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Potential of wastelands for carbon sequestration- A review

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Abstract

One of the most important issues of the 21st century in India is carbon (C) management through carbon sequestration and its long term storage. Enhancing carbon sequestration in degraded agricultural lands has direct environmental, economic, and social benefits for local people. The best practical method for sequestration of excess CO₂ from atmosphere is by storing it into a biological system like plant biomass and finally into the soil. According to Intergovernmental Panel on Climate Change (IPCC, 2000) one of the best reservoirs of carbon is soil. Soil plays a major role in global carbon cycle as it is an important pool of active carbon. Restoration of depleted soils can lead to a new SOC equilibrium over 25 to 50 years through adoption of Recommended Management Practices (RMP) (Lal *et al.*, 1998) ^[15]. The average rate of carbon sequestration in uplands is 300-500 kg ha⁻¹ (0.01- 0.02%) and in wet lands, 800-1000 kg ha⁻¹ (0.04- 0.05%) (Lal *et al.*, 2007) ^[20]. Soils with greatest potential for C accumulation are those that are severely C depleted but still retaining the requisites such as nutrients, structure and microbial population for primary production or can be suitably managed to increase the productivity in short term. Several approaches and tools are required to develop reliable estimates of changes in soil C at scales ranging from the individual experimental plot to whole regional and national inventories. Increasing the soil organic carbon pool is a long term process. Practice of combined land use system will serve the purpose. Knowledge of soils related to SOC pool sequestration and their sustainable management on priority basis is a must to increase the SOC levels for enhancing productivity and sustainability.

Keywords: Carbon sequestration, waste lands, potential, climate change, management

Introduction

Carbon management through carbon sequestration and its long term storage is a matter of concern and is one of the most important issues of 21st century in India with regard to facing the problems of climate change. Carbon in the atmosphere is increasing by 3.5 Pg per annum. The process of removing the atmospheric carbon to the terrestrial biosphere and storing them in a recalcitrant form can be used as one of the solutions. According to the IPCC (2000), among the different carbon sinks, soil acts as one of the best option for reducing the atmospheric CO₂ and has recognized soil organic carbon pool as one of the five major carbon pools for the Land Use, Land Use Change in Forestry (LULUCF). Each ton of soil organic matter build removes about 3.667 tons of CO₂ from the atmosphere. Maximum soil organic carbon (SOC) sequestration (fig. 1) of different land use systems is an effective strategy for removal of atmospheric CO₂ and improving the quality of soil.

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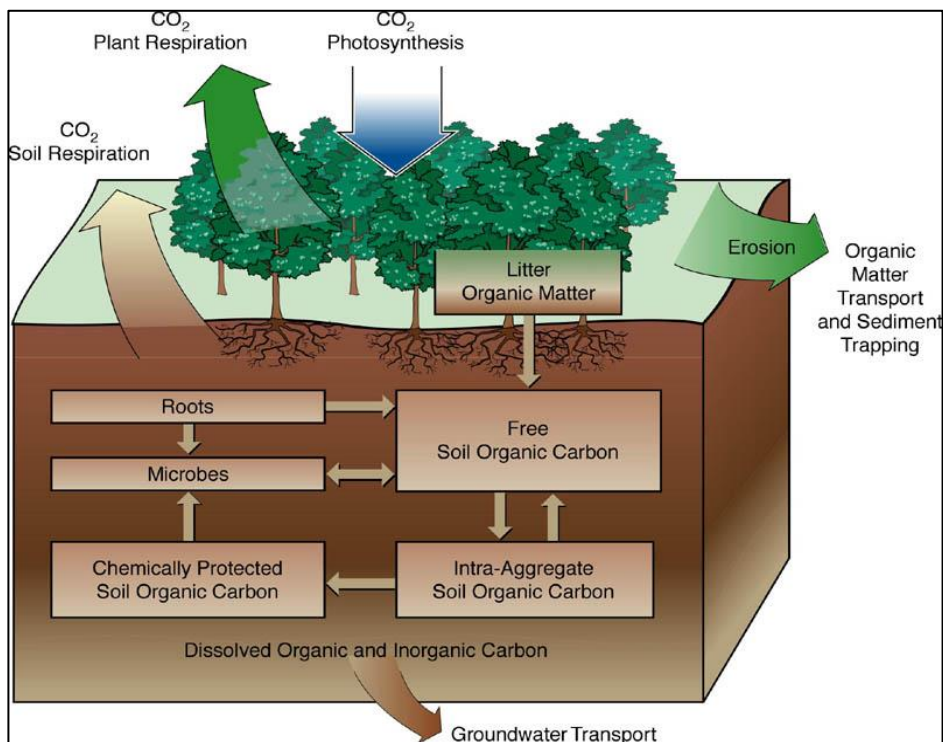


Fig 1: Soil carbon sequestration process

The importance of different land uses in mitigating the climate change globally has been highlighted through climate change negotiations. The global croplands sequester about 0.75-1Pg C/y and accounts about 50 per cent of the 1.6-1.8 Pg C/y lost due to deforestation and other agricultural activities. The emphasis should be given to the land use systems which have the higher potential of carbon sequestration capacity like wastelands than the existing plant community or land use.

2. Mechanism of carbon sequestration

Substantial amounts of SOC are held within stable macroaggregates and are likely to be protected from decomposition through close association with microaggregates and fine mineral fractions (Chander *et al.*, 1997) [31]. The strength and stability of organo-mineral bonds in soil tend to increase with complexity of organic compounds, possibly through physical interaction and chemical protection. Thus, a combination of physical occlusion and chemical recalcitrance results in the stabilization of SOC within aggregates.

3. Waste land

As per National Wasteland Development Board (NWDB), waste land is a degraded land which can be brought under vegetative cover with reasonable effort, which is currently under utilized and is deteriorating for lack of appropriate water and soil management or on account of natural causes. Tropical deforestation, intensive farming, monoculture, over grazing and unskilled cultivation are some of the reasons associated with degradation of the soil and indirectly they also enhance climate change and decrease the productivity of the soil.

Oldeman (1994) [31] assessed that about 2×10^9 ha of soils in the world are degraded and, therefore, increasing the SOC

pool in degraded soils at the rate of 0.01 per cent per year (on soil weight basis) to 1m depth at an average bulk density 1.5 Mg m^{-3} can lead to SOC sequestration of 3 Pg per year, an amount equivalent to the net annual increase of atmospheric CO_2 .

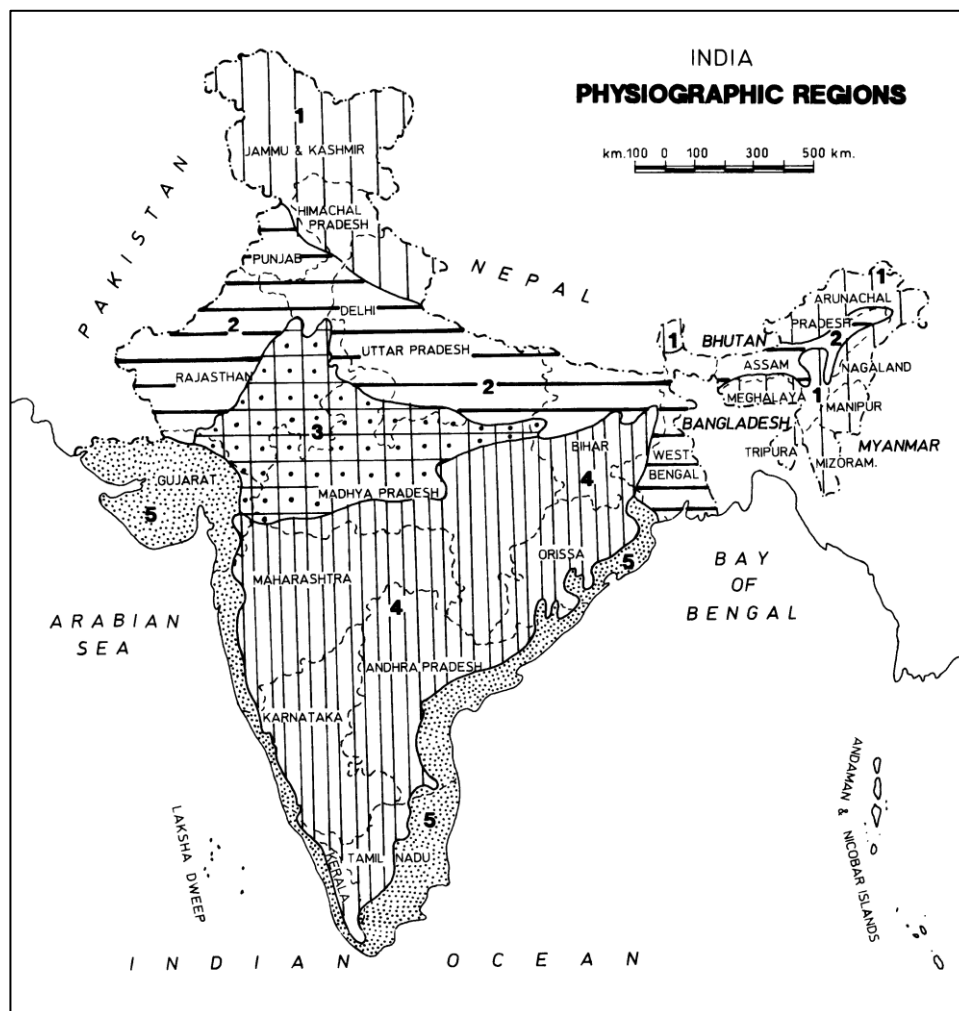
3.1. Classification of wastelands

Broadly wastelands are classified as

1. Cultivated land affected by soil erosion
2. Degraded forest land
3. Degraded land with special problems which is further divided into
 - a. Salt affected lands
 - b. Wind eroded deserts
 - c. Water logged lands
 - d. Gullies and ravines
 - e. Shifting cultivation lands

Table 1: Waste lands in India

Class	Area (km ²)	Area (%)
Gullied land	20553	0.65
Land with scrub	194014	6.13
Waterlogged land	16568	0.52
Saline land	20477	0.65
Shifting cultivation	35142	1.11
Degraded forest land	140652	4.44
Degraded pasture	25978	0.82
Degraded plantation	5828	0.18
Sands inland	50021	1.58
Mining wasteland	1252	0.04
Barren rocky	64584	2.04
Steep sloping area	7656	0.24
Snow covered area	55788	1.76



4. Carbon stocks in Indian soils

The total area under the entire Indian Peninsula is about 328.5 m ha. A recent account of the total carbon stock in soils i.e. alluvial soils (table 2) of Indo-Gangetic plains (IGP) indicates that the soils under hot humid and per humid climates are deficient in SOC due to intensive agricultural practices. Most part of the humid and sub-humid regions of the Great Plains punctuated by 2 to 3 cooler months and dominated by non-

calcareous soils fall under the sufficient zones of SOC content. It has been reported that the soils of arid and semi-arid climates occupying more than one-third area of IGP are poor in SOC content and are thus prone to become calcareous sodic soils. Proper rehabilitation programmes can make these sodic soils resilient and can thus form an important step for carbon sequestration to improve the soil quality.

Table 2: Soil organic carbon stocks in India

Types of soil	Area (m ha)	Carbon stocks (Pg)	Carbon carrying capacity (Pg)
Alluvium derived soil	66.10	3.77	5.65
Red loamy soil	50.50	4.20	6.01
Shallow and medium black soil	33.10	2.71	3.57
Medium and deep black soil	26.62	2.45	3.30
Red and lateritic soil	20.80	1.99	3.22
Brown forest and podzolic soil	17.71	1.36	1.87
Red and yellow soil	13.32	0.60	0.85
Coastal alluvium derived soil	8.13	0.43	0.70
Brown and red hill soil	8.34	1.04	1.68
Desert soil	29.63	0.84	1.30
Mixed red and black soil	39.21	4.75	6.51
Shallow and skeletal soil	15.64	0.19	0.28
Total	328.50	24.33	34.95

Relatively low rainfall and high summer temperature have been found to be the main reason for poor SOC content in the black cotton soils as well as other red soils occurring in the Indian Peninsula. Sequestration of OC in soils of these climates is not possible due to high temperature and less rainfall impairing the fate of vegetative cover over the land. The dominant soils in this part of India are characterized by

shrink-swell minerals and are commonly known as black cotton soils. The SOC reserves are found to vary from 3.64 to 13.34 Pg in the first 30 cm and 150 cm soil depths respectively. This region covers 17 per cent of the total geographical area (TGA) of the country and contributes similar percentage of SOC share. Soils under arid and semi-arid climates irrespective of physiographic regions are

impoverished in SOC despite their ability to interact with organic matter in binding OC in terms of clay–organic complex. The importance of expanding 2:1 clay minerals in the accumulation of SOC is well demonstrated in the ferruginous red soils (Alfisols and Ultisols) of north-eastern, eastern, western and southern parts of the country. Studies indicate that even in the Ultisols of Kerala and in the north-eastern regions of India, the presence of smectite and/or vermiculite either in the form of interstratifications with 0.7 nm mineral or in a discrete mineral form is quite common. The presence of these minerals favours the accumulation of OC in the soil. Calcareous soil in India occurs in 228.8 m ha and cover 69.4 per cent of the TGA. It is spread over 38 out of 60 AESRs. Such soil is present in arid and semi-arid, and also in humid and per-humid climatic regions. The CaCO_3 stock (2 mm) in the top 100 cm of soil in major climatic regions is estimated to be 195.5 Pg and the soil of arid and semi-arid climate constitutes 78 per cent of the stock.

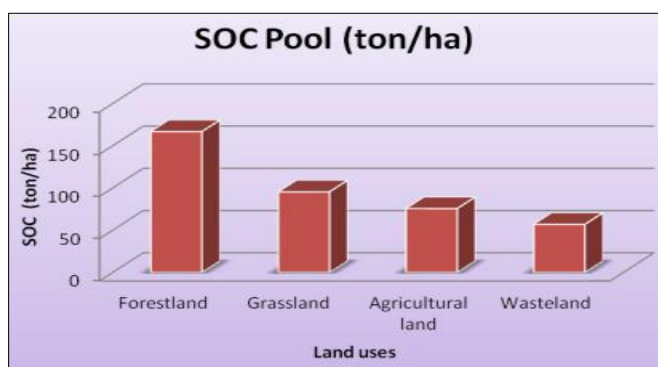


Fig 3: SOC pools in various land uses

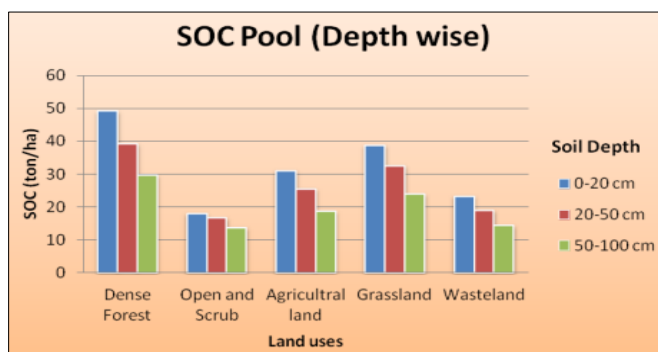


Fig 4: Depthwise SOC pools

Major portion of SOC is retained through clay–organic matter complex formation, indicating the importance of inorganic part of the soil as a substrate to build the SOC. Smectites and vermiculites have the largest specific surface area, and are capable of accumulating greater amounts of OC than the non-expanding minerals. It however, is paradoxical that smectitic Vertisols of India of the arid and semi-arid climates are low in OC content (0–30 cm depth). The OC in clayey, smectitic Vertisols (Haplusterts) decreases rapidly from humid to arid ecosystem, despite that they possess large surface area and bulk density.

5. Ways to increase carbon

Degraded soils exist in remote areas where land managers and farmers cannot afford the inputs needed for soil restoration. The most critical inputs are nutrient elements (e.g., N, P, and K), which must be replenished to enhance biomass production

and convert cropland residues into humus. Lal (2002) [18] identified three strategies to increase SOC concentrations:

- (1) restoration of degraded soils,
- (2) conversion of agriculturally marginal soils to pastures or forest lands, and
- (3) adoption of RMPs on cropland.

Restoration of SOM pool in agricultural soils occurs through adoption of recommended management practices (RMPs) which increase C input into the soil and decrease C decomposition, thereby creating a positive C balance and making soil a net C sink (Lal *et al.*, 1998) [15]. The most important ones are-

- Bio sequestration
- Conservation tillage cropping
- Animal manure application
- Green - manure cropping system
- Improved grassland management
- Cropland-grazing land rotation
- Optimal fertilization

5.1. Bio- sequestration

Bio- sequestration refers to a category of biological processes that absorb carbon dioxide (CO_2), the primary GHG from the atmosphere and contain it in living organic matter, soil, or aquatic ecosystems. Bio sequestration occurs naturally in the global carbon cycle (Fig.5). Terrestrial vegetation, soils, and organic matter contain the equivalent of up to 8,030 G t CO_2 or just under 3

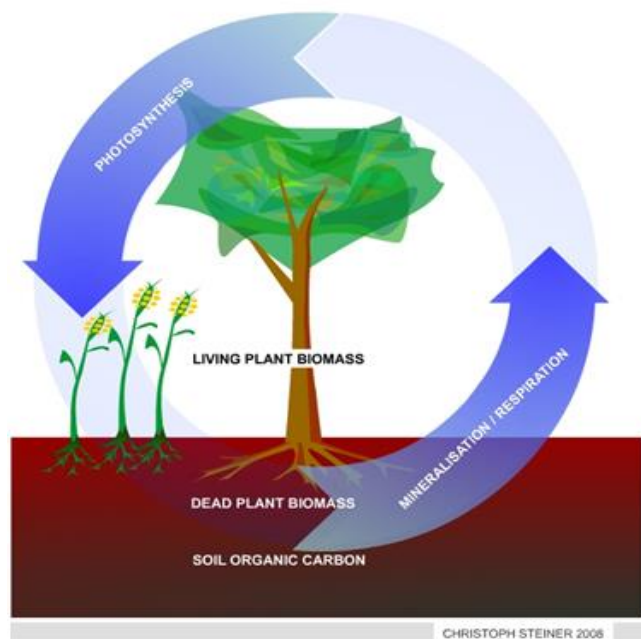


Fig 5: Bio- sequestration at the level of an organism

times the amount contained in the atmosphere. Enhancing the capacity for carbon storage or the rate that CO_2 is bio sequestered (table 3) is an important strategy for mitigating climate change.

The first major category of carbon-sequestering permanent agriculture is perennial crop systems. These crops offer multiple benefits once established, as they are no-tilled, require minimal fossil fuel inputs, and offer long-lived productivity. Systems using these crops include traditional orchards, multi-layer food forests and forest gardens.

Table 3: Sequestration rate of various land management practices

Biome	CO ₂ sequestration rate (Mt acre ⁻¹ y ⁻¹)
Cropland	0.2-0.6
Forest	0.05-3.9
Grassland	0.12-1.0
Swamp/ floodplain/ wetland	2.23-3.71

The amount sequestered vary hugely, depending on several variables

1. Rainfall: humid climates sequester more than dry ones
2. Climate: temperate climates sequester more than tropical ones
3. Species: sequestration varies by species, with some standouts like mesquite
4. Management: layout and management practices have a huge impact
5. Design: polycultures sequester more carbon than monocultures in some studies

5.2. Afforestation and reforestation

Afforestation means planting trees where there were previously none. Reforestation means restoring areas where the trees have been cut down or degraded. Reforestation is almost universally desirable in its own right, particularly if it means re-planting native trees, and is already widely recognised and used to tackle climate change. Many countries are already practising it, such as Brazil, which has pledged to restore 12 m ha of forest. Estimates suggest that afforestation and reforestation can sequester CO₂ at a rate of 3.7 tonnes per hectare per year.

5.3. Bio energy with carbon capture and storage – BECCS

BECCS is widely viewed as the negative emissions technology offering the most promise of drawing significant quantities of CO₂ out of the atmosphere at the lowest cost. BECCS achieves net negative emissions through sequestering underground the emissions resulting from the burning of biomass for power. Negative emissions are achieved because of a “double gain” with the biomass, as it grows, having already drawn CO₂ out of the atmosphere before the carbon capture and storage process begins at the power plant. e.g. miscanthus, willow, neem, pungam, jatropha, hemp, reed etc. The details of *Jatropha* is given below

5.3.1. Jatropha

Jatropha curcas, belonging to the family *Euphorbiaceae*, is a low-growing tree, native to South America, but widely cultivated also throughout Central America, Africa and Asia. *Jatropha* biomass production would sequester 5.50 ton CO₂ ha⁻¹ y⁻¹ and a substantial is unique among renewable energy sources in terms of the number of potential benefits that can be expected to result from its widespread cultivation. As a clean renewable energy, it has zero emission of carbon dioxide, causing almost no environmental pollution. Plantation of energy crop is useful in alleviating the CO₂ level in the atmosphere and emission of CO₂ by burning of biodiesel will always be lower as compared to fossil fuel (petro-diesel). *Jatropha* is unique among renewable energy sources in terms of the number of potential benefits that can be expected to result from its widespread cultivation. As a clean renewable energy, it has zero emission of carbon dioxide, causing almost no environmental pollution. Plantation of energy crop is useful in alleviating the CO₂ level in the atmosphere and emission of CO₂ by burning of biodiesel will always be lower as compared to fossil fuel

(petro-diesel). *Jatropha* proportion of the carbon may enter in the soil because of seed cake mulching. *Jatropha* can help to sequester atmospheric carbon (CO₂) when it is grown on wastelands and in severely degraded ecosystems. A study based on the assessment of the biomass potential of marginal lands in Northern China, (table 5) the reduction of CO₂ emission by using bio-energy is expected to be about 75 million ton of carbon equivalents in 2020, which would account for

Table 4: Economic benefits of biodiesel production in wastelands

Category	2010	2020	2030
Wasteland to be cultivated (m ha)	0.4	2.0	10
Production of biodiesel(mt y-1)	0.2	1.01	5.07
Foreign exchange saving(mUS\$ y-1)	67	334	1672
Savings of CO ₂ consumption(mt y-1)	0.5	2.7	13.4
CO ₂ sequestered in soil (mt y-1)	0.9	4.6	22.9
Possible income (mUS\$ y-1)	14.5	72.5	362.5
Employment generation(man days)	200,000	1,000,000	5,000,000

4 per cent of the total 1.8 billion ton of carbon equivalent of CO₂ emissions in China. In 2050, the reduction of CO₂ emission due to bio-energy is expected to be 150 million ton of carbon equivalents, accounting for 5 per cent of total CO₂ emission. The carbon sink could be sold in the world carbon trade market, which can reduce the cost of bio-energy production and boost the bio-energy development. Utilization of *Jatropha* biodiesel reduces CO₂ emissions and lowers the carbon footprints. Another special feature of *Jatropha* lies in its high level of carbon absorption from the atmosphere and stores it in woody tissues and assists in the building of soil carbon to earn carbon credits.

5.4. C sequestration by cassava

In an experiment conducted at CTCRI, Thiruvananthapuram by John *et al.* 2014, the initial SOC under absolute control (AC-0.67%) and package of practices (POP-0.80%) were increased to 0.82% and 1.08% respectively in the treatments over a period of 20 years. The C sequestered during this period was calculated as 0.147% (1470 ppm) and 0.278% (2780 ppm) for AC and POP respectively. Though the C sequestration values varied across years, the process being mediated to a great extent by soil physico-chemical and biological processes influenced by environmental factors, the enhancement appears to be high in POP than AC (Fig.6).

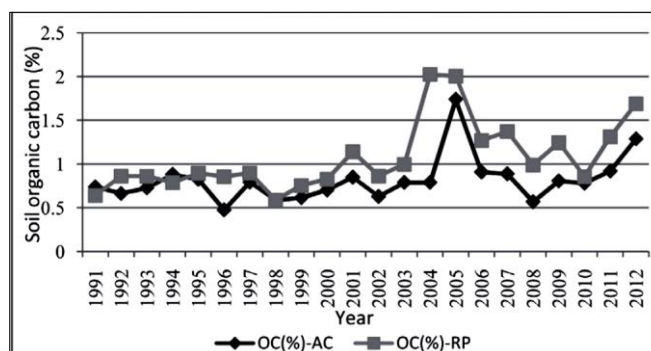


Fig 6: SOC (%) under absolute control (AC) and recommended practice (POP) over a period of 20 years

This could be due to cassava's potential to respond positively to manures and fertilizers. High rate of C sequestration by cassava can be attributed to its high leaf dry matter production to the tune of 3-6 t ha⁻¹, coupled with leaf residue

incorporation in soil due to leaf shedding which in turn resulting an increase in SOC and sufficient foliage canopy giving a shade and thereby a cool soil climate slowing down organic matter mineralization and increases SOC accretion.

5.4.1. Tuber yield

The mean tuber yield obtained in AC and POP over the 20 years was 14.27 and 25.69 t ha⁻¹ respectively. Though the climatic and soil conditions differed during this period, the crop produced substantially good amount of leaf dry matter which might have increased the SOC and consequently improved the soil physico-chemical and biological properties for better tuberization and bulking. At the same time, the data demonstrated the positive effect of manures and fertilizers applied (as per recommended levels) in enhancing the leaf dry matter productivity than absolute control.

Table 5: Carbon sequestration and tuber yield of cassava

Management practice	Leaf dry matter (t ha ⁻¹)	Soil organic carbon content (mg kg ⁻¹)	Carbon sequestered (mg kg ⁻¹)	Tuber yield (t ha ⁻¹)
Recommended practice	3.75	1.08	2780	25.69
Absolute control	2.69	0.82	1470	14.27

According to Lal (2007) [15], the average rate of C sequestration in uplands is 300-500 kg ha⁻¹ (0.01-0.02%) and in wet lands, 800-1000 kg ha⁻¹ (0.04- 0.05%). Moreover, the average rate of C sequestration by adopting recommended crop management practices ranged from 50 to 1000 kg ha⁻¹.

5.5 Conservation tillage

Conservation tillage (CT) is “any tillage and planting system that maintains at least 30% of the soil surface covered by residue after planting to reduce water erosion; or where wind erosion is primary concern, maintain at least 1000 kg ha⁻¹ of flat, small grain residue equivalent on the surface during the critical wind erosion period”. The peak rate of SOC increase by converting plow-till to no-till system may occur within 5–10 y with SOC reaching new equilibrium within 15–20 y (West and Post, 2002). While tillage and cultivation result in a decline in SOC, conservation tillage or no-till practices increase SOC concentration. There are about 1.5 billion ha of cropland in the world (FAO, 2000).

Returning more crop residues is associated with an increase in SOC concentration (Larson *et al.*, 1978), and effect of rotation on SOC concentration also depends on the quantity of residues returned. Larson *et al.* (1978) found that different types of crop residues (e.g., wheat, corn, and alfalfa) applied in equal amounts show similar ability to maintain the SOM pool. Crop residues placed on the soil surface reflect light and protect soil from high temperatures and evaporative losses of water (Franzluebbers *et al.*, 1995), and are beneficial to enhancing soil fertility and SOC concentration (Jacinthe *et al.*, 2002).

Crop residues are the source of C for microbes and fauna, which stabilize soil structure and provide physical protection of the soil surface against structure-altering processes like rainfall or vehicular traffic. In undisturbed no-till soils, surface plant residues contribute indirectly to macropore/biopore formation and provide food for the earthworms (Edwards *et al.*, 1989).

The role of crop residues on carbon sequestration in soils would be an added advantage in relation to climate change and GHGs mitigation. Establishment and maintenance of soil health is inextricably linked to the achievement of effective

and efficient nutrient management goal in conservation agriculture. The conservation agriculture builds a stratified layer of crop nutrients, especially P on or near the soil surface. While reduced tillage and soil organic C build-up contribute to stable soil structure, this undisturbed structure produces macro pores and preferential flow channels that can direct nutrients, including P, downward into deeper parts of the soil profile. The choice of cropping systems can have a strong influence on the soil quality through processes such as nutrient depletion and/or enrichment through production of biomass/crop residues, need for external inputs and impact on environment. Conservation tillage can reduce overall nitrogen loss by reducing ammonium-nitrogen loss and organic-nitrogen loss with sediment; however, it may not reduce nitrogen leaching in the nitrate form.

5.6. Cover crop

Including a cover crop within a rotation cycle is also beneficial to SOC sequestration (Lal and Bruce, 1999) [16] but increase in SOC concentration can be negated when the cover crop is incorporated into the soil (Utomo *et al.*, 1987). Cover crops enhance soil protection, soil fertility, groundwater quality, pest management, SOC concentration, soil structure, and water stable aggregates (Lal *et al.*, 1991) [25]. The beneficial effects of growing cover crops on aggregation are generally more on heavy-textured than light-textured soils. Cover crops promote SOC sequestration by increasing input of plant residues and providing a vegetal cover during critical periods as table 8 (Bowman *et al.*, 1999). A systematical use of cover crops has long-term effects, including protection of soil and environment, and uptake and storage of plant nutrients between seasons when available nutrients are susceptible to leaching.

5.7. Improved grassland management

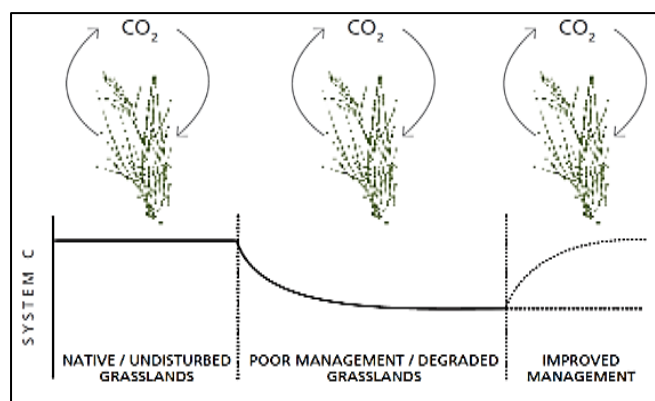


Fig 7: Soil carbon level under different management systems

5.8. Biochar and its role in carbon sequestration

Studies have shown that biochar can be used as an excellent source of sequestering carbon and they can retain about 50% of the carbon present in the biomass feedstock depending on the type of the input. A recent study found that biochar has the potential to sequester up to 4.8 bn tonnes of CO₂ per year. Biochar, has a very high longevity in the forest soil and they raise up to around 10,000 years in some soil. In some of the tropical agro ecosystem they enhanced the crop yield by 2–3 folds and at the same time reduce the field operations which include decrease in the use of the diesel oil. Thus they help in stimulating the overall growth of the organism, primary productivity and at the same time, they are very useful in the net uptake of the carbon (Singh *et al.*, 2007).

The biochar has a very positive impact on the soil. The foremost contribution of bio char to soil is the enhancement of the soil fertility, they increase the water retention capacity, and they also help in the reduction of the runoff from the agricultural input. They are nowadays considered as a potential sink for the soil carbon sequestration because they help in the reduction of the emission of the green house gases like methane and nitrous oxide. They can be used as a simple yet efficient tool for combating climate change. In most of the cases when the organic matter undergo the decay process, green house gases like carbon dioxide and methane are released to the atmosphere. However the carbon present in the biomass can get fixed by charring of the organic matter and this tie up process has a huge potential to reduce the current global carbon emissions by 10 per cent (Woolf *et al.*, 2010).

5.9. 'Blue carbon' sequestration

Salt marshes, mangroves, and sea grass beds act as natural defences against climate change, capturing CO₂ from the atmosphere – even faster than terrestrial forests – and storing it in their leaves, stems and in the soil. Carbon stored in coastal or marine ecosystems is known as 'blue carbon'. Globally, the destruction of a third of coastal and marine wetlands to make way for houses, ports and other commercial activity is shrinking the size of the 'blue carbon' sink. Exposed soils also release CO₂, turning coastal ecosystems from net absorbers of greenhouse gases to net sources. Carbon emissions from degraded mangroves, tidal marshes and sea grasses are thought to be equivalent to 3–19 per cent of those produced annually from deforestation, though some large uncertainties still remain.

6. Carbon Impacts

Sequestering carbon is not the only impact of agricultural practices. Perennial agriculture measures require less fossil fuel inputs, both from mechanization and from chemical fertilizers. Some of the other impacts are:

6.1. Climate change mitigation

The agricultural soils in the tropics have underwent a massive decline in their carbon content due to the long extractive farming practices. Even though they have lost most of their native carbon, they can act as potential sink for the carbon and it is possible by implementing proper management practices. Carbon sequestration has been cited as one of the potential strategy for the removal of the green house gases which are present in the atmosphere. Majority of the tropical ecosystem have lost around 30–40 t C per ha and thus they have very high potential to sequester carbon.

6.1.1. Cassava as a crop to mitigate global warming

The increase in CO₂ level of the atmosphere is the major cause for increase in atmospheric temperature, which in turn results in warming up of the entire environment including land, water and air. Crops like cassava can be presumed to possess global warming mitigation potential due to its effect in reducing the atmospheric CO₂ and consequently the atmospheric temperature through the production of large quantities of leaf biomass.

6.1.2. C sequestration versus soil productivity

Relation between C sequestration and food security can be interpreted in terms of two aspects viz., enhanced soil acquisition of carbon and humus/ residue accumulated in the soil forming a source of nutrients. Enhancing soil carbon

acquisition results in increasing soil organic carbon levels, increase in soil quality, improvement in soil environment and increase in nutrient use efficiency which helped to increase the biomass yield.

7. Assessment of carbon turnover in soils

In order to make biomass decomposition and C turnover in specific systems visible and measurable labeling procedures have been applied. They are

- 7.1. Stable or radio isotope labeled biomass turnover in soils
- 7.2. Measurement of C residence time in soils, based on thin layer wise ¹⁴C dating
- 7.3. Scanning soil profiles by ¹⁴C measurements

8. Challenges in development of bio sequestration practices

- a. Carbon storage easily reversed and re-emitted to the atmosphere
- b. Establishing "baseline" measurements
- c. Transaction costs
- d. Property rights and decision-making

9. Conclusion

Key to sustainable management of soil during the 21st century lies in using ecological principles in agricultural ecosystems (Pierce and Lal, 1991) [25]. Agricultural practices which promote the input of C and slow decomposition of SOM lead to SOC sequestration and improve soil quality. Crop management practices interact with one another and with the environment, and no single practice guarantees enhancement of soil quality. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), improved crop management in the world scale can sequester 125 MMT by 2010 and 258 MMT of SOC in 2040. Better management of agroforestry can bring additional 26 MMT in 2010 and 45 MMT of SOC in 2040. Similarly, improved management of grazing land has the potential to sequester 168MMTin 2010 and 474MMT of SOC in 2040.

The soils in the Asia/pacific region and Sub-Saharan Africa are impoverished in SOC and nutrient reserves, and severely degraded, which make about 90% of the 1,020 million people food-insecure. Due to climate change, the increase in temperature and decrease in mean annual rainfall (MAR) is expected to cause further food insecurity in these regions. The twin crisis of climate change and food insecurity can however, be overcome by restoring the SOC pool and the attendant improvement in soil quality. Among the several options to mitigate climate change, the sequestration of C in agricultural soil is an important one. Much of the demand for food in tropical areas of Increasing SOC concentration is a long-term process. In most cultivated soils, changes in SOC are slow and may not occur over a short period of <10 years. Soil fertility management practices may not change SOC concentration by more than 10% (Jenkinson *et al.*, 1987; Paustian *et al.*, 1992). Restoration of depleted soils can lead to a new SOC equilibrium over 25 to 50 years through adoption of RMPs (Lal *et al.*, 1998b) [21]. Oldeman (1994) [31] assessed that about 2×10⁹ ha of soils in the world are degraded and, therefore, increasing the SOC pool in degraded soils at the rate of 0.01% per year (on soil weight basis) to 1m depth at an average bulk density 1.5Mgm⁻³ can lead to SOC sequestration of 3Pg year⁻¹, an amount equivalent to the net annual increase of atmospheric CO₂ (Lal, 1997) [15]. Despite this vast potential, it is important to realize that improving SOC concentration in degraded soils is a challenging task.

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