



RESEARCH ARTICLE

Dynamics of soil organic carbon stocks and fractions in diverse fruit growing ecosystems under subtropics North-Western Himalayas

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Abstract

Soil organic carbon (SOC) serves as a reliable indicator of soil quality and efficiency. It exists in labile and non-labile forms, which play a critical role in maintaining soil health under different fruit orchard systems. A study was carried out in the Shiwalik foothills of Northwest India to evaluate changes in total soil organic carbon (C_{tot}), oxidisable organic carbon (C_{oc}), very labile carbon (C_{frac1}), labile carbon (C_{frac2}), less labile carbon (C_{frac3}), non-labile carbon (C_{frac4}), microbial biomass carbon (C_{mic}) and SOC sequestration in various fruit orchards. The orchards following intercropping-horticulture (aonla + phalsa), agri-horticulture (aonla + maize) and monocultures of mango, guava, aonla, kinnow mandarin and phalsa showed increases in C_{tot} by 32.5, 28.0, 24.7, 19.0, 14.7, 10.3 and 7.5 % respectively, compared to land without trees. The intercropping-horticulture system showed the most significant increases in C_{frac1} (39.2 %), C_{frac2} (28.3 %), C_{frac3} (34.7 %) and C_{frac4} (26.4 %) over no-tree land. Carbon fractions showed greater accumulation in the 0–30 cm soil layer. Total active carbon pool was highest (58.95 Mg C ha⁻¹) in the intercropping-horticulture system, which was 1.3 times greater than that in the no-tree system. The passive carbon (c) pool, accounting for approximately 58.9 % of C_{tot} , also peaked in the intercropping-horticulture system. Microbial biomass carbon (C_{mic}) reached its maximum of 357 mg C kg⁻¹ in the same system, representing 2.6 % of C_{tot} . Carbon management index (CMI) was highest in intercropping-horticulture orchard (1.35), followed by agri-horticulture (1.30), mango (1.27), guava (1.22), aonla (1.16), kinnow mandarin (1.12) and phalsa (1.09), all showing improvement compared to no-tree land. The intercropping-horticulture system also recorded the maximum annual carbon accumulation rate (2.77 Mg C ha⁻¹ year⁻¹), which was 31.1 % greater than the no-tree baseline. Among the carbon (c) fractions, C_{frac1} was strongly correlated ($r = 0.960^{**}$) with C_{mic} .

Keywords: carbon buildup; carbon stock; fruit gardens; liability index; North west India

Introduction

Soil, water and air are essential natural resources necessary for life. Among them, soil is a critical, finite resource composed of minerals, water and organic matter. Organic matter plays a vital role in fruit production and nutrient accessibility while improving soil physico-chemical and biological characteristics. In subtropical regions, soil organic carbon (SOC) plays a critical role in maintaining the productivity of subtropical soils since it provides energy and substrates while promoting microbial diversity that helps preserve soil quality and ecosystem functioning. The SOC is more than just a passive carbon (c) reservoir-it significantly influences the soil physico-chemical and biological traits (1), which are critical for sustainable

agriculture. As such, SOC is therefore an indicator of both soil quality and ecological health (2). Since capturing atmospheric CO₂ in soil is a key strategy for mitigating global warming (3), having accurate baseline data on SOC storage is essential for understanding carbon dynamics and enabling carbon trading (4). Therefore, assessing and modelling the spatial distribution of SOC is crucial to determine the carbon sequestration potential of soils (5). Atmospheric CO₂ levels can be reduced either by limiting emissions or by eliminating CO₂ from the environment and sequestering it in terrestrial, aquatic, or marine ecosystems. Numerous studies have shown that carbon storage and sequestration through orchards offer a relatively low-cost approach to reducing net greenhouse gas emissions (6).

Carbon stock of soil is primarily influenced by surface soil characteristics, along with factors such as C concentration, soil depth and bulk density. The submontane region of Jammu is located at the base of the lower Shiwalik hills and forming part of the fragile Himalayan ecosystem, faces serious challenges related to soil erosion and degradation due to improper land use and widespread deforestation. This problem is particularly severe in the Shiwalik region, which includes the Northwestern Himalayan foothills across the Union Territory of Jammu and Kashmir and the states of Punjab, Himachal Pradesh, Haryana and Uttar Pradesh. Geologically, the Shiwalik region is composed of sandstone, grit and gravel-predominantly composed of fluvial deposits. Although these regions have deep soils, areas near the foothills are characterised by slopes with pebbles and boulders, making the terrain unstable and geologically sensitive (7). Spanning approximately 2.14 million ha, the Shiwalik foothills experience severe soil erosion due to irregular terrain, high soil erodibility and intense rainfall (8). Even in areas with clay loam soil and gentle slopes of 2–3 %, soil loss can reach up to 106.5 t ha⁻¹ (9). The soils in this region are generally light-textured are deficient in nutrients and organic C and suffers from surface stone and weak water retention (10). Approximately 80 % of the annual rainfall is concentrated in July and August, often occurring as erratic, high-intensity storms that accelerate erosion. Due to the extreme and variable climatic conditions, the productivity of the soil is not only low but also very unstable (11). Runoff and erosion drastically reduce the fertility of the soil as the as nutrients are removed from the soil. The establishment of fruit orchards and improved cropping systems enhances the return of organic matter through leaf litter and crop residues. It is crucial to identify and adopt such sustainable systems to raise soil productiveness and agricultural efficiency. In subtropical, tropical, dry and semi-arid areas, soils release more CO₂ per unit of SOC than soil in cold temperate zones. Moreover, the selection of crop species is an essential factor in maintaining C stocks, as variations in amount and quality of organic residue affect their decomposition rate and residence time in the soil (12). Emphasised the specific fractions of soil organic matter (SOM) are particularly important to sustain soil quality and serve as sensitive marker of soil management effects. However, due to the management methods, it is challenging to find changes in the SOC, as this shift is gradual, relatively low in comparison to the SOC pool and is subjected to spatial and temporal variability (13).

The natural alteration apparatus appears in advance, some of its C is stable in organic C and is discreet between the different groups of a single part. To recognise the mechanisms again through the use of which the C is out of place or stabilises on the ground and the general organic C account of the soil (TSOC) divided the labile pool or actively bicycle, a slow pool and a solid or passive and

recalcitrant pool with varying residence times (14). Labile C pool and its TSOC fraction are faster income charge. The labile pools consist of residential microbes and their merchandise in addition to the organic memories of the soil. These pools are essential from the agronomic perspective for crop production while they maintain the food network in the soil. Therefore, manipulating nutrient cycling to retain soil characteristics and its aptitude to produce crops (15). Meanwhile, application of biochar and tryptophan were also significantly improve growth, availability nutrients, microspores and microbial movement (16, 17). The greatly recalcitrant or passive pool is changed very slowly through microbial movements (18). The passive group is moderately greater stable than that of the dynamic pool and is not much disintegrated that has a better profit era. In this exploration, we imagine the numerous fruit growing orchards might affect the soil C pools and stocks in the submontaneous soil. We tested the soil in the bearings orchard of mango, guava, kinnow mandarin, aonla, phalsa, inter cropping-horticulture (aonla + phalsa) and agriculture (aonla + maize) and no tree regions within the Shiwalik foothills of Himalayas vicinity with recognize to pools, C stock and the ability of the soil to accumulate C.

Materials and Methods

Study site

The study was carried out in the Shiwalik foothills of Jammu, Jammu and Kashmir, in the Himalayan region of India. This area is characterised by undulating terrain with small, dry hillocks and an uneven, rising and falling landscape. Situated at an elevation of less than 1200 m above mean sea level, the Shiwalik range lies within a subtropical climatic zone and is considered one of the most ecologically fragile areas of the lower Himalayas. The region receives an average annual rainfall of approximately 1100 mm, of which 70–80 % is received during the southwest monsoon season between July and September. Despite this, the area experiences significant climatic challenges. Rainfall is highly erratic in terms of timing, spatial distribution, frequency and intensity, often leading to moisture stress for much of the year. The average annual temperature in this area is about 27° C, average maximum and minimum temperatures of 33°C and 21° C respectively. The soil in this area is usually coarse in texture and ranges from slightly acidic to slightly alkaline, with pH values between 6.71 and 8.21. They are generally low in organic matter and deficient in essential nutrients (Table 1). Land use is further constrained by moderate erosion, varying degrees of stoniness and occasional flooding.

Table 1. Primary soil properties of chosen fruit growing plantation at North-western Himalayas, India

Soil properties	No tree	Mango (<i>Mangifera indica</i> L.)	Kinnow mandarin (<i>Citrus reticulata</i> Blanco)	Aonla (<i>Emblia officinalis</i> Gaertn.)	Guava (<i>Psidium guajava</i> L.)	Phalsa (<i>Grewia asiatica</i> L.)	Intercropping-horticulture (aonla+phalsa)	Agri-horticulture (aonla+maize)
pH	8.81	7.12	7.27	7.22	7.18	7.32	7.65	6.71
Organic carbon (g kg ⁻¹)	3.68	4.40	4.10	4.25	4.35	3.83	4.68	4.52
Bulk density (g cm ⁻³)	1.69	1.63	1.66	1.65	1.64	1.67	1.61	1.62
Available nitrogen (kg ha ⁻¹)	141.44	184.09	166.13	175.11	181.85	161.64	170.62	190.83
Available phosphorus (kg ha ⁻¹)	10.87	12.62	11.00	10.87	12.12	11.05	11.76	13.69
Available potassium (kg ha ⁻¹)	98.78	114.50	105.52	107.76	112.25	103.27	117.19	119.25

Soil samples compilation and preparation

The study was conducted in mature orchards located in the Shivalik foothills region of Jammu, North-western India. Soil samples were collected from orchards of mango, kinnow mandarin, aonla, guava and phalsa, as well as from an intercropping-horticulture system (aonla + phalsa), an agri-horticulture system (aonla + maize) and areas without tree cover (Fig. 1). A total of 32 soil profiles (8 treatments × 4 replications) were sampled at four soil depths: 0–0.15 m, 0.15–0.30 m, 0.30–0.60 m and 0.60–1.00 m. The agricultural system was represented primarily by maize cultivation, while the horticultural systems included the various orchard types. Maize has been cultivated in the region for over a century and has been passed down through generations, whereas the orchards are relatively recent, ranging in age from 15–35 years. The no-tree (barren) areas were either devoid of vegetation or sparsely covered with natural vegetation. After collection, each soil sample was air-dried, gently crushed using a wooden pestle and mortar and sieved through a 2.0 mm stainless steel sieve.

Field-moist samples were stored at 4° C and used within 24 hr for microbial biomass carbon analysis. The air-dried, sieved samples were used to assess various key physico-chemical properties using standard procedures. Additionally, bulk density was determined for each soil layer using a core sampler (inner diameter, 5.3 cm; height, 5 cm).

Soil properties

Soil pH was measured electrometrically using 1:2.5 soil-to-water ratio, with air-dried soil passed through a 2 mm sieve, following the method outlined (19). The soils ranged from slightly acidic to slightly alkaline. Soil texture was determined using the hydrometer method based on mechanical analysis (20). The predominant soil textures were sandy loam, followed by sandy clay loam. Bulk density was determined using the core sampling technique (19). Oxidisable organic C and stock: The utilise of oxidisable fraction of organic C known as SOC was measured by the wet oxidation technique created (21).

Soil organic carbon stock (SOCS), expressed as Mg ha^{-1} for specific soil depths, was calculated by multiplying the SOC concentration by the soil bulk density and the thickness of the corresponding soil layer, following (22):

$$\text{Soil organic carbon stocks (SOCS)} = \text{SOC}/1000 \times \text{BD} \times \text{SD} \times 10000$$

where; SOCS is the SOC stock that is measured in Mg ha^{-1} , SOC g kg^{-1} , the BD is the soil bulk density (g cm^{-3}), SD is the depth of soil layer (m). The assessment of 10000 indicates the stock for 1 ha of land.

Carbon (c) build-up/ upsurge in various orchards were predictable in the following process:

$$\text{Carbon (c) build-up (\%)} = [(\text{C orchard} - \text{C control}) / \text{C control}] \times 100$$

where C orchard stands for C in orchard soil and C control stands for the C in no-tree soil, respectively.

$$\text{Carbon (C) build-up rate (Mg C ha}^{-1}\text{soil year}^{-1}) = (\text{C orchard} - \text{C control}) / \text{Time (year of testing)}$$

Soil organic carbon fractions

Soil organic carbon fractions were determined using a customised Walkley and Black method (12). Different concentrations of sulfuric acid (H_2SO_4) (12, 18 and 24 N) were prepared by adding 5, 10 and 20 mL of concentrated H_2SO_4 respectively and producing 3 acid-to-water proportion: 0.5 : 1, 1 : 1 and 2 : 1, which communicate to acid potency of 12 N, 18 N and 24 N H_2SO_4 respectively. These acid strengths enabled the separation of total SOC (C_{tot}) into four oxidisable fractions: C_{frac1} , C_{frac2} , C_{frac3} and C_{frac4} and Total SOC (C_{tot}) was designed as the sum of these four fractions. The C fractions were defined based on their ease of oxidation under varying acid strengths: Fraction I (C_{frac1}): Organic C oxidised by 12 N H_2SO_4 ; Fraction II (C_{frac2}): The variation in C content between 18 N and 12 N H_2SO_4 extractions; Fraction III (C_{frac3}): The variation in C extracted between 24 N and 18 N H_2SO_4 (24 N corresponds to the standard Walkley and Black method); Fraction IV (C_{frac4}): The enduring organic C remaining after treatment with 24 N H_2SO_4 and subtracted from C_{tot} .

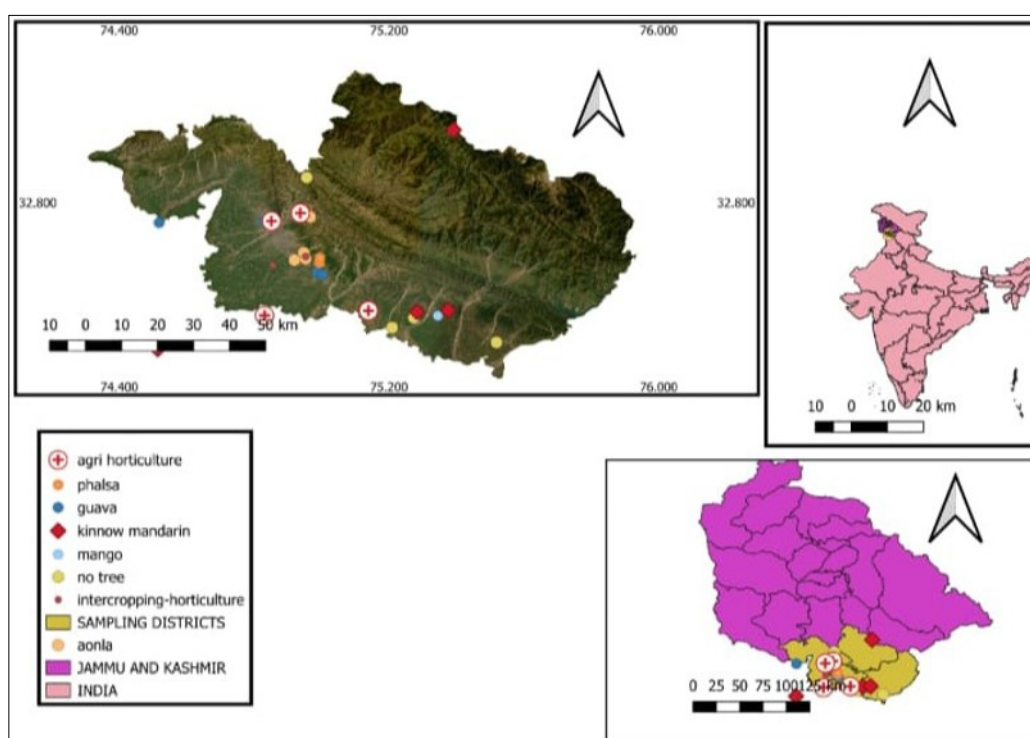


Fig. 1. Location map of the soil sampling sites in the subtropical region of Jammu and Kashmir.

Active and passive pools

Organic C oxidised was classified by 12 N H₂SO₄ as a very labile C pool (C_{frac1}), while the variation in C oxidised between 18 N and 12 N H₂SO₄ was defined as the labile pool (C_{frac2}). Together, these two fractions form an active pool of organic C of soil which is characterised by their advanced sensitivity of oxidation in weaker acid concentrations (12 and 18 N H₂SO₄). In dissimilarity, the passive C pool stands for the less labile (C_{frac3}) and non-labile (C_{frac4}) fractions of total organic carbon (C_{tot}), which is extra resistant to oxidation.

Soil microbial biomass carbon (C_{mic}):

The soil microbial biomass carbon (MBC) was thought by the chloroform fumigation extraction strategy (23). New soil tests stored at 4°C were taken for the show think about. Fumigated and unfumigated soil tests were extracted using 0.5 M K₂SO₄. The C within the fumigated and unfumigated extricates was measured and the contrast gotten was utilised to calculate MBC. Soil MBC can be given as:

$$C_{mic} = Fc / 0.45$$

where, Fc stand for organic C extracted from 0.5 M K₂SO₄ from fumigated SOC extracted from non-fumigated soil. Microbial quotient (MQ) was measured as the proportion of C_{mic} to C_{tot} and communicated as percentage.

Carbon management index (CMI)

Way I - proposed the liability index (24), the details are given below:

The liability index (LI) for the SOC was computed utilising three of the specific C fractions: C_{frac1}, C_{frac2} and C_{frac3} said over. C_{frac1}, C_{frac2} and C_{frac3} have been assigned as very labile, labile and less labile and are given weight age of 3, 2 and 1, separately. Thus, their genuine values are changed to a corresponding amount of C_{tot} and weighed with the weighing calculate to urge a LI for the organic C substance in each of the soil depths distinctive profundities (24).

$$LI = [(C_{frac1}/C_{tot}) \times 3 + (C_{frac2}/C_{tot}) \times 2 + (C_{frac3}/C_{tot}) \times 1]$$

Way II - proposed the C pool index (24), the details are given below: The carbon pool index (CPI) was resultant using the formula.

$$CPI = \text{Sample total C (g kg}^{-1}\text{)} / \text{reference total C (g kg}^{-1}\text{)}$$

where reference total C stands for total C content (g kg⁻¹) of no-tree land²², there is an estimate of the following CMI:

$$CMI = CPI \times LI \times 100$$

Data analysis

The information examination of the comes about was carried out utilising investigation of measurable Statistical Package for the Social Sciences (SPSS) version 16.0 (e.g., SPSS Inc., Chicago, IL, USA). Programs with treatment impacts were examined utilising randomised block design (RBD) based on analysis of variance (ANOVA). When ANOVA showed that there was a noteworthy esteem, numerous assessments of treatment implies were achieved utilising the least significant difference (LSD). The imperative decision on the impact of the treatment was used for the *F*-test.

Results and Discussion

Soil organic carbon and its fractions

A significant difference ($p \leq 0.05$) in total soil organic carbon (C_{tot}) was observed in soil profile seen by various orchard systems in (0–1.00 m) soil depth (Table 2). C_{tot} values generally declined with increasing soil depth. The control treatment (no-tree land) exhibited the lowest C_{tot} value, measuring 75.45 Mg ha⁻¹ across the entire soil profile. Previous studies observed that fallowing decreases SOC by declining the quantity of non-harvested plant build-up arrival to the soil (25), whereas rising the cropping intensity escalated expanded SOC (26). The highest C_{tot} was observed within the upper soil than subsurface soil layer attributed to the increased in plant and roots biomass in upper soil layers and need of supplement and natural movement into more profound layers, which eventually imperatives the establishing profundity of soil (27). The highest C_{tot} (99.98 Mg ha⁻¹) in the 0–1.00 m profile was found in the intercropping-horticulture system (aonla + phalsa), reflecting a 35.5 % increase over the no-tree land. Similarly, significant ($p \leq 0.05$) increases in C_{tot} be observed in agri-horticulture (aonla + maize), mango, guava, aonla, kinnow mandarin and phalsa orchards-showing 28.0, 24.7, 19.0, 14.6, 10.3 and 7.5 % increases over the control respectively. The elevated C_{tot} in the intercropping-horticulture orchard can be attributed to a diverse input of organic materials such as leaf litter, root biomass and biological activity (28). Regular additions of organic residues, farmyard manure (FYM) and fertilisers in fruit orchards contribute substantially to SOC levels. Furthermore, long-term C storage in sub soils may be linked to reduced microbial decomposition. Conversely, lower C_{tot} in no-tree areas may result from exposed soil surfaces and the disintegration of soil aggregates, which increase susceptibility to erosion under heavy rainfall, especially in sparsely vegetated zones (29).

Table 2. Total and oxidisable organic C (Mg C ha⁻¹ soil) in soils in various layers (m) of different fruit growing plantation at North-western Himalayas, India

Orchard	Soil organic carbon (Mg C ha ⁻¹ soil)									
	Total soil organic carbon (C _{tot})					Oxidisable organic carbon (C _{oc})				
	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Total	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Total
No tree	15.78 ^c	13.04 ^b	22.43 ^c	24.21 ^c	75.46 ^d	10.65 ^d	8.81 ^e	11.62 ^d	13.43 ^d	44.51 ^d
Mango	19.84 ^a	16.53 ^a	28.00 ^b	29.75 ^{ab}	94.12 ^{ab}	12.40 ^b	11.83 ^a	14.08 ^b	16.12 ^a	54.43 ^{ab}
Kinnow mandarin	18.10 ^b	15.12 ^{ab}	23.46 ^c	26.57 ^b	83.25 ^c	11.28 ^c	10.50 ^c	13.66 ^b	14.94 ^c	50.38 ^{bc}
Aonla	18.50 ^{ab}	15.15 ^{ab}	24.79 ^c	28.13 ^b	86.57 ^{bc}	12.33 ^b	10.64 ^c	13.42 ^c	15.30 ^b	51.69 ^b
Guava	19.08 ^{ab}	15.71 ^a	27.11 ^b	27.91 ^b	89.81 ^b	12.56 ^b	11.62 ^b	13.67 ^b	15.38 ^b	53.23 ^{ab}
Phalsa	15.91 ^c	14.65 ^b	23.92 ^c	26.63 ^b	81.11 ^{cd}	11.08 ^c	9.93 ^d	13.35 ^c	14.02 ^c	48.38 ^c
Intercropping-horticulture	20.73 ^a	16.91 ^a	31.39 ^a	30.95 ^a	99.98 ^a	14.13 ^a	12.52 ^a	15.37 ^a	16.36 ^a	58.38 ^a
Agri-horticulture	20.11 ^a	16.30 ^a	28.49 ^{ab}	31.70 ^a	96.60 ^a	13.78 ^a	11.57 ^b	14.91 ^a	16.32 ^a	56.58 ^a
Mean	18.51	15.42	26.19	28.23	88.35	12.28	10.93	13.76	15.23	52.20

Within a column, values designated by similar letters are not significantly different at the 0.05 level of probability.

The oxidisable organic carbon (C_{oc}) stock varied between 44.50 and 58.38 Mg C ha⁻¹ across the different orchard systems (Table 2). A gradual decline in C_{oc} was observed with increasing soil depth. The lowest C_{oc} value (44.5 Mg ha⁻¹) was recorded in the control treatment (no orchard) across the full 1.0 m soil profile. The increase in C_{oc} under orchard systems is attributed to significantly higher ($p \leq 0.05$) organic inputs, such as leaf litter and organic manure, which enhance C accumulation in the soil (30). Alike developments in SOC afterward excrement application were moreover depicted in long-term tests at Rothamsted, UK (31). The highest C_{oc} value (58.38 Mg ha⁻¹) was observed in the intercropping-horticulture system (aonla + phalsa) within the 0–1.0 m depth, marking a 31.1 % increase compared to the no-tree land. The hierarchy of C_{oc} content among the different orchard systems was as follows: intercropping-horticulture > agri-horticulture > mango > guava > aonla > kinnow mandarin > phalsa > no-tree. Likewise, significantly higher ($p \leq 0.05$) C_{oc} values were recorded in agri-horticulture, mango, guava, aonla, kinnow mandarin and phalsa orchards showing respective increases of 27.1, 22.2, 19.5, 16.1, 13.0 and 8.7 % over the no-tree land.

Different orchard systems significantly improved the very labile carbon fraction (C_{frac1}) compared to no-tree land (Table 3). The highest and statistically significant ($p \leq 0.05$) increase under C_{frac1} within the sub-surface layer (0.60–1.00 m) was recorded under the agri-horticulture system, followed by the intercropping-horticulture orchard. Across the entire soil profile, the intercropping-horticulture system had the highest total C_{frac1} (35.08 Mg ha⁻¹), reflecting a 39.2 % increase over no-tree land. Other orchard systems also showed notable improvements in C_{frac1} , with agri-horticulture, mango, guava, aonla, kinnow mandarin and phalsa orchards registering increases of 33.4, 29.1, 23.8, 16.6, 11.8 and 10.4 % respectively, compared to the no-tree control.

Table 3. Oxidisable organic carbon fractions (Mg ha⁻¹ soil) in soils in various layers (m) of different fruit growing plantation at North-Western Himalayas, India

Orchard	Soil organic carbon fraction (Mg C ha ⁻¹ soil)									
	Very labile carbon (C_{frac1})					Labile carbon (C_{frac2})				
	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Total	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Total
No tree	5.01 ^b	4.41 ^c	8.16 ^e	7.61 ^e	25.19 ^c	3.61 ^b	3.09 ^b	5.51 ^d	6.39 ^b	18.60 ^c
Mango	6.25 ^a	5.94 ^b	9.78 ^c	10.56 ^b	32.53 ^a	4.52 ^a	3.92 ^a	6.90 ^b	7.29 ^a	22.63 ^a
Kinnow mandarin	5.91 ^a	5.15 ^b	8.46 ^d	8.63 ^d	28.16 ^b	3.99 ^a	3.89 ^a	5.71 ^d	6.62 ^b	20.21 ^b
Aonla	5.93 ^a	5.04 ^b	8.85 ^d	9.57 ^c	29.38 ^b	4.20 ^a	3.82 ^a	5.77 ^c	6.93 ^a	20.71 ^b
Guava	6.02 ^a	5.57 ^a	10.30 ^b	9.32 ^c	31.21 ^b	4.40 ^a	3.79 ^a	6.12 ^c	7.09 ^a	21.40 ^a
Phalsa	5.13 ^b	4.72 ^b	8.32 ^c	9.63 ^c	27.80 ^c	3.80 ^b	3.67 ^a	6.08 ^c	6.31 ^b	19.86 ^b
Intercropping-horticulture	6.61 ^a	6.10 ^a	11.38 ^a	10.98 ^b	35.08 ^a	4.67 ^a	3.92 ^a	7.67 ^a	7.61 ^a	23.87 ^a
Agri-horticulture	6.38 ^a	5.55 ^a	10.05 ^b	11.65 ^a	33.62 ^a	4.56 ^a	3.98 ^a	7.00 ^b	7.54 ^a	23.08 ^a
Mean	5.91	5.31	9.41	9.74	30.37	4.22	3.76	6.34	6.97	21.30

Within a column, values designated by similar letters are not significantly different at the 0.05 level of probability.

Table 4. Oxidisable organic carbon fractions (Mg ha⁻¹ soil) in soils in various layers (m) of different fruit growing plantation at North-Western Himalayas, India

Orchard	Soil organic carbon fraction (Mg C ha ⁻¹ soil)									
	Less labile carbon (C_{frac3})					Non-labile carbon (C_{frac4})				
	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Total	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Total
No tree	3.31 ^b	2.23 ^b	3.07 ^c	3.60 ^c	12.21 ^f	3.85 ^c	3.31 ^c	5.69 ^e	6.61 ^c	19.45 ^e
Mango	4.45 ^a	2.66 ^a	4.28 ^a	4.25 ^a	15.63 ^b	4.62 ^a	4.01 ^a	7.04 ^b	7.65 ^a	23.31 ^b
Kinnow	4.05 ^b	2.28 ^b	3.15 ^c	4.18 ^a	13.65 ^c	4.15 ^b	3.80 ^b	6.14 ^d	7.14 ^b	21.23 ^d
Aonla	4.13 ^a	2.41 ^b	3.88 ^b	4.38 ^a	14.79 ^d	4.24 ^b	3.88 ^b	6.29 ^d	7.25 ^b	21.65 ^c
Guava	4.19 ^a	2.51 ^a	4.18 ^a	4.15 ^b	15.03 ^c	4.47 ^a	3.84 ^b	6.51 ^c	7.35 ^a	22.17 ^c
Phalsa	2.93 ^c	2.78 ^a	3.41 ^b	4.05 ^b	13.17 ^f	4.05 ^b	3.48 ^c	6.11 ^d	6.64 ^c	20.27
Intercropping-horticulture	4.58 ^a	2.80 ^a	4.45 ^a	4.62 ^a	16.45 ^a	4.87 ^a	4.09 ^a	7.89 ^a	7.74 ^a	24.59 ^a
Agri-horticulture	4.46 ^a	2.75 ^a	4.35 ^a	4.51 ^a	16.06 ^a	4.71 ^a	4.02 ^a	7.09 ^b	8.00 ^a	23.82 ^b
Mean	4.01	2.55	3.84	4.22	14.62	4.37	3.80	6.60	7.30	22.06

Within a column, values designated by similar letters are not significantly different at the 0.05 level of probability.

Additionally, the labile carbon fraction (C_{frac2}) changed essentially ($p \leq 0.05$) between the fruit plantation at the upper soil layer. The intercropping cultivation orchard resulted in more noteworthy collection of C_{frac2} in the surface layer. The overall C_{frac2} in intercropping cultivation plantation (23.87 Mg ha⁻¹) was altogether ($p \leq 0.05$) most elevated no-tree coming about in 28.3 % raise. Agri-horticulture, mango, guava, aonla, kinnow mandarin and phalsa orchards also contributed to increased C_{frac2} levels, with respective gains of 24.1, 21.6, 15.0, 11.3, 8.6 and 6.7 % over the no-tree control. New leaf drop and root build-up are the essential resource of organic C foremost to upgraded quantity of C_{frac1} and C_{frac2} into a few plantations (28).

The less labile carbon fraction (C_{frac3}) illustrates significant variation ($p \leq 0.05$) among the plantation within the surface soils (Table 4). Intercropping-horticulture plantation exhibited the highest accumulation of C_{frac3} in the topsoil, with a total of 16.45 Mg ha⁻¹ representing a 34.7 % increase over the no-tree and statistically significant ($p \leq 0.05$). The order of C_{frac3} accumulation across orchard systems was as follows: intercropping-horticulture $\geq$ agri-horticulture $\geq$ mango $\geq$ guava $\geq$ aonla $\geq$ kinnow mandarin $\geq$ phalsa $\geq$ no-tree. Likewise, the non-labile carbon fraction (C_{frac4}) also diverse significantly ($p \leq 0.05$) across plantation in surface soil (0–0.15 m). The greatest and statistically significant ($p \leq 0.05$) enhance in C_{frac4} be recorded in the intercropping-horticulture system, followed by agri-horticulture. The intercropping-horticulture orchard had the highest total C_{frac4} value of 24.59 Mg ha⁻¹, marking a 26.4 % increase over no-tree land. Other orchard systems also demonstrated notable increases in C_{frac4} : agri-horticulture (22.5 %), mango (19.8 %), guava (14.5 %), aonla (11.3 %), kinnow mandarin (9.1 %) and phalsa (4.2 %), relative to no-tree land. Around the entire soil profile, the sharing of C fraction follows in this order: $C_{frac1} > C_{frac4} > C_{frac2} > C_{frac3}$. The predominant extent of non-labile C_{frac4} under orchard systems was

licensed to the quick transformation of natural inputs and labile C into more stable, recalcitrant forms and its perseverance beneath positive circumstance of dampness, profound root, bulky shade cover and negligible soil unsettling influence (32). The comparative adjustment in C_{frac1} , C_{frac2} and C_{frac3} to cropping systems, indicating their sensitivity to land use changes (33). Among the plantations, a sensibly predominant extent of C fractions was observed in surface soil layer, though it was established to decline with upgrades in soil profundity layer. Remaining to bring and the openness of included mineralisable and promptly hydrolysable C coming about in progressed microbial action in upper soil layers (34).

Active and passive carbon pool

The active C pool corresponds to very labile and labile fractions of oxidisable organic C and diverse altogether ($p \leq 0.05$) across the diverse plantations (Table 5). Notably, the intercropping-horticulture and agri-horticulture systems showed significantly ($p \leq 0.05$) superior active C pools than no-tree control in the 0–0.60 m profundity. Regardless of orchard type, the most extreme active C pool was evidenced within 0–0.15 m layer being most elevated in intercropping cultivation plantation (11.28 Mg ha⁻¹) and was most reduced in no-tree land (8.62 Mg ha⁻¹). Although total active C pools in the 0–1.00 m profile did not show notable differences between orchard systems, they were extensively higher ($p \leq 0.05$) as over to the no-tree area. Intercropping-horticulture system recorded the highest total active C pool (58.95 Mg ha⁻¹), followed by agri-horticulture (56.70 Mg ha⁻¹). The lowest was observed in no-tree land (43.79 Mg ha⁻¹), which was approximately 1.3 times lower than the highest esteem recorded. The higher active C pool in several plantation than that no-tree may be due to credited to the tannins and lignin fixings shaped from the deterioration of leaf rubbish and biomass of root the plantation frameworks controlled the C from quick deterioration and consequently conserved it within the totals (35).

The passive C pool compares to less labile and non-labile pool of oxidisable natural C (Table 6). The most extreme passive C pool in 0–0.15 m depth recorded in intercropping cultivation plantation (9.45 Mg ha⁻¹) and lowest in no-tree (7.16 Mg ha⁻¹). The

passive C pool regularly reduces with the expansion of the soil profile. They come about affirmed that the total passive C pool in 0–1.00 m profundity amongst soils of distinctive plantation appeared significant variety and altogether ($p \leq 0.05$). Intercropping-horticulture orchard recorded the highest total passive C pool (41.04 Mg ha⁻¹), followed by agri-horticulture (39.88 Mg ha⁻¹), mango (38.94 Mg ha⁻¹), guava (37.20 Mg ha⁻¹), aonla (36.44 Mg ha⁻¹), kinnow mandarin (34.88 Mg ha⁻¹) and phalsa (33.44 Mg ha⁻¹).

Soil microbial biomass carbon and microbial quotient

The soil (C_{mic}) in surface soil changed essentially ($p \leq 0.05$) between the different orchards (Fig. 2). The highest C_{mic} value was observed in the intercropping-horticulture orchard (357.35 mg kg⁻¹), followed by the agri-horticulture orchard (307.89 mg kg⁻¹), representing a 69.7 % increase over the no-tree (control) land. The C_{mic} content among orchard systems followed the order: intercropping-horticulture $\geq$ agri-horticulture $\geq$ guava $\geq$ mango $\geq$ aonla $\geq$ kinnow mandarin $\geq$ phalsa $\geq$ no-tree. The low C_{mic} value in no-tree land was attributed to poor environmental conditions, such as nutrient depletion due to lack of fertilisation and surface runoff. In contrast, higher C_{mic} levels in orchard systems were likely due to more favourable conditions for microbial growth, including the regular addition of FYM, active root zones and considerable efforts of leaf rubbish (36).

The aggregate leaf debris biomass included within bearing plantations intercropping-horticulture, followed by agri-horticulture, guava, mango, aonla, kinnow mandarin and phalsa orchards. Elevated C_{mic} levels in the intercropping-horticulture and agri-horticulture systems reflect substantial litter fall, which provides organic substrates for microbial decomposition. Furthermore, the higher C_{mic} in intercropping-horticulture, agri-horticulture, guava and mango plantation was credited to the sum and quality of litter with superior rate of decay, superior accessibility of supplements remaining in the expansion of advanced plant quality (37). The microbial quotient (MQ), calculated as the extent of C_{mic} to total organic carbon (C_{tot}), extended from 2.66–3.57 %, with a average of 3.08 % (Fig. 3). Differences in MQ between agri-horticulture and guava, kinnow mandarin, aonla and phalsa were not statistically significant ($p > 0.05$). However, MQ differed significantly ($p \leq 0.05$)

Table 5. Active carbon pool in soils in various layers (m) of different fruit growing plantation at North-Western Himalayas, India

Orchard	Active carbon pool (Mg ha ⁻¹)				
	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Total
No tree	8.62 ^c	7.50 ^c	13.67 ^d	14.00 ^d	43.79 ^d
Mango	10.77 ^{ab}	9.86 ^a	16.68 ^{cd}	17.85 ^{ab}	55.16 ^{ab}
Kinnow mandarin	9.90 ^b	9.04 ^a	14.17 ^d	15.25 ^c	48.37 ^c
Aonla	10.13 ^{ab}	8.86 ^b	14.62 ^d	16.50 ^b	50.09 ^{bc}
Guava	10.42 ^{ab}	9.36 ^a	16.42 ^c	16.41 ^b	52.61 ^b
Phalsa	8.93 ^b	8.39 ^b	14.40 ^d	15.94 ^{bc}	47.66 ^{cd}
Intercropping-horticulture	11.28 ^a	10.02 ^a	19.05 ^a	18.59 ^a	58.95 ^a
Agri-horticulture	10.94 ^{ab}	9.53 ^a	17.05 ^b	19.19 ^a	56.70 ^a
Mean	10.13	9.07	15.75	16.71	51.67

Within a column, values designated by similar letters are not significantly different at the 0.05 level of probability.

Table 6. Passive carbon pool in soils in various layers (m) of different fruit growing plantation at North-Western Himalayas, India

Orchard	Passive carbon pool (Mg ha ⁻¹)				
	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Total
No tree	7.16 ^c	5.54 ^c	8.76 ^c	10.21 ^c	31.66 ^c
Mango	9.07 ^{ab}	6.67 ^a	11.32 ^{ab}	11.90 ^a	38.94 ^{ab}
Kinnow mandarin	8.20 ^b	6.08 ^b	9.29 ^c	11.32 ^b	34.88 ^{bc}
Aonla	8.37 ^b	6.29 ^b	10.17 ^b	11.63 ^b	36.44 ^{bc}
Guava	8.66 ^b	6.35 ^a	10.69 ^{bc}	11.50 ^b	37.20 ^b
Phalsa	7.48 ^c	6.26 ^b	9.52 ^c	10.69 ^c	33.44 ^c
Intercropping-horticulture	9.45 ^a	6.89 ^a	12.34 ^a	12.36 ^a	41.04 ^a
Agri-horticulture	9.17 ^a	6.77 ^a	11.44 ^{ab}	12.51 ^a	39.88 ^{ab}
Mean	8.38	6.35	10.44	11.52	36.68

Within a column, values designated by similar letters are not significantly different at the 0.05 level of probability.

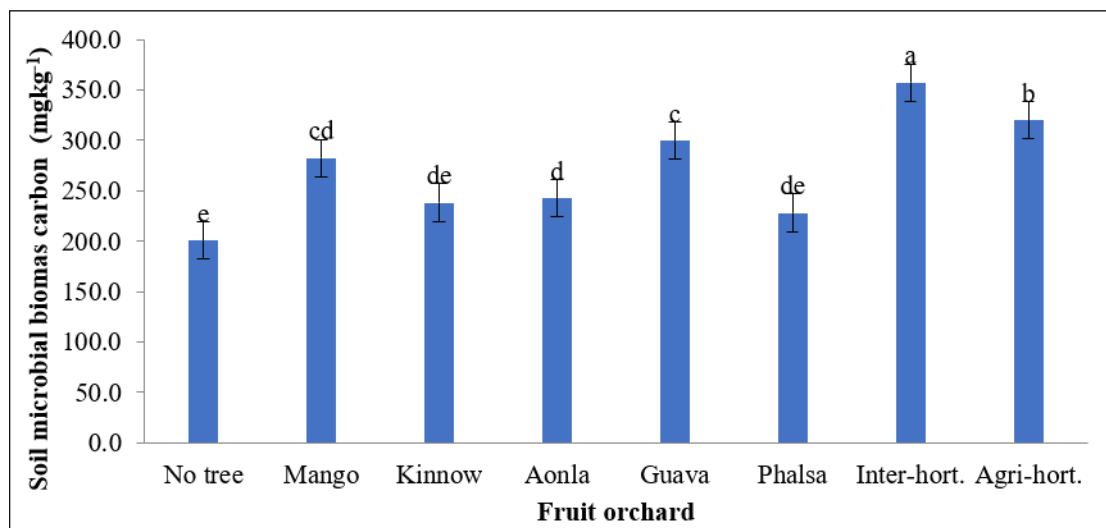


Fig. 2. Microbial biomass carbon in soils of diverse fruit growing plantation at North-Western Himalayas, India. Bars are $\pm$ SE of the mean values show the similar letters are not significantly.

when intercropping-horticulture, agri-horticulture, mango, phalsa and no-tree systems were compared. The observed MQ values fall inside the benchmark range of 1–5 %, as suggested with several analysts (38). Superior MQ within the intercropping-horticulture, agri-horticulture, guava and mango systems indicate greater stability and availability of organic C in these orchards (39). The lowest esteem of MQ within the no-tree area points to reduced microbial biomass and diminished soil quality, highlighting impaired C cycling capacity (40). Improved nutrient availability in the orchard soils also contributed to higher MQ, supporting healthier microbial populations (41).

Carbon management index (CMI), carbon pool index (CPI) and carbon build-up

The carbon management index (CMI) supplies a comprehensive assessment of both the quantity and quality of SOC. Unlike relying solely on total SOC concentration, the CMI serves as a more sensitive indicator for detecting modified in SOC owing to shifts in soil management customs. Carbon management index as a valuable tool in favour of assessing soil fruitfulness (42). Among all orchard systems, the intercropping-horticulture orchard consistently showed the highest CPI values throughout the 0–0.60 m soil profile, indicating its strong potential to restore original SOC levels (Table 7).

The maximum CPI (1.40) was recorded in the 0.30–0.60 m depth under intercropping-horticulture (aonla + phalsa) orchard. Overall, all orchard systems exhibited an increase in CPI compared to the no-tree land. In contrast, the lability index (LI) did not show great difference between orchard systems across the soil depth (Table 8). The highest LI was observed in the guava orchard (1.75), closely followed by the intercropping-horticulture orchard (1.72) at the 0.30–0.60 m insight. This design appeared that guava plantation bears least oxidative environment, give superior physical security in organic matter favouring a lifted extent of labile C than to TSOC by upgrading the rate of C lability within the soil (24).

The CMI values differed extensively ($p \leq 0.05$) across the plantation systems in the topsoil (0–0.15 m) layer (Table 9). The maximum CMI value, 240.44, was found in the 0.30–0.60 m depth of the intercropping-horticulture orchard, which was 1.4 times greater than that of the no-tree land. The elevated CMI values in orchard systems are because of more organic matter being added every year and better quality of that organic matter. The C : N ratio and the structure of lignin, cellulose, hemicellulose, protein and carbohydrates contribute to more oxidative forms to the changes of C (43). The average CMI across plantation types followed the order: intercropping-horticulture (223.56) > agri-horticulture (214.67) > mango (210.38) > guava (201.11) > aonla (191.55) > kinnow mandarin

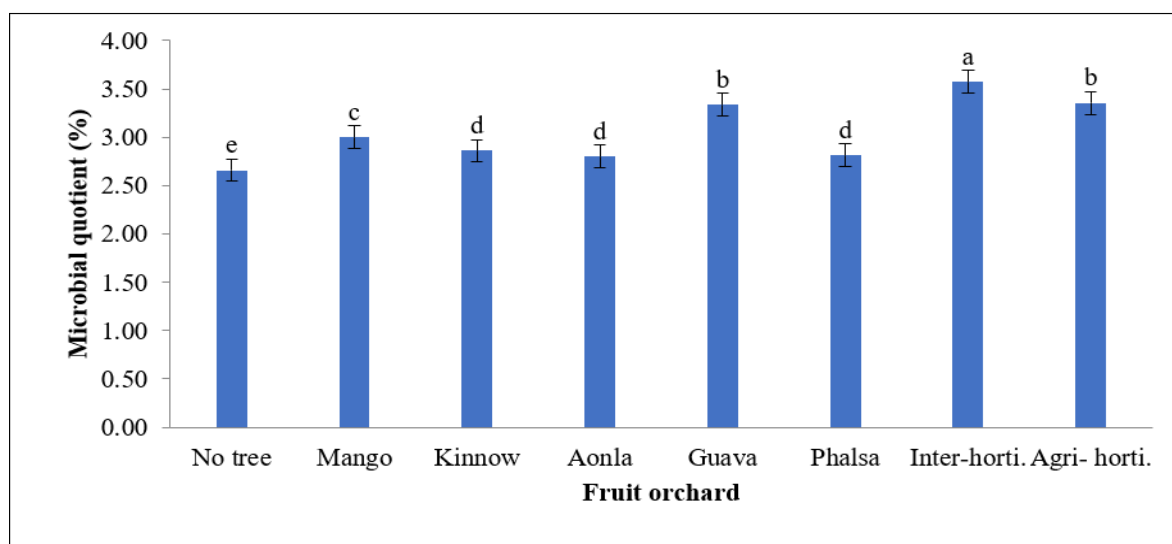


Fig. 3. Microbial quotient (%) in soils of diverse fruit growing plantation at North-Western Himalayas, India. Bars are $\pm$ SE of the mean values show the similar letters are not significantly.

Table 7. Carbon pool index (CPI) of soil organic carbon (SOC) in various layers (m) of different fruit growing plantation at North-Western Himalayas, India

Orchard	Carbon pool index (CPI)				
	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Mean
No tree	1.00 ^c	1.00 ^b	1.00 ^c	1.00 ^c	1.00
Mango	1.26 ^{ab}	1.27 ^a	1.25 ^a	1.23 ^{ab}	1.25
Kinnow mandarin	1.15 ^b	1.16 ^{ab}	1.05 ^c	1.10 ^{bc}	1.11
Aonla	1.17 ^{ab}	1.16 ^{ab}	1.11 ^{bc}	1.16 ^b	1.15
Guava	1.21 ^{ab}	1.20 ^{ab}	1.21 ^b	1.15 ^b	1.19
Phalsa	1.01 ^c	1.12 ^b	1.07 ^c	1.10 ^c	1.07
Intercropping-horticulture	1.31 ^a	1.30 ^a	1.40 ^a	1.28 ^{ab}	1.32
Agri- horticulture	1.27 ^{ab}	1.25 ^{ab}	1.27 ^a	1.31 ^a	1.28

Within a column, values designated by similar letters are not significantly different at the 0.05 level of probability.

Table 8. Liability index (LI) of soil organic carbon (SOC) in various layers (m) of different fruit growing plantation at North-Western Himalayas, India

Orchard	Liability index (LI)				
	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Mean
No tree	1.62 ^a	1.66 ^a	1.71 ^a	1.62 ^a	1.65
Mango	1.63 ^a	1.71 ^a	1.69 ^a	1.70 ^a	1.68
Kinnow mandarin	1.64 ^a	1.69 ^a	1.70 ^a	1.63 ^a	1.67
Aonla	1.64 ^a	1.66 ^a	1.69 ^a	1.67 ^a	1.67
Guava	1.63 ^a	1.71 ^a	1.75 ^a	1.66 ^a	1.68
Phalsa	1.63 ^a	1.66 ^a	1.69 ^a	1.71 ^a	1.67
Intercropping-horticulture	1.63 ^a	1.71 ^a	1.72 ^a	1.71 ^a	1.69
Agri- horticulture	1.63 ^a	1.68 ^a	1.70 ^a	1.72 ^a	1.68

Within a column, values designated by similar letters are not significantly different at the 0.05 level of probability.

Table 9. Carbon management index (CMI) of soil organic carbon (SOC) in various layers (m) of different fruit growing plantation at North-Western Himalayas, India

Orchard	Carbon management index (CMI)				
	0–0.15	0.15–0.30	0.30–0.60	0.60–1.00	Mean
No tree	161.98 ^e	165.95 ^e	171.96 ^d	161.96 ^e	165.46
Mango	204.31 ^b	217.18 ^{ab}	211.41 ^b	208.63 ^b	210.38
Kinnow mandarin	188.59 ^d	195.63 ^c	178.11 ^c	178.89 ^d	185.31
Aonla	192.14 ^c	193.02 ^c	187.12 ^c	193.93 ^{bc}	191.55
Guava	196.77 ^{bc}	205.52 ^{bc}	210.97 ^b	191.20 ^c	201.11
Phalsa	164.26 ^e	186.20 ^d	180.70 ^c	188.19 ^d	179.83
Intercropping-horticulture	213.88 ^a	221.93 ^a	240.44 ^a	218.01 ^{ab}	223.56
Agri- horticulture	207.35 ^{ab}	209.82 ^b	216.23 ^b	225.28 ^a	214.67

Within a column, values designated by similar letters are not significantly different at the 0.05 level of probability.

(185.31) > phalsa (179.83) > no-tree (165.46). This ranking reflects differences in the amount and decomposition rates of organic litter from each system. The intercropping-horticulture system (aonla + phalsa) showed the highest overall increase in total SOC (TSOC), suggesting net C accumulation across all orchards compared to the no-tree land. These results communicate to conclusions by early results (44).

Carbon build-up was greatest in the intercropping-horticulture orchard (31.16 %), followed by agri-horticulture (27.12 %), mango (21.84 %), guava (18.76 %), aonla (15.10 %), kinnow mandarin (13.01 %) and lowest in phalsa orchard (6.22 %) (Fig. 4).

Looking at the 5-year perspective of C accumulation, the intercropping-horticulture orchard showed the highest C build-up rate at 2.77 Mg C ha⁻¹ year⁻¹, while the phalsa orchard had the lowest at 0.98 Mg C ha⁻¹ year⁻¹ in the 0–1.00 m soil depth (Fig. 5).

Lower C developed in phalsa orchards may be due to its leaf litter's low nitrogen (N) content and high lignin concentration, which slows decomposition (45). In contrast, plantation that is mango and guava, whose debris is richer in N, tend to be more effective in promoting soil C sequestration.

Correlation between various organic carbon pools

Relationship between the various C pools revealed to most were significantly interrelated (Table 10). The total organic carbon (C_{tot}) showed strong and significant correlations with its various fractions, with the strength of association decreasing in the order: C_{frac1} ($r = 0.998^{**}$) > C_{frac2} ($r = 0.997^{**}$) > C_{frac4} ($r = 0.996^{**}$) > C_{oc} ($r = 0.968^{**}$) > C_{frac3} ($r = 0.963^{**}$) > C_{mic} ($r = 0.950^{**}$). The exceptionally strong correlation between C_{tot} and C_{frac1} ($r = 0.998^{**}$) suggests a close link between these C pools, with C_{frac1} alone contributing approximately 65 % of total SOC. This highlights the relevance of more stable fractions like C_{frac4} as sensitive indicators of changes in C_{tot} (18).

The more dynamic C fractions, such as C_{frac1}, C_{frac2} and C_{mic} are widely considered effective pointer of soil quality suitable to their consistent behaviour in relation to their accountability and SOC changes for environmental variations (46). The strong relationship among C_{frac1} and C_{mic} ($r = 0.960^{**}$) further supports the classification of C_{frac1} as a labile carbon pool (12). Additionally, notable correlations between C_{frac1} and C_{oc} ($r = 0.957^{**}$), C_{mic} and C_{frac2} ($r = 0.947^{**}$) and C_{mic} and C_{frac4} ($r = 0.943^{**}$) imply that labile C pools serve as essential energy sources for microbial communities and are heavily influenced by microbial activity. Hence, these labile fractions are strongly linked to C_{mic}, which underscores an integral role of microbial processes to shape soil C dynamics.

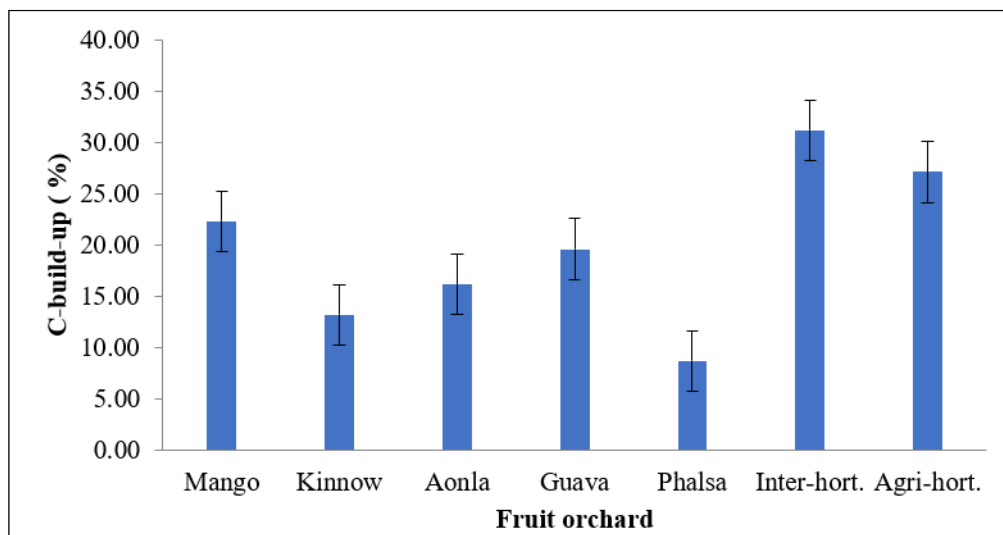


Fig. 4. Carbon-build-up (%) in soils of diverse fruit growing plantation at North-Western Himalayas, India. Bars are $\pm$ SE of the mean values show the similar letters are not significantly.

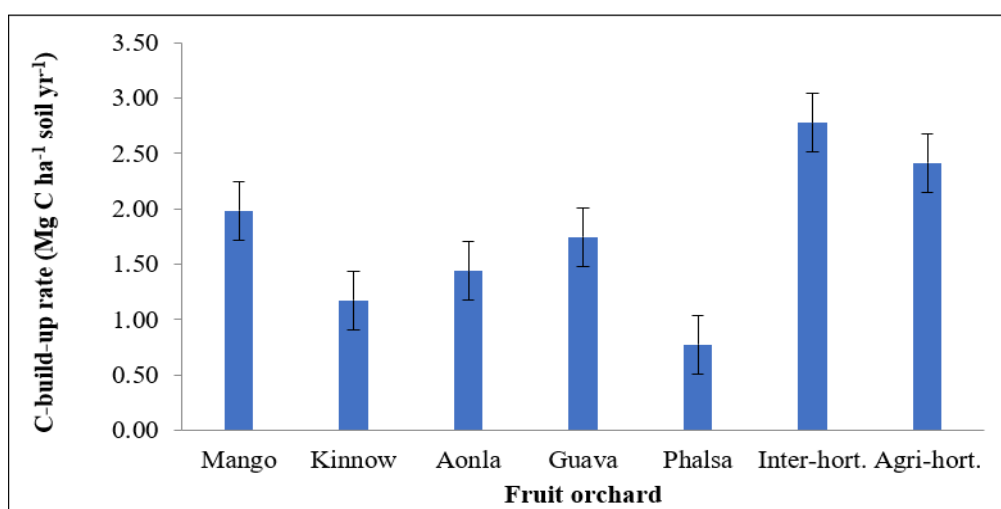


Fig. 5. Carbon-build-up rate in soils of diverse fruit growing plantation at North-Western Himalayas, India. Bars are $\pm$ SE of the mean values show the similar letters are not significantly.

Table 10. Correlation coefficients (r) between various soil organic carbon pools

Parameters	C _{frac1}	C _{frac2}	C _{frac3}	C _{frac4}	C _{oc}	C _{tot}
C _{frac2}	0.996**					
C _{frac3}	0.982**	0.976**				
C _{frac4}	0.990**	0.995**	0.981**			
C _{oc}	0.957**	0.965**	0.963**	0.976**		
C _{tot}	0.998**	0.997**	0.988**	0.996**	0.968**	
C _{mic}	0.960**	0.947**	0.917**	0.943**	0.907**	0.950**

** Correlation coefficient (r) is significant at $p = 0.01$.

Conclusion

The findings revealed that total soil organic carbon (SOC) (C_{tot}) followed the order: intercropping-horticulture > agri-horticulture > mango > guava > aonla > kinnow mandarin > phalsa > no-tree land across the 0–1.00 m soil depth, with the highest SOC (99.98 Mg ha⁻¹) recorded in the intercropping-horticulture (aonla + phalsa) orchard. Among the various carbon (c) fractions examined (C_{frac1} , C_{frac2} , C_{frac3} and C_{frac4}), their respective increases over the no-tree control were 39.2, 28.3, 34.7 and 26.4 %, following the general trend: $C_{frac1} > C_{frac3} > C_{frac2} > C_{frac4}$ across all orchard types throughout the soil profile. All SOC fractions were most concentrated within soil (0–0.30 m) layer and step by step diminished with soil depth. The intercropping-horticulture system showed greater accumulation of C_{frac2} and C_{frac3} , whereas the agri-horticulture orchard had higher C_{frac1} and C_{frac4}

levels in the 0.60–1.00 m layer. A strong correlation ($r = 0.960^{**}$) between C_{frac1} and microbial biomass carbon (C_{mic}) suggests that microbial decomposition of leaf litter and farmyard manure (FYM) predominantly contributed to the formation of this highly labile C fraction. Both active and passive C pools were utmost in the intercropping-horticulture orchard, showing 33.6 % and 29.6 % increases over no-tree land, respectively. The very labile fraction (C_{frac1}), which constitutes the more dynamic pool of C in surface soils, proves to be a reliable indicator of soil fertility and crop productivity. Overall, the intercropping-horticulture system (aonla + phalsa) demonstrated superior SOC content, greater active and passive C pools and enhanced C accumulation establishing it as the most effective orchard-based strategy for C sequestration in the Shiwalik foothills of the North-Western Himalayas, India.

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Authors' contributions

VK, VBS and RK contributed to the development of the research concept, study design and experimental work. BS and RS contributed to the literature review. SK¹, NS, SG, SK² and AK conducted the field survey and contributed to manuscript preparation. SKS and BD contributed to data interpretation. VK contributed to manuscript preparation, statistical analysis, presentation of the results and critical revision of the manuscript for important intellectual content. VB and RK contributed to the activities mentioned above, including data collection. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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