	Medium	6			Medium	4		
Phosphorus	Low	1	2.0	Medium	Low	6	1.7	Medium
	Medium	19			Medium	14		
Potassium	Low	1	2.0	Medium	Low	5	1.8	Medium
	Medium	19			Medium	15		

Table 3 Earthworm population and biological properties of orchard soils at different depths

Orchard	Earthworm population density (number/m)	Soil microbial biomass carbon (µg/g)		Dehydrogenase activity (µg TPF/g/h)		Acid phosphatase activity (µg PNP/g/h)	
	0–0.20 m	0–0.20 m	0.20–0.40 m	0–0.20 m	0.20–0.40 m	0–0.20 m	0.20–0.40 m
Banana	15.0	237.36	215.69	15.26	9.83	176.0	165.50
Citrus	7.0	190.64	177.49	8.98	6.53	162.0	150.50
Litchi	9.0	234.57	207.44	7.25	5.21	164.0	153.75
Mango	12.0	258.29	231.70	11.31	6.84	175.0	166.00
Pineapple	10.0	270.13	244.23	9.54	7.72	173.33	171.25
SD	3.05	40.55	35.08	3.04	1.71	6.49	8.84
CV (%)	28.77	17.39	16.70	29.08	23.71	3.82	5.47

organic matter of different crops further supported by quantity and quality of organic matter plays a very vital role for survival and multiplication of earth worms. On the other hand, the correlation study indicated positive and significant relationship between earthworm population and available nutrients under the study as well as organic matter. This might be due to availability of abundant food materials for worms in the form of organic matter (OM). Earthworms are the best convertor of organic matters in the soil as nutrients therefore it is evident from the fact that more earthworms can be held responsible for more mineral nutrient availability in soil. These results are in conformity with the findings of Kalu *et al.* (2015). The experimental results reveals that the soil microbial biomass carbon (SMBC) content at the depth of 0–0.20 m for pineapple orchard was found maximum (270.13 µg/g) which was followed by mango (258.29 µg/g) and banana (237.36 µg/g) based horticultural orchard. This might be due to more accumulation of organic matter as well as availability of soil organic carbon in the pine apple based horticultural orchard as compare to others orchards under the study. However, the least soil microbial biomass carbon (SMBC) content was recorded in sub-surface soils of citrus based horticultural orchard (152.49 µg/g). The highest soil organic carbon (OC) and available N content (Table 3) in pineapple based horticultural orchard might have provided enough substrate materials with easily mineralizable nitrogen source for rapid multiplication of microorganisms and thus increased their mass. The SOC sequestration can not occur in absence of N is also reported by William and Yakoov (2018). These results are in conformity with the findings of Chattopadhyay *et al.* (2012). The experimental result reveals that the dehydrogenase activity (DHA) in surface soils of all the horticultural based orchards were found more as compared to sub-surface soils. This might be due to more biological activities of microbes on the upper layers of soil as compare to sub-surface layer. The soils of banana orchard recorded highest DHA in surface (15.26 µg TPF/g/h) and sub-surface (9.83 µg TPF/g/h) soil respectively. Soils of litchi and citrus orchard had less DHA activity compared to other orchards (Table 3). Velmourougane *et al*. (2013) revealed that the major reason for increased DHA in the surface soil compared to sub-surface soil may be due to the greater availability of organic carbon, nutrients and stimulated microbial activity in the surface soil. Singha *et al.* (2016) recorded spatio-temporal variability of dehydrogenase activity as a function of soil moisture and temperature in high density guava orchards of subtropical climate. Maximum average content of acid phosphatase activity (PHA) was recorded in banana orchard (176.0 µg PNP/g/h) in surface soil and minimum average PHA in citrus orchard (150.50 µg PNP/g/h) in sub-surface soil. Maximum content of PHA in surface soil of banana orchard compared to other orchard may be related to more earthworm population in banana orchard, which might have secreted PHA enzymes during their metabolic processes. The average SOC stock for different orchard soils under investigation was 40.24 (mg/ha) and 38.78 (mg/ha) in surface and sub-surface soils respectively. Maximum SOC stock in surface soil was recorded for pineapple orchard (46.77 mg/ha) followed by litchi (44.08 mg/ha) and mango orchard (40.67 mg/ha). Less stock of organic carbon was recorded in sub-surface soils with least SOC in citrus orchard (32.42 mg/ha) (Table 1). Adak *et al.* (2019) scientifically explained the variations of soil physical properties under soil management systems in tree, agroforestry and other related ecosystem. Such quantification is actually needed to improve the soil functions and orchard sustainability. Even, grower can think of intercropping of turmeric, asparagus and fern in the interspaces of planted trees to improve the soil health also. Significant negative correlation was observed between OC-BD; positive correlation was observed between organic carbon and available N, P, K, indicating that organic matter was the major source of these nutrients under different land use systems. Significant positive correlation was also obtained between OC-MBC, OC-DHA, OC-PHA (Supplementary Table 1). This indicated that the organic matter is the source of energy for soil organisms and their activities to convert the organic matter for mineralization.

The present study indicated that integrated farming system like, horticultural-based land use systems are found to have impacted upon the soil health parameters, especially on soil bulk density (BD), soil organic carbon (SOC), availability of soil major and micro nutrients, dehydrogenase activity (DHA) and phosphatase activity (PHA). The evaluation of different horticultural-based land use system reveals that banana orchard soils exhibited relatively better biological health compared to other orchards with more earthworm population density, increased dehydrogenase and acid phosphatase enzyme activity. Pineapple orchard soils also showed high organic carbon content and availability of primary nutrients. In terms of soil biological health, pineapple, mango and banana orchard soils had greater biological properties. The study revealed the opportunities for farmers in the region to utilize their lands for growing location specific fruit trees with scientific management practices in order to preserve more carbon in soil and maintain soil fertility for sustainable productivity.

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