CHAPTER 1:

INTRODUCTION
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The atmospheric CO\textsubscript{2} represents the balance between emissions of carbon (C) and removal of CO\textsubscript{2} by terrestrial and oceanic processes [1]. Over the 20\textsuperscript{th} century, population and economic growth caused an ever increasing demand for energy, food and space which evidently resulted in the increased use of conventional fossil fuels (coal, oil and natural gas), deforestation and land use change. These factors substantially enhanced the anthropogenic CO\textsubscript{2} emissions and altered the sink-capacity of land and ocean. According to the emission database of 2011, the global CO\textsubscript{2} emission was estimated at 33.4 billion tonnes in 2011, which is 48\% more than that of the CO\textsubscript{2} concentration 20 years ago [2]. Over the past century, atmospheric CO\textsubscript{2} increased at a decadal growth of 1.15 ppm reaching the present concentration of 407.18 ppm [2]. To mitigate the adverse effect of rising atmospheric CO\textsubscript{2} concentration, the Kyoto Protocol under Article 3.4 identified that capture and storage of C by soil management can aid in controlling the emission of this greenhouse gases. The Intergovernmental Panel on Climate Change [3] estimated that approximately 2000 Pg C can be sequestered in soil and aboveground biomass of the terrestrial system. Agricultural soil has also been recognized as an important tool for sequestering atmospheric CO\textsubscript{2} with an estimated sequestration of 0.4–0.9 Pg C year\textsuperscript{-1} globally [4]. This has generated a broad interest in studying the dynamics of C sequestration in agricultural soils worldwide through alterations or improvement of the management practices [5].

Soil C sequestration refers to the capture of atmospheric C into the soil and its storage for a considerable period of time. Soil holds around 2344 Gt organic C and little disturbance to the soil organic carbon (SOC) pool could result in significant effects on the atmospheric CO\textsubscript{2} concentration [6]. Increasing the input of C into soil compared to output through good soil management practices enhance SOC sequestration while higher output causes loss of C into the atmosphere [7]. Hence, based on the applied practices soil acts as a sink or source of CO\textsubscript{2} [8]. Intensive agriculture has resulted in diminishing the soil organic matter (SOM) and SOC thereby leading to yield stagnation or sometimes declined yield [9]. Soil organic matters are the major sources of soil C, nutrients for plants and microbes and improve soil physical (reduce bulk density (BD) and increase aggregation, porosity and water retention) and biological (enhanced enzyme activities and microbial growth) properties. These ameliorations of soil health
provide environment for profuse root and shoot growth which subsequently increase crop yield. Therefore, comprehensive evaluation of the management practices (considering the regional climate and soil condition) is necessary to identify the most promising management practices for a region to augment SOC sequestration.

The common management practices that enhance soil C sequestration potentiality include agricultural water management, use of balanced fertilization (especially use of organic amendments), crop residue management, conservation tillage, agro-forestry system, multiple cropping system and inclusion of cover crops [7,10].

Management of soil water status is one of the key attributes for maintenance and long-term sustainability of SOC. Under rainfed system, precipitation is critical to maintain crop productivity and limited or erratic rainfall often results in lower yields and sometimes even total crop failure. On the other hand, water supply through irrigation in agricultural lands greatly increase photosynthesis, biomass production and crop yield and thus, sequester large amount of CO₂ in biomass which consequently enhance C sequestration [11,12]. But, it has been widely reported that the availability of water accelerate SOM breakdown by promoting the activities of both microbes and invertebrates [12,13]. Irrigation remoistens dry soil which often disrupts soil structure, exposes the SOM to microbial activity and enhances C mineralization [12]. Therefore, judicious application of irrigation in terms of time and quantity is important as this can promote biomass production, enhance SOC concentration and decrease C-loss through mineralization and microbial decomposition. However, in rainfed system, fertilization, tillage and residue-management practices are the main ways to modify soil environment and to enhance productivity and subsequent C sequestration.

Among the management practices, fertilizer management offers the greatest possibility to increase SOC sequestration [7,14]. Long-term fertilizer experiments reported the importance of balanced fertilization in improving soil nutrient status, sustainable crop yield and residue return which in turn positively contribute to the SOC pool [8,11,14].

The application of inorganic fertilizer to supply nutrients in the crop production systems is a dominant practice world-wide. Presently, 50% of the global population depends on N fertilizer for food production [15]. Unfortunately, N fertilizer is not
judiciously applied in the agricultural ecosystem thereby reducing the N recovery in soil–plant system to less than 50% of the applied N [16]. Increased SOC with the increasing rates of N application have been reported in long-term continuous winter wheat (Triticum aestivum L.) fertility experiments in Oklahoma, USA [17]. Many other studies also documented significant positive effects of balanced fertilization using inorganic N fertilizers on SOC pool, soil health and crop productivity [18,19]. Conversely, some studies suggested no significant effects of inorganic fertilizer application on SOC or its fractions [10,18]. However, the positive effects of N fertilizers are largely negated by the low N recovery and high mobility and transformation of N in soil system which leads to loss of N through denitrification, leaching, volatilization and more especially as N₂O emission [20]. Owing to these detrimental effects in the current agricultural system, reducing the rate of N fertilizer and its substitution with organic amendments is considered to be a sustainable option to uphold crop productivity, soil health and SOC pool [21,22].

Inclusion of organic amendments in crop fertility program has been gaining attention because of the observed environmental benefits and maintenance of soil health along with agricultural sustainability [23]. Organic amendments are the sources of slow-releasing nutrients and energy for soil microorganisms [24] which improve soil aggregation and porosity, increase water holding capacity (WHC), cation exchange capacity and nutrient availability, reduce BD and stabilize soil pH [5,25,26] and consequently promote plant growth and sustainable yield. Organic amendments also serve as the direct source of SOC and thus, application of organics is an efficient way to improve, restore and finally to sequester C in soil. However, organic amendments serve as a substrate for microbial biomass and alter soil microbial community structure and thereby, enhance the microbial mineralization to release nutrients and CO₂ (mainly through respiration) [27]. Annually 75×10¹⁵ g C is reported as global soil respiration flux which accounts for 80% of the gross ecosystem respiration [28]. This indicates that, a minor change in the soil respiration can dramatically alter soil C sequestration and atmospheric CO₂ concentrations [29]. Thus, selecting organic amendments that lowers CO₂ emission, uphold soil quality and SOC pool is necessary for sustainable C sequestration. Application of farmyard manure (FYM) as organic amendment in the
crop field has been practiced traditionally. Farmyard manure application not only directly supplies SOC, but also favors soil aggregate stability by binding with humic substances, supplies plant nutrients and improves crop productivity and soil physico-chemical health [21,30]. However, FYM serves as a readily available substrate for microbes due to less humified nature which consequently results in rapid mineralization. But in the last few decades, composted materials are extensively used. These constitute the composites and vermicomposts from different sources which have high nutritive value with more humified C and act as slow nutrient releasing material and thereby, supply nutrients throughout the crop growth period. Vermicompost is a finely-divided material with high porosity and WHC which makes it an excellent soil conditioner [31]. Addition of vermicompost increases seed germination rate, plant growth and yield [31,32] as it contains plant growth regulators such as cytokinins, gibberellins and auxins [25,33] and is also reported to enhance grain quality of wheat [21,34]. Vermicompost has large particulate surface areas which retains nutrients [35]. Biochar, a pyrolysis product of biomass, is another organic amendment which has recently been introduced in the fertility program of different crops world-wide. Application of biochar to agricultural soil develops fertility and due to its highly porous surface, its application result in increasing WHC, soil aeration, nutrient retention and reduce BD [36]. Furthermore, biochemically recalcitrant and predominantly aromatic C in biochar resist microbial degradation and enhance SOC storage in soil [37]. Biochar application also reduces the emission of GHGs (N\textsubscript{2}O and CO\textsubscript{2}) from agricultural soil due to immobilization and adsorption of N into porous surfaces, thereby, reducing nitrification and denitrification [37]. Positive effects of biochar application from various sources on above-ground plant biomass and yield have been demonstrated [38]. However, application of these organic amendments alone cannot sustainably maintain crop productivity which restricts the framer’s willingness to accept these amendments. Thus, to uphold crop productivity and improve soil health along with increased SOC, integrated application of organic with mineral fertilizers is recommended [7,14,22].

Soil organic carbon stock is a major determinant of sustainable agriculture and soil management practices (fertilizer and water) in the agro-ecosystem influence the quality and quantity of both total and different fractions of C pools [39]. Nevertheless,
owing to the vast size of total SOC pool, the management practice-induced changes in total SOC stock are difficult to quantify within a short time as these changes occur slowly and are relatively small compared to the large SOC pool [4,40]. Under such conditions, study of different SOC fractions acts as the early indicators of management-induced changes over a short period of time [14,22,41]. The SOC is composed of two major pools: labile and stable pools/fractions [42]. The stable fraction comprises the bulk of total C pool, and has turnover times of thousands of years and are largely unaffected by soil management practices [42]. The labile fraction has a much shorter turnover time (mostly less than 10 years) and thus is affected much more rapidly by management-induced changes [43].

Labile organic C fractions mainly constitute of dissolved organic C, easily oxidizable organic C, light fraction organic C, particulate organic C (POC) and microbial biomass C (MBC) [39,44,45]. The POC pool represents the active and easily decomposable fraction which comprise of partly decomposed plant material at an early stage of decomposition and thus, symbolizes a transitional stage in the humification process [45]. Microbial biomass C represents the living pool of SOC and is a vital component of ecosystem cycling [46], serves as source (mineralization) or sink (immobilization) of labile nutrients and regulates all SOM transformations. The dissolved organic C, easily oxidizable organic C and light fraction organic C are the chemical fractions separated based on chemical reactivity. The stable or resistant fractions of SOC include the humic substances. These mainly constitute humic acid C (HAC), fulvic acid C (FAC) and humins and are formed by chemical and biological transformations of plant and animal matter [47]. The stable fractions resist microbial mineralization and hence, management practices that can uphold higher stable C fractions are desirable for long-term soil C storage.

Apart from these fractions, other soil physical (soil texture, moisture content, BD, WHC), chemical (available N, P, K and pH) and biological properties (soil enzymes, microbial population) also directly or indirectly affect SOC storage. Clay particles tend to form smaller aggregates than sand or silt particles, thereby offer greater physical protection to the SOM [48]. Bulk density and WHC indirectly enhance the SOC pool by increasing prolific root and shoot growth which subsequently increase the
residue return and contribute to the SOC pool [21]. In context to SOC sequestration, direct and strong relation of SOC with available N, P and K is well documented in many literatures [5,49]. Optimum nutrient availability may influence SOC cycling by affecting both biological (e.g. enzyme activities) and chemical (e.g. soil pH) soil properties [49] or by increasing crop residue return. Soil pH influences the decomposition of SOM through hydrolysis and protonation processes. Moreover, at low soil pH, soil structure becomes fragile [50] which affect SOC stabilization. Soil enzymes are among the other factors also regulate the SOC stabilization. Soil enzymes are the indicators of microbial activities and thus, with increased SOM, the activities of soil enzymes also increase [51].

The type of crop and its growth stages also play significant role in enhancing SOC. Higher biomass production (both shoot and root) and yield under different management practices is of prime importance for SOC enhancement. Root exudates and sloughed off roots are the sources of labile SOC pool, POC which acts as substrate for MBC [45,52]. Also plants translocate the photosynthate to below-ground biomass which is finally added to the SOC pool. For example, cereal crops translocate about 20-30% of its fixed C to roots, of which two-third is added to the SOC pool [53]. Multiple cropping sequences are reported to increase SOC at a higher rate than mono-cropping sequence. Inclusion of leguminous crop is also considered as another sustainable option to increase SOC pool [7].

Literatures are available on long-term application of organic amendments in conjunction with inorganic fertilizers on SOC and its fractions from various countries and even from different regions of India [14,41,54]. However, there is little published information on SOC and C dynamics of agricultural soils of northeastern region of India more particularly from the north bank plain zone of Assam with acidic new alluvial soil (typic Inceptisols). Majority of the C stock studies from northeast India is on forest ecosystems [55]. Also, to our knowledge, study on the C dynamics due to the application of inorganic fertilizers and different organic amendments (especially biochar) under two water regimes (rainfed and irrigated) in the upland crop sequence (wheat - okra – green gram) has not been reported. This study aimed to reduce the dose of inorganic N fertilizer by the inclusion of organic amendments and to select an
organic amendment from the conventionally used FYM and vermicompost (used from decades) and recently introduced biochar (not yet tested in northeast India) which upholds crop productivity with higher SOC sequestration. Findings of this research work will help to identify the best management practices that uphold productivity of the test crops, enrich the SOC pool and increase the long-term sustainability of C sequestration in the alluvial soil (Inceptisols) of northeast India.

*Hypothesis of the study:*  
- Inorganic N fertilizer doses can be reduced by organic amendments.  
- Different organic amendments have differential responses in terms of soil physico-chemical and biological health.  
- The quantity and quality of organic amendments determine the potentiality to uphold SOC and thus, the CO$_2$ emission.

*Objectives of the study:*  
- To investigate the role of N on the dynamics of SOC enhancement in upland cropping sequence of Assam.  
- To evaluate the role of management practices and soil amendments on SOC sequestration in this cropping sequence.  
- To estimate the C mineralization rate and calculate the turnover period of SOC under different management and cultivation practices.  
- To formulate sustainable soil management practices for higher SOC sequestration in upland agro-ecosystem of Assam.
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References


[41] Nayak, A.K., Gangwar, B., Shukla, A.K., Mazumdar, S.P., Kumar, A., Raja, R.,
Kumar, A., Kumar, V., Rai, P.K., and Mohan, U. Long-term effect of different
integrated nutrient management on soil organic carbon and its fractions and
sustainability of rice–wheat system in Indo Gangetic Plains of India. Field Crops

[42] Haynes, R.J. Labile organic matter fractions as central components of the quality

dynamics and their relationship to soil quality. In: Gregorich, E.G., Carter, M.R.
(Eds.), Soil Quality for Crop Production and Ecosystem Health. Elsevier,

carbon active fractions as early indicators for total carbon change under straw

a grassland cultivation sequence. Soil Science Society of America Journal, 56: 777-
783, 1992.

carbon pools in subtropical forest and agricultural ecosystems as influenced by
management practices and vegetation types. Agriculture, Ecosystems and

affecting soil humic substances in three semi-arid agro-ecosystems in South Africa.

of soil properties on the aggregation of some Mediterranean soils and the use of


[50] Jobbagy, E.G., and Jackson, R.B. Patterns and mechanisms of soil acidification in

[51] Burns, R.G., DeForest, J.L., Marxsen, J., Sinsabaugh, R.L., Stromberger, M.E.,
Wallenstein, M.D., Weintraub, M.N., and Zoppini, A. Soil enzymes in a changing


