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Chapter

Sugar Industry Wastes as Wealth of Organic Carbon for Soil

Anbalagan Krishnaveni, Sivakumar Chinnasamy, Jamuna Elumalai and Pandiyan Muthaiyan

Abstract

The organic carbon management in the soil and its relationship with soil physiochemical and biological characteristics to increase the crop productivity have been described based on the byproducts of sugarcane. In this chapter, the available information on the nutrient content especially the organic carbon of various by-products of sugarcane, paves the way for incorporation of waste materials and its compost for improving the soil fertility by soil scientists and agronomists, and further, the ecologists will realize the importance of sugarcane waste and its meritorious characteristics of toxic residue free soil and food products in addition to reducing the emission of greenhouse gases to the atmosphere, especially methane and nitrous oxides due to applied of synthetic fertilizer in the cultivating field. We have compiled the information on relationship between organic carbon and soil characteristic, factors responsible for depletion of soil organic carbon and its management. The composting process for sugarcane press mud, bagasse, and trash to produce nutrient-rich manure for soil fertility management and its value on saving the purchase of chemical fertilizer leads to easy adoption of organic farming. Overall, we emphasized the importance of waste products of sugarcane and it's nutritive value to increase the soil fertility, crop productivity, and farm income.

Keywords: nutrient composition, press mud, bagasse, molasses, microbial status, enzyme activity

1. Introduction

The organic carbon is essential to activate the physical, chemical, and biological components formation in the soil. The organic carbon is a perennial element because all macro- and micronutrients utilized by flora and fauna are decomposed and finally deposited as carbon-rich organic matter, humus, fossil fuel, etc., in the soil layers. But, the formation and deposition processes have become very low due to intensive cropping system, monocropping system without incorporation of leguminous crops as a sole crop or intercrop, lack of in situ crop residue recycling, poor application of organic manures, leaching of soil top fertile layer due to improper soil conservation measures, and excessive use of chemical fertilizers and other socio-economic factors. In this world, enormous quantity of organic by-products of animal and plant based are available to enrich or sustain the carbon level in the soil. There are many agro-based industries, especially the sugarcane-based sugar industry is widely located and generates different types of by-products like press mud, molasses, bagasse, etc., during the production of crystal sugar for commercial purpose. These by-products are not being utilized as organic manure to the soil due to lack of awareness of its nutrient's richness, particularly organic carbon and other nutrients. Instead, these by-products have been heaped or improperly disposed in and around the industrial factories resulting major health impacts to local residents and livestock are in addition to soil and air pollution. The sugarcane-based by-products contain lignocellulosic compounds that are the main source of carbon through microbial decomposition. In turn, the organic carbon is very essential for the microbial nitrogen mineralization and also crucial for the solubilization of fixed nutrients, particularly phosphorus and potassium in the clay particles of different soil types. Overall, the organic carbon is the heart of the soil for its nature to activate the action of biotic and abiotic components in the soil ecosystem. The knowledge on status, importance, and sources of organic carbon in the soil is very important to manage the continuously decreasing the organic carbon content, which ultimately affect the floral biodiversity of the soil.

1.1 Status of soil organic carbon in different types of soil

The status of organic carbon in the soil varies according to the soil organic matter content and its nature of origin, i.e., plants, animals, minerals, etc. The organic carbons will be estimated easily based on the soil organic matter status. In general, the organic carbon content of the soil is 1.72 times lesser than the soil organic matters. Overall, the higher end of soil organic carbon ranges between 0.1 and 10.0 per cent in various types of soil in the different region. its productivity is assessed based on physical, chemical, and biological traits in addition to floral and faunal diversity. The biodiversity of the soil is directly connected to the soil organic carbon or fertility status and also crop productivity. The soil nutrient status is very important for the growth and development of crop for different stages like seedling, vegetative, reproductive, and maturity to complete its life cycle and finally to attain its senescence. If the soil is having major and micronutrient deficiency means it will be shown on the plant as nutritional deficiency symptoms due to improper physiological activities and to some extent it will invite different pest and pathogens attack, which result to lowest yields when compared to its maximum yield potentiality. The organic carbon content in the different ecosystems like terrestrial, aquatic, grassland, forest, etc., contain different levels with maximum of 60 %. The organic carbon in the organic matter in the 1 m of Earth soil is 2200 Gt. Soil is a mother to flora, fauna, and human being through its sacrifices as habitat, food generator in the form of fruits, vegetables, grains, and medicines to cure different diseases in addition to maintaining the ecological and climate balance of the Earth.

1.2 Formula for estimating soil organic carbon

Soil organic carbon available in different pools is 15–225 t Carbon per ha in the 0–30 cm soil layer. The formation of soil organic carbon is due to mineralization of carbon and nutrients [1]. The total mass of organic matter, i.e., 58%, exists as carbon. To measure the total organic carbon (%), the conversion factor is 1.72 or 100/58; hence, organic matter (%) = total organic carbon (%) $\times$ 1.72. This conversion factor will differ from soil to soil. But, the value 1.72 gives reasonable value of soil organic matter.

1.3 Importance of organic carbon in the soil

The physicochemical and biological properties in the soil are either directly or indirectly depending on the soil organic carbon for its formation and reaction.

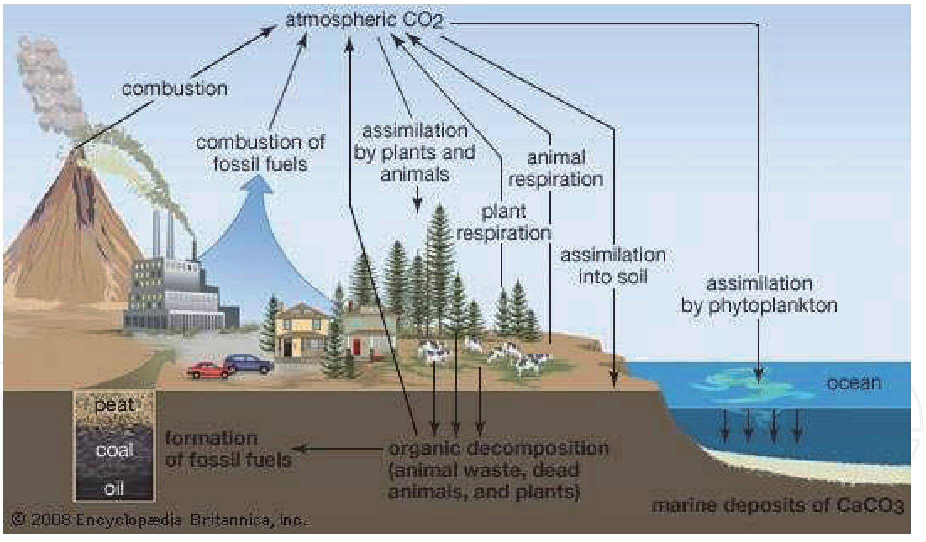

Figure 1.
Flow carbon in the soil ecosystem depending on many factors, for example changing climate, land use, soil layer in the critical zone (editors of Encyclopedia Britannica).

The soil organic carbon is calculated and expressed in the unit percentage (%). The minimum level of organic carbon in the soil plays a major role in the activation of soil chemical reactions and microbial growth and development. The major source of organic carbons is from organic matter of either plant or animal origin. Generally, the differences of soil organic matter, inorganic soil carbon, and organic carbon differ through its persistence in the soil. **Figure 1** indicates that the particulate organic carbons comes from fresh leaf residues and living organism with labile nature of 1–5 years. The humus organic carbon has 20–40 years of association with the soil organic matter of soil, whereas the resistant organic carbon from humus and charcoal has 500–1000 years of bond with the soil organic matter. Soil functions are the important function on Earth's land zone to support the living and nonliving things formation and disintegrate into different organic and inorganic compounds to supply energy and nutrient to the flora and fauna species. The carbon is the basic element for the entire living organism to build its body mass and further multiplication. The flow carbon in the soil ecosystem depends on many factors, for example, changing climate, land use, and soil layer in the critical zone (**Figure 1**).

2. Soil physical properties

The physical properties are mainly the structure and texture of soil. It mainly depends on size of soil particles bond with particulate organic carbon of clay particles of different types of involves in the structural stability of soil from silt to sand. The particle size of the soil varies from coarse sand (2.0–0.2 mm), fine sand (0.2–0.02 mm), silt (0.02–0.002 mm), and fine clay (<0.002). The particle density of the good soil are 2.65 mega grams per cubic meter.

2.1 Soil color

The physical property like color of the soil indicates the organic carbon content, for example, the soil color is black means it has more organic carbon, which absorbs maximum solar radiation and paves for long-time photosynthesis that results in more crop productivity. The red soil shows rich in iron compounds, whereas the light yellow color indicate the iron oxidized soil. The light blue color soil is water logged soils.

2.2 Soil pH and EC

The pH of the soil varies from scale 0 to 14. The acid soil indicates the pH from 0 to 6.5. The neutral soil falls in the range of 6.5–7.5, whereas the alkaline soils has the pH value of >7.5. The soil is EC of indicate soil indicator of soluble salts present in the soil, 0–1.0, 1.1–3.0, >3.1 ds m^{-1}. The montmorillonite clay has the highest ion change capacity particularly positive ion exchange. The positive and negative ions exchange in the outside layer of clay particles. The iron-and aluminum-rich soil show the maximum level of negative ion exchange.

2.3 Soil particles

The soil particles will be classified into microaggregates like 2–20 and 20–250 mm and macro aggregates >250. Microaggregates diameters (2–20 mm) were formed through flocculation of silt clay particles. The negatively charged clay particles are increased through addition of exchangeable calcium cation and also the available trivalent aluminum cation. The microaggregates (20–250 mm) were formed initially from the products available through decomposition of organic debris.

The soil macroaggregates (>250 mm) contains primary particles, whereas the microaggregates are associated with plant root mycorrhizae and particulate organic matter and its stability maintained by soil management. The water holding capacity, porosity, bulk density, and strength of the soil depend on the stability of the soil aggregate. The soil organic carbon of the soil is decreasing from 1.5 to 1.2%, which means that the stability of micro- and macro aggregates of soil is also decreasing simultaneously. About 2% level of soil organic carbon is required to stabilize the soil micro- and macro aggregates [2]. The maximum soil organic carbon for the soil aggregates stability is 3.2–4.0% [3]. The soil particles aggregates stability does not reach a limit; the process of stability will increase with increase in soil organic matter content of the soil due to microbial decomposition [4].

3. Chemical properties

The chemical properties of the soil will influence the certain functions of the floras. The organic carbon contributes to the chemical elements cation exchange capacity and also enhances buffer capacity in accordance to changing pH of the soil. Chemical functions of the organic carbon contribute to the chemical elements cation exchange capacity and also enhance buffer capacity in accordance to changing pH of the soil. The cations and anions' complexes reduce the availability of toxic cation like Al_3^+ in the soil solution. The cations and anions' complexes reduce the availability of toxic cation like Al_3^+ in the soil solution. To estimate the capacity of soil carbon, fractions to undertake some of the functions vary with different soil types. The main organic carbon sources in the soil are humic and fulvic acids, which are holding highest chemical activity, whereas the particulate organic carbon is mainly involving in soil aggregates stability and texture. In general, the standard amount of the soil carbon compounds are essential for the soil functions like water holding capacity and enzymatic microbial activity for the mineralization of nutritive elements. Krull et al. [5] reported that the importance of the different organic carbon fractions for its role in plant physiological functions varies with respect to different soil types. The soil organic matter paves the importance functions of provide cation exchange capacity in sandy type of soil. The most important function

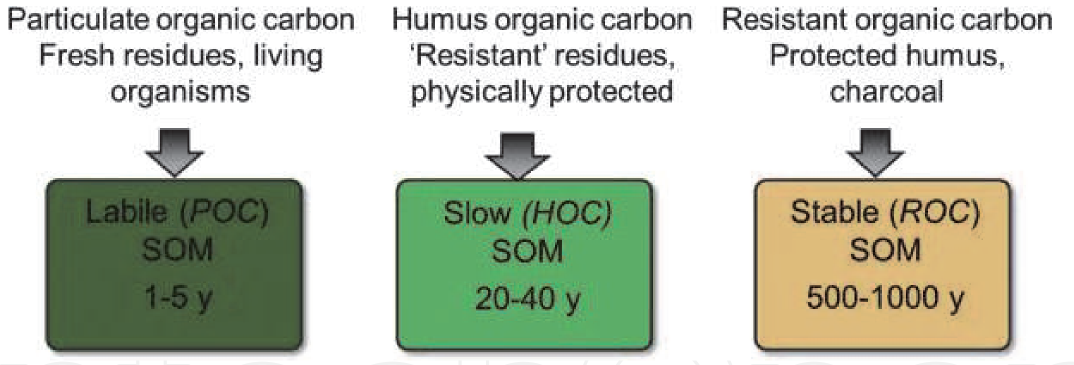

Figure 2.
Different types of carbon and its longevity with soil organic matter. (University of Minnesota Extension Publication WW-07402).

the need for soil organic matter to provide a food and energy source for the microbial populations is needed in all soils, regardless of clay content or texture

3.1 Soil organic matter

Soil organic matter in the soil comprises of all the organic materials available in soils through natural or external application. The natural sources include microbial organisms, flora and fauna, particulate organic matter, humus, charred organic materials, and charcoal. The definition of soil organic matter excludes larger than 2 mm size organic materials [6].

3.2 Soil organic carbon

Soil organic matter consists of carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur. The soil organic matter has been actually determined analytically based on the level of soil organic carbon. The common conversion factor is 1.72. The content of soil organic matter will be calculated through the soil organic carbon multiplied with 1.72 [6]. The different types of carbon and its longevity with soil organic matters are shown in **Figure 2**.

3.3 Inorganic soil carbon

The inorganic carbon will originate in arid soils in combination with more mineral materials like basalts, limestone, and calcium, and is also formed from magnesium carbonate or dolomite. The inorganic carbon is not counted in the soil organic carbon level. The inorganic carbon will not contribute the soil organic matter [7].

4. Biological functions

The biological function of carbon-containing organic matters provides a major carbon, hydrogen, and nitrogen sources of energy to microorganisms for its metabolism. The microbial load and its activity are very essential for the biological processes like nutrient elements mineralization, decomposition of organic residues, and also solubilization of fixed nutrients in clay particles of the soil. The microbial action in the soil is highly dependent on the organic carbon through organic matter decomposition which further involves in the nutrient recycling in the crop land ecosystem (**Table 1**). The different microbial categories are involving in different function for the nutrients uptake by plants.

4.1 Factors influencing the organic carbon content in the soil

The organic carbon balance is very important for initiation of all the physical processes to build the soil structure and texture, which are essential for plant growth and further establishment. The organic carbon balance of the soil is varying due to natural and manmade causes that imbalance the input (addition) and output (depletion) ratio. The positive balance is essential for the soil fertility and crop productivity. The carbon source in the form of CO_2 absorbed from the atmosphere by floras in the soil and deposited as either organic or inorganic form in the soil particles for long period of time through natural process. The negative balance is being occurring in the soil when the uptake is more than addition. So, the basic understanding on factor responsible for carbon deposition and depletion is required to sustain the carbon load in soil ecosystem for its utilization by flora and fauna (**Table 2**).

5. Sources of carbon to the soil ecosystem

5.1 Soil organic matter cycling

The type of soil, climatic factors, and management practices influence the organic matter addition to soil through its turnover or decomposition. Among the weather factors, rainfall is critical for plant growth and soil microbial activity, which leads to decomposition of organic residues available in the soil ecosystem. There are different soil organic matter fractions, viz. particulate, dissolved, humus, and resistant types. Their turn over in the soil is very different in terms of duration (**Table 3**). Furthermore, soil organic matter cycles occurring continuously between livings, stable and decomposing fractions in the soil (**Figure 3**).

5.2 Natural carbon cycle

Carbon cycle is the combination of different processes like respiration, translocation, absorption, photosynthesis, and decomposition. In the carbon cycle, carbon containing living and nonliving things are cycling between different ecosystems, like terrestrial, aquatic, forest with living organisms in the atmosphere. The carbon element is taken up by plants from the atmosphere through respiration for food

S. No	Microorganisms	Function in the soil
1.	Bacteria	Decomposition of organic matters for nitrogen fixation and carbon accumulation Mineralization of nitrate and nitrite nitrogen and release of carbon compounds Oxidation of ion- and sulfur-containing organic matters
2.	Fungi	Decomposition of organic matters which releases organic carbon to the soil
3.	Actinomycetes	Absorption of nutrients and decomposition of organic mater
4.	Earthworm	Lifting of organic carbon to the upper layer of the soil

Table 1.
Microorganisms and its role in soil.

S. No.	Carbon status	Level
1.	Organic C is around 2 × greater C content than Earth's atmosphere[a]	60%
2.	Amount of carbon in top 1 m of Earth's soil [b] 2/3 as organic matter	2200 Gt
3.	Fraction of antecedent soil and vegetation carbon characteristically lost from agricultural land since 19th century[c]	25%
4.	Fraction of global land area degraded in past 25 years due to soil carbon loss[d]	1 mm $year^{-1}$
5.	Rate of soil loss due to conventional agriculture tillage soil formation[e]	0.01 mm $year^{-1}$
6.	Global mean land denudation rate [a, f]	0.06 mm $year^{-1}$
7.	Rate of peat lands loss due to drainage compared to peat accumulation rate[g]	20× faster
8.	Equivalent fraction of anthropogenic greenhouse gas emissions from peatland loss[g]	6% annually
9.	Soil greenhouse gas contributions to anthropogenic emissions, in CO_2 Equivalents[h]	25%

Source: Banwart et al. [8].
[a]*Rate of land lowering due to chemical and physical weathering losses.*
[b]*Batjes [9].*
[c]*Houghton [10].*
[d]*Bai et al. [11].*
[e]*Montgomery [12].*
[f]*Wilkinson and McElroy [13].*
[g]*Joosten [14].*
[h]*2004 data not including CH4, IPCC (2007).*

Table 2.
Fact sheet of global soil carbon reserves.

Microorganisms	Compounds	Composition	Amount in soil	Fractions for models
Nonliving organic matter	Dissolved organic matter	Litter	<0.1%	Labile soil carbon Active pool
	Particulate organic matter	Macro-organic material	5–20%	Decomposable plant materials (low C:N ratio, low lignin) Resistant plant material (high C:N ratio, high lignin)
		Light fraction		
	Humus	Non-humic biomolecules	65–80%	Resistant plant material (high C:N ratio, high lignin)
		Humic substances		
	Inert organic matter	Charcoal/char		
Living organic matter	Phytomass	Plant roots, litter	1%	Labile soil carbon
	Microbial biomass	Bacteria	2–5%	Active pool Decomposable plant materials (Low C:N ratio, low lignin)
	Faunal biomass	Fungal	<1%	Resistant plant material (High C:N ratio, high lignin) (High C:N ratio, high lignin)

Table 3.
Fractions of soil organic matter based on Baldock and Sjemstad [16] and use for soil carbon models [17].

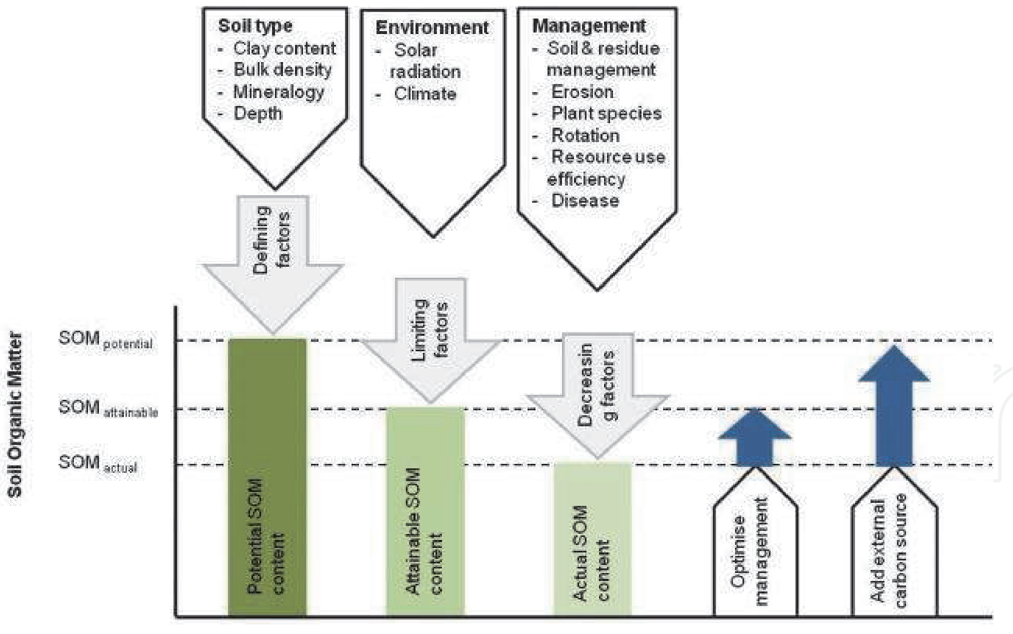

Figure 3.
The influence of soil type, climate, and management factors on the retention of soil organic matter in soils (Ingram et al. [15]).

production to maintain the food chain of the ecosystem. In the atmosphere, carbon is available in the gaseous form as carbon dioxide (CO_2) due to the attachment of carbon to oxygen. The carbon dioxide from the air is taken up by the plants to produce the food as carbohydrate in the presence of sun and water. Later, the carbon in plants and animals will enter into the soil ecosystem due to decaying process of plant parts and animal bodies after completing their life cycle at senescence stage. There are certain exceptional conditions like earthquake and tsunami, where the plant and animal parts will be buried in the deeper depth of the soil system which are converted into fossil fuel after millions and millions of years. The carbon moves from the ground to atmosphere due to burning of fossil fuels, debris of plant and animal origin. The movement of carbon from fossil fuels to the atmosphere is occurring in a fast manner due to burning of fossil field and then quantity of five and a half billion tons of carbon are released into the atmosphere (**Figure 4**).

Another important process in the carbon cycle is releasing carbon dioxide gas (CO_2) into the atmosphere by each exhale of living organisms. Animals and plants are getting carbon dioxide gas through the respiration process.

The role of carbon for regulation of global climate is inevitable. The activities of living organisms on the Earth, including the human beings, increased the carbon releasing form as carbon dioxide through burning of crop residues and fossil fuels. Forest ecosystem is a major sink for carbon. But, the deforestation due to infrastructure development and forest fire are causing the leaf mass reduction, which ultimately affect the CO_2 sink in the ecosystem. The floral green masses are major storage green cylinder for CO_2, especially during photosynthesis to produce carbohydrate (CHO). On the other hand, the atmospheric carbon concentration is an increasing trend due to population, urbanization, changing life styles, etc., which ultimately affect the climatic condition of the region, habitat loss, floral and faunal extinction, and health risk to human and animals due to global warming.

5.3 Decomposing of natural flora and fauna

The decomposition of plant and animal residues will result in the formation of different soil organic carbon fractions, which ultimately improves the pH buffering

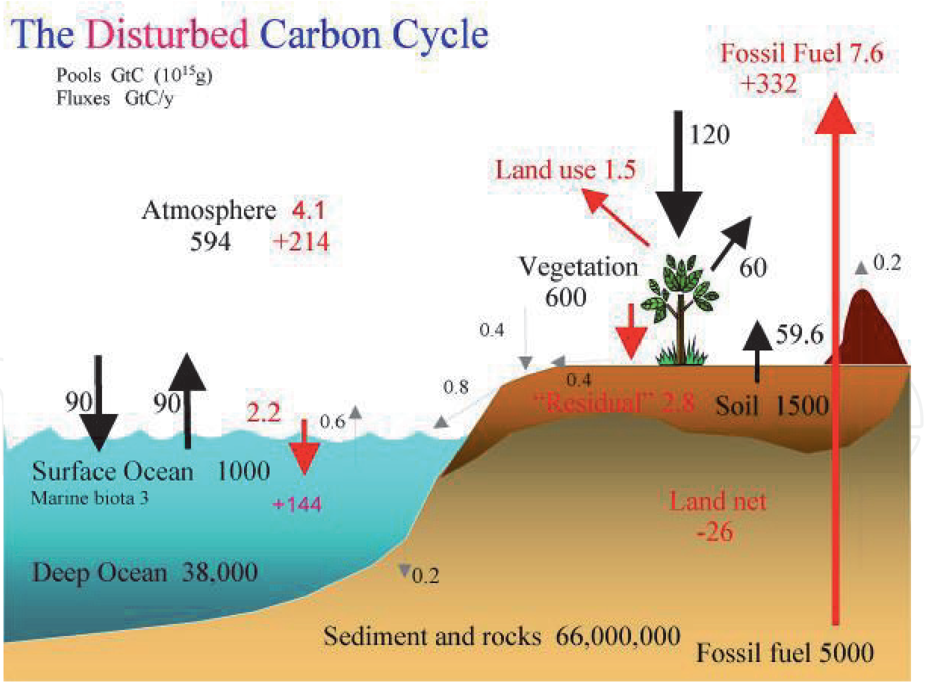

Figure 4.
Carbon cycle in between both natural and manmade fluxes. Ning Zeng, 2008.

capacity and cation exchange capacity in the soil. The transformation of nitrogen-based organic crop residues occurs during decomposition to inorganic molecules; for example, organic nitrogen (N) to ammonia ($NH4^+$) and nitrate ($NO_3{}^-$) adds nutrient to soil and also organic matter. Sometimes, the production of these gases (CO_2, N_2O, NH_3, N_2, and CH_4) contributes to the greenhouse effect and global warming. The beneficial microbial agents like bacteria, fungi, and actinomycetes are decompose the organic residues available on the soil and make around 90% of the organic carbon entering in soil. In doing so, they respire the carbon back into the atmosphere as carbon dioxide. Based on the soil types and climatic conditions, 30% of organic inputs are converted into humus due to activity of microorganisms. The clay soils will retain more organic matter than sandy soils, so the organic carbon content also increased. The cool climatic condition will not favor for the microbial action on organic residues which paves way for slow buildup of organic carbon in the soil.

5.4 Industrial organic wastes

The waste materials are generated by various industrial sectors in the different parts of the country. Organic wastes such as cassava rind, sugarcane bagasse, potato peel, coffee husk, and banana bark have been used as a substrate in solid-state fermentation using different microorganisms for the production of aromatic substances [18]. It is found that most of the aromatic compounds are industrially produced by microbial fermentation [20]. The wastes' by-products produced from food and agricultural industries are voluminous and rich in carbon-containing compounds such as carbohydrates, proteins, and other nutrients, which can be utilized as a substrate for the production of chemicals and enzymes by the solid-state fermentation technique [21]. In this technique, the nature of the solid substrate is a very important aspect. However, the solid substrate contains nutrients for microbial multiplication and renders physical support for the growth of microbial cells. Currently, there has been an increasing trend toward the recycling of agro-industrial waste including sugarcane press mud and bagasse. Pandey et al. [22]

reported various processes on sugarcane by-products for different purposes like paper production, power generation, the production of paper, and manure and alcohol based on fermentation.

6. Role of sugarcane by-products for soil fertility

6.1 Status of sugarcane by-products

India is highly dependent on agriculture, which is the main income source and employment generating sector for its development. Sugarcane is one of the important crops; crystal sugar is produced in commercial quantity. India is the second largest sugar producing country in the point of crystal sugar production. The sugarcane by-products like bagasse, molasses, and press mud are generated from this industry; so to handle this large quantity of waste products in a safe and eco-friendly disposal manner is highly required in this hour. Press mud is a by-product obtained from sugarcane syrup during processing. If it is discharged into environment without proper treatment, it causes soil and water pollution. In addition, the sugarcane by-products possess many plant nutrients and organic matter to enhance the soil physiochemical and biological properties [23]. Sugarcane is one of the commercial crops and cultivated across all the agro-climatic zones of the world [24, 25]. Choudhary et al. [26] stated that the areas of the crops are around 26.9 million hectares (M ha) and cover more than 110 countries with production of 1.91 billion tonnes (bt) [27]. Sugarcane is a cash crop as well as long-duration nutrient exhaustive crop [28]. Though many commercial crops are available in different parts of the country, sugarcane is the maximum cultivated crop due to its commercial valued commodities like crystal sugar and jaggery and its by-products, viz. trash press mud, bagasse, for organic manure usage, and alcohol from the molasses (**Table 4**).

6.2 Important soil amending nutrient rich sugarcane by-products

Brazil is the first largest sugar producing country and then India ranks second. In India, Maharashtra state is the first in sugar production. So, industries are producing huge volume of waste products which requires safe and eco-friendly management practices to obtain the organic manure for cropping land. The press mud contains higher amount of nutrients, so it has to be composted to be used as biomanure for different crops. Among the industries, sugarcane industries are generating various by-products, viz. trash, press mud, and bagasse of nutrient-rich organic nature. Hence, these by-products have to be processed effectively for

States	Press mud	Bagasse	Bagasse ash
Punjab	0.111	0.555	0.094
Haryana	0.160	0.801	0.136
Uttar Pradesh	3.516	17.571	2.987
Karnataka	0.913	4.566	0.773
Maharashtra	1.925	9.624	1.630
All India	**8.774**	**43.845**	**7.454**

Table 4.
Sugarcane by-products produced by the sugar mills in India (Mt) [29] (Fertilizer Statistics 2011).

utilizing as nutrient source for various crop cultivation programs and incorporated as reclaim the problem soil especially sodic soil.

7. Press mud

The estimated production of crystal sugar is around 354.95 million tons in the world and nearly 704 sugar mills are running in India. The sugarcane by-products are about 8 million tons in the form of press mud [30]. Press mud is used as biocompost to maintain the soil fertility and increase the crop productivity because the by-products contains the maximum amount of nutrients, viz. cellulose, hemicellulose, fiber, organic carbon in addition to nitrogen, phosphorus, potassium, magnesium, and calcium; and the micronutrients like zinc (Zn), iron (Fe), Copper (Cu), and manganese (Mn) [31] and also contains beneficial microorganisms. These by-products are holding many beneficial effects on soil properties particularly the fertility, which ultimately increase the productivity of the crop [32].

The advantage of applying the organic inputs to the soil environment will prevent indiscriminate usage of chemical fertilizer to the soil. The composted press mud manure is produced after drying crop residues to maintain the moisture content and also for active microbial population [33].

The well-decomposed press mud is odorless, dark brown, soft, and spongy nature with many cellulosic and hemic cellulosic materials including fibers, wax, and organic aggregates [34]. The cost of chemical fertilizers is increasing in rapid manner which results unaffordable by cultivators, so the by-products like press mud has promise as a cheap cost source of plant nutrient for cost effective crop production and also for improvement in the physical parameters like texture, structure, porosity, water-holding capacity, and moisture content.

The chemical characteristics such as pH, electrical conductivity (EC), cation exchange capacity (CEC), and biological factors like microbial pollution have been improved due to application of composted press mud [35]. The by-products of sugar industry can be utilized for carbon sequestration, which means transferring of carbon fractions or CO_2 into various carbon pools like forest, soil for long periods of time that can be stored [36]. Application of press mud as an organic manure shows 150% increase in the organic carbon after first application, and it has the potential to store more carbon and also help in reducing the impact of global warming.

7.1 Nutrient status of the press mud

Sugarcane press mud contains many nutrients, so it can be applied as organic manure to the crop and composted for value addition for easy uptake by the plants. Generally, the compost sample contains C/N ratio of 725.95, total potassium of 1.43%, and total organic carbon of 12.53%. The organic residues inoculated with microbial cultures such as *Trichoderma, Aspergillus niger*, *Pleurotus*, and *Phanerochaete* are effectively reducing the wastes into valuable organic manure (**Table 5**). This final organic manure contains maximum amount of nutrients so it can directly be applied to the agriculture field to meet out the nutrient requirement of crops.

7.2 Effect of press mud on soil physical properties

Generally, the addition of organic residues to soil maximizes the organic carbon content and also activate the other nutrients [36]. Further, the application of organic compounds enhances the microbial population and microbial diversity in

SI. No.	Parameter	Raw press mud	Unit
1	pH	6.25	
2	Electrical conductivity	6.554	mS/cm
3	Moisture content	72.50	%
4	Total organic carbon	12.53	%
5	Total Kjeldahl nitrogen	0.48	%
6	Total phosphorus (as P_2O_5)	0.40	%
7	Total potassium (as K_2O)	1.09	%
8	C/N ratio	25.95	
9	Iron	0.15	mg/kg

Table 5.
Nutrient composition of raw press mud from sugar industry.

the soil, because the organic residues contain organic sources for its energy [37]. The organic source like filter cake increased the cation exchange capacity for 30 months after its application [38], and the residual effect remains up to 4 years in soil [39]. Regular addition of organic materials such as press mud compost, municipal biosolids, animal manures, and crop residues is of most importance in maintaining the tilth, fertility, and productivity of agricultural soils [40]. Press mud or filter cake is one of the important organic by-products of sugar industry which is capable of supplying sufficient amount of plant nutrients to soil, due to its favorable effects on soil texture, structure, water holding capacity, infiltration, soil porosity, hydraulic properties, and bulk density of soil, and can be linked to most of the fundamental soil properties [41]. However, these are accompanied by improvements in soil aggregate stability [42]. The physical environments of the soil ecosystem are critical for a healthy soil and sustainable agriculture. The higher amount of N, P, and K in soil has made it a valuable nutrient resource, which is due to increased SOM by adding press mud compost [42]. Addition of press mud improves soil aeration and drainage in heavy soils, whereas in sandy soils, it helps in improving the retention of moisture. When added to agriculture fields, it increased the cane yield, improved the juice quality, and enhanced the ammonifying power of the soils [43].

7.3 Effect of press mud on soil chemical properties

Many research finding stated that the press mud can be utilized for crop cultivation and also to improve chemical properties of the soil. The press mud contains the maximum amount of organic matter and significant quantity of micronutrients such as zinc, copper, iron, and manganese. Therefore, the application of press mud will likely to improve the micronutrient status and enhance the beneficial microbial population in the soil system. Soil organic matter increases cation exchange capacity (CEC) through enhancing the adsorbing power of the soils and then producing cations such as, Mg^{2+}, $Ca2^{+}$, and K^{+} during the organic residues decomposition [43]. The composted press mud contains the essential plant nutrients such as nitrogen (N), phosphorus (P), and number of micronutrients in higher concentrations than soils [44] fertilizer value and have been used to replace or partially replace inorganic fertilizers to increase soil, available Phosphorus (P) [45] and exchangeable potassium (K) [46], calcium (Ca), and magnesium (Mg) [47]. Continued decomposition of more stable organic N sources as press mud compost over a sustained period regulates the subsequent mineralization of available N in soil [48], which is balanced by partial biological immobilization by soil microbes and this balance provide a residual source of N available for plant uptake. The CEC (capacity to retain and exchange cations) of soils is measured as the sum of exchangeable Ca, Mg, K, sodium (Na), and aluminum (Al) cations present per unit weight of soil; however, the level and balance of these ions are important factors in structural stability, nutrient availability, pH, and the soil reaction to fertilizers and other amendment [49]. The press mud contains potash and phosphorus, inoculation of potash mobilizing bacteria (*Frateuria aurantia*), and phosphate solubilizing bacteria in the composting materials that increases the availability of K_2O and P_2O5 in the wastes. This may be used later like other organic amendments.

7.4 Effect of press mud on soil biological properties

Soil organic carbon is a complex and heterogeneous mixture of materials. These materials vary in their physical size, chemical composition, and degree of interaction with soil minerals and extent of decomposition. An industrial waste like press mud is taken as fertilizer to increase organic carbon in soil, with an intention of utilizing the waste and building up organic carbon in the soil. Application of press mud greatly increased bacterial and fungal population in soil [50]. Enhancement of fungal, bacterial, and actinomycetes populations by the application of press mud in agricultural soils marks their roles in decomposition of organic materials to release nutrient for plants growth and development. Furthermore, the higher C biomass and N contents in the soils treated with press mud showed changes in soil organic matter content caused by microbial enzymatic activities. Application of press mud was responsible for a large increase in the number of non-spore-forming bacteria and various fungi including *Neurospora crassa*, *Trichoderma viride*, *Aspergillus* sp., and *Penicillium* sp. An increase in the spore-forming fungi, *Bacillus* and Actinomycetes has a positive influence on soil aggregate stability, which was observed during the final stage of composting of press mud [51].

8. Composting of press mud

The sugarcane by-products are not being utilized or underutilized due to less awareness. As per the views of many researchers, these by-products had the significant impact on soil quality when applied to agricultural soils as organic fertilizer. It improves the soil health and sustainable agronomic productivity. Press mud is a by-product of sugar industry and for every 100 tons of sugarcane crushed, about 3 tons of press mud cake is left behind as by-product. When this by-product is composted, it is converted into a very nutritive organic manure, because composting is a most promising technology of waste disposal, enabling recycling and solid treatment of waste organic matter and by this process, organic solid waste can be biodegraded and can be made suitable by composting and the final compost products could be used in agricultural fields as the fertilizing agent which is rich in micro- and macronutrients; with organic carbon or soil conditioner, it increases the microbial population, prepares beneficial microbial communities, improves microbiological standard and substance which can manage, store, convert, generate various important enzymes and thus, apply to the field without adversely affecting the transformation of organics and reduce odorous gas to release into environment so it is eco-friendly. It is also used to protect the plants from various soil-borne diseases and to maintain soil fertility and enhance sustainable crop production in the degraded lands due to continuous and excessive uses of chemical fertilizers and pesticides. The nutrient mixture act as a catalyst for accelerating the composting process and the microorganisms involved are

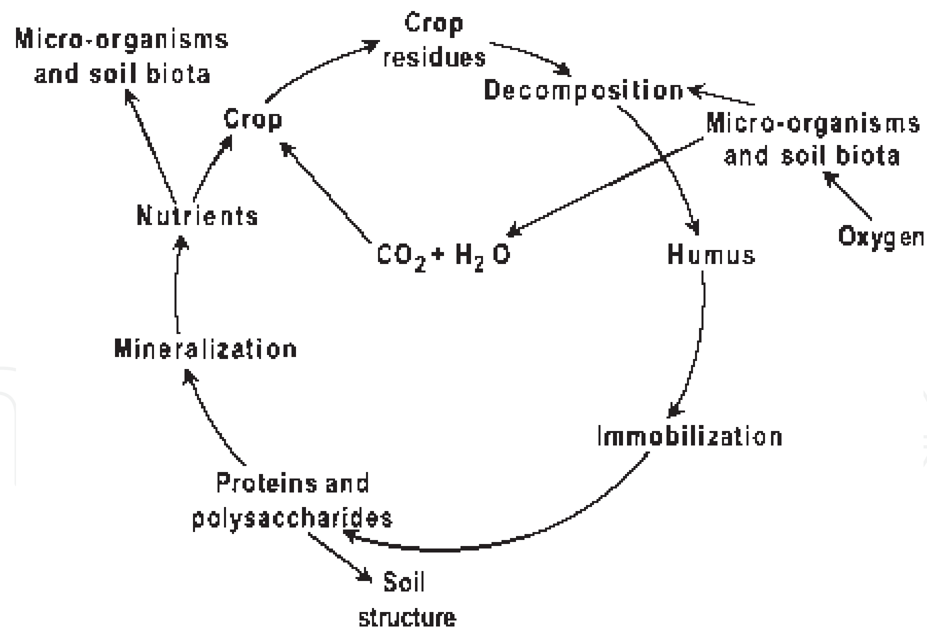

Figure 5.
Crop microbial decomposition cycle (Alexandra Bot, FAO, 2005).

Trichoderma, *Aspergillus niger*, *Pleurotus*, and *Phanerochaete*. *Trichoderma* is a fungus and also biofungicide, which is playing an important role to decompose the cellulosic matter of the organic residues into glucose. The fungus, *Pleurotus* is an Oyster Mushroom and a commonly cultivated species, and is also found in dead plants. The fungi are white or grayish brown or brown in color.

The important saprophytic fungus is *Phanerochaete*, called as white root fungus because it has the ability to decompose the polymers like lignin and chemicals at the moderate temperature of 40°C and efficiency changes based on the chemical content of the waste. The chemical composition of organic residues varies based on soil conditions, cane duration, cane varieties, and geographical variations. The crop decomposition cycles is shown in **Figure 5**.

9. Microbial biomass of press mud compost

The appropriate quality and quantity of organic residues are not only sources of organic matter and nutrients but improves the soil particle size, floral and faunal biodiversity, and microbial populations in soil [52]. The organic manure-added soil has maximum bacterial, fungal, and other microbial populations, which has a great effect on soil quality and sustainability [53]. The good quality press mud compost contain many nutrients and beneficial microorganisms (**Table 6**).

10. Sugarcane bagasse

Sugarcane bagasse is one of the major cellulosic agro-industrial by-products of Brazil and is being used almost entirely as fuel for the sugar industry. In recent years, there has been a tendency to use efficient agro-industrial waste such as sugarcane bagasse, not only as a fuel but also as a raw material for biotechnological processes, due to its lignocellulosic composition, which can be used for the metabolism of microorganisms to obtain products and metabolites of interest [54]. Sugarcane bagasse contains approximately 50% cellulose and 25% hemicelluloses and lignin. Chemically, bagasse contains about 50% of α-cellulose, 30% of pentosans, and 2.4% ash.

No.	Nutrients	Ave amount/100 g of press mud (%)
1	Organic compound	50
2	Calcium	11
3	Phosphorus	2–3
4	Potassium	1–2
5	Nitrogen	1.5–2.5
6	Magnesium	1
7	Sulfur	0.3
8	Cellulose	11.4
9	Hemicellulose	10.0
10	Lignin	9.3
11	Protein	15.5
12	Wax	8.4
13	Total bacterial count	3.6×10^8 cfu/g
14	Total fungal count	8.1×10^5 cfu/g
15	Total actinomycetes count	2.5×10^5 cfu/g
16	Total *Azotobacter* sp. count	1.2×10^4 cfu/g
17	Total phosphate solubilizers	2.1×10^4 cfu/g

Table 6.
Nutrients composition of composted sugarcane press mud.

A large number of microorganisms, including bacteria, yeasts, and filamentous fungi, have also been used in fermentation processes with sugarcane bagasse as support. Filamentous fungi, especially the basidiomycota, have been widely used and are preferred in the production of enzymes or enrichment of protein. The sugarcane bagasse contributes a significant proportion of the waste produced. In comparison with other agro-industrial residues, sugarcane bagasse is considered a rich solar energy reserve, due to its high growth rate (about 80 t/ha in comparison with 1, 2, and 20 t/ha of wheat, and other plants and trees, respectively) and annual regeneration capacity [55]. Another finding shown an increased amount of nitrogen and phosphorus due to application of vermicompost prepared with bagasse [56].

10.1 Nutritional value of sugarcane bagasse

The nutritional value of sugarcane bagasse is low when compared to other sugarcane by-products. It is highly lignocellulosic residues and contains cell constituents [57]. **Table 7** indicates the value of macronutrients of sugarcane bagasse for soil application.

Sugarcane bagasse	Composition (%)
Moisture	17.3 ± 0.35
Total sugars (in glucose)	30.9 ± 0.15
Protein	1.8 ± 0.33
Lipids	0.7 ± 0.15

Table 7.
Chemical composition of sugarcane bagasse.

10.2 Effect of sugarcane bagasse on soil properties

The average moisture content of the sugarcane bagasse was 17.3%. The filamentous fungi will proliferate well on sugarcane bagasse at moisture content of 50–70% to precede the natural decomposition [58]. The sugarcane bagasse having the moisture content of 17.3% means the bagasse has to saturate with a nutrient solution to increase the moisture percentage in order to grow the fungus. The lipids content was 0.7% [59].

Bonnarme et al. [60] reported that the low percentage of lipids in agro-industrial waste was not useful for the development of the microorganism. The carbohydrate is 30.9% of the wet weight of the press mud residue analyzed [61]. Another finding shown an increased amount of nitrogen and phosphorus through the application of vermicompost prepared with biogases [56]. Hossain et al. [59] stated that plant wastes can be applied as organic fertilizer and soil conditioner and used as soil amendment. El-Halim [62] stated that the water holding capacity attributed to the application of sugarcane bagasse in the soil is due to the coherent interaction of soil and bagasse particles cause soil aggregation. The soil aggregation property is responsible for soil water holding capacity. In [62], it is stated that the total sugar content is 16.4 % in unprocessed bagasse. Glucose can be used by the microbes during fermentation [63]. The filamentous fungus will grow rapidly in different substrates using different carbohydrate substances and produces different metabolites.

Carvalho et al. [64] stated that the amount of 2.0–2.4% of crude protein is found in the sugarcane bagasse. The crude protein content will be raised by the use of chemical additives like urea and ammonia anhydrous of non protein nitrogen compounds. Bagasse is explode as soil basel dose for the cultivation of crops which gives soil physical and economic responses in addition to productivity of the animals [65]. The overall facts on the importance of sugarcane bagasse management are related to disposal of agro-based waste products to the environment which causes environmental pollution [66].

10.3 Nutrient enrichment techniques like composting to enhance the organic carbon and nutrients of sugar factory by-products

The important organic by-product of sugar mills is press mud. This by-product is utilized widely as soil application to provide a nutrient-rich, high quality organic matter especially in subcontinental countries. The organic residue, i.e., press mud is dark brown material that contain macro- and micronutrients. The chemical compounds such as carbohydrate, protein, cellulose, lignin, and sugar fiber, which can be composited into carbon-rich final end product like biomanure [67]. The press mud also involves the production of biocompost and biofuel [68]. The application of pressmud at 20 tons per ha will save 25% of the recommended dose of fertilizers and also leaves the residual nutrient effects on the succeeding crops [69]. The press mud contains 25–30% of organic matter. Further, the pressmud contains major plant nutrients like nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur in addition to the minor micronutrients such as Zn, Fe, Mn, B, Cu, Mo and also the beneficial microorganisms for the composting [70].

11. Composting process

The organic wastes are mainly used for producing organic manure through biocomposting and vermicomposting processes. The sugarcane by-products particularly the press mud is nutritive organic materials of converting itself into organic manure through proper composting technique. Generally, the composting of press mud will be carried out by inoculating inoculum of different microorganisms along with cow dung is an important at the initial stage of composting. The present study concentrates on effectiveness of various microorganisms on decomposition of press mud with a nutrient mixture. As per the literatures, four microorganisms are chosen for the study which is capable of decomposing the press mud as a stable material. Details of the same are discussed below.

12. Microbial compost mixture for sugarcane by-products

Based on many literatures, the general composting procedure is as follows. The collected press mud is dried to remove the moisture content. Later, 5 kg of press mud was weighed and added with 0.60 kg of decomposed cow dung followed by mixing with 2.5 liter of water. The microbial mixtures containing *Trichoderma*, *Aspergillus niger*, *Pleurotus*, and *Phanerochaete* were added to accelerate the composting process. The viable dosage of microorganisms for the composting of this organic waste was 1.0% of the weight of press mud. The mixture of microorganisms and wastes were mixed together to imitate the composting. Moisture content of the composting mixture was 40–60% for the growth and development of the microorganisms. The composting process in container requires proper aeration and maintain the optimum moisture and temperature.

Composting is major technique to reduce the volume of waste. It is a considered as the simple method for recycling the sugarcane by-products of the sugar factories to produce the nutrient-rich manure. It can be used for agricultural amendment to compensate the fertilizer dose in the fertilization schedule of crops [71]. Addition of organic residues to soils is an eco-friendly way to increase soil organic matter content and stability of micro and macro-soil aggregates. The effect of these organic wastes will vary based on the quality of the organic materials added to the soil. The effects of the organic materials on plant growth and the nutrient levels of the organic materials will vary from waste to waste and also one soil type to another. The reviews conducted by NSW Agriculture [72] also indicated the usage of organic waste for different crop cultivation.

13. Effect of sugarcane by-products on soil organic carbon

Razzaq [73] stated that application of sugarcane press mud continuously to the cultivating land for crop production results increased the considerable quantity soil organic carbon in within 5 to 6 years. The soil health has been increased because of addition of sulfur, carbon ions and organic matters. There were numerous findings on the application of press mud as basal dose in the soil for farming any crops like cereals, pulses, oilseeds, commercial crops, and ornamentals, resulting in increased crop productivity in addition to soil carbon build up. Therefore, the application of press mud in the land is a common cultural practice to improve the soil properties in many countries, especially the sugarcane countries like Brazil, India, Pakistan, and Sri Lanka [74]. Above all, the waste to wealth concept is highly suitable to sugarcane by-products because of its numerous traits to sustain the yield, improving the soil fertility and maintaining clean environment in and around the sugar factories in addition to preventing the global warming.

14. Challenges

The level of soil carbon in the soil ecosystem is under threat worldwide due to improper management of soil organic matter through the application of organic manures from crop residues, livestock wastes, industrial waste, etc. In the case of nutrient depletion, the soils are particularly facing the deletion of organic carbon for every cropping operation due to its utilization, and there is no recycling of crop residues in the soil. Instead, the crop residues are either burned or underutilized through heaping and landfilling.

The organic carbon in the soil is highly associated with soil structure. The weather factors like heavy rainfall will erode the top fertile layer of the soil. The cool condition will not support microbial action for composting of different organic residues in the soil, which ultimately affects the organic carbon content of the soil. The different soil management strategies are essential to recycle the carbon through management of soil, crop, and nutrient during the cropping programme. The zero tillage will reduce the physical disturbances to soil. The intensive cropping system should not be adopted even the soil is very fertile because depletion process of carbon is faster than accumulation. Adoption of integrated nutrient management through the application of farm yard manure and adoption of green and green leaf manures incorporation provides an opportunity for the soil to build up its organic carbon. To meet increasing chemical nutrient resource demands and maintain resilience in soil actions due to high-tech farming and climate change, we are in a position to recycle the waste products from different agro-based industries, especially intensive nutrient up taking by crop like sugarcane.

15. Conclusion

Soil carbon is the nuclear element for the fertility status of any type of soil which will be mainly associated with organic matter in the soil ecosystem. The content of soil carbon is very important to catalyze the soil to execute its functions like transformation of nutrient to plants, water holding capacity, floral and faunal biodiversity, and transformation of energy among the different species present in the food chain. The sugar mills are producing huge quantity of by-products like press mud and bagasse, which are heaped in and around the sugar mills resulting in an environmental pollution and health hazard to the human beings and animals. The way for the effective management of waste materials is a need of this hour because it contains many nutrients. The waste products can be used for crop cultivation as soil mulch, manure in the place of chemical fertilizers. The major problem in the disposal of press mud and bagasse is due to their bulkiness and difficulty in transportation. The effective way for reducing the volume of these materials is composting to utilize as organic manure to the soil to enrich its nutrient status. Further, the press mud and bagasse of the sugar industries will be used as an organic manure after the composting process, which is also nutrient for nursery plants, garden plants and different crops cultivated in main fields. Generally, the sugar industry waste products are slightly acidic in nature and contain higher amount of organic matter, so it will be highly suitable to reclaim the alkaline soil contain higher amount of sodium. The available nutrients in this waste materials are composted through effective and suitable environmental friendly technology to enhance its easy absorption by plant system. Above all, the waste materials have to be processed into nutrient-enriched organic products in a commercial mode for marketing and wide adoptability by different sectors like farming, industries, households etc., and to eliminate the environmental pollution.

Acknowledgements

The authors are thankful to IntechOpen, for their motivation to write this book chapter and patience in completing this task. We also thank Dr. M. Pandiyan, Dean, Agricultural College and Research Institute, Vazhavachanur, TNAU.

Conflict of interest

The authors acknowledge that we have not conflict with any findings and suggestions of other authors.

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