ESTIMATION OF TERRESTRIAL CARBON STOCKS AS INFLUENCED BY SAPOTA ORCHARD AT REGIONAL FRUIT RESEARCH STATION, GANESHKHIND, PUNE

by

Mr. Murodiye Kishor Ramchandra

(Reg. No. 019/096)

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI – 413 722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA

In partial fulfillment of the requirements for the Degree

of

MASTER OF SCIENCE (AGRICULTURE)

in

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

DIVISION OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE, PUNE – 411005

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Place : A.C., Pune **(K. R. Murodiye)**
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LIST OF ABBREVIATIONS AND SYMBOLS

@	:	At the rate of
AGB	:	Above Ground Biomass
B	:	Boron
BGB	:	Below Ground Biomass
C	:	Carbon
^0C	:	Degree Celsius
$CaCO_3$	:	Calcium Carbonate
CCS	:	carbon capture and storage
CD	:	Critical Difference
CLI	:	Carbon Lability Index
cm	:	Centimeter (s)
CMI	:	Cabon Management Index
CO_2	:	Carbon dioxide
CO_2-e	:	Carbon dioxide equivalents
C_{oc}		Oxidizable organic carbon
CPI	:	Carbon Pool Index
Cu	:	Copper
DBH	:	Diameter at Breast Height
dSm^{-1}	:	Deci Siemens per meter
DTPA	:	Diethylene triamine pentaacetic acid
DOC	:	Dissolved organic carbon
EPA	:	Environmental Protection Agency
EC	:	Electrical Conductivity
e.g.	:	Exempli gratia (For example)
et al.	:	And other (etalli)
Etc	:	Et cetera
FRBD	:	Factorial Randomized Block Design
Fe	:	Iron
Fig.	:	Figure
FYM	:	Farm Yard Manure
g	:	Gram
g ha^{-1}	:	Gram per hectare
GM	:	Green manure

GT	:	Gigatonne of carbon
GWP	:	Global Warming Potential
ha^{-1}	:	Per hectare
IC	:	Inorganic carbon
IPCC	:	Intergovernmental Panel on Climate Change
i.e.	:	Id est (that is)
K	:	Potassium
kg ha^{-1}	:	Kilogram per hectare
kg $tree^{-1}$	:	Kilogram per tree
l	:	Litre
LFC	:	Light fraction carbon
LI	:	Lability Index
LOC	:	Labile organic carbon
LSOMs	:	Labile soil organic matter pools
m	:	Meter (s)
MBC	:	Microbial biomass carbon
ml	:	Milliliter
Mn	:	Manganese
max.	:	Maximum
mg	:	Milligram (s)
mg ha^{-1}	:	Milligram per hectare
mg kg^{-1}	:	Milligram per kilogram
min.	:	Minimum
Mo	:	Molybdenum
N	:	Nitrogen
NDF	:	Neutral detergent fiber
NDIR	:	Non-dispersive infrared detector
O.C.	:	Organic carbon
OM	:	Organic matter
P	:	Phosphorus
%		Percentage
pg		Petagram
pH	:	*Puissance de* Hydrogen
POC	:	Particulate organic carbon

POMC	:	Particulate organic matter carbon
POSC	:	Permanganate extractable soil organic carbon
ppm	:	Part per million
RDF	:	Recommended dose of fertilizer
RH	:	Relative humidity
S.E.	:	Standard error
SMBC	:	Soil microbial biomass carbon
SOC	:	Soil organic carbon
SOM	:	Soil organic matter
T	:	Tonne
TOC	:	Total organic carbon
TB	:	Total plant biomass
t C	:	Tonnes of carbon
t ha^{-1}	:	Tonnes per hectare
Tg C	:	Teragrams of carbon
USDA	:	United States Department of Agriculture
viz.	:	Videlicet (Namely)
WSC	:	Water soluble carbon
WCS		wheat cut straw
wt.	:	Weight
Zn	:	Zinc

ABSTRACT

ESTIMATION OF TERRESTRIAL CARBON STOCKS AS INFLUENCED BY SAPOTA ORCHARD AT REGIONAL FRUIT RESEARCH STATION, GANESHKHIND, PUNE

By

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A candidate for the degree of

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2021

Research Guide	**:**	**Dr. D. D. Sawale**
Department	**:**	**Soil Science and Agricultural Chemistry**

The present investigation entitled "Estimation of terrestrial carbon stocks as influenced by sapota orchard at Regional Fruit Research Station, Ganeshkhind, Pune" was conducted during 2020-2021. The experiment was conducted on sapota orchard of age 18 years having eight genotypes planted in the year 2002. The experiment was laid out in Factorial Randomized Block Design with two replications. Representative soil samples from two depth (0-30 and 30-60 cm) were collected beneath the tree volume 100 cm apart from tree trunk and analyzed for active (water soluble carbon, soil microbial biomass carbon, permanganate oxidizable soil carbon) and passive (particulate organic matter carbon) carbon fractions along with physical and chemical properties. Soil samples also collected from conventionally cultivated soil from same depth and considered as control. Biometric observations *viz*., tree height, diameter at breast height, volume of tree, above ground biomass, below ground biomass, total plant biomass and plant carbon were taken uniformly for the estimation of carbon stock from sapota genotypes.

Among the sapota genotypes, CO-2 recorded higher tree height (540 cm), diameter at breast height (57 cm), volume of tree (1377251.10 cm^3), above ground biomass (1115.57 kg $tree^{-1}$), below ground biomass (290.04 kg $tree^{-1}$) and total plant biomass (1405.62 kg $tree^{-1}$) which resulted into higher accumulation of plant carbon (702.81 kg $tree^{-1}$) followed by PKM-1 and PKM-Hy-7/1.

The soil samples collected beneath the sapota genotype CO-2 was recorded significantly higher active carbon pools viz., water soluble carbon (78.00, 55.00 mg kg^{-1}), soil microbial biomass carbon (543.00, 413.50 mg kg^{-1}), permanganate oxidizable soil carbon (1429, 1331 mg kg^{-1}) and passive carbon pool like particulate organic carbon (1170, 570 mg kg^{-1}) at 0-30 and 30-60 cm depth as compared to conventionally cultivated soil. Significantly higher values of all soil carbon fractions under study were found in upper depth (0-30 cm) than the lower depth (30-60 cm). Similar results were also reported for higher total organic carbon content (0.94 and 0.88 %) in soil which was closely followed by PKM-1 (0.93 and 0.86 %) at

Abstract contd… **Mr. K. R. Murodiye**

both soil depths. Significantly the lowest total organic carbon content in soil was recorded in conventionally cultivated soil at 0-30 (0.73%) and 30-60 cm (0.67%) depth, respectively. However, interaction effect among sapota genotypes and soil depth in all carbon fractions found non significant. Among all sapota genotypes CO-2 recorded significantly higher carbon pool index (1.28 and 1.31), carbon lability index (1.16 and 1.25) and carbon management index (150.26 and 164.53) at 0-30 and 30-60 cm depths, respectively than the rest of the sapota genotype and over conventionally cultivated soil (control). However, interaction among sapota genotypes and soil depths was found non significant with respect to all indices.

Significantly higher soil organic carbon stock was recorded from CO-2 (36.94 and 35.64 Mg ha^{-1}) followed by PKM-1 (36.70, 35.08 Mg ha^{-1}) while lower soil organic carbon stock was observed in Cricket ball (32.56 and 31.46 Mg ha^{-1}) sapota genotypes at both depths. However least soil organic carbon stock was recorded in conventionally cultivated soil i.e. control (29.78 and 27.93 Mg ha^{-1}). In case of carbon sequestration per plant after eighteen years of sapota orchard age, CO-2 genotype was recorded higher (369.42 and 356.40 kg $tree^{-1}$) among all the genotype studied which was closely followed by PKM-1 (367.08 and 350.88 kg $tree^{-1}$) at 0-30 and 30-60 cm depth.

Higher soil availability of nitrogen, phosphorus and potassium along with DTPA- extractable iron, manganese, zinc and copper were recorded in soil beneath the CO-2 sapota genotype than rest of the genotypes and over conventionally cultivated soil (without sapota tree). Positive correlation was observed among carbon stock and available nitrogen (0.819** and 0.857**), phosphorus (0.752** and 0.73**) and potassium (0.721** and 0.789**) at both the depths (0-30 and 30-60 cm) after eighteen years of sapota plantation grown on Inceptisol.

1. INTRODUCTION

Carbon is a significant element found in all living species, mostly in the form of plant biomass, soil organic matter, and the gas carbon dioxide, which is dissolved in soil water. Carbon sequestration refers to the long term storage of carbon in the oceans, soils, vegetation (particularly forests), and geologic formations (William,1999 and Dharmesh *et al*., 2014).

Carbon sequestration is the process through which CO_2 from the atmosphere is taken by trees, plants and crops and stored as carbon in biomass such as tree trunks, branches, foliage, roots, and soils through photosynthesis (EPA, 2010). Carbon dioxide is emitted by a range of human activities, which are referred to as sources of CO_2, while it is is removed by sinks of CO_2. Forests and soils, on the other hand, have a significant impact on CO_2 levels in the atmosphere since forest vegetation is a major component of the global carbon cycle, storing at least 350 pg of carbon (Dixon *et al*., 1994). Despite the forest's ability to store large amounts of CO_2, its projected carbon storage is vulnerable to change due to variables such as conversion of forest areas to other land uses, timber harvesting, mining, and other activities that result in changes in carbon fluxes to the atmosphere. Tree species, soil type, regional climate, terrain, and management practises all affect carbon sequestration rates (EPA, 2010). In the South-east of the United States, 90 year old pine plantations can deposit 2.5 Mg ha^{-1} of carbon per year (Birdsey, 1996). The increasing carbon emission is of major concerns for entire world as well addressed in Kyoto protocol (Chavan and Rasal, 2010; Ravindranath *et al*., 1997). Biomass production in various forms is vital for tree carbon sequestration. Live and dead above and below ground biomass, as well as wood products with long and short lives and possible applications, make up these carbon pools. The principal carbon pools in any ecosystem include above ground biomass, below ground biomass, dead wood, litter, and soil organic matter (IPCC, 2006). Carbon sequestration or the removal of carbon dioxide from the atmosphere, is aided by trees. Carbon storage is the active absorption of CO_2 from the environment through photosynthesis and subsequent storage in various plant components in the form of biomass in developing trees (Baes *et al*., 1977). The evaluation of biomass equations for improving carbon budget estimations is based on the link between individual tree and whole stand biomass estimates (Clutter *et al*., 1983), as well as the assumption that wood mass is around 50% carbon (Birdsey, 1992).

Until a tree develops, the quantity of carbon stored by it continues to increase significantly over time and age. Different parameters, such as tree age, leaf area, and photosynthetic efficiency, influence the carbon capture process in photosynthesis. Increased

carbon emissions are a big source of concern around the world, and the Kyoto Protocol does a good job of addressing it (Ravindranath *et al.,* 1997; Chavan and Rasal, 2010). The rate of carbon storage increases in young tree species, but diminishes as the stand ages after full development (Jana *et al*., 2009). Above ground biomass (AGB) of tree includes all living biomass of all its parts above the soil, while below ground biomass (BGB) includes all the plant biomass of live roots excluding the fine roots of sizes < 2 mm diameter (Ravindranath and Ostwald, 2008).

Carbon is a crucial building block for life on Earth and can be found in all living species. Plant biomass, soil organic matter, geologic deposits, and the gas carbon dioxide (CO_2) in the atmosphere and dissolved in seawater are all examples of carbon in the environment. The long-term storage of carbon in seas, soils, vegetation (particularly forests), and geologic formations is known as carbon sequestration. Large stocks of carbon from fossils (oil and coal deposits) and forests have been turned into atmospheric carbon dioxide as a result of high levels of fossil fuel consumption and deforestation. Despite the fact that oceans store the majority of the earth's carbon, soils contain over 75% of the carbon pool on land, which is three times more than the amount stored in living plants and animals. (Ecological Society of America, 2000). As a result, soils play a critical role in sustaining a stable global carbon cycle. Researchers, policymakers, farmers, and the general public are all interested in soil carbon sequestration since most scientists believe there is a direct link between higher CO_2 levels in the atmosphere and rising global temperatures.

Biomass is an essential component of blockage in the global carbon cycle, particularly carbon sequestration, and is used to quantify basins and changes in gas from the terrestrial biosphere in the atmosphere related with terrestrial covering. Photosynthesis is the process of removing CO_2 from the atmosphere and storing it in the terrestrial biosphere. Carbon sequestration in growing agro ecosystems is known to be a cost effective strategy for reducing global warming and climate change. Estimates of carbon stocks and changes in stocks in tree biomass (above and below ground) are required to investigate climate change within the United Nations framework. The production of biomass in various forms contributes significantly to carbon sequestration in trees. The principal carbon pools in any ecosystem are aboveground biomass, belowground biomass, dead wood litter, and soil organic matter. Carbon emissions are increasing, which is a big worry for the entire globe and is addressed in the Kyoto Protocol (Victor *et al*., 2019).

As carbon is collected in plant cell development and oxygen is released, carbon is sequestered in the process of plant growth. As the biomass of a tree grows, the amount of

carbon retained by the plant grows as well. As the forest biomass grows, carbon is trapped in the forest floor, where it can be stored until it decomposes.

Additionally, through root/soil interactions, tree/soils may trap some of the degrading plant litter. Through the natural process of photosynthesis, trees extract carbon dioxide from the atmosphere and store it in their leaves, branches, stems, bark, and roots. Carbon makes up about half of the dry weight of a tree's biomass. One tone of C = 3.67 tons of 'carbon dioxide equivalent' (CO_2-e). Carbon dioxide equivalents (CO_2-e) are a universal unit of measurement that can be used to assess the impact of achieving (or avoiding the release of, or actively sequestering) various greenhouse gas reductions. Every greenhouse gas has a Global Warming Potential (GWP), which is a measurement of the impact of that gas on 'radiative forcing,' or the additional heat/energy retained in the Earth's atmospheric system as a result of its addition to the atmosphere. The Global Warming Potential (GWP) of a gas describes its impact on climate change in comparison to a similar amount of carbon dioxide. Carbon dioxide is 1.0 as a base unit. This enables greenhouse gases regulated under the Kyoto Protocol to be released.

Carbon dioxide is required for plant and animal existence. However, too much can lead to the extinction of all life on Earth. Carbon dioxide is not only necessary for plants and animals to survive, but it also keeps them warm because it is a component of the Earth's atmosphere. Carbon dioxide is a greenhouse gas that occurs naturally. Water vapour, methane, and nitrous oxide are among the others. By absorbing the sun's energy and transferring it back to the Earth's surface, these gases aid in keeping the planet warm. An increase in carbon dioxide levels results in an overabundance of greenhouse gases, which trap more heat. As a result of the trapped heat, ice caps are melting and ocean levels are rising.

Carbon sequestration is the process by which plants extract carbon dioxide from the environment. Plants store carbon dioxide in biomass before releasing it. The amount emitted is typically less than the amount eaten by the plant. Depending on the activities used on these lands, farms (orchards), grasslands, and woods are considered carbon sources or sinks. For example, cows produce methane, but the gas is sequestered by grass on the farm.

Carbon is stored in the environment's various natural stocks. Oceans, fossil fuel deposits, the terrestrial system, and the atmosphere are all natural stocks. Carbon sequestration on land is a natural approach for storing enormous amounts of carbon. Living organisms, trash, and soil organic matter store around 2100 GT carbon in terrestrial ecosystems, which is about three times the amount now presents in the atmosphere.

"**The carbon sequestration phenomenon is the extraction of atmospheric carbon dioxide and long-term storage in terrestrial ecosystems**."

Sapota (*Achras zapota L.*) is a delicious fruit introduced from tropical America and first planted at Gholrad near Mumbai in 1898. The country that produces the most sapota is India. Gujarat, Karnataka, Maharashtra and Tamil Nadu are among the states where it is grown. Gujrat is the largest producer of sapota in India, followed by Karnataka. In India, sapota farming covers over 97 thousand hectares. Total sapota production in the country is about 3.87 lakh tonnes. It is a tropical fruit tree that is evergreen, has a spreading habit, and can survive for up to 100 years. When completely mature, the sapota is tasty and used as a dessert fruit. The pulp is delicious and melts in your mouth. Sapota fruits are employed in several Ayurvedic medicines in addition to their nutritional value. Sapota is a tropical fruit crop that may be produced anywhere from sea level to 1200 metres above sea level. It thrives in both dry and damp environments and favours a warm, humid climate. The ideal temperature ranges is from 12°C to 36°C. The sapota tree is a hardy perennial and evergreen tree that can thrive in a variety of soil types. The importance of drainage cannot be overstated. In the sub soil, there should not be a hard pan. Soils that are deep and porous promote healthy growth. To some extent, the Sapota may survive the presence of salts in the soil or irrigation water.

Keeping the above facts in view, the present investigation was under taken to study the soil organic carbon sequestration under sapota plantation with the following objectives:

1. To quantify the soil organic carbon stock in sapota orchard.
2. To estimate the soil carbon pools in sapota orchard.
3. To find out correlation between carbon stock with available nutrient status.

2. REVIEW OF LITERATURE

Much less work has been carried out on carbon sequestration potential of sapota trees. The available literature pertaining to the consequent effect of different sapota species on soil organic carbon fractions, soil chemical properties, soil physical properties, carbon stock and carbon sequestration potential over years of plantation have been reviewed in this chapter. The literature on these aspects has been reviewed under the following heads and sub heads:

2.1 Effect of Tree Species on Total Plant Biomass

Kaur *et al*. (2002) observed that, 1.18 to 18.55 t C ha^{-1} of carbon is stored in trees and grass systems and in net primary production, the carbon input ranged from 0.98 to 6.50 t C ha^{-1} $year^{-1}$. Integrating *Dalbergia sissoo* and *Prosopis cinraria* along with grasses resulted in a substantial increased in carbon flow in net primary production.

Anil *et al.* (2005) observed that, trees act as a sink for carbon dioxide by fixing carbon during photosynthesis and storing excess carbon as biomass in different parts of the tree. Carbon sequestration rate was evaluated for *Simarouba glauca* DC in three different age classes (2, 5 and 10 years) under two site conditions viz., transition zone (Bengaluru urban district) and dry zone (Hassan district) by estimating above ground biomass. The carbon stock of above ground biomass per hectare was found to be 0.33, 2.73, and 11.04 t respectively.

Nath and Das (2011) reported that all across the world, small scale farming systems may be used as sinks to capture atmospheric CO_2. A small scale bamboo cultivation technique in Assam's Barak Valley the aboveground biomass was estimated using the harvest technique, and the C stock was calculated using the biomass values. The amount of carbon stored in bamboo's aboveground vegetation ranged from 6.51 Mg ha^{-1} in 2004 to 8.95 Mg ha^{-1} in 2007, with culm, branch, and leaf storing 87, 9 and 4% of the total carbon, respectively.

Chavan and Rasal (2012) measured aboveground and belowground carbon sequestration potential of *Mangifera indica* from nine sectors of Aurangabad city. The total standing aboveground biomass and belowground biomass of *Mangifera indica* in 2847 hectares of Aurangabad were 82.83 t ha^{-1} and 21.54 t ha^{-1}, respectively, while the total standing biomass of *Mangifera indica* in 2847 hectares of Aurangabad was 104.41 t ha^{-1}. *Mangifera indica* has a sequestered carbon stock of 44.73 t ha^{-1} in aboveground and 11.63 t ha^{-1} in belowground standing biomass, respectively, and a total sequestered carbon stock of 56.36 t ha^{-1} in 2847 hectares.

Ting Wu *et al*. (2012) reported that apple orchards in China played an important role in the carbon (C) cycle of terrestrial ecosystems and contribute to C sequestration. The carbon

sequestration capabilities of apple orchards were investigated using a field model research and literature to establish a set of potential assessment parameters and their weighting factors. Between 1990 and 2010, the net C sink in Chinese apple orchards was 14 to 32 Tg C, and C storage in biomass was 230 to 475 Tg C. From 1990 to 2010, the projected net C sequestration in Chinese apple orchards was 4.5 percent of the total net C sink in China's terrestrial ecosystems. As a result, apple production systems might be regarded C sinks in addition to provided fruits, excluding the energy related with fruit production

Mattsson *et al.* (2015) conducted study on aboveground biomass carbon and tree species diversity of trees was quantified in home gardens around two villages in the dry south-eastern part of Moneragala district of Sri Lanka. In total 4,278 trees were sampled and 70 tree species identified and recorded. The results showed a vast heterogeneity in terms of carbon stock and tree diversity within the less studied dry zone home gardens; results that contribute to more knowledge of their expansion potential as well as climate mitigation and adaptation potential.

2.2 Effect of Different Tree Species on Soil Carbon Content Over Several Years

2.2.1 Effect of Different Tree Species on Active Carbon Pools

2.2.1.1 Water soluble carbon (WSC)

Zhang *et al*. (2007) conducted an investigation for calculation of soil organic carbon in pure rubber and tea rubber plantations in South-Western China. An incubation approach of sequential fumigation was used to measure labile organic carbon in soil samples that had gone through a 2 mm filter. Using air-dried soil samples that were pulverized and sieved through a 60-mm mesh, the total organic carbon (TOC) was calculated. H_2SO_4 $K_2Cr_2O_7$ oxidation was used to estimate the TOC. There was no inorganic carbon in the acidic soils, hence it was not necessary to acidify the soils prior to analysis. LOC pools and turnover time were estimated using a sequential fumigation incubation process. Fumigated sub-samples were incubated for a total of five cycles in order to estimate soil LOC. For measuring labile organic carbon, carbon dioxide evolved from the first and subsequent incubations of the fumigated soils.

Kalambukattu *et al.* (2013) studied that active carbon pool corresponds to very labile and labile pool of oxidisable organic carbon and varied significantly among the different orchard in surface soil (0–0.30 m), whereas it was non-significant in the sub-surface soil (0.30–0.60 m). In the 0–0.30 m depth, the mango and guava orchards had a substantially higher active carbon pool than the control. The biggest active carbon pool was found in the 0–0.15 m layer in all orchard systems, with guava orchard (12.06 Mg ha^{-1}) having the highest and control having the lowest (10.57 Mg ha^{-1}). The total active carbon pool in 0–0.60 m depth did not

differ significantly across soils from different orchards; however, it did differ significantly when compared to the control (P 0.05). Mango orchards had the highest total active carbon pool (36.2 Mg ha^{-1}), followed by guava orchards (34.57 Mg ha^{-1}). The smallest total active carbon pool was discovered under test conditions. The tannins and lignin elements created from the decomposition of leaf litters and root biomass of the orchard systems shielded the carbon from quick decomposition and so maintained it in the aggregates, resulting in a greater active carbon pool in different orchards compared to control.

Pandya *et al.* (2013) reported that trees are carbon reservoir on earth. Photosynthesis is the only mechanism in nature that allows carbon to pass through ecosystems and be used by plants in the form of CO_2. Every year, we lose a large number of trees around the world; the reasons are well recognized, and the result is global climate change. We estimated the carbon storage using a non destructive or allometric method based on the available data on tree girth and height. In Gujarat, India, they calculated the carbon storage in 25 species. *Tamarindus indica* has the highest carbon storage at 55.95 t C, followed by *Terminalia arjuna* with 44.81 t C. *Emblica officinalis* has the lowest carbon storage value of 1.77 t C.

Massaccesi *et al*. (2018) reported that in 30 years organic C stock of the olive grove was no different from that of the arable soil, but the distribution of SOC pools changed with the age of the olive groves. The WSC and POC increased in the upper horizon of olive groves, probably because of the herbaceous cover and distribution of chipped prunings on the soil. There were fewer sand size aggregates in 7 years olive groves than arable soil, possibly because of pedoturbations from deep tillage before the olive trees were established, but they increased in 30 years olive groves. The increased in sand size aggregates and silt clay aggregates in the slightly lower and lower horizons of 30 years olive groves was associated with humic-C and unextractable-C and a smaller phenol content than arable soils. This suggested that olive tree roots had a positive role through rhizodeposition and root turnover, which favoured the stabilization of organic matter into aggregates at depth. In contrast to the active and intermediate C pools, the passive C pool did not vary following the change in land use from arable to olive grove.

2.2.1.2 Soil microbial biomass carbon (SMBC)

Lovell *et al*. (1995) conducted a study on soil microbial biomass and activity in long term grassland effects of management change and observed that application of nitrogenous fertilizer significantly reduced soil microbial biomass and activity. Due to a reduction in the botanical diversity of the understory plants and the application of fertilizers, intensively managed soils have relatively weak soil microbial communities.

Louise *et al*. (2000) studied management influences on soil microbial communities and their function in botanically diverse hay meadows of northern England and Wales and observed that plant species (productivity and species composition) are fundamental to the soil microbial community in the grasslands.

Dilly *et al*. (2003) conducted a study on variation of stabilized, microbial and biologically active carbon and nitrogen in soil and reported that amount of carbon in the soil microbial biomass carbon mostly accounts for 1 to 5% of the total soil organic carbon (TOC), and its turnover time is less than 12 months.

Gupta and Singh (2010) reported that increased in soil microbial biomass was found to be a good predictor of better soil conditions when Grevillea was used in soil enrichment by increasing plant biomass.

2.2.1.3 Permanganate oxidizable carbon (POSC)

Purakayastha *et al.* (2008) studied that oxidizable organic carbon varied from 40.1 to 46.94 Mg C ha^{-1} soil among the different orchards under study. In orchard, oxidizable organic carbon content was not significant, but when compared to the control, it was significantly different from the orchard. There was a substantial increased in carbon intake from organic manure and leaf litter in diverse orchard systems, contributing to the increase in oxidizable organic carbon.

Laik *et al*. (2009) worked on labile soil organic matter pools in a calciorthent after 18 years of afforestation by different plantations. They are the fine indicators of soil quality that are affected by changes in management practices. LSOMs include soil respiration, dissolved organic carbon (DOC), microbial biomass carbon (MBC), and light fraction carbon (LFC). However, after 18 years of planting, the LSOMs and soil respiration had increased to varied degrees, based on the results.

2.2.2 Effect of Different Tree Species on Particulate Organic Matter Carbon (Passive Pool)

Purakayastha *et al*. (2008) studied that irrespective of soil depth, POC was greater in the agro-forestry plantation. At all soil depths, sewage-irrigated rice–wheat soils accumulated more POC than vegetable field and tube-well irrigated rice–wheat soils. Uncultivated and tube-well irrigated rice–wheat soils had the lowest POC content at the 0–0.05 m soil depth, whereas these two, along with vegetable field soils, had similar POC contents at the other two depths. POC decreases were greater in vegetable fields, agro-forestry plantations, and sewage irrigated rice–wheat than in tube-well irrigated rice–wheat and uncultivated soils along soil depth (POC 0–0.05 m/POC 0.10–0.20 m). In the agro-forestry plantation, the percent POC of

SOC was higher. In terms of percent POC of SOC, sewage irrigated rice–wheat soil was similar to agro-forestry plantation soil at 0.05–0.10 m soil depth, whereas vegetable field and tube-well irrigated rice–wheat soils were similar to agro-forestry plantation soil at 0.10–0.20 m. They also studied that particulate organic C stock in the 0–0.20 m soil layer was highest in agro-forestry plantation (3.58 Mg ha^{-1}) and lowest in uncultivated soil (jointly with tube-well irrigated rice–wheat soil) (1.76 Mg ha^{-1}). In terms of POC stock, sewage irrigated rice–wheat came in second (2.42 Mg ha^{-1}). The highest and lowest POC stock values were found in vegetable field soil. The absolute change in POC stock in agro-forestry plantations was the greatest when compared to uncultivated soil. In terms of POC stock, sewage irrigated rice–wheat and vegetable field soil showed significantly positive changes.

Naik and Maurya (2016) studied that passive carbon pool corresponds to less labile and non labile pool of oxidizable organic carbon. As a result, the mango orchard had the highest passive carbon pool (0–0.15 m depth) at 8.60 Mg ha^{-1} and the lowest in the control (7.92 Mg ha^{-1}). Gradually, as soil depth increased, the passive carbon pool shrank. Results confirmed that total passive carbon pool in 0–0.60 m depth did not vary significantly among soils of different orchards, but it did vary significantly when compared to control soil. Mango orchards had the highest total passive carbon pool at 26.27 Mg ha^{-1}, followed by guava orchards (25.52 Mg ha^{-1}).

Massaccesi *et al*. (2018) observed the largest amount of POMC is at 30 year old olive grove orchard, followed 7 year old orchard as compared to arable soil.

2.2.3 Effect of Different Tree Species on Total Organic Carbon (TOC)

Ingram and Fernandes (2001) observed that maximum TOC was recorded in the surface soil as compared with lower depth due to the addition of roots and plant biomass in surface layer and lack of nutrient and biological activity in 30-60 cm which ultimately constraints the rooting depth.

Calegari *et al.* (2008) conducted a study on v*arious* winter cover crop treatments in a Rhodic Hapludox in southern Brazil and reported reduced soil organic carbon by decreasing the amount of non-harvested plant residue retained to the soil.

Suryawanshi *et al.* (2014) was estimated the carbon sequestration potential of selected tree species of North Maharashtra University campus in Jalgaon city. A non-destructive method was used to estimate total biomass and carbon sequestration in tree species. Each species' total organic carbon, aboveground and belowground organic carbon (tones $tree^{-1}$), and total organic carbon were calculated. The total organic carbon calculated was compared to an allometric model. The species *Moringa olifera* was found to be the most dominant,

sequestering 15.78 tonnes of carbon followed by *Azadirachta indica*, which sequestered 12.27 tonnes among 14 trees. *Eucalyptus citriodora* has the lowest carbon sequestration potential (1.81 tonnes).

Ananthi *et al.* (2016) focused on the evaluation of carbon sequestration potential, physiochemical, and microbiological features in *Mangifera indica L.* (Mango), *Manilkara zapota L.* (Sapota), *Cocos nucifera L.* (Coconut), and *Tectona grandis L.* (Teak) trees maintained for 5, 10, 15, and 20 years. According to the results, the maximum total organic carbon was found in soil farmed with teak (0.69 to 1.11 percent), followed by sapota (0.36 to 1.07 percent), mango (0.64 to 0.85 percent), and coconut (0.57 to 0.81 percent) in the 0-20 cm depth of 20 year old trees. Whereas standing biomass, standing carbon and equivalent CO_2 were recorded higher in teak (17.93 to 365.87 t ha^{-1}) followed by coconut (9.14 to 285.68 t ha^{-1}), mango (1.85 to 80.74 t ha^{-1}) and sapota (2.86 to 24.45 t ha^{-1}) in 20 year old trees.

Kour and Sharma (2016) assessed the aboveground and belowground carbon sequestration potential of tree species growing in various educational institutions of Vijaypur, Samba, J&K. Using a non-destructive method and allometric equations, the total biomass and carbon sequestered by the tree species were calculated. Each species' total organic carbon (tonne) and aboveground and belowground organic carbon (tonne $tree^{-1}$) were calculated. The findings show that *Ficus religiosa* was the dominant species with the highest carbon storage, both above and below ground, of 17.51 tonnes ha^{-1}, followed by *Ficus benghalensis* (5.64 tonnes ha^{-1}), and *Annona squamosa* (0.05 tonnes ha^{-1}).

2.2.4 Effect of Different Tree Species on Carbon Indices

Blair *et al*. (1995) observed that, CPI value was higher in mango orchard throughout the depth of soil profile highlighting the high potential of mango orchard in restoring the original soil organic C stocks. The highest CPI value of 1.29 was found in a mango orchard at a depth of 0.15–0.30 m. CPI increased across the board in all orchards compared to the control. The lability index varies little from orchard to orchard throughout depth of the soil profile. In the 0–0.15 m depth, the guava orchard had the highest lability index (1.72), followed by mango orchard (1.68). This pattern revealed that guava orchard provided a less oxidative environment, providing greater physical protection to the SOM and favouring a higher proportion of labile C compared to SOC by increasing C lability in the soil. They also suggested that a lability index (LI) for the SOC was computed using three of the pools i.e., very labile carbon, labile carbon, less labile carbon. The very labile, labile and less labile are given weightage of 3, 2 and 1, respectively. The actual values are then converted to a proportional amount of total soil

organic carbon and weighed with the weighing factor to produce a LI for the organic carbon content in each of the soils at various depths in mango orchard.

Whitebread *et al*. (1998) suggested that soil carbon management index (CMI) can be used to describe soil fertility as it is more sensitive indicator for the rate of change in SOC in response to soil management changes than single measures such as the total SOC. Where well managed legume leys had recently been grown, the loss of C was reduced resulted in higher CMI.

2.2.5 Effect of Different Tree Species on Soil Organic Carbon Stock

Akala and Lal (1997) conducted study on soil organic carbon sequestration on reclaimed mine soil. The SOC pool in relation to soil aggregate fractions was calculated as g kg^{-1} (grams carbon per kilogram of soil). Significant differences in SOC pool between the reclamation duration and fractions were calculated as least significant difference (LSD) with a probability level of 0.05. The statistical package MINITAB (V13.1) was used to carry out all the statistical tests Minitab, (2000). For both depths and treatments, the total SOC content increased over the course of the reclamation.

Bhattacharya and Pal (2001) conducted research on carbon sequestration in soils of Indo Gangetic Plains and concluded that present scenario of temperature and shrinking of annual rainfall in the major geographical area of the Indo Gangetic Plains will continue to remain as a potential threat for soils of the region. However, understanding the stock of Soil Organic Carbon (SOC) and Soil Inorganic Carbon (SIC) can aid in focusing areas for immediate rehabilitation in order to improve SOC. However, the carbon stock equation cause and effect relationship of the various factors that control both SOC and SIC stock in the IGP should be taken into account. The strategic perspective for soils of the Indo Gangetic Plains should be based on the restoration of SOC balance and its follow-up by enlarging the soil carbon pool using appropriate management techniques.

Dey (2005) reported that rubber plantations in the Northeast (Agartala, Tripura) have a carbon stock of 136 t ha^{-1}, with soil contributing 92.7 t C $ha^{-1}$and falling litter contributing 2.40 t C ha^{-1}.

Kirby and Potvin (2007) reported that including all vegetation-based C stocks and soil C to 40 cm depth, forests held an average of 335 Mg C ha^{-1}, traditional agroforests 145 Mg C ha^{-1}, and pastures 46 Mg C ha^{-1}. They found no link between diversity and C storage in forests and agroforests, although the relative contributions of species to C storage per hectare were extremely skewed and sometimes not proportional to species relative abundances. They concluded that preventing forests from transformation to pasture, would have the most positive

effect on carbon stocks, even though the woods are managed for timber and non-timber forest products by community members. Community members, on the other hand, named many of the tree species that contribute the most to C storage in forests as preferred wood species. They indicated that species-level management 12 will be critical in avoiding C depletion in these forests due to selective logging. According to the data, extending agroforests into pasture regions may sequester substantial quantities of carbon while simultaneously delivering biodiversity and livelihood advantages that region's most prevalent reforestation method - monoculture teak plantation – do not.

Gupta and Sharma (2011) conducted a study to generate the information on Soil Organic Carbon (SOC) pool under forests and orchards in Bhageswer district of Uttarakhand. Under forest land use, the organic carbon pool in Deodar (*Cedrus deodara*), Quercus (*Quercus leucotrichophora*), Chir (*Pinus roxburghi*), and miscellaneous forests was estimated. SOC was calculated in mango and guava orchards under horticulture land use. In comparison to soils supporting orchards, forest soils had higher levels of SOC. Deodar Forest soils had the highest SOC pool (128.29 t ha^{-1}) followed by Quercus Forest soils (109.63 t ha^{-1}).

Gupta and Negi (2012) conducted a study to estimate soil organic carbon pool (SOC) in three land uses viz. forest, horticulture and grassland in Chamoli district. Under forest land use, soil organic carbon pool was estimated in Deodar (*Cedrus deodara*), Quercus (*Quercus leucotrichophora*), Chir (*Pinus roxburgghið*), Silver fir and Spruce (*Abies pindrow and Picea smithiiana*) and miscellaneous forests. In a mango orchard, SOC was estimated under horticulture land use, and in a grassland, SOC was estimated. Soil organic carbon pool under deodar was maximum (121.81 t ha^{-1}) followed by silver fir and spruce (113.05 t ha^{-1}) Quercus (105.52 t ha^{-1}), Chir (56.73 t ha^{-1}) and the least (52.48 t ha^{-1}) was under miscellaneous SOC pool in the soils.

2.3 Effect of Different Tree Species on Chemical Properties of Soil over Several Years of Plantation

2.3.1 Soil pH and Electrical Conductivity

Mandal (2005) studied on regular fertilization effects on the nutrient distribution of bamboo components in a Moso Bamboo (*Phyllostachys pubescens*) grown in Gajwa National Experimental Forest, Jinju of South Korea with culm density 4633 & 6833 culms ha^{-1} respectively in fertilized and unfertilized plots and reported variation in soil pH and EC between the fertilized and the unfertilized plots. In fertilized plot, soil pH was observed to be (4.59 and 4.45) and EC (290 and 263 µS cm^{-1}) at 0-10 cm and 10-20 cm soil depth, respectively. Whereas, in unfertilized plot, soil pH was found to be (4.69 and 4.56) and EC

(138 and 116 µS cm^{-1}) at 0-10 cm and 10-20 cm soil depth accordingly. The EC of the soil was significantly improved in fertilized plots compared to unfertilized plots, while the difference in soil pH between fertilized and unfertilized plots was not significant.

Mandal *et al*. (2010) studied soils under natural woodlands and reported reduction in soil pH i.e. soil acidification due to rapid and continuous decomposition of organic matter.

Kaushal *et al.* (2020) studied rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported variation in soil pH values after six years of plantation under the influence of different bamboo species as compared to initial soil pH values. Soil pH was found to be reduced under *Bambusa bamboos* 5.54 (5.65), *B. nutans* 5.48 (5.85), *B. vulgaris* 5.38 (5.65), *Dendocalamus hamiltonii* 5.66 (5.95), *D. strictus* 5.56 (5.65). Whereas, increased in soil pH was observed under *B. balcooa* 5.83 (5.70) and *D. stocksii* 5.81 (5.35). In comparison to bamboo species, the control plot had the highest soil pH (6.25). The decreased in soil pH could be attributed to increased leaf litter biomass production, which may have produced some organic acids during decomposition, resulting in a slight decreased in soil pH under the influence of various bamboo species. (Values in parentheses refer to the initial pH of the soil).

2.3.2 Calcium Carbonate

Sekhon and Bajwa (1993) reported that incorporation of farmyard manure (FYM), *Sesbania aculeate* green manure (GM) or rice straw in a soil and irrigated with sodic water reduced $CaCO_3$ precipitation, increased Na^+ in drainage water, decreased soil pH and ESP and enhanced crop yield on a pot experiment. In addition, the use of organic materials, notably FYM, as an organic amendment for the restoration of sodic soils has long been promoted.

Zhu *et al.,* (2002) reported that manganese (Mn) availability in soils is determined by various factors like organic matter, pH, $CaCO_3$, and redox conditions. The soil characteristics that encourage the growth of reducing habitats and their availability in soil.

Choudhary *et al.* (2011) in northwestern India, a long-term field experiment (15 years, 1991-2006) was undertaken on the utilization of sodic water irrigation, additives and crop residues in sandy loam soil and reported that organic materials like FYM, sesbania green manure and wheat straw were successful in mobilizing Ca^{2+} from both inherent and precipitated $CaCO_3$ resulting in a decreased in soil pH and ESP as well as an increased in infiltration rate. Organic material application causes an increased in soil atmospheric CO_2 concentration and the formation of organic acids which leads to an increase in the solubility of $CaCO_3$ and other calcic minerals

Chang *et al*. (2017) studied that the transformation of CO_2 into a precipitated mineral carbonate through an *ex situ* mineral carbonation route is considered a promising option for carbon capture and storage (CCS) since (i) the captured CO_2 can be stored permanently and (ii) industrial wastes (i.e., coal fly ash, steel and stainless steel slags, and cement and lime kiln dusts) can be recycled and converted into value added carbonate materials by controlling polymorphs and properties of the mineral carbonates. In terms of market needs and qualities, the ex situ mineral carbonation route's final products can be split into two categories: low end high volume and high end low volume mineral carbonates (i.e., purity). As a result, it is predicted that this will offset a portion of the entire cost of the CCS procedures. Temperature, pH of the solution, reaction duration, ion concentration and ratio, stirring, and the quantity of additives all play a role in the polymorphs and physicochemical properties of $CaCO_3$. Various efforts to control and fabricate polymorphs of $CaCO_3$ have been made to date. We give a summary of existing understanding and recent research, including mechanistic studies on the generation of precipitated $CaCO_3$ and the effects of synthesis variables on polymorphs, in this review.

2.3.3 Available Nitrogen

Xue *et al*. (2002) studied variation of soil nutrient dynamics under *Dendrocalamus membranaceus* forest grown in Xishuangbanna and reported that increased in the soil available nitrogen content in bamboo plantation indicates the slow mineralization of nitrogen which may be attributed due to decomposition activities carried out by soil microorganisms. Whereas, decreased in the soil available nitrogen with respective increasing depth may be attributed due to their fast use by soil microorganisms for their growth and functioning at the surface layer of soil but they are found to be lacking at subsurface.

Rai *et al.* (2009) reported that pressure on land is increasing day by day to grow food and fodder, fuel and wood due to increased in human and livestock population. It has been estimated that annually about 6,600 tonnes top soil and 5.4 to 8.4 tonnes plant nutrients are washed away to the ocean. Under such situations, multistorey system of vegetation could be of great help in restoring and sustaining health of soils. When physico chemical properties of soils was compared after 10 years of establishment of pasture and different silvipastoral systems the organic carbon and available nutrients (NPK and S) increased as compared to pasture alone except K in *Hardwickia binata*.

Rana *et al.* (2010) found carbon and nutrient budgets for two Central Himalayan Sal (*Shorea robusta Gaertn*.) forest. The total Carbon storage in Sal old growth forest (379 t C ha^{-1}) was greater than Sal new growth forest (242 t C ha^{-1}). However, net primary

productivity values (9.3-10.1t C ha^{-1} yr^{-1}) revealed almost similar potential of both forests, of the total carbon uptake in ecosystem, the net accumulation accounted for 33%. of the total nutrient storage in two forests, vegetation pool accounted for 53-54% N; 67.72%, P; 90-93% K; 18034% Ca; and 77-78% Na.

2.3.4 Available Phosphorus

Lal and Singh (1999) studied sustainable forestry in India for carbon mitigation and reported seasonal variations in soil available phosphorus content in the agroforestry systems grown in Rajasthan for one year and soil available phosphorous content was found to be increased within one year period.

Geetha and Balagopalan (2005) conducted a study on soils as influenced by teak and eucalyptus plantation in Peechi Vazhani Wildlife Sanctuary, Kerala and reported that the total phosphorous content was found to be decreased with increasing depth of soil under teak and eucalyptus plantation grown in Kerala.

Mandal *et al*. (2010) conducted a study on landscape and land use effects on soil resources in a Himalayan watershed and reported that soils under the natural wood stands are found to be high in soil available phosphorus content as compared to adjacent control plots (without wood stands) this may be attributed due to favourable rhizosphere environment created by the roots of natural wood stands, which aids in dissolution of inorganic phosphorus.

2.3.5 Available Potassium

Singh and Singh (1999) studied on biomass net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region and reported that due to increasing demand by growing bamboo plants over the years do not allow potassium to accumulate in top soil layer.

Patil *et al*. (2004) conducted a research study on soil profile, organic matter build up and nutritional status of soil under bamboo based agroforestry system and observed that soil available potassium content was found to be increased in soil under *Dendrocalamus strictus* based agroforestry systems within a one year study.

Kim *et al*. (2018) conducted a research study on regular fertilization (*i.e*., N:P:K = 244:196:196 kg ha^{-1} $year^{-1}$ approximately for 30 years) effects on the nutrient distribution of bamboo components in a Moso Bamboo (*Phyllostachys pubescens*) stand grown in Gajwa National Experimental Forest, Jinju of South Korea with culm density 4633 and 6833 culms ha^{-1} respectively in fertilized and unfertilized plots and reported nonsignificant variation in Exchangeable K^+ content between the fertilized and the unfertilized plots. In fertilized plot Exchangeable K^+ content was found to be (3.84 and 3.74 c mol c kg^{-1}), whereas in unfertilized

plot Exchangeable K^+ content was observed to be (3.18 and 2.27 c mol c kg^{-1}) at 0-10 cm and 10-20 cm soil depth respectively.

2.3.6 Effect of Different Tree Species/Crops on Micro-Nutrients over Several Years of Plantation

Degryse *et al*. (2008) observed a positive effect of excreted labile carbon compounds from roots on Zn diffusion that enhances the Zn uptake. Several studies have shown that adding organic matter to the soil aids in the accumulation of Zn in its accessible fraction owing to soil decomposition. Higher levels of organic matter, on the other hand, favour a decreased in the accessible form of Zn due to chelation.

Scheid *et al*. (2009) studied that turnover of SOM can positively affect the solubility of Zn as decomposition of litter releases Zn in soil solution but may be leached into the deeper layers of soil or sorbed by the organic matter of the soil surface.

Walia *et al*. (2010) reported that slight increased in the Cu content (1.35–1.66 mg kg^{-1}) was notably observed in plots treated with organic manures over the control plots. When FYM, green manure (GM), and wheat cut straw (WCS) are added to the soil, more micronutrients are released in accessible forms than when chemical fertilization is used alone. The addition of organic manure decreases the soil redox potential, resulting in an increase in the amount of Cu accessible in the soil. Increased extractable Cu from Diethylene triamine pentaacetic acid (DTPA) may be linked to the chelating action of organic compounds liberated during the decomposition of FYM, GM, and WCS, which aids in the availability of micronutrients by preventing certain processes such as fixation, oxidation, precipitation, and leaching.

Dhaliwal *et al*. (2012) reported significant changes in different fractions of Fe and Mn when FYM, WCS and GM were applied in conjunction with different combinations of chemical fertilizers. In a broader aspect, the results indicated an increasd in the concentrations of WS + EX, AFeOX, CFeOX and OM-bound fractions of Fe and Mn under the application of GM, FYM and WCS before transplantation of rice whereas, decreased in their fractions held on SPAD on inorganic sites and MnOX decreased with the incorporation of these organic manures was also noted.

Matijevic *et al*. (2014) found an appreciable increased in total Cu in soil as a result of SOM application. Rise in total soil Cu with application of SOM may be attributed to adsorption of Cu^{2+} ions on OM as sorption and formation of complexation with OM influence the bioavailability of Cu.

Roussos *et al*. (2017) found an increased in Cu in an experiment where organic fertilizers were applied in two newly planted olive (*Olea europaea L*.) cultivars which may be due to the ability of organic matter to form stable metal complexes, especially in calcareous soils. In the paddy-soils, 32.6% Cu, 12.1% Fe and 14.7% Zn was found to be higher in the RFS (rainfed system) system.

Dhaliwal *et al*. (2019) observed that the dynamics and transformations of micronutrients (Zn, Cu, Fe, Mn, B and Mo) in soils, are governed by various factors like pH, EC, soil organic matter etc. The addition of SOM boosted complexed forms of micronutrients in a decreased environment. Adsorbed fractions are converted to more plant accessible forms of micronutrients as SOM builds up in the soil. The addition of organic matter to the soil enhanced the water soluble and exchangeable forms of micronutrients, which increased micronutrient uptake even more. The presence of a large amount of SOM in soils aids the different interactions of micronutrients, resulting in the production of more stable micronutrient complexes. Because Zn, Cu, B, and Mo are less sensitive to redox changes, soil organic matter binds more of them than Fe and Mn. The accretion of organic matter near the soil surface increased transformations (towards adsorbed fractions) of Mn and Fe and possibly decreased the availability of Zn, Cu, B and Mo by causing their redistribution among other complex fractions.

2.4 Effect of Different Tree Species on Physical Properties of Soil over Several Years of Plantation

2.4.1 Bulk Density

Purakayastha *et al*. (2008) studied that irrespective of soil depth, there was a greater relative decreased in bulk density in agro forestry soil, taking uncultivated soil as the benchmark, which showed the highest bulk density jointly with the vegetable field soil at all depths. Even under the same cropping system (rice-wheat), sewage irrigation resulted in lower bulk density than tube well irrigation.

Kaushal *et al.* (2020) conducted a research study on rooting behaviour and soil properties as influenced by different bamboo species grown in Western Himalayan Foothills of India and reported slight reduction in soil bulk density under the influence of different bamboo species as compared to control plot (without bamboo). Lowest soil bulk density was observed under *Dendrocalamus hamiltonii* and *Bambusa bamboos* of 1.42 Mg m^{-3}. The increased fine root biomass production, litterfall turnover, amount and types of leaf litter, presence of soil fauna, and other relevant biological activities may be responsible for the slight reduction in bulk density under the effect of bamboo species as compared to control.

2.4.2 Soil Texture

Nath (2014) studied the soil texture and total organic matter content as well as their effects on soil water holding capacity in the Sivasagar district of Assam. The soil samples were found to have sandy clay loam and sandy loam textures. Total organic matter ranged from 2.16 per cent to 3.38 per cent, with a mean of 2.71 per cent. The water holding capacity varied from 50.44 per cent to 59.18 per cent with average value 54.41 per cent. The findings revealed that the soil samples have a medium water retention capacity and a greater total organic matter content. The water retention capacity of the tea grown soil was found to be influenced by soil texture and soil organic matter concentration. It was proposed that soils with high concentrations of organic matter be added to improve water holding capacity. Water holding capacity was shown to have a significant positive connection with organic matter content and clay but a negative relationship with sand content.

2.4.3 Soil Colour

Pillai and Natarajan (2004) observed that colour of the soils in Garakahalli watershed in Karnataka varied from red to reddish brown in upland and reddish brown to greyish brown in the lowland. The strong brown colour in the surface horizons was due to high organic matter content whereas in deeper layers the dark colour may be influenced by the parent material or ferrous iron oxide. The soils located on gently sloping topography exhibited yellowish brown (10 YR 5/6) to dark red (2.5 YR 3/6) while the soils found on nearly level topography showed light yellowish brown (10 YR 6/4) to very dark greyish brown (10 YR 3/2) in Sivagiri micro watershed of Chittoor district in Andhra Pradesh.

Onti and Schulte (2012) observed that decomposition of biomass by soil microbes results in carbon loss as CO_2 from the soil due to microbial respiration, while a small proportion of the original carbon is retained in the soil through the formation of humus, a product that often gives carbon-rich soils their characteristic dark color.

2.5 Correlation between Soil Carbon Stock with Soil Nutrient Status

Bernardi *et al*. (2007) reported that the highest contents of SOC and N were found in the surface layer. The stocks of SOC and total N under secondary forest at 0-0.40 m layer were 27.6 and 2.4 Mg ha^{-1}, respectively. Caatinga Forest conversion into fruit orchard cultivation led to a decreased of 5 to 23% and 4 to 21% on SOC and N stocks, respectively. Compared to other soil uses, sapota and bullock's heart contributed for a lower decreased of SOC and N stocks after deforestation. Guava, bullock's heart, mango and sapota contributed for improving the SOC stratification index. The soil organic matter accumulation provides benefits to soil productivity and reduces atmospheric carbon concentration.

Ogunwole *et al*. (2008) conducted the trial on influence of *Jatropha curcas* cultivation with or without soil amendments on the structural stability, carbon and nitrogen content, and structural stability of a deteriorated Entisol under rehabilitation in western India. They observed that cultivation of *Jatropha curcas* resulted in an average increased of 11 per cent in soil mean weight and 2% increased in soil macro-aggregate turnover. Cultivation of *Jatropha curcas* with or without nitrogen and phosphorus enhanced macro-aggregate stability when compared to adjacent native vegetation. Organic carbon and mean weight diameter had a significant correlation, according to regression analysis. *Jatropha* farming appears to have improved the condition of these soils by preserving organic carbon and nitrogen stocks and perhaps increasing carbon sequestration rates.

Xiang *et al*. (2018) conducted an approximately 2 year long field experiment in lateritic soil in South China with an objective to evaluate the effects of legume introductions on soil properties, carbon (C) and nitrogen (N) pools. Two leguminous and one non-leguminous plant species, including *Arachis hypogaea L*. (a leguminous oilseed crop species, DA), *Stylosanthes guianensis* (a perennial herbaceous leguminous species, DS) and *Lolium perenne L.* (an annual nonleguminous forage species, DL), were introduced into a *Dimocarpus longan* orchard as three treatments and compared to the monoculture of *D. longan* (the control, D0). The harvested biomass residues of the three cover plants were returned to their corresponding plots as green manure. Soil samples were collected from depths of 0–10 and 10–20 cm approximately 2 years after treatment application. The results showed that, compared with D0, DA significantly improved the contents of soil available phosphorus, dissolved organic carbon (DOC), total nitrogen, ammonium and the N pool. In addition, DS significantly increased the contents of DOC, microbial biomass carbon and ammonium in the soil. However, DL 21 did not affect any soil properties or the C and N pools. In addition, neither DA nor DS altered the soil bulk density or the contents of available nitrogen, total organic carbon and the C pool. The improvement of soil properties by DS and DA was positively correlated with the plant residues amount, plant N content but negatively correlated with the plant C:N ratios. Besides, the plant growth of longan was significantly improved by DA. In conclusion, compared with that of *S. guianensis*, the introduction of *A. hypogaea L*. was more helpful for restoring and improving soil properties, N pool and longan growth within the young hillside orchard in South China.

3. MATERIALS AND METHODS

A field experiment entitled “Estimation of terrestrial carbon stocks as influenced by sapota orchard at Regional Fruit Research Station, Ganeshkhind, Pune” was conducted during 2020-2021. The details of experiment techniques followed, materials used, methodology and criteria adopted for evaluation during the course of investigation are described in this chapter.

3.1 Details of Experimental Research

3.1.1 Location

Geographically, Pune is situated at 18^0-32’ North latitude and 73^0-51’ East longitude at 569 meters above sea level on Deccan plateau at the confluence of Mula and Mutha rivers. Pune is second largest city of Maharashtra and is considered the state’s cultural capital.

3.1.2 Experimental Site

Sapota orchard with 8 genotypes (more than 18 years old) at Regional Fruit Research Station, Ganeshkhind, Pune was selected for present study. The Regional Fruit Research Station, Ganeshkhind, Pune has sought heritage status from the state government for its Ganeshkhind premises. The status enables the research station, spread across 58 acres, conserve and protect tree species that are historically significant.

3.1.3 Soil and Climate

The research station is having light to medium and well drained soil. The mean annual rainfall varies between 650-750 mm and normally distributed from June to October. The average maximum and minimum temperature recorded during the experiment was 40.0 ^{0}C and 11.6 ^{0}C, respectively. The average maximum and minimum relative humidity recorded during the period 96 per cent and 18 per cent, respectively.

3.1.4 Other Materials

Measuring tape was used to measure the diameter at breast height, Plant height was measured by using wooden stick with measuring tape, Scale was used to measure depth of soil (0-30 and 30-60 cm) and cloth bags were used for collecting of soil samples.

Table 3.1 Weekly mean meteorological data during experimental period recorded at RFRS, Ganeshkhind, Pune

Met. Week	Date	Temp. max (ºC)	Temp. min (ºC)	RH I (%)	RH II (%)	Wind Speed	Rain fall (mm)	No. of Rainy Days	Evapo-ration (mm)	Sun Shine (hr.)
January, 2020										
1	1-4	29.7	12.3	96	43	2.6	0.0	0	2.9	7.6
2	5-11	28.2	14.4	94	49	2.8	0.0	0	2.5	6.9
3	12-18	29.1	12.2	93	38	2.2	0.0	0	3.2	8.7
4	19-25	31.4	14.6	92	41	1.8	0.0	0	3.0	8.7
5	26-1	29.1	12.8	94	38	2.8	0.0	0	3.7	9.5
February, 2020										
6	2-8	29.4	14.2	86	40	3.4	0.0	0	4.4	8.1
7	9-15	31.6	15.7	89	34	2.2	0.0	0	4.3	7.5
8	16-22	34.3	15.8	83	25	1.8	0.0	0	4.7	9.5
9	23-29	32.8	14.3	77	28	2.8	0.0	0	5.4	9.5
March, 2020										
10	1-7	31.8	15.1	83	27	4.8	0.0	0	6.0	9.5
11	8-14	32.7	15.5	75	32	4.4	0.0	0	6.0	9.5
12	15-21	35.7	16.6	69	18	3.4	0.0	0	7.2	9.8
13	22-28	35.4	20.0	87	36	2.3	12.7	2	4.1	7.3
April, 2020										
14	29-4	38.0	18.7	73	22	2.6	0.0	0	7.0	9.7
15	5-11	37.9	19.8	70	19	3.6	0.2	0	7.9	9.7
16	12-18	39.4	22.3	71	23	4.0	0.0	0	8.0	10.1
17	19-25	38.1	20.9	62	25	5.4	0.0	0	8.8	11.1
18	26-2	39.1	22.6	69	26	4.7	20.9	1	7.5	9.6
May, 2020										
19	3-9	40.0	22.3	63	18	4.8	0.0	0	9.9	11.2
20	10-16	37.9	23.6	72	34	4.4	13.9	2	7.1	7.5
21	17-23	38.3	23.4	67	29	7.8	0.0	0	9.6	11.3
22	24-30	36.2	23.3	77	44	7.4	6.9	2	7.7	7.6
June, 2020										
23	31-6	30.1	21.5	81	62	7.0	101.1	4	5.6	6.9
24	7-13	32.3	23.3	82	67	5.6	9.7	1	4.9	4.1
25	14-20	30.5	22.1	80	64	5.7	34.3	2	4.4	5.5
26	21-27	32.9	22.5	86	57	3.8	69.6	2	4.5	5.1
July, 2020										
27	28-4	30.2	22.5	83	75	6.2	19.4	3	3.2	3.4
28	5-11	30.0	22.5	87	70	4.8	21.0	2	3.2	3.2
29	12-18	30.2	21.0	87	66	5.4	1.0	0	3.9	3.6
30	19-25	31.3	20.4	89	71	3.5	77.4	3	3.6	4.3
31	26-1	31.0	21.9	86	66	3.9	22.7	2	3.7	3.4
August, 2020										
32	2-8	27.5	21.6	92	80	5.1	113.6	5	2.4	1.5
33	9-15	26.1	21.5	92	88	5.4	77.1	5	1.9	0.1
34	16-22	27.7	21.7	90	79	5.6	26.0	4	2.6	3.3
35	23-29	28.2	20.8	89	76	4.4	17.2	3	3.0	3.3

Contd…

Contd…

September, 2020										
36	30-5	32.3	21.7	93	57	2.1	44.3	2	3.7	7.1
37	6-12	31.2	22.1	88	67	2.6	87.3	4	3.4	4.2
38	13-19	29.6	22.3	89	77	2.6	52.0	3	2.6	2.7
39	20-26	29.7	21.3	88	67	4.0	14.1	2	3.4	5.2
40	27-3	31.2	22.0	89	54	3.1	1.0	0	3.3	5.9
October, 2020										
41	4-10	32.2	21.3	94	58	1.4	42.2	2	3.3	4.4
42	11-17	29.5	20.9	93	71	2.3	181.5	6	2.2	3.1
43	18-24	31.8	19.8	93	56	0.8	87.7	4	3.1	7.4
44	25-31	31.8	17.2	91	39	0.9	0.0	0	3.0	8.6
November, 2020										
45	1-7	31.0	13.6	92	34	1.9	0.0	0	3.5	8.8
46	8-14	31.2	14.6	92	41	2.9	0.0	0	3.9	9.5
47	15-21	32.1	18.1	93	46	1.0	5.3	1	3.1	7.3
48	22-28	29.4	16.3	86	44	3.8	0.0	0	3.6	7.1
December, 2020										
49	29-5	30.3	11.8	95	30	2.2	0.0	0	3.2	9.1
50	6-12	29.0	17.0	90	54	1.2	4.5	1	2.5	4.4
51	13-19	29.1	11.6	96	37	1.8	0.0	0	2.8	8.3
52	20-26	29.3	11.7	93	38	1.6	0.0	0	2.6	7.8

3.2 Experimental Details:

1.	Location	:	Regional Fruit Research Station, Ganeshkhind, Pune.
2.	Orchard	:	Sapota
3.	Date of planting	:	27.06.2002
4.	Age of the garden	:	18 years old
5.	No. of Sapota genotypes	:	Eight genotypes + One conventionally cultivated soil (control) (without sapota tree)
6.	Spacing	:	10 x 10 m
7.	Recommended dose of fertilizer (RDF)	:	1000 : 500 : 500 g tree^{-1} year^{-1} ($N:P_2O_5:K_2O$) and FYM 50 kg tree^{-1} year^{-1} **Application time** : Fertilizers applied in two splits, one half at the beginning of monsoon and the remaining half in the post-monsoon period (September-October).
8.	Depth of sampling	:	I. 0-30 cm II. 30-60 cm
9.	Period of sampling	:	I. Soil sampling (Nov 2020) II. Plant biometric observations (Dec 2020)
10.	Soil type	:	Inceptisol
11.	Replication	:	2
12.	Design	:	Factorial Randomized Block Design (FRBD)
13.	Factors	:	I : Eight genotypes + One conventionally cultivated soil (without sapota tree) II : Soil depth : Two depth

3.2.1 Details of Treatments

Genotypes

1. Kalipatti
2. CO-1
3. Cricket Ball
4. Kirti Bharti
5. PKM-1
6. CO-2
7. PKM-Hy-7/1
8. PKM-2
9. Conventionally cultivated soil (Without sapota tree)

3.3 Methodology

In order to quantify the terrestrial carbon stock in eight genotypes of sapota orchard biometric observations viz., tree height, stem diameter at breast height, volume of tree, above ground biomass, below ground biomass, total plant biomass and plant carbon were taken.

3.3.1 Tree height

Tree height for eight sapota genotypes were measured by using measuring tape from ground level to top growing point and average height was about 510 cm.

3.3.2 Stem Diameter at Breast Height

The Diameter at Breast Height (DBH) of trunk of the eight trees was measured in centimeters at breast height (1.37 m from ground level) with the help of measuring tape.

3.3.3 Volume of Tree

Volume of tree was estimated by using diameter at breast height (DBH) of tree and computed as per the formula given by Ravindranath and Ostwald, (2008)

$$\text{Volume of tree (V) } (cm^3) = \pi \times r^2 \times H$$

Where,

V = volume of tree in cubic centimetres or cubic metre

r = radius of the tree 1.3 m above ground = DBH/2

H = height of the tree in centimetres or metres

3.3.4 Above Ground Biomass

Above ground biomass includes all living biomass above the soil. The above ground biomass (ABG) has been calculated by multiplying volume of tree and wood density (Ravindranath and Ostwald, 2008).

The volume was calculated based on diameter and height. The wood density value for the sapota tree species for India obtained from the database of website www.worldagroforestry.org.

$$AGB\ (g) = \text{Volume } (cm^2) \text{ x Wood density } (g\ cm^{-3})$$

3.3.5 Below Ground Biomass

The below ground biomass (BGB) has been calculated by multiplying above ground biomass taking 0.26 as the shoot ratio (Ravindranath and Ostwald, 2008).

$$BGB\ (Kg) = AGB\ (Kg) \times 0.26$$

3.3.6 Total plant biomass:

Total plant biomass the sum of the above and below ground biomass (Chavan and Rasal, 2011).

$$TPB = AGB + BGB$$ (All values are in kilogram)

3.3.7 Plant carbon:

Generally, for any plant species 50% of its biomass is considered as carbon (Chavan and Rasal, 2011).

Plant Carbon = Total plant biomass x 50% or Biomass / 2

Table 3.2 Carbon Stock Measurement

Sr. No.	Parameters	Measurement method	Reference
I. Plant biomass and carbon measurement			
1.	Tree height	--	--
2.	Diameter at breast height	Measuring tape	--
3.	Volume of tree	V (cm^3) = DBH x H	Ravindranath and Ostwald (2008)
4.	Above ground biomass (AGB)	AGB = Volume of biomass (cm^3) x Wood density (g cm^{-3}) (Wood density of sapota plant is 0.81 g cm^{-3})	Ravindranath and Ostwald (2008)
5.	Below ground biomass (BGB)	BGB = AGB x 0.26	Ravindranath and Ostwald (2008)
6.	Total plant biomass (TB)	AGB + BGB	Chavan and Rasal (2011)
7.	Plant Carbon	Total plant biomass x 50 % or Biomass / 2	Chavan and Rasal (2011)

3.4 Collection of Soil Sample

The soil samples were collected from all the eighteen quadrats at different depth i.e. 0-30 cm and 30-60 cm. The first soil sample was collected from the depth of 0-30 cm from all the quadrats. The soil was mixed thoroughly and spread on the ground in circular fashion and was divided into four parts and then, one part was selected as sample and collected for analysis. The same process was repeated to collect the soil from 30-60 cm. Further, all the 36 samples were taken for analysis in the soil laboratory.

The soil sample collected from the site were dried under shade to remove the moisture content. Then crushed with the help of wooden mortar and pestle. The soil was sieved through 2 mm sieve to obtain a uniform sample.

3.5 Methodology Adopted for Analysis of Soil Carbon Fractions

3.5.1 Total Organic Carbon (TOC)

Total carbon content of soils is determined by dry combustion at high temperatures in a furnace with the collection and detection of evolved CO_2 (Nelson and Sommer, 1982).

In dry combustion technique, soil samples less than (0.002 mm) were fed into the inert boat (about 250 mg) and the boat was fed inside the furnace having temperature of 900-1000 ^{0}C. The sample was combusted at high temperature in presence of pure oxygen. The evolved CO_2 gas was detected by non-dispersive infrared detector (NDIR) and the carbon content of sample was shown automatically as the instrument was pre-calibrated for total organic carbon with standard like sucrose. Analyses were stopped after a known volume of gas has collected or after a given amount of time has passed and the TOC content was determined. Carbon concentrations were determined by dry combustion.

3.5.2. Water Soluble Carbon (WSC)

The water soluble carbon in soil was extracted by hot and cold extractions as described by McGill *et al*. (1986).

Water soluble carbon was evaluated by mixing 10 g air dried soil in a centrifuge tube with 20 ml distilled water for an hour on a horizontal shaker, then centrifuging at 6000 RPM for 5-10 minutes to clear the supernatant. 10 ml of the supernatant or filtrate was taken in 250 ml conical flask followed by addition of 2 ml of 0.1 *N* $K_2Cr_2O_7$. This was then mixed with 10 mL of concentrated sulphuric acid 112 and 5 mL of orthophosphoric acid. After that, the conical flask was placed in a water bath at 100°C for half an hour. Finally, using 0.01 *N* FAS and 1 ml diphenylamine indicator, the sample was titrated. A blank (soil-free) extract was retained to calculate the amount of potassium dichromate absorbed by the carbon in the sample.

3.5.3. Soil Microbial Biomass Carbon (SMBC)

The soil microbial biomass carbon from soil was determined by the fumigation extraction technique in fresher incubated soil samples at 27 ^{0}C described by Brooks *et al*. (1985).

In two sets of 10 g field moist or incubated soil, 100 ml beakers were used. In the case of field moist samples, recorded moisture content in a subset of soil for proper soil weight. At field capacity, the soil was incubated for 5 days at 27 + 1 ^{0}C. In a 100 mL beaker, combine 40

mL ethanol-free chloroform with some glass beads and place it in the vacuum desiccators. Desiccators' inner surfaces were lined with damp filter paper. One set of samples was kept in the vacuum desiccators for fumigation. Using a rubber tube to divert the exhaust through water, the lid is joined to ensure adequate sealing. The vacuum pump was then turned on and left on until the chloroform had boiled for roughly 5 minutes. Closed outlet and keep the desiccators in dark place for 24 hours. After 24 hours, release the vacuum and remove the chloroform beaker as well as the inside paper lining. Back suction was also used to ensure that any surplus chloroform vapours were removed, and the vacuum was gently released.

All the unfumigated samples from the refrigerator and fumigated samples were taken and transferred these samples in 250 ml conical flask and added 25 ml of 0.5 *M* potassium sulphate (K_2SO_4). Shaked it for 30 minutes and filtered the content. Transferred 10 ml aliquot in a 250 ml conical flask and added 2 ml of potassium dichromate (0.2 *N*), 10 ml concentrated sulphuric acid and 5 ml of orthophosphoric acid to each flask. At least 2 blanks samples were runned with 10 ml of distilled water simultaneously. Kept the flasks on a water bath or hot plate at 100 ^{0}C for half an hour. Then added about 25 ml of distilled water to each and allowed them to cool down to room temperature. Added 2 to 3 drops of ferroin indicator and titrated the contents against standard 0.01 *N* ferrous ammonium sulphate to brick red end point.

3.5.4. Permanganate Oxidizable Soil Carbon (POSC)

Alkaline $KMNO_4$ oxidizable labile carbon in soil sample was analyzed as per procedure outlined by Blair *et al.* (1995) is determined by 20 *mM* $KMNO_4$ method.

In a centrifuge tube, 5 g of air dried soil was placed, and 20 ml of 20 *mM* $KMNO_4$ was added. It was agitated on a horizontal shaker for 2 minutes at 120 RPM, then centrifuged (4000-5000 RPM) to remove the supernatant. 2 mL of clear supernatant was added to 50 mL of water and the absorbance was measured at 550 nm. Pipette 0, 1, 1.5, 2.0, 2.5, and 5.0 ml of 0.02 *M* $KMnO_4$ to a volume of 50 ml to create a standard curve. At 550 nm, the absorbance was measured. Plotted a concentration vs. absorbance curve and took note of the slope. Also, the absorbance of 0.02 *M* $KMnO_4$ solution was recorded and used as a blank reading.

3.5.5. Particulate Organic Matter Carbon (POMC)

Particulate organic matter carbon was determined by dry combustion method outlined by Cambardella and Elliott (1992).

The 2 mm sieved 10 g soil sample was dispersed by sodium hexameta phosphate and shaken continuously for 18 hours. The dispersed material was then passed through a 53 m sieve, with the material remaining sand fraction on screen being collected in an aluminium dish and dried at 50 ^{0}C for 24 hours. For organic carbon determination, the processed sand

fraction was digested with chromic acid and back titrated with ferrous ammonium sulphate. Before estimating, all identifying plant residues were removed with care.

3.5.6 Calculation of Soil Carbon Fractions to Total Organic Carbon

It was calculated how much percentage of soil carbon fractions in total organic carbon.

3.6 Computation of Carbon Management Indices

3.6.1 Carbon Pool Index

Carbon Pool Index at two depths were estimated by using following formula given by Blair *et al.* (1995).

$$\text{Carbon pool index (CPI)} = \frac{\text{Total C in sample}}{\text{Total C in reference}}$$

3.6.2 Carbon Lability Index

Carbon Lability Index at two depths were estimated by using following formula given by Blair *et al*. (1995).

$$\text{Carbon liability index (CLI)} = \frac{\text{Liability of C in sample soil}}{\text{Liability of C in reference soil}}$$

3.6.3 Carbon Management Index

Carbon Management Index at two depths were estimated by using following formula given by Blair *et al*. (1995).

$$\text{CMI}=\text{CPI} \times \text{LI} \times 100$$

3.6.4. Computation of Carbon Management Index (CMI)

Calculation of CMI requires sample of the soils of interest and of reference site. Since continuity of (supply) depend upon both size and ability, both are taken into account in during CMI. Various carbon indices were worked out as follows (Blair *et al*., 1995).

$$\text{Carbon pool index (CPI)} = \frac{\text{Total C in sample}}{\text{Total C in reference}} \quad \ldots\ldots (1)$$

$$\text{Carbon liability index (CLI)} = \frac{\text{Liability of C in sample soil}}{\text{Liability of C in reference soil}} \text{------(2)}$$

Where, liability of C represents the ratio of easily oxidized C to unoxidised C by $KMNO_4$.

CMI = CPI x CLI …

3.7 Soil Organic Carbon Stock

Soil organic carbon stock at two depths were estimated by using following formula given by (Jasmine *et al.* 2021).

$$\text{SOC Stock} = \text{TOC} \times \text{BD} \times \text{d}$$

Where, TOC = Total organic carbon

BD = Bulk density of soil

d = Depth of soil layer.

3.8 Soil Carbon Sequestration

Soil carbon sequestration (kg tree^{-1}) = SOC stock / Number of plants per hector

3.9 Standard Methods Used for Soil Analysis

Representative soil samples from two depths 0-30 and 30-60 cm were collected and analyzed by using following standard analytical methods.

Table 3.3 Standard methods used for soil analysis

Sr. No.	Parameter	Method Used	Reference
I.	**Carbon Fraction**		
1.	Total organic carbon	Dry ashing / TOC analyser	Nelson and Sommer (1982)
2.	WSC	Water extraction method	Mc Gill *et al*. (1986)
3.	SMBC	Chloroform fumigation extraction method	Brooks *et al*. (1985)
4.	Labile and Non Labile C pool of carbon (POSC)	Permanganate oxidation method	Blair *et al*. (1995)
5.	POC	Wet sieving method	Cambardella *et.al*. (1992)
6.	Carbon Pool Index (CPI)	$\frac{SOC_{cultivated}}{SOC_{Noncultivated}}$	Blair *et al*. (1995)
7.	Lability Index (LI)	$\frac{L_{cultivated}}{L_{Noncultivated}}$	Blair *et al*. (1995)
8.	Carbon Management Index (CMI)	CPI x CLI x 100	Blair *et al*. (1995)
9.	Soil carbon stock	TOC X BD X Depth	Jasmine *et al.* (2021)
II.	**Chemical Properties**		
1.	pH (1:2.5)	Potentiometric	Jackson (1973)
2.	EC (1:2.5)	Conductometric	Jackson (1973)
3.	$CaCO_3$	Acid neutralization	Allison and Moodier (1965)
4.	Available N	Alkaline Permanganate	Subbiah and Asija (1956)
5.	Available P	0.5 *M* $NaHCO_3$ (pH 8.5)	Watanabe and Olsen (1965)
6.	Available K	1 *N* NH_4OAc	Jackson (1973)
7.	DTPA (Fe, Mn, Cu, and Zn)	Atomic absorption spectrophotometer	Lindsay and Norvell (1978)
III.	**Physical properties**		
1.	Bulk density	Core method	Blake and Hartage (1986)
2.	Soil Texture	International Pipette method	Piper (1966)
3.	Soil Colour	Colour Chart	Munsell (1900)

3.10 Statistical Analysis

The data contained in the replication were analyzed statistically by the method describe by Panse and Sukhante (1973).

4. RESULTS AND DISCUSSION

The observations recorded in the field experiment entitled, **"**Estimation of terrestrial carbon stocks as influenced by sapota orchard at Regional Fruit Research Station, Ganeshkhind, Pune**"** pertaining to the effect of different sapota species on soil organic carbon fractions, soil chemical properties, soil physical properties, carbon stock and carbon sequestration potential after eighteen years of plantation have been tabulated, statistically processed and discussed in this chapter.

4.1 Effect of Different Sapota Genotype on Total Plant Biomass after Eighteen Years of Plantation Grown on Inceptisol

The effect of the different sapota genotypes on total plant biomass and plant carbon is presented in Table 4.1 and Fig. 4.1 & 4.2.

The sapota genotype CO-2 recorded higher above ground biomass (ABG) (1115.57 kg tree^{-1}) and below ground biomass (BGB) (290.04 kg tree^{-1}) as compared to all other genotypes. However, lower ABG (417.82 kg tree -1) and BGB (108.63 kg tree^{-1}) were observed in Cricket ball genotype. Similarly other parameters like tree height, trunk diameter at breast height and volume of tree were also observed higher in CO-2 as compared to other sapota genotypes.

Further, the sapota genotype CO-2 recorded higher total plant biomass (1405.62 kg tree^{-1}) and plant carbon (702.81 kg tree^{-1}) as compared to other genotypes. However, lower total plant biomass (526.46 kg tree^{-1}) and plant carbon (263.23 kg tree^{-1}) was recorded in Cricket ball genotype. Among the all sapota genotypes, CO-2 recorded 2.3 times more total plant biomass over Cricket ball sapota genotype from eighteen years of plantation. The same trend was also observed for plant carbon.

Among the different genotypes, CO-2 recorded higher tree height, trunk diameter at breast height, volume of tree, above ground biomass, below ground biomass, total plant biomass than rest of the treatments and on the base of these biometric observations higher plant carbon were reported after calculation than rest of the treatments. It might be due to higher leaf fall or litter fall consistently for the period of eighteen years, it's genetic character and well adoption to climatic conditions. Similar observations were also be recorded by Kaur *et al.* (2002) and Chavan and Rasal (2012).

Table 4.1 Effect of sapota genotype on total plant biomass and plant carbon after eighteen years of plantation

Sr. No.	Genotypes	Tree height (cm)	Diameter at breast height (cm)	Volume of tree (cm^3)	Above ground biomass (kg $tree^{-1}$)	Below ground biomass (kg $tree^{-1}$)	Total plant biomass (kg $tree^{-1}$)	Plant carbon (kg $tree^{-1}$)
1	Kalipatti	490	47.50	867866.56	702.97	182.77	885.74	442.87
2	CO-1	510	52.00	1082546.40	876.86	227.98	1104.84	552.42
3	Cricket ball	480	37.00	515839.20	417.82	108.63	526.46	263.23
4	Kirti Bharti	510	51.50	1061828.30	860.08	223.62	1083.70	541.85
5	PKM-1	520	55.50	1257358.10	1018.46	264.80	1283.26	641.62
6	CO-2	540	57.00	1377251.10	1115.57	290.04	1405.62	702.81
7	PKM-Hy-7/1	510	55.00	1211058.80	980.95	255.04	1236.00	618.00
8	PKM-2	520	50.00	1020500.00	826.60	214.91	1041.52	520.76

4.2 Effect of Different Sapota Genotypes and Depths on Soil Carbon Content after Eighteen Years of Plantation Grown on Inceptisol

Different sapota genotypes significantly influenced the soil carbon content and carbon fractions on Inceptisol.

4.2.1 Effect of Different Sapota Genotype on Active Carbon Pools at 0-30 and 30-60 cm Depth

4.2.1.1 Water soluble carbon

Water soluble carbon in soil and it's ratio with total organic carbon was influenced significantly by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and soil depth was found non significant is presented in Table 4.2 and Fig. 4.3

Significantly higher WSC content was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (78.00 and 55.00 mg kg^{-1}) which was at par with PKM-1 (76.00 and 53.00 mg kg^{-1}), PKM-Hy-7/1 (75.00 and 52.00 mg kg^{-1}) and CO-1 (74.00 and 50.00 mg kg^{-1}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota plantation) lower WSC was reported (53.00 and 35.00 mg kg^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in water soluble content under sapota genotypes (0-30 cm) varies from 24.53% to 47.16 % as compared to conventionally cultivated soil after eighteen years of plantation.

Further, the ratio between WSC to TOC found significantly higher in CO-2 (0.82 and 0.62) followed by PKM-1 (0.82 and 0.61) as compared to conventionally cultivated soil (0.72 and 0.52) at 0-30 and 30-60 cm depth respectively. However, higher WSC to TOC ratio was found in 0-30 cm depth than 30-60 depth in all the treatments.

Interaction effect of sapota genotypes and depth of soil on WSC content and it's ratio with total organic carbon in soil was found non significant.

Higher WSC at 0-30 cm soil depth was observed which might be due to accumulation of leaf fall litter over the period of eighteen years. The oxidation of organic matter from the surface and remaining WSC may have accumulated at lower depths. In case of conventionally cultivated soil which does not have any leaf litter fall hence WSC content was reported lower at both the depth than sapota genotypes.

The amount of water soluble carbon in upper layer of the orchard was found to be higher than in the conventionally cultivated soil. Similar observation recorded by Massaccesi *et al*. (2018) and Kalambukattu *et al.* (2013).

Table 4.2 Effect of sapota genotype and depth on soil water soluble carbon (WSC) after eighteen years of plantation

Sr. No.	Genotype	WSC (mg kg^{-1})			% WSC of TOC		
		Depth (cm)			Depth (cm)		
		0-30	30-60	Mean	0-30	30-60	Mean
1.	Kalipatti	67.00	44.50	55.75	0.78	0.57	0.67
2.	CO-1	74.00	50.00	62.00	0.82	0.60	0.71
3.	Cricket ball	66.00	43.00	54.50	0.81	0.56	0.69
4.	Kirti Bharti	72.50	48.00	60.25	0.80	0.57	0.69
5.	PKM-1	76.00	53.00	64.50	0.82	0.61	0.72
6.	CO-2	78.00	55.00	66.50	0.82	0.62	0.72
7.	PKM-Hy-7/1	75.00	52.00	63.50	0.81	0.61	0.71
8.	PKM-2	71.00	46.00	58.50	0.80	0.56	0.68
9.	Conventionally Cultivated soil	53.00	35.00	44.00	0.72	0.52	0.62
	Mean	70.28	47.39		0.80	0.58	
		Genotype	**Depth**	**G × D**	**Genotype**	**Depth**	**G × D**
	S.E.(m) ±	0.58	1.22	1.73	0.02	0.01	0.03
	CD at 5%	1.72	3.65	NS	0.07	0.03	NS

4.2.1.2 Soil microbial biomass carbon

The influence of different sapota genotype on soil microbial biomass carbon and it's effect on ratio between SMBC and TOC was significant at 0-30 and 30-60 cm depth (Table 4.3 and Fig. 4.4).

Significantly higher SMBC content was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (543.00 and 413.50 mg kg^{-1}) which was at par with PKM-1 (537.00 and 409.50 mg kg^{-1}), PKM-Hy-7/1 (533.50 and 407.50 mg kg^{-1}) and CO-1 (517.00 and 396.00 mg kg^{-1}) at 0-30 cm and 30-60 cm depth, respectively. However, in case of conventionally cultivated soil (without sapota plantation) lower SMBC was reported (413.00 and 254.50 mg kg^{-1}) at 0-30 cm and 30-60 cm soil depth, respectively. Overall increased in soil microbial biomass carbon content under sapota genotypes (0-30 cm) varied from 19.12% to 31.47 % as compared to conventionally cultivated soil after eighteen years of plantation. The same trend was observed in 30-60 cm depth of soil but it is numerically lower than 0-30 cm depth.

Further, the ratio between SMBC to TOC found significantly higher in PKM-1 (5.83 and 4.76) followed by PKM-2 (5.82 and 4.83) as compared to conventionally cultivated soil (5.65 and 3.79) at 0-30 and 30-60 cm depth respectively. However, higher SMBC to TOC ratio was found in 0-30 cm depth than 30-60 depth in all the treatments.

Interaction effect on SMBC content and it's ratio with total organic carbon in soil found non significant for sapota genotypes and soil depth.

Higher SMBC at 0-30 cm soil depth was observed which might be due to as soil under sapota genotype remained unaffected by tillage practices and litter fall over the period of eighteen years tend to accumulate and decompose which contribute soil carbon, their substrate provide favorable resource for microbial activities and indirectly result in increased of soil microbial biomass carbon. In case of conventionally cultivated soil which does not have any leaf litter fall hence SMBC content was reported lower at both the depth than sapota genotype Similar observation recorded by Gupta and Singh (2010). The amount of carbon in the soil microbial biomass carbon mostly accounts for 1 to 5% of the total soil organic carbon (TOC) observed by Dilly *et al*. (2003).

Table 4.3 Effect of sapota genotype and depth on soil microbial biomass carbon (SMBC) after eighteen years of plantation

Sr. No.	Genotype	SMBC (mg kg^{-1})			% SMBC of TOC		
		Depth (cm)			Depth (cm)		
		0-30	30-60	Mean	0-30	30-60	Mean
1.	Kalipatti	494.50	386.50	440.50	5.81	4.95	5.38
2.	CO-1	517.00	396.00	456.50	5.74	4.82	5.28
3.	Cricket ball	492.50	384.00	438.25	6.08	5.05	5.57
4.	Kirti Bharti	514.50	393.00	453.75	5.71	4.73	5.22
5.	PKM-1	537.00	409.50	473.25	5.83	4.76	5.30
6.	CO-2	543.00	413.50	478.25	5.77	4.69	5.23
7.	PKM-Hy-7/1	533.50	407.50	470.50	5.79	4.79	5.29
8.	PKM-2	512.50	391.50	452.00	5.82	4.83	5.33
9.	Conventionally Cultivated soil	413.00	254.50	333.75	5.65	3.79	4.72
	Mean	506.39	381.78		5.80	4.71	
		Genotype	**Depth**	**G × D**	**Genotype**	**Depth**	**G × D**
	S.E.(m) ±	1.12	2.38	3.37	0.11	0.23	0.32
	CD at 5%	-3.35	7.10	10.05	0.32	NS	NS

4.2.1.3 Permanganate oxidizable carbon

The effect of the different sapota genotypes on permanganate oxidizable soil carbon and ratio between POSC to TOC in 0-30 and 30-60 cm soil depth after eighteen years of plantation grown on Inceptisol is presented in Table 4.4 and 4.5.

Soil beneath the sapota genotype CO-2 recorded significantly higher permanganate oxidizable soil carbon (1429 and 1331 mg kg^{-1}) in soil which was at par with PKM-1 (1383 and 1284 mg kg^{-1}), PKM-Hy-7/1 (1379 and 1277 mg kg^{-1}) and CO-1 (1366 and 1268 mg kg^{-1}) at 0-30 cm and 30-60 cm depth, respectively. However, in case of conventionally cultivated soil (without sapota plantation) lower POSC was reported (1225 and 1131 mg kg^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in permanganate oxidizable content under sapota genotypes (0-30 cm) varies from 6.61 % to 16.65 % as compared to conventionally cultivated soil after eighteen years of plantation. The same trend was observed in 30-60 cm depth of soil but it is numerically lower than 0-30 cm depth.

The results of POSC to TOC ratio among the treatments found non significant. However, in case of soil depth POSC to TOC ratio was significantly higher at 0-30 cm than the 30-60 cm.

Interaction effect for sapota genotype and soil depth POSC content and it's ratio with total organic carbon in soil was found non significant.

This increased in permanganate oxidizable carbon content under sapota genotypes might be due to significant increase in carbon input with organic manure and leaf litter of orchard system. Similar observation were also recorded by Purakayastha *et al.* (2008) and Laik *et al*. (2009).

Table 4.4 Effect of sapota genotype and depth on permanganate oxidizable carbon (POSC) after eighteen years of plantation

Sr. No.	Genotype	POSC (mg kg^{-1})			% POSC of TOC		
		Depth (cm)			Depth (cm)		
		0-30	30-60	Mean	0-30	30-60	Mean
1.	Kalipatti	1307	1209	1258	15.39	15.50	15.45
2.	CO-1	1366	1268	1317	15.18	15.46	15.32
3.	Cricket ball	1306	1206	1256	16.12	15.86	15.99
4.	Kirti Bharti	1346	1246	1296	14.95	15.01	14.98
5.	PKM-1	1383	1284	1333	15.03	14.93	14.98
6.	CO-2	1429	1331	1380	15.20	15.13	15.17
7.	PKM-Hy-7/1	1379	1277	1328	14.99	15.02	15.01
8.	PKM-2	1340	1240	1290	15.22	15.30	15.26
9.	Conventionally Cultivated soil	1225	1131	1178	17.28	16.86	17.07
	Mean	1342	1244		15.48	15.45	
		Genotype	**Depth**	**G × D**	**Genotype**	**Depth**	**G × D**
	S.E.(m) ±	3.45	7.32	10.35	0.17	0.35	0.50
	CD at 5%	10.30	21.85	NS	NS	1.05	NS

4.2.2 Effect of Different Sapota Genotype and Soil Depth on Particulate Organic Matter Carbon (Passive Pool)

Particulate organic matter carbon in soil and it's ratio with total organic carbon was influenced significantly by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and soil depth was found non significant is presented in Table 4.5 and Fig. 4.6.

Significantly higher POMC content was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (1170 and 570 mg kg^{-1}) which was at par with PKM-1 (1160 and 560 mg kg^{-1}), PKM-Hy-7/1 (1155 and 555 mg kg^{-1}) and CO-1 (1145 and 545 mg kg^{-1}) at 0-30 cm and 30-60 cm depth respectively. However, in case of conventionally cultivated soil (without sapota tree) lower POMC was reported (1015 and 455 mg kg^{-1}) at 0-30 cm and 30-60

cm soil depth. Overall increased in particulate organic carbon content under sapota genotypes (0-30 cm) varies from 7.88% to 15.27 % as compared to conventionally cultivated soil after eighteen years of plantation. The same trend was observed in 30-60 cm depth of soil but it is numerically lower than 0-30 cm soil depth.

Further, higher POMC to TOC ratio was found in 0-30 cm depth than 30-60 depth in all the treatments. However, Interaction effect of POMC content and it's ratio with total organic carbon in soil was found non significant for sapota genotypes and soil depth.

This increase in POMC content in Sapota genotypes might be due to addition of plant biomass and litter fall in surface layer and lack of nutrient in 30-60 cm depth. However, POMC is more in 0-30 cm depth. Similar results have been reported by Purakayastha *et al*. (2008) and Massaccesi *et al*. (2018)

Table 4.5 Effect of sapota genotype and depth on particulate organic matter carbon (POMC) after eighteen years of plantation

Sr. No.	Genotype	POMC (mg kg^{-1})			% POMC in TOC		
		Depth (cm)			Depth (cm)		
		0-30	30-60	Mean	0-30	30-60	Mean
1.	Kalipatti	1115	515	815	13.11	6.10	9.61
2.	CO-1	1145	545	845	12.72	6.64	9.68
3.	Cricket ball	1095	495	795	13.51	6.51	10.01
4.	Kirti Bharti	1130	530	830	12.55	6.38	9.47
5.	PKM-1	1160	560	860	12.60	6.51	9.56
6.	CO-2	1170	570	870	12.44	6.47	9.46
7.	PKM-Hy-7/1	1155	555	855	12.55	6.52	9.54
8.	PKM-2	1120	520	820	12.72	6.41	9.57
9.	Conventionally Cultivated soil	1015	455	735	13.90	6.79	10.35
	Mean	1123	527		12.90	6.48	
		Genotype	**Depth**	**G × D**	**Genotype**	**Depth**	**G × D**
	S.E.(m) ±	3.39	7.20	10.18	0.09	0.18	0.26
	CD at 5%	10.12	21.47	NS	0.26	0.54	NS

4.2.3 Effect of Different Sapota Genotype and Soil Depth on Total Organic Carbon (TOC) after Eighteen Years of Plantation

Total organic carbon in soil was influenced significantly by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and soil depth was found non significant is presented in Table 4.6 and Fig. 4.6

Significantly higher TOC content was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (0.94 % and 0.88 %) which was at par with PKM-1 (0.93 and 0.86 %), PKM-Hy-7/1 (0.92 and 0.85 %) and CO-1 (0.91 and 0.83 %) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota tree) lower TOC was reported (0.73 % and 67.00 %) at 0-30 cm and 30-60 cm soil depth. Overall increased in total organic carbon content under sapota genotypes (0-30 cm) varies from 10.95 % to 28.76 % as compared to conventionally cultivated soil after eighteen years of plantation.

This increased in TOC content under sapota genotypes may be due to addition of organic manures supported by mulching effect of sapota biomass. The maximum TOC was recorded in the surface soil as compared with lower depth due to the addition of roots and plant biomass in surface layer and lack of nutrient and biological activity in 30-60 cm which ultimately constraints the rooting depth. Similar results have been reported by Ingram and Fernandes (2001) and Ananthi *et al*. (2016).

Table 4.6 Effect of sapota genotype and depth on total organic carbon (TOC) after eighteen years of plantation

Sr. No.	Genotype	TOC (%)		
		Depth (cm)		
		0-30	30-60	Mean
1.	Kalipatti	0.85	0.79	0.82
2.	CO-1	0.91	0.83	0.87
3.	Cricket ball	0.82	0.76	0.79
4.	Kirti Bharti	0.90	0.83	0.87
5.	PKM-1	0.93	0.86	0.89
6.	CO-2	0.94	0.88	0.91
7.	PKM-Hy-7/1	0.92	0.85	0.89
8.	PKM-2	0.88	0.81	0.85
9.	Conventionally Cultivated soil	0.73	0.67	0.70
	Mean	0.87	0.81	
		Genotype	**Depth**	**G × D**
	S.E.(m) ±	0.01	0.02	0.02
	CD at 5%	0.02	0.05	NS

4.2.4 Effect of Different Sapota Genotype and Soil Depth on Soil Carbon Pools Index (CPI) after Eighteen Years of Plantation

The carbon pool index is the ratio of total carbon in soil sample to the total carbon in reference soil sample (conventionally cultivated soil without sapota tree). The effect of the different sapota genotypes significantly influenced the carbon pool index (CPI) with two depth (0-30 and 30-60 cm) after eighteen years of plantation grown on Inceptisol is depicted in Table 4.7.

Significantly higher CPI content was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (1.28 and 1.31) which was at par with PKM-1 (1.26 and 1.28), PKM-Hy-7/1 (1.26 and 1.26) and CO-1 (1.23 and 1.22) at 0-30 cm and 30-60 cm depth. All the sapota genotypes recorded higher CPI as compared to conventionally cultivated soil (1.00 and 1.00) at 0-30 cm and 30-60 cm soil depth. Overall increased in carbon pool index under sapota genotypes (0-30 cm) varies from 10 % to 28 % as compared to conventionally cultivated soil after eighteen years of plantation. However, interaction effect of CPI in soil was found non significant for sapota genotypes and soil depth.

The CPI of sapota orchards increased across the depth of the soil profile, indicating that sapota orchards have a significant potential for rebuilding original soil organic carbon reserves (Blair *et al*., 1995).

Table 4.7 Effect of sapota genotype and depth on soil carbon pools index (CPI) after eighteen years of plantation

Sr. No.	Genotype	CPI		
		Depth (cm)		
		0-30	30-60	Mean
1.	Kalipatti	1.16	1.16	1.16
2.	CO-1	1.23	1.22	1.23
3.	Cricket ball	1.10	1.13	1.12
4.	Kirti Bharti	1.23	1.23	1.23
5.	PKM-1	1.26	1.28	1.27
6.	CO-2	1.28	1.31	1.30
7.	PKM-Hy-7/1	1.26	1.26	1.26
8.	PKM-2	1.20	1.20	1.20
9.	Conventionally Cultivated soil	1.00	1.00	1.00
	Mean	1.19	1.20	
		Genotype	**Depth**	**G × D**
	S.E.(m) ±	0.01	0.02	0.03
	CD at 5%	0.02	0.07	NS

4.2.5 Effect of Different Sapota Genotype and Soil Depth on Soil Carbon Lability Index (CLI) after Eighteen Years of Plantation

The CLI is the ratio of labile carbon i.e. POSC of soil sample to the labile carbon i.e. POSC of reference soil sample. The effect of the different sapota genotypes significantly influenced the carbon lability index (CLI) at 0-30 and 30-60 cm depth from eighteen years of plantation grown on Inceptisol is presented in Table 4.8.

Significantly higher CLI content was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (1.16 and 1.25) which was at par with PKM-1 (1.12 and 1.23), PKM-Hy-7/1 (1.12 and 1.21) and CO-1 (1.11 and 1.12) at 0-30 cm and 30-60 cm depth. All the sapota genotypes recorded higher CLI as compared to conventionally cultivated soil (1.00 and 1.00) at 0-30 cm and 30-60 cm soil depth. Overall increased in carbon lability index under sapota genotypes (0-30 cm) varies from 6 % to 16 % as compared to conventionally cultivated soil after eighteen years of plantation. However, interaction effect of CLI in soil was found non significant for sapota genotypes and soil depth.

The higher CLI pattern in both the depth showed that sapota orchard provided a less oxidative environment, giving greater physical protection to the SOM favouring a higher proportion of labile carbon compared to total soil organic carbon by increasing the rate of carbon lability in the soil. Similar observations were also be recorded by Blair *et al*. (1995).

Table 4.8 Effect of sapota genotype and depth on soil carbon lability index (CLI) after eighteen years of plantation

Sr. No.	Genotype	CLI		
		Depth (cm)		
		0-30	30-60	Mean
1.	Kalipatti	1.06	1.06	1.06
2.	CO-1	1.11	1.12	1.12
3.	Cricket ball	1.06	1.06	1.06
4.	Kirti Bharti	1.09	1.16	1.13
5.	PKM-1	1.12	1.23	1.18
6.	CO-2	1.16	1.25	1.21
7.	PKM-Hy-7/1	1.12	1.21	1.17
8.	PKM-2	1.09	1.14	1.12
9.	Conventionally Cultivated soil	1.00	1.00	1.00
	Mean	1.09	1.14	
		Genotype	**Depth**	**G × D**
	S.E.(m) ±	0.01	0.03	0.04
	CD at 5%	0.04	0.08	NS

4.2.6 Effect of Different Sapota Genotype and Soil Depth on Soil Carbon Management Index (CMI) after Eighteen Years of Plantation

Carbon management index in soil was influenced significantly by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and sosil depth was found non significant is presented in Table 4.9

Significantly higher CMI content was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (150.26 and 164.53) which was at par with PKM-1 (142.30 and 157.97), PKM-Hy-7/1 (141.92 and 154.74) and CO-1 (137.50 and 137.36) at 0-30 cm and 30-60 cm depth. All the sapota genotypes recorded higher CMI as compared to conventionally cultivated soil (100.00 and 100.00) at 0-30 cm and 30-60 cm soil depth. Overall increased in carbon management index under sapota genotypes (0-30 cm) varies from 18 % to 50 % as compared to conventionally cultivated soil after eighteen years of plantation.

The CMI is an integrated measure quality and quantity of SOC. CMI can be utilised as a more sensitive indication of the rate of change of SOC in response to soil management changes than a single measure such as total SOC concentration (Whitbeard *et al*., 1998).

Table 4.9 Effect of sapota genotype and depth on soil carbon management index (CMI) from eighteen years of plantation

Sr. No.	Genotype	CMI		
		Depth (cm)		
		0-30	30-60	Mean
1.	Kalipatti	125.87	124.55	125.21
2.	CO-1	137.50	137.36	137.43
3.	Cricket ball	118.29	121.06	119.68
4.	Kirti Bharti	135.49	144.30	139.90
5.	PKM-1	142.30	157.97	150.14
6.	CO-2	150.26	164.53	157.40
7.	PKM-Hy-7/1	141.92	154.74	148.33
8.	PKM-2	131.86	138.16	135.01
9.	Conventionally Cultivated soil	100.00	100.00	100.00
	Mean	131.50	138.07	
		Genotype	**Depth**	**G × D**
	S.E.(m) ±	0.78	1.66	2.35
	CD at 5%	2.34	4.96	7.02

4.2.7 Effect of Different Sapota Genotype and Depth on Soil Organic Carbon Stock and Carbon Sequestration after Eighteen Years of Plantation

Soil organic carbon stock was significantly influenced by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and soil depth was found non significant is presented in Table 4.10 and Fig. 4.9.

Significantly higher SOC stock was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (36.94 and 35.64 Mg ha^{-1}) which was at par with CO-1 (36.72 and 34.19 Mg ha^{-1}), PKM-1 (36.70 and 35.08 Mg ha^{-1}) and PKM-Hy-7/1 (36.43 and 34.42 Mg ha^{-1}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota tree) lower SOC was reported (29.78 and 27.93 Mg ha^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in organic carbon content under sapota genotypes (0-30 cm) varies from 9.33 % to 24.04 % as compared to conventionally cultivated soil after eighteen years of plantation. The same trend was observed in 30-60 cm depth of soil but it is numerically lower than 0-30 cm depth

Soil carbon sequestration was significantly influenced by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and soil depth was found non significant is presented in Table 4.10 and Fig. 4.10

Significantly higher carbon sequestration was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (369.42 and 356.40 kg $tree^{-1}$) which was at par with CO-1 (367.20 and 341.94 kg $tree^{-1}$), PKM-1 (367.08 and 350.88 kg $tree^{-1}$) and PKM-Hy-7/1 (364.30 and 344.20 kg $tree^{-1}$) at 0-30 cm and 30-60 cm depth.

This increased in SOC stock and carbon sequestration under sapota genotypes might be due the different quantities and qualities of organic matter input through fresh litterfall, living organisms and root activity. Similar results have been reported by Gupta and Sharma (2011) and Gupta and Negi (2012).

Table 4.10 Effect of sapota genotype and depth on soil organic carbon stock and carbon sequestration after eighteen years of plantation

Sr. No.	Genotype	SOC (Mg ha^{-1})			Carbon sequestration per plant (kg tree^{-1})	
		Depth (cm)			Depth (cm)	
		0-30	30-60	Mean	0-30	30-60
1.	Kalipatti	34.17	32.05	33.11	341.70	320.58
2.	CO-1	36.72	34.19	35.46	367.20	341.94
3.	Cricket ball	32.56	31.46	32.01	325.62	314.64
4.	Kirti Bharti	35.91	34.61	35.26	359.10	346.11
5.	PKM-1	36.70	35.08	35.89	367.08	350.88
6.	CO-2	36.94	35.64	36.29	369.42	356.40
7.	PKM-Hy-7/1	36.43	34.42	35.43	364.30	344.20
8.	PKM-2	35.11	33.29	34.20	351.12	332.91
9.	Conventionally Cultivated soil	29.78	27.93	28.86	297.84	279.39
	Mean	34.92	33.19		---	---
		Genotype	**Depth**	**G × D**	---	---
	S.E.(m) ±	0.37	0.78	1.11	---	---
	CD at 5%	1.10	2.33	NS	---	---

4.3 Effect of Different Sapota Genotypes and Depth on Soil Chemical Properties of Soil after Eighteen Years of Plantation

4.3.1 Soil pH and Electric Conductivity

Soil pH was influenced significantly by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and soil depth was found non significant is presented in Table 4.11.

Significantly lowest soil pH was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (7.08 and 7.90) which was at par with PKM-1 (7.28 and 8.15), PKM-Hy-7/1 (7.29 and 8.19) and CO-1 (7.47 and 8.30) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota tree) higher soil pH was reported (8.25 and 8.75) at 0-30 cm and 30-60 cm soil depth. Overall decreased in soil pH under sapota genotypes (0-30 cm) varies from 1.45 % to 14.07 % as compared to conventionally cultivated soil after eighteen years of plantation.

The reduction in soil pH may be attributed due to higher leaf litter biomass production, whose decomposition may have produced some organic acids, which resulted in slight

reduction of soil pH under the influence of different sapota genotypes. Similar observation recorded by Kaushal *et al.* (2020), Mandal *et al*. (2010) and Sanchez *et al*. (2002).

Soil electrical conductivity was significantly influenced by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and soil depth was found non significant is presented in Table 4.11 and Fig. 4.13.

Significantly higher EC was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (0.17 and 0.19 dS m^{-1}) which was at par with PKM-2 (0.17 and 0.17 dS m^{-1}), PKM-1 (0.16 and 0.18 dS m^{-1}) and Kirti Bharti (0.16 and 0.16 dS m^{-1}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota plantation) lower EC was reported (0.12 and 0.13 dS m^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in electrical conductivity content under sapota genotypes (0-30 cm) varies from 27.27 % to 54.54 % as compared to conventionally cultivated soil after eighteen years of plantation.

This reduction in electrical conductivity may be due to lack of soluble salt content in soil which resulted due to high leaching caused by rapid water movement through soil profiles. Similar observation recorded by Mandal (2005) and Kim *et al.* (2018).

Table 4.11 Effect of sapota genotype and depth on soil pH and electric conductivity (EC) after eighteen years of plantation

Sr. No.	Genotype	pH			EC		
		Depth (cm)			(dS m^{-1})		
		0-30	30-60	Mean	0-30	30-60	Mean
1.	Kalipatti	7.90	8.41	8.15	0.13	0.15	0.14
2.	CO-1	7.47	8.30	7.88	0.15	0.15	0.15
3.	Cricket ball	8.13	8.57	8.35	0.14	0.14	0.14
4.	Kirti Bharti	7.50	8.32	7.91	0.16	0.16	0.16
5.	PKM-1	7.28	8.15	7.71	0.16	0.18	0.17
6.	CO-2	7.08	7.90	7.49	0.17	0.19	0.18
7.	PKM-Hy-7/1	7.29	8.19	7.74	0.14	0.15	0.14
8.	PKM-2	7.73	8.38	8.05	0.17	0.17	0.17
9.	Conventionally Cultivated soil	8.25	8.75	8.50	0.12	0.13	0.12
	Mean	7.62	8.33		0.15	0.15	
		Genotype	**Depth**	**G × D**	**Genotype**	**Depth**	**G × D**
	S.E.(m) ±	0.03	0.07	0.10	0.00	0.01	0.01
	CD at 5%	0.10	0.21	NS	NS	0.02	NS

4.3.2 Calcium Carbonate

The effect of the different sapota genotypes on soil calcium carbonate in 0-30 and 30-60 cm depth after eighteen years of plantation grown on Inceptisol is presented in Table 4.12

Lowest calcium carbonate was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (5.05 % and 6.37 %) which was at par with PKM-1 (5.87 % and 7.62 %), PKM-Hy-7/1 (6.15 % and 6.92 %) and Kirti Bharti (6.62 % and 7.30 %) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota plantation) higher 45.39 % to 82.84 % was reported (7.78 % and 8.87 %) at 0-30 cm and 30-60 cm soil depth. Overall decreased in calcium carbonate under sapota genotypes (0-30 cm) varies from 10.67 % to 35.09 % as compared to conventionally cultivated soil after eighteen years of plantation.

The slight increase in calcium carbonate might be due to accumulation of carbon in the soil resulted from turn over of biomass. Similar observation recorded by Zhu *et al*., (2002) and Chang *et al*. (2017).

Table 4.12 Effect of sapota genotype and depth on calcium carbonate after eighteen years of plantation

Sr. No.	Genotype	$CaCO_3$ (%)		
		Depth (cm)		
		0-30	30-60	Mean
1.	Kalipatti	5.94	7.62	6.78
2.	CO-1	6.75	7.50	7.13
3.	Cricket ball	6.95	7.37	7.16
4.	Kirti Bharti	6.62	7.30	6.96
5.	PKM-1	5.87	7.62	6.75
6.	CO-2	5.05	6.37	5.71
7.	PKM-Hy-7/1	6.15	6.92	6.54
8.	PKM-2	6.75	7.10	6.93
9.	Conventionally Cultivated soil	7.78	8.87	8.33
	Mean	6.43	7.41	
		Genotype	**Depth**	**G × D**
	S.E.(m) ±	0.04	0.09	0.13
	CD at 5%	0.13	0.28	0.40

4.3.3 Available Nitrogen

Available nitrogen of soil was significantly influenced by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and soil depth was found non significant is presented in Table 4.13.

Higher available nitrogen of soil was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (186.75 and 139.07 kg ha^{-1}) which was at par with PKM-1 (180.43 and 135.26 kg ha^{-1}), CO-1 (178.43 and 131.07 kg ha^{-1}) and PKM-Hy-7/1 (178.21 and 136.53 kg ha^{-1}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota plantation) lower available nitrogen was reported (146.71 and 101.62 kg ha^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in available nitrogen of soil content under sapota genotypes (0-30 cm) varies from 5.88 % to 27.29 % as compared to conventionally cultivated soil after eighteen years of plantation. The same trend was observed in 30-60 cm depth of soil but it is numerically lower than 0-30 cm depth.

The decreased in the soil available nitrogen with respective increasing depth might be attributed due to their fast use by soil microorganisms for their growth and functioning at the surface layer of soil but they are found to be lacking at subsurface. Similar observation recorded by Xue *et al*. (2002) and Rana *et al.* (2010).

Table 4.13 Effect of sapota genotype and depth on soil available nitrogen after eighteen years of plantation

Sr. No.	Genotype	Available N (kg ha^{-1})		
		Depth (cm)		
		0-30	30-60	Mean
1.	Kalipatti	164.16	116.53	140.35
2.	CO-1	178.43	131.07	154.75
3.	Cricket ball	155.34	115.26	135.30
4.	Kirti Bharti	174.25	129.28	151.77
5.	PKM-1	180.43	135.26	157.85
6.	CO-2	186.75	139.07	162.91
7.	PKM-Hy-7/1	178.21	136.53	157.37
8.	PKM-2	170.19	118.99	144.59
9.	Conventionally Cultivated soil	146.71	101.62	124.17
	Mean	170.50	124.85	
		Genotype	**Depth**	**G × D**
	S.E.(m) ±	1.90	4.03	5.69
	CD at 5%	5.66	12.01	NS

4.3.4 Available Phosphorus

Available phosphorus of soil was significantly influenced by sapota genotypes and with two depths (0-30 and 30-60 cm) from eighteen years of plantation grown on Inceptisol is presented in Table 4.14.

Significantly higher available phosphorus of soil was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (26.30 and 15.11 kg ha^{-1}) which was at par with PKM-1 (23.46 and 14.20 kg ha^{-1}), PKM-Hy-7/1 (21.93 and 12.85 kg ha^{-1}) and CO-1 (20.93 and 12.12 kg ha^{-1}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota tree) lower available phosphorus was reported (10.63 and 8.93 kg ha^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in available phosphorus of soil content under sapota genotypes (0-30 cm) varied from 32.63 % to 147.41 % as compared to conventionally cultivated soil after eighteen years of plantation. The same trend was observed in 30-60 cm depth of soil but it is numerically lower than 0-30 cm depth.

This increased in soil available phosphorus content might be attributed to slight build up in the soil, as favorable environment created by roots, which aids in dissolution of inorganic P. Similar observation recorded by Mandal *et al*. (2010), Lal and Singh (1999).

Table 4.14 Effect of sapota genotype and depth on soil available phosphorus after eighteen years of plantation

Sr. No.	Genotype	Available P (kg ha^{-1})		
		Depth (cm)		
		0-30	30-60	Mean
1.	Kalipatti	16.01	10.53	13.27
2.	CO-1	20.93	12.12	16.53
3.	Cricket ball	14.10	10.29	12.20
4.	Kirti Bharti	19.54	13.52	16.53
5.	PKM-1	23.46	14.20	18.83
6.	CO-2	26.30	15.11	20.71
7.	PKM-Hy-7/1	21.93	12.85	17.39
8.	PKM-2	13.95	9.08	11.52
9.	Conventionally Cultivated soil	10.63	8.93	9.78
	Mean	18.54	11.85	
		Genotype	**Depth**	**G × D**
	S.E.(m) ±	0.28	0.59	0.84
	CD at 5%	0.84	1.77	2.51

4.3.5 Available Potassium

Available potassium of soil was influenced by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and soil depth was found non significant is presented in Table 4.15.

Significantly higher available potassium of soil was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (675.86 and 498.97 kg ha^{-1}) which was at par with PKM-1 (657.58 and 480.06 kg ha^{-1}), PKM-Hy-7/1 (644.97 and 486.92 kg ha^{-1}) and CO-1 (582.81 and 444.14 kg ha^{-1}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota plantation) lower available potassium was reported (445.26 and 360.61 kg ha^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in available potassium of soil content under sapota genotypes (0-30 cm) varies from 5.08 % to 51.78 % as compared to conventionally cultivated soil after eighteen years of plantation.

The increased in soil available potassium content may be due to fertigation and their rapid uptake by sapota biomass components as it is evidence by higher K concentration in aboveground biomass and easy turnover to soil through litter biomass shedding. Similar observation recorded by Chauhan *et al*. (1981), Patil *et al*. (2004), Singh and Singh (1999),

Table 4.15 Effect of sapota genotype and depth on soil available potassium after eighteen years of plantation

Sr. No.	Genotype	Available K (kg ha^{-1})		
		Depth (cm)		
		0-30	30-60	Mean
1.	Kalipatti	520.82	431.37	476.09
2.	CO-1	582.81	444.14	513.47
3.	Cricket ball	467.92	423.12	445.52
4.	Kirti Bharti	593.34	441.51	517.42
5.	PKM-1	657.58	480.06	568.82
6.	CO-2	675.86	498.97	587.41
7.	PKM-Hy-7/1	644.97	486.92	565.94
8.	PKM-2	582.24	429.65	505.94
9.	Conventionally Cultivated soil	445.26	360.61	402.94
	Mean	574.53	444.04	
		Genotype	**Depth**	**G × D**
	S.E.(m) ±	8.85	18.78	26.56
	CD at 5%	26.42	56.04	NS

4.3.6 Effect of Different Sapota Genotypes and Soil Depth on DTPA Extractable Micro-Nutrients after Eighteen Years of Plantation (0-30 and 30-60 cm Depth).

4.3.6.1 DTPA - Iron

The effect of the different sapota genotypes on iron at 0-30 and 30-60 cm depth after eighteen years of plantation grown on Inceptisol is presented in Table 4.16.

Significantly higher iron content was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (8.43 and 8.29 mg kg^{-1}) which was at par with PKM-1 (7.08 and 6.90 mg kg^{-1}), Kalipatti (6.62 and 6.61 mg kg^{-1}) and Kirti Bharti (6.59 and 6.42 mg kg^{-1}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota tree) lower iron content was reported (5.41 and 6.61 mg kg^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in iron content of soil content under sapota genotypes (0-30 cm) varies from 18.51 % to 56.11 % as compared to conventionally cultivated soil after eighteen years of plantation.

Fe is more in deeper layer because of leaching activity on soil. Fe availability in soil determined by various factor like organic matter, pH, $CaCO_3$ and redox condition. The condition of soil that factors increase of reducing environment and its availability in soil. Similar observation recorded by Dhaliwal *et al*. (2012). Bacterial activity is mostly determined by the availability of organic carbon, which comes from the heavier biomass of sapota genotypes in the form of litter and aboveground biomass. When compared to chemical fertilisation alone, the addition of organic matter leads in higher micronutrient release in available forms in the soil (Dhaliwal *et al*. 2019).

4.3.6.2 DTPA- Manganese

The effect of the different sapota genotypes on manganese at 0-30 and 30-60 cm depth after eighteen years of plantation grown on Inceptisol is presented in Table 4.16.

Significantly higher manganese content was recorded in the soil at two depths collected beneath the sapota genotype Kalipatti (13.29 and 9.55 mg kg^{-1}) which was at par with Kirti Bharti (12.49 and 10.65 mg kg^{-1}), CO-2 (12.25 and 11.30 mg kg^{-1}) and PKM-2 (12.17 and 10.48 mg kg^{-1}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota tree) lower manganese content was reported (10.74 and 8.19 mg kg^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in manganese content of soil content under sapota genotypes (0-30 cm) varies from 5.67 % to 14.05 % as compared to conventionally cultivated soil after eighteen years of plantation. However, interaction effect of manganese in soil was found non significant sapota genotypes and soil depth.

Organic matter during its decomposition liberates as number of organic acids, lower the soil pH and increased the intensity of reduction in soil. In this way organic matter enhance the availability of Mn in soil. Similar observation were recorded by Dhaliwal *et al*. (2012). Organic content, pH, $CaCO_3$, and redox conditions are influence manganese (Mn) availability in soils (Zhu *et al.*, 2002).

Table 4.16 Effect of sapota genotype and soil depth on DTPA - iron and manganese after eighteen years of plantation

Sr. No.	Genotype	Fe (mg kg^{-1})			Mn (mg kg^{-1})		
		Depth (cm)			Depth (cm)		
		0-30	30-60	Mean	0-30	30-60	Mean
1.	Kalipatti	6.62	6.61	6.61	13.29	9.55	11.42
2.	CO-1	6.21	6.79	6.50	10.99	10.55	10.77
3.	Cricket ball	6.41	6.51	6.46	11.35	9.47	10.41
4.	Kirti Bharti	6.59	6.42	6.51	12.49	10.65	11.57
5.	PKM-1	7.08	6.90	6.99	11.90	11.27	11.59
6.	CO-2	8.43	8.29	8.36	12.25	11.30	11.77
7.	PKM-Hy-7/1	6.14	7.79	6.96	10.94	10.38	10.66
8.	PKM-2	6.24	6.18	6.21	12.17	10.48	11.33
9.	Conventionally Cultivated soil	5.41	6.61	6.01	10.74	8.19	9.46
	Mean	6.57	6.90		11.79	10.20	
		Genotype	**Depth**	**G × D**	**Genotype**	**Depth**	**G × D**
	S.E.(m) ±	0.09	0.19	0.27	0.19	0.41	0.58
	CD at 5%	0.27	0.58	0.82	0.58	1.23	NS

4.3.6.3 DTPA - Zinc

The effect of the different sapota genotypes on zinc content at 0-30 and 30-60 cm depth after eighteen years of plantation grown on Inceptisol is presented in Table 4.17.

Higher zinc content was recorded in the soil at two depths collected beneath the sapota genotype Kalipatti (3.60 and 2.14 mg kg^{-1}) which was at par with CO-2 (3.19 and 2.28 mg kg^{-1}), Cricket Ball (2.93 and 1.88 mg kg^{-1}) and PKM-Hy-7/1 (2.80 and 2.50 mg kg^{-1}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota tree) lower zinc content was reported (2.00 and 1.37 mg kg^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in zinc content of soil content under sapota genotypes (0-30 cm) varies from 24 % to 80 % as compared to conventionally cultivated soil after eighteen years of plantation.

As litter decomposes, Zn is released into the soil solution, although it may be leached into the deeper layers of soil or sorbed by the organic matter of the soil surface. Similar observation recorded by Scheid *et al*. (2009) and Degryse *et al*. (2008).

4.3.6.4 DTPA - Copper

The effect of the different sapota genotypes on copper content at 0-30 and 30-60 cm depth after eighteen years of plantation grown on Inceptisol is presented in Table 4.17.

Significantly higher copper content was recorded in the soil at two depths collected beneath the sapota genotype CO-2 (24.08 and 22.43 mg kg^{-1}) which was at par with Kalipatti (22.11 and 12.92 mg kg^{-1}), CO-1 (19.15 and 14.52 mg kg^{-1}) and PKM-2 (18.16 and 22.06 mg kg^{-1}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota tree) lower copper content was reported (13.22 and 7.15 mg kg^{-1}) at 0-30 cm and 30-60 cm soil depth. Overall increased in copper content of soil content under sapota genotypes (0-30 cm) varies from 5.67 % to 14.05 % as compared to conventionally cultivated soil after eighteen years of plantation.

Because of the increased of SOM in the form of leaf litter and above ground plant parts, the Cu availability in sapota genotypes is more noticeable. Similar findings are also observed by Dhaliwal *et al*. (2019). Walia *et al*. (2010) also recorded small rise in Cu content in organic manure-treated plots as compare to control plots.

Table 4.17 Effect of sapota genotype and soil depth on DTPA - zinc and copper after eighteen years of plantation

Sr. No.	Genotype	Zn (mg kg^{-1})			Cu (mg kg^{-1})		
		Depth (cm)			Depth (cm)		
		0-30	30-60	Mean	0-30	30-60	Mean
1.	Kalipatti	3.60	2.14	2.87	22.11	12.92	17.52
2.	CO-1	2.81	1.66	2.24	19.15	14.52	16.83
3.	Cricket ball	2.93	1.88	2.40	18.13	8.98	13.56
4.	Kirti Bharti	2.51	1.79	2.15	15.29	9.79	12.54
5.	PKM-1	2.49	1.67	2.08	18.20	21.59	19.90
6.	CO-2	3.19	2.28	2.73	24.08	22.43	23.25
7.	PKM-Hy-7/1	2.80	2.50	2.65	17.46	16.69	17.07
8.	PKM-2	2.57	2.20	2.39	18.16	22.06	20.11
9.	Conventionally Cultivated soil	2.01	1.37	1.69	13.22	7.15	10.18
	Mean	2.77	1.94		18.42	15.13	
		Genotype	**Depth**	**G × D**	**Genotype**	**Depth**	**G × D**
	S.E.(m) ±	0.07	0.15	0.21	0.49	0.90	1.28
	CD at 5%	0.21	0.45	NS	1.27	2.69	3.81

4.4 Effect of Different Sapota Genotypes and Depth on Soil Physical Properties after Eighteen Years of Plantation

4.4.1 Bulk Density

Soil bulk density was influenced by sapota genotypes and with two depths (0-30 and 30-60 cm). However, the interaction effect among sapota genotypes and soil depth was found non significant is presented in Table 4.18.

The lowest soil bulk density was recorded in the soil at both depths collected beneath the sapota genotype CO-2 (1.31 and 1.35 g cm^{-3}) followed by PKM-Hy-7/1 (1.32 and 1.35 g cm^{-3}), PKM-2 (1.33 and 1.36 g cm^{-3}) and PKM-1 (1.33 and 1.37 g cm^{-3}) at 0-30 cm and 30-60 cm depth. However, in case of conventionally cultivated soil (without sapota tree) higher soil bulk density was reported (1.36 and 1.39 g cm^{-3}) at 0-30 cm and 30-60 cm soil depth. Overall decreased in soil bulk density under sapota genotypes (0-30 cm) varies from 1.45 % to 14.07 % as compared to conventionally cultivated soil after eighteen years of plantation.

As compared to conventionally cultivated soil slight reduction in soil bulk density was recorded under the influence of sapota genotype. This reduction may be attributed due to the higher fine root biomass production, turnover of litterfall, presence of soil microbes and other related biological processes. Whereas, higher reduction under CO-2 and PKM-Hy-7/1 might be due to comparatively higher leaf litter production and its deposition through leaf litter shedding after eighteen years of plantation. Similar observation recorded by Kaushal *et al.* (2020) and Zang *et al*. (2019).

Table 4.18 Effect of sapota genotype and soil depth on soil bulk density after eighteen years of plantation

Sr. No.	Genotype	Bulk density (g cm^{-3})		
		Depth (cm)		
		0-30	30-60	Mean
1.	Kalipatti	1.34	1.37	1.36
2.	CO-1	1.36	1.39	1.38
3.	Cricket ball	1.34	1.38	1.36
4.	Kirti Bharti	1.33	1.39	1.36
5.	PKM-1	1.33	1.36	1.35
6.	CO-2	1.31	1.35	1.33
7.	PKM-Hy-7/1	1.32	1.35	1.34
8.	PKM-2	1.33	1.37	1.35
9.	Conventionally Cultivated soil	1.36	1.39	1.38

4.4.2 Soil Texture

The effect of the different sapota genotype on soil texture of soil at 0-30 cm and 30-60 cm depth is presented in table 4.19.

All the sapota genotype as well as conventionally cultivated soil recorded sandy clay loam textural class. The same trend observed in 30-60 cm depth of soil. Soil texture which is used to describe the size distribution of mineral particles is reported as another important factor influencing the accumulation soil organic matter. Generally, clay and salt particle protect soil organic matter by stabilizing them against microbial mineralization.

The results showed that there was a higher degree of carbon sequestration in depths that ranged from 0–30 cm, compared to soil at 30–60 cm depth. The results of correlation coefficients showed that percentage of clay was the strongest parameter that contributed to carbon sequestration recorded by Chinchmalatpure *et al*. (2000) and Nath (2014).

Table 4.19 Effect of sapota genotype and soil depth on soil texture after eighteen years of plantation

Sr. No.	Genotype	Sand (%)			Silt (%)			Clay (%)		
		Depth (cm)			Depth (cm)			Depth (cm)		
		0-30	30-60	Mean	0-30	30-60	Mean	0-30	30-60	Mean
1.	Kalipatti	54.52	53.42	53.97	21.66	23.63	22.65	23.32	22.45	22.89
2.	CO-1	54.28	53.15	53.72	21.91	23.97	22.94	23.41	22.48	22.95
3.	Cricket ball	54.15	53.66	53.91	21.86	23.56	22.71	23.39	22.18	22.79
4.	Kirti Bharti	54.42	53.25	53.84	21.61	23.21	22.41	23.17	22.74	22.96
5.	PKM-1	54.29	53.74	54.02	21.64	22.68	22.16	23.37	22.88	23.13
6.	CO-2	54.35	53.42	53.89	21.07	23.04	22.06	23.98	22.94	23.46
7.	PKM-Hy-7/1	54.41	53.47	53.94	21.94	23.7	22.82	23.25	22.43	22.84
8.	PKM-2	54.16	53.69	53.93	21.47	23.34	22.41	23.87	22.47	23.17
9.	Conventionally Cultivated soil	55.15	54.56	54.86	22.01	23.19	22.60	22.44	21.85	22.15

4.3.3 Soil Colour

The effect of the different sapota genotype on soil colour of soil at 0-30 cm and 30-60 cm depth is presented in table 4.20.

All the sapota genotype as well as conventionally cultivated soil recorded very dark grey soil colour at 0-30 cm depth and very dark grey brown soil colour at 30-60 cm depth. The dark grey or brown colour in soil indicate that soil has a high organic matter content. Wet soil will appear darker than dry soil. However, the presence of water also affects soil colour by affecting oxidation state.

Decomposition of biomass by soil microbes results in carbon loss as CO_2 from the soil due to microbial respiration, while a small proportion of the original carbon is retained in the soil through the formation of humus, a product that often gives carbon-rich soils their characteristic dark color observation recorded by Onti and Schulte (2012), Pillai and Natarajan (2004).

Table 4.20 Effect of sapota genotype and soil depth on soil colour after eighteen years of plantation

Sr. No.	Genotype	Soil Depth (cm)			
		0-30		30-60	
		Hue-Value-Chroma	Soil colour	Hue-Value-Chroma	Soil colour
1.	Kalipatti	10 YR 3/1	Very Dark Grey	10 YR 3/2	Very Dark Grey Brown
2.	CO-1	10 YR 3/1	Very Dark Grey	10 YR 3/2	Very Dark Grey Brown
3.	Cricket ball	10 YR 3/1	Very Dark Grey	10 YR 3/2	Very Dark Grey Brown
4.	Kirti Bharti	10 YR 3/1	Very Dark Grey	10 YR 3/2	Very Dark Grey Brown
5.	PKM-1	10 YR 3/1	Very Dark Grey	10 YR 3/2	Very Dark Grey Brown
6.	CO-2	10 YR 3/1	Very Dark Grey	10 YR 3/2	Very Dark Grey Brown
7.	PKM-Hy-7/1	10 YR 3/1	Very Dark Grey	10 YR 3/2	Very Dark Grey Brown
8.	PKM-2	10 YR 3/1	Very Dark Grey	10 YR 3/2	Very Dark Grey Brown
9.	Conventionally cultivated soil	10 YR 3/1	Very Dark Grey	10 YR 3/2	Very Dark Grey Brown

4.5 Correlation between Soil Carbon Stock with Nutrient Status after Eighteen Years of Sapota Plantation Grown on Inceptisol

Correlation between soil carbon stock with nutrient status in 0-30 and 30-60 cm soil depth from eighteen years of sapota plantation grown on Inceptisol is presented in table 4.21.

Soil organic carbon stock is highly correlated with nitrogen (0.819** and 0.857**), phosphorus (0.752** and 0.73**) and potassium (0.721** and 0.789**) at 0-30 and 30-60 cm depths respectively. However, soil organic carbon stock is highly correlated with all nutrients (N, P and K) except Fe, Mn, Zn and Cu at 0-30 cm depth. Whereas at 30-60 cm depth soil organic carbon stock is correlated with all nutrients (N, P, K, Mn and Cu) except Fe and Zn.

Table 4.21 Correlation between carbon stock with nutrient status on sapota genotype after eighteen years of plantation

Nutrients	0-30	30-60
N	0.819**	0.857**
P	0.752**	0.73**
K	0.721**	0.789**
Fe	0.508*	0.339
Mn	0.265	0.834**
Zn	0.187	0.424
Cu	0.352	0.603**

*=at 0.05 level and **=at 0.1 level

5. SUMMARY AND CONCLUSIONS

The observations recorded in the field experiment entitled, **"**Estimation of terrestrial carbon stocks as influenced by sapota orchard at Regional Fruit Research Station, Ganeshkhind, Pune**"** pertaining to the effect of different sapota species on soil organic carbon fractions, carbon stock and carbon sequestration potential after eighteen years of plantation have been summarized and concluded in this chapter.

5.1 Plant Carbon Content as Influenced by Sapota Genotypes

Among the sapota genotypes CO-2 recorded higher tree height (540 cm), diameter at breast height (57 cm), volume of tree (1377251.10 cm^3), above ground biomass (1115.57 kg $tree^{-1}$), below ground biomass (290.04 kg $tree^{-1}$) and total plant biomass (1405.62 kg $tree^{-1}$) which resulted into higher accumulation of plant carbon (702.81 kg $tree^{-1}$) followed by PKM-1 and PKM-Hy-7/1.

5.2 Carbon Pools as Influenced by Sapota Genotypes and Soil Depths

5.2.1 Active Carbon Pools

5.2.1.1 Water soluble carbon (WSC)

The soil sample collected beneath the sapota genotype CO-2 recorded significantly higher water soluble carbon (78.00 and 55.00 mg kg^{-1}) followed by PKM-1 (76.00 and 53.00 mg kg^{-1}) as compare to conventionally cultivated soil (53.00 and 35.00 mg kg^{-1}) at 0-30 and 30-60 cm depth respectively. Water soluble carbon content in soil at 0-30 cm depth was significantly higher in all the sapota genotypes along with conventionally cultivated soil (without sapota tree) over 30-60 cm depth. However, the interaction effects among sapota genotypes and soil depth were found non significant.

5.2.1.2 Soil microbial biomass carbon (SMBC)

Soil beneath the sapota genotype CO-2 recorded significantly higher soil microbial biomass carbon (543.00 and 413.50 mg kg^{-1}) at 0-30 and 30-60 cm depth which was at par with PKM-1 (537.00 and 409.50 mg kg^{-1}). All sapota genotypes recorded higher soil microbial biomass carbon as compared to conventionally cultivated soil (without sapota tree) (413.00 and 254.50 mg kg^{-1}) at 0-30 and 30-60 cm depth. SMBC content in soil at 0-30 cm depth was found significantly higher in all the sapota genotypes along with conventionally cultivated soil over 30-60 cm depth.

5.2.1.3 Permanganate oxidizable soil carbon (POSC)

Soil beneath the sapota genotype CO-2 recorded significantly higher permanganate oxidizable soil carbon (1429 and 1331 mg kg^{-1}) which was at par with PKM-1 genotype (1383

and 1284 mg kg^{-1}) at 0-30 and 30-60 cm depth respectively. However, in case of conventionally cultivated soil (without sapota tree) lower POSC (1225 and 1131 mg kg^{-1}) was reported at 0-30 cm and 30-60 cm soil depth. POSC content in soil at 0-30 cm depth was found significantly higher in all the sapota genotypes along with conventionally cultivated soil over 30-60 cm depth. Interaction effect of POSC content in soil was found non significant for sapota genotypes and soil depth.

5.2.2 Particulate Organic Matter Carbon (POMC) (Passive pool)

Soil beneath the sapota genotype CO-2 recorded significantly higher particulate organic matter carbon (1170 and 570 mg kg^{-1}) followed by PKM-1 (1160 and 560 mg kg^{-1}) and PKM-Hy-7/1 (1155 and 555 mg kg^{-1}) as compared to conventionally cultivated soil (1015 and 455 mg kg^{-1}) at 0-30 and 30-60 cm depth respectively. POMC content in soil at 0-30 cm depth was found significantly higher in all the sapota genotypes along with conventionally cultivated soil over 30-60 cm depth. Interaction effect of POMC in soil was found non significant for sapota genotypes and soil depth.

5.3 Carbon Indices as Influenced by Sapota Genotypes and Soil Depth

Among all sapota genotypes CO-2 recorded significantly higher carbon pool index (1.28 and 1.31), carbon lability index (1.16 and 1.25) and carbon management index (150.26 and 164.53) at 0-30 and 30-60 cm depth respectively than the rest of the sapota genotypes and conventionally cultivated soil. Among the sapota genotypes carbon indices in soil at 30-60 cm depth was found significantly higher over 0-30 cm depth. However, interaction among sapota genotypes and soil depth was found non significant.

5.4 Total Organic Carbon as Influenced by Sapota Genotypes and Soil Depth

The soil beneath sapota genotype CO-2 recorded significantly higher total organic carbon content (0.94 and 0.88 %) which was closely followed by PKM-1 (0.93 and 0.86 %) at 0-30 and 30-60 cm depth. However, conventionally cultivated soil (0.73 and 0.67 %) recorded lowest TOC as compared to genotype. TOC content in soil at 0-30 cm depth was found significantly higher in all the sapota genotypes along with conventionally cultivated soil over 30-60 cm depth. However, interaction effect of TOC content in soil was found non significant for sapota genotypes.

5.5 Soil Organic Carbon Stock and Carbon Sequestration as Influenced by Sapota Genotypes and Soil Depths

Sapota genotype CO-2 recorded higher soil organic carbon stock (36.94 and 35.64 Mg ha^{-1}) followed by PKM-1 (36.70 and 35.08 Mg ha^{-1}), whereas higher carbon sequestration per plant was recorded in CO-2 (369.42 and 356.40 kg $tree^{-1}$) followed by PKM-1 (367.08,

350.88 kg tree^{-1}) in 0-30 and 30-60 cm depth respectively. While lower soil organic carbon stock was recorded in conventionally cultivated soil (29.78 and 27.93 Mg ha^{-1}). SOC stock and carbon sequestration per tree in soil at 0-30 cm depth was found significantly higher in all the sapota genotypes over 30-60 cm depth. However, the interaction effect for soil organic carbon stock among sapota genotypes and soil depth was found non significant.

5.6 Soil Chemical and Physical Properties as Influenced by Sapota Genotypes and Soil Depth

Higher availability of nitrogen (186.75 and 139.07 kg ha^{-1}), phosphorus (26.30 and 15.11 kg ha^{-1}) and potassium (675.86 and 498.97 kg ha^{-1}) along with DTPA- extractable iron (8.43 and 8.29 mg kg^{-1}), manganese (12.25 and 11.30 mg kg^{-1}), zinc (3.19 and 2.28 mg kg^{-1}) and copper (24.08 and 22.43 mg kg^{-1}) at 0-30 and 30-60 cm depth of soil beneath sapota genotype CO-2 respectively as compare to conventionally cultivated soil (without sapota tree). Whereas significantly lower soil bulk density (1.31 and 1.35 g cm^{-3}) was recorded in the soil beneath sapota genotype CO-2 as compared to conventionally cultivated soil (1.36 and 1.39 g cm^{-3}) at 0-30 and 30-60 cm depth respectively.

5.7 Correlation between Soil Carbon Stock with Soil Nutrient Status after Eighteen Years of Sapota Plantation Grown on Inceptisol

Soil organic carbon stock is highly correlated with nitrogen (0.819** and 0.857**), phosphorus (0.752** and 0.73**) and potassium (0.721** and 0.789**) at 0-30 and 30-60 cm depths respectively.

Conclusion

It is concluded that the CO-2 sapota genotype was found most suitable for improving carbon fractions, carbon stock, carbon sequestration and fertility status of soil at 0-30 and 30-60 cm depth during eighteen years of sapota plantation in Inceptisol. The second most effective genotype is PKM-1 for improving carbon sequestration.

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7. VITAE

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MASTER OF SCIENCE (AGRICULTURE)

IN

SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

2021

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