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Grass based cropping system source or sink for carbon sequestration to mitigate changing climate: A review

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Abstract

Indian agriculture challenges due to changing climate are natural resource degradation, loss of biodiversity, loss of quality water, increase pollution hazards and environmental security. Incorporation of perennial grasses can be effective to allocate a higher percentage of plant biomass carbon to below ground soil carbon sequestration, extend the growing season, better utilize soil water and reduce tillage disturbance compared to annual crops. Grasses based cropping system (GBCS) help in increasing the fodder yield and resource use efficiency through their vegetation cover, greater root production ability especially bind soil particles, help in soil conservation, sustainable fodder production, adapting to mitigating global climate change, improving water quality, availability and ensuring food security. The rate of carbon sequestration depends on the net balance between carbon inputs and carbon losses per unit time. Mitigation of CO_2 emission from agriculture can be achieved by increasing carbon sequestration in soil which implies storage of carbon as soil organic matter as minimum soil disturbance (tillage), increasing the mass and quality of plant and animal inputs to soils, improving soil *i.e.* microbial diversity, abundance and maintaining continuous living plant cover on soils year-round. This paper reviews Grass based cropping system improves carbon sequestration to mitigate climate change. It provides a unique opportunity to combine the twin objectives of climate change and carbon enhance in to the soil.

Keywords: Carbon sequestration, carbon stock, climate change, grass based cropping system and soil health

Introduction

Climate change refers to any change in climate over time, due to natural variability or as a result of human activity. (Singh *et al.*, 2017; Jakhar *et al.*, 2018b; Kumhar *et al.*, 2019c; Kumar *et al.*, 2019a; Agrawal, K.K., and Jain, Sanjay., 2008; Agrawal, K.K.,2010; Bhadauria *et al.*, 2019) [78, 37, 51, 4, 2, 9]. Intensive agricultural practices lead to poor soil health caused by changes in soil physical and chemical properties, as well as in microbial activity. The large response to mineral fertilizers during the green revolution followed by a shift from animal-based to mechanized farming have led to the indiscriminate use of inorganic fertilizers in the north-western Indo-Gangetic Plains region of India. This has also led to less organic matter input to the soil, which ultimately decreased SOC content to a very small amount. The increase in global temperature because of radioactive forcing of greenhouse gases (GHGs) in the atmosphere has been estimated at 0.6°C during the 20th century and is projected to be 1.4 to 5.8 °C by 2100 relative to 1990 (IPCC, 2001)[76].The concentration of CO_2 has increased from 280 parts per million by volume (ppmv) in 1750 to 367 ppmv in 1999 and currently is increasing at the rate of 1.5 ppmv/yr or 3.3 Pg/yr (1 Pg = petagram = 1 billion metric tons = 1 × 1015 g). The concentration of CH_4 has increased from about 700 ppbv to 1745 ppbv over the same period and is increasing at the rate of 7 ppbv/yr. Similarly, the concentration of N_2O has increased from about 270 ppbv in 1750 to 314 ppbv and is increasing at an average rate of 0.8 ppbv/yr (IPCC, 2001) [76].

Table 1: Present scenario of greenhouse gases

Greenhouse gases (GHGs)	Pre-industrial level 1750	20th century level 1999	Global warming potential	Current level2018	Increase (%)	Radioactive forcing (W/m^2)
CO_2	280 ppmv	367 ppmv	1	406 ppmv	41.2	1.46
CH_4	700 ppbv	1745 ppbv	21	1893ppbv	170.4	0.5
N_2O	270 ppbv	314ppbv	310	326 ppbv	20.7	0.15
CFC-12	0	533pptv	10900	-	-	0.17

PPMV= parts per million by volume, Courtesy (IPCC, 2001) [76]
PPBV=parts per billion by volume,
PPTV= PPMV= parts per trillion by volume

These gases influence the radiation balance by permitting the short-wave radiation to enter the Earth's atmosphere but capturing a fraction of the long-wave radiation emitted by the Earth (Lal R. 2003)[53]. The current radiative forcing of these gases is 1.46 W/m^2 for CO_2 (global warming potential or GWP = 1), 0.5 W/m^2 for CH_4 (GWP = 21), and 0.15 W/m^2 for N_2O (GWP = 310) (IPCC, 2001) [76]. Atmosphere concentration of several greenhouse gases (GHG) has changed drastically since the industrial revolution because of fossil fuel combustion, cement manufacturing, land use change, and the attendant agricultural practices, such as ploughing, biomass burning, use of fertilizers and manure. The global climate regulation service is a regulating ecosystem service mitigating climate change induced by anthropogenic emissions and is mainly supported by plant photosynthesis and the activity of soil microorganisms (Dignac *et al.,* 2017) [13].

Climate change is poised to have a sharply differentiated effect as between agroecological regions, farming systems, social classes and groups other impacts are. (Singh *et al.*, 2017; Agrawal *et al.*, 2019) [78, 91]

Shift in climatic and agriculture zones

1. Impact on agriculture soil
2. Effect on soil organic matter and soil fertility
3. Effect on biological health of soil
4. Soil erosion and sediment transport
5. Reduced soil water availability
6. Impact on soil processes
7. Salinization and alkalization
8. Pest, diseases and weeds
9. Impact on plant growth
10. Impact on crop production

At the dawn of the 21st century, principal global issues include the accelerated greenhouse effect, emission of CO_2 and other GHGs from agricultural practices and food security in relation to soil and environmental degradation. There are several agricultural practices that are C-intensive because of the fossil fuel and energy involved in their use. Important among these are ploughing, fertilizers, pesticides and irrigation. The importance of C sequestration relies in its use as a strategy for mitigating climate change, which is believed to be caused by the increasing greenhouse gases concentrations, mostly CO_2 (IPCC 2014) [33].

Carbon sequestration

Carbon sequestration is the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere. The idea is (1) to prevent carbon emissions produced by human activities from reaching the atmosphere by capturing and diverting them to secure storage, or, (2) to remove carbon from the atmosphere by various means and 'storing' it in the soil (Parihar *et al.,* 2018) [70].

The Department of Energy (2006) refers to carbon sequestration as the provision of long-term storage of carbon in the terrestrial biosphere, underground or the oceans so that the buildup of CO_2 (the principal GHG) concentration in the atmosphere will reduce or slow." The C sequestration process may be naturally or anthropogenic-driven. The natural process includes terrestrial sequestration in soil (humification and formation of secondary carbonates) and trees such as biomass production and storage in above ground and below ground components.

Soil carbon sequestration

Soil organic carbon is considered to be one of the largest carbon reservoirs of terrestrial ecosystems and also plays an important role in the global carbon cycle (Lal R, 2005) [10]. Soil organic carbon is normally estimated to a depth of 0-30 cm since most of it is present in the top layers and root activity is also concentrated in this horizon (Ravindranath and Ostwald, 2008) [77]. Thus the quantity of SOC in the 0-30cm layer is about twice the amount of carbon in atmospheric carbon dioxide (CO_2) and three times that in global above ground vegetation (Powlson *et al.,* 2011) [73]. It is estimated that the global stock of SOC to a depth of 30 cm is 684-724 Pg (Batjes NH, 1996) [8]. A small change in soil carbon results in a large change in atmospheric concentration (IPCC, 2000) [28]. Ground covers (GC) is an efficient practice to reduce soil and nutrient losses in grass based cropping system, so they can act as a sink of atmospheric carbon and improve soil fertility, efficient tool for atmospheric carbon sequestration and to protect the soil from erosion. The selection of species with greater biomass in the shoot and root systems usually increases the C input. On the other hand, carbon sequestration with GC is usually more effective as the initial carbon content in soil was lower before the change in the soil management practices (Miguel *et al*., 2018) [64].

Soil holds the maximum quantity of carbon (C) in terrestrial ecosystems and has the potential to mitigate climate change (Paustian *et al.,* 2016) [11]. Soil organic carbon (SOC) content is at the centre of soil physical, chemical and biological properties and a prime indicator of soil health (Chen *et al.,* 2017) [65]. Soil with better health and quality can produce larger crop yields under both favourable and extreme climatic conditions. Increased soil organic matter content and biological activity, improved soil structure with the maintenance of soil aggregates and reduced oxidation of soil organic matter. Similarly, diversification in crop rotations can also affect soil health by affecting carbon contents because of differences in root activities and chemical composition of different crop residues that are added to soil (Jakhar *et al.,* 2018) [37].

Soil organic Carbon (SOC) concentration, along with its quality and dynamics, is essential to diverse soil functions and ecosystem services. Soil organic matter (SOM), comprising about 45-60% of its mass as SOC, is a principal source of energy for soil microorganisms. (Lal R., 2016) [11].

Three principal components of SOM are as follows: (1) plant and animal residues and living microbial bio-mass; (2) active or labile SOM; and (3) relatively stable. The live biomass in a healthy and dynamic soil may be as much as 5 Mg/ha (Mg = mega-gram = 10^6 g = 1 metric ton). Soil functions, intricately linked with soil quality, depend on specific land use and include sustaining plant and animal productivity (agricultural land use), forest productivity (silviculture land use), air and water quality in relation to human health and habitation (urban land use), contamination with heavy metals (mine-lands and urban lands) etc. Important soil functions of relevance to human well- being and nature conservancy, include: retention and cycling of nutrients, formation and stabilization of soil structure (aggregation), retention and transmission of water, aeration and gaseous exchange, buffering of soil reaction, transformation of compounds and maintenance of biodiversity.). CS enhancing SOC stocks will improve infiltration and soil water holding capacity. Soil quality is related to soil functions or what it does, whereas soil health presents the soil as a finite and dynamic living soil resource and is directly related to plant health. More specifically, soil health is defined as "capacity of soil to function as a vital living system to sustain biological productivity, maintain environment quality and promote plant, animal and human health.).

Soil attributes essential to life include: (1) physical for provisioning of air, water, gaseous exchange and habitat; (2) chemical for moderating soil reaction and availability and transformation of nutrients; (3) biological for source of energy and food and nutrient cycling; and (4) ecological for hydrological and energy budget and landscape process).

SOC is a heterogeneous mixture of organic materials including fresh litter, carbohydrates, and simple sugars, complex organic compounds, some inert materials and pyrogenic com-pounds. The SOC is a highly reactive component and is the basis of numerous pedogenic processes. Because of a high surface area and charge density, it reacts with clay and minerals to form organic–mineral complexes. The mean residence time (MRT) or the rate of its turnover depends on the degree of protection within the soil matrix (Dungait *et al.* 2012) [14].

Hayne (1940) stated that, "if we feed the soil, it will feed us," and that "only productive soil can support a prosperous people." Thus, maintaining soil health is essential to human health, ecosystem functions and nature conservancy. Soil health is more pertinent to global issues now than ever before. Its management is essential to advancing food and nutritional security, critical to mitigating and adapting to changing and uncertain climate, important to reducing non-point source pollution and eutrophication, pertinent to enhancing soil biodiversity and needed to sustainable intensification of agro ecosystems through enhancing use efficiency of inputs (water, nutrients and reducing losses). (Lal R., 2016) [11].

Rate of soil carbon sequestration

Rates of SOC sequestration through adoption of best management practices have been assessed for diverse land uses and eco-regions throughout the country, including for a wide variety of management practices on cropland such as the inclusion of cover crops for conversions to perennial grass for improved management on grazing lands. C out of the atmosphere and into healthy soils will help the agricultural sector feed a growing population, buffer against climate change impacts and contribute to greenhouse gas (GHG) mitigation. Quantity, quality and dynamics/turnover of SOC are critical to soil health (Lal 2014) [14]. Threshold level of SOC in the rootzone is 1.5–2.0%. Maintenance of SOC pool at above the threshold/critical level is essential to: (1) soil structure and aggregation which govern soil tilth and aeration; (2) water retention and use efficiency which control tolerance to drought, heat wave and abrupt climate change; (3) nutrient retention and use efficiency which moderate non-point source pollution, water quality and toxic algal blooms; (4) rhizospheric processes which influence elemental transformations and creation of disease- suppressive soils; and (5) gaseous emissions (e.g., CO_2, CH_4,N_2O) which moderate atmospheric chemistry and regulate climate change.).

The rate of soil organic carbon sequestration with adoption of recommended technologies depends on soil texture and structure, rainfall, temperature, farming system and soil management. Strategies to increase the soil carbon pool include soil restoration and woodland regeneration, no-till farming, cover crops, nutrient management, manuring and sludge application, improved grazing, water conservation and harvesting, efficient irrigation, agroforestry practices and growing energy crops on spare lands. (Lal R. 2004) [54]. The rate of SOC sequestration and quality of soil C stock depend on the complex interaction between climate, soils, tree species management and chemical composition of the litter as determined by the dominant tree species (Lal R. 2005) [10].

Soil organic carbon (SOC) strongly impacts soil quality, functionality and health. Terms soil quality and soil health should not be used interchangeable. Soil quality is related to what it does (functions), whereas soil health treats soil as a living biological entity that affects plant health. Through plant growth, soil health is also connected with the health of animals, humans, and ecosystems within its domain. Through supply of macro and micro-nutrients, soil health, mediated by SOC dynamics is a strong determinant of global food and nutritional security. Soil C pool consists of two related but distinct components: SOC and soil inorganic C (SIC). Soil functions and ecosystem services depend on SOC and its dynamics. Improvements in soil health, along with increase in availability of water and nutrients, increases soil's resilience against extreme climate events (*e.g.*, drought, heat wave) and imparts disease-suppressive attributes. Enhancing and sustaining soil health is also pertinent to advancing sustainable development goals of the U.N. such as alleviating poverty, reducing hunger, improving health, and promoting economic development

Global warming and increasing atmospheric greenhouse gas concentrations have underlined the importance of increasing carbon sequestration in grassland soil (IPCC, 2001; Lal, 2004) [76].

The SOC stock (Mg/ha) for each soil depth (cm) was calculated following Lal (1998) as: TOC stock = TOC content × soil depth × bulk density × 10000.

Estimated C-stocks were converted into CO_2 equivalents (quantity of C × 44/12) for calculating CO_2 assimilation by biomass of grasses/trees (Kanime *et al.*, 2013) [40].

Dry biomass was converted to carbon stock with a factor 0.47 (IPCC, 2006) [30].

Table 2: Sources of GHG emission in atmosphere

S. No.	Source	Value	References
1.	Fossil carbon combustion	9.3 Gt C	Le Querer *et al.*, 2016
2.	Emissions in agriculture	CO_2 eq. 636 071 Gg	FAO databook 2018 [16]
3.	Net emissions in land use	CO_2 eq. 122 469 Gg	FAO databook 2018 [16]
4.	Organic carbon stored in soils	2400 Gt C	Batjes, 1996 [8]
5.	Global anthropogenic carbon emissions	9.3 Gt C/yr	(Minasny *et al.*, 2017 [65]

Inclusion of Legumes

The symbiotic plant trait of legumes enables atmospheric N_2 to be fixed and partly made available to subsequent crops, leading to increased soil quality and SOC (Abberton, 2010) [1]. The connection between legumes and soil improvements such as increased yields was established by Hellriegel and Wilfarth (1888) [26]. Furthermore, the increased N made available to crops can lead to reduced needs of N fertilizers. The previously mentioned study by Fornara and Tilman (2008) [17] identified a doubled soil C accumulation at one m depth in perennial grasslands where legume species are present, disregarding the level of diversity within the field after 12 years.

The study also showed that legumes increased the total root biomass (0-60 cm) as well as the accumulation of N which, according to the authors, stimulates the storage of C in the soils by increasing above and below-ground biomass production and thereby enhancing C input. Our findings offer an insight into the potential impacts of restoration practices to increase plant diversity on soil C sequestration and the role of N-fixing plant species. Specifically, we show that long-term biodiversity restoration practices increased soil C and N storage especially when these treatments were combined with the recent promotion of the legume (Gerlinde *et al.,* 2011) [21].

Table 3: Inclusion of legumes in grass-based cropping system accumulated carbon sequestration.

S. No.	Crop	Carbon sequestration (t CO_2/ha/year)	References
1.	Cumbu Napier grass	112.12	Sathiya BK and Babu C (2016) [86]
2.	multicut fodder sorghum	148	Sathiya BK and Babu C (2016) [86]
3.	Lucerne	86.4	Sathiya BK and Babu C (2016) [86]
4.	BN hybrid	4.15	AICRP on FCU, 2017 [87]
5.	Guinea grass	3.03	AICRP on FCU, 2017 [87]
6.	BN hybrid + Lucerne	4.28	AICRP on FCU, 2017 [87]
7.	BN hybrid + Desmanthus	4.42	AICRP on FCU, 2017 [87]
8.	BN hybrid + Sesbania	4.33	AICRP on FCU, 2017 [87]
9.	Guinea grass + Lucerne	3.18	AICRP on FCU, 2017 [87]
10.	Guinea grass + Desmanthus	3.31	AICRP on FCU, 2017 [87]
11	Guinea grass + Sesbania	3.28	AICRP on FCU, 2017 [87]

Nitrogen fixed through legume pastures and forages provides an important contribution (Peoples *et al.,* 2015; Li *et al.,* 2015; Jain *et al.,* 1993; Agrawal *et al.,* 2004) [72, 60, 35]. Legumes develop deep root systems, which may promote soil water infiltration and retention, as well as water and nutrients exploitation from deep soil, increasing resource availability for plant growth (Wu *et al.,* 2016; Yuan *et al.,* 2016; Kumhar *et al.,* 2017). The inclusion of legumes also enhances soil carbon sequestration by improving plant production in artificial grasslands (Fornara and Tilman, 2008) [17].

Perennial grasses

Most of the C content in soil derives from plants, mainly from decaying plant tissue or from roots storing and exuding C (De Deyn *et al.,* 2008) [12]. It has been shown that perennial plants, with greater root biomass and root length, store more C in roots compared to annual plants (Warembourg & Estelrich, 2001) leading to a higher content of SOC, which accounts for the differences between perennial grasslands and annual croplands (DuPont *et al.,* 2014) [15]. A significant effect of higher C accumulation in perennial grasslands depending on total below ground biomass has also been detected (Fornara and Tilman, 2008) [17]. Perennial grasses and their roots for maintenance of soil quality and productivity, combined with reduced requirements of external inputs. Further advantages of perennial crops with deeper roots are improved access to water during dry periods and less mobile phosphorus, in addition to their contribution to improved soil stability and reduced SOC losses through soil erosion (Kell, 2012; DuPont *et al.,* 2014; Lal, 2004, Kumhar *et al.,* 2019) [42, 20, 54]. Perennial forages provide a range of environmental benefits in managing water, nutrients and carbon (Li *et al.,* 2019). Grass based cropping system has been recognized as a means to reduce CO_2 emissions as well as enhance carbon sinks.

Table 4: Fodder crops stored organic carbon

S. No.	Crop	Carbon	References
1.	Cumbu Napier grass	9.2 g/kg of soil organic carbon	Sathiya BK and Babu C (2016) [86]
2.	Multicut fodder sorghum	(8.7 g/kg)	Sathiya BK and Babu C (2016) [86]
3.	Hybrid napier	59.02%	Sivakumar *et al*., 2014[79]
4.	Hedge lucerne	58.60%	Sivakumar *et al*., 2014[79]
5.	Fodder maize	54.17%	Sivakumar *et al*., 2014[79]
6.	Fodder cowpea	53.46%	Sivakumar *et al*., 2014[79]

Fortunately, the soil carbon stock can be restored through converting arable land to perennial grassland. Globally, soils are the largest terrestrial carbon (C) reservoir, but there is compelling evidence that over the last few decades large amounts of C have been lost from soils of natural and agricultural ecosystems through erosion, leaching and accelerated soil respiration (Quinton *et al.* 2010) [75].

Plant C inputs into the soil and their subsequent transformation have been quantified and reviewed for upland crops (maize, wheat and barley) and grasses (rye grass, Festuca and Bromus) using 14C or 13C labelling under controlled and field conditions. Such differences are mainly due to (1) differences in the root growth rate and root biomass; *i.e.*, the root biomass of rice plants is larger than that of wheat plants but smaller than that of maize plants; (2) anaerobic conditions in paddy soil, which reduce root growth and activity, as well as the development of fine roots and root branching; (3) anaerobic production of toxic substances, such as ethanol and lactate, which hinder root development and root-microbiota interactions; and (4) slower diffusion of atmospheric O_2 to the roots through aerenchyma in rice. (Luo *et al.*,2017; Pausch and Kuzyakov, 2018; Kumar *et al.,* 2017) [61, 71, 43].

Carbon stocks are a function of carbon inputs and outputs

All ecosystems such as forest ecosystems, agro-ecosystems and grassland ecosystems, *etc*. taken up atmospheric CO_2 and mineral nutrients and transform them into organic products. In grasslands, carbon assimilation is directed towards the production of fibre and forage by manipulating species composition and growing conditions. Ecosystems are a major source and sink for the three main biogenic greenhouse gases

(GHG) –CO_2, nitrous oxide (N_2O) and methane (CH_4). In undisturbed ecosystems, the carbon balance tends to be positive: carbon uptake through photosynthesis exceeds losses from respiration, even in mature, old growth forest ecosystems (Luyssaert *et al.*, 2008; Gough *et al.*, 2008) [62, 24].

In the presence of climate change, land degradation and biodiversity loss, soils have become one of the most vulnerable resources in the world. burning of fossil fuels, land use and land cover change (which includes agriculture) is the largest anthropogenic source of carbon into the atmosphere and within agriculture, soils have been a global net source of GHGs. SOM is composed of roughly 58% carbon which corresponds to SOC and is influenced by microbial activity, accessibility of organic residues to microbes, various site conditions and management practices. Managing SOC through sustainable agricultural and land use practices has become a widely acknowledged strategy to restore healthy soil properties to combat degradation, desertification and enhance the resilience of agro-ecosystems to environmental shocks. (GSOC17, 2017).

Agriculture has a significant task to play towards an effort to mitigate the climate change due to atmospheric enrichment of CO_2. Scientific agriculture can be an explanation to ecological issues but especially to plummeting the rate of fortification of CO_2 in the atmosphere. Recommended management approaches comprise translation from cultivate till to no-till, amalgamation of wrap crops and forages in the crop rotation, nutrient management including compost/manures and cautious exploitation of fertilizers. The immovability of soil C accumulation depends on the permanence of the recommended scientific approaches adopted. With continuation of recommended management practices, however, the sequestered C stays for a relatively extensive time in the soil pool and declines the rate of enhancement of atmospheric CO_2 absorption. Decline in the enlarged rates of farming invention and productivity is a solemn concern bearing in mind the questions of food security, livelihood, and environment. As such, a decisive assessment of the advance for sustainable agricultural expansion is indispensable (Nishanth *et al*., 2013; Gautam *et al.*, 2019) [69, 20].

Forestry has been recognized as a means to reduce CO_2 emissions as well as enhancing carbon sinks.

Agriculture practices and carbon stocks

Agricultural activities (*e.g*., deforestation, burning, plowing and intensive grazing) contribute considerably to the atmospheric pool. Expansion of agriculture may have contributed substantially to the atmospheric carbon pool. Human activities on wetlands (*e.g*. drainage, agriculture, forestry, peat extraction and aquaculture) and their effects (*e.g.* oxidation of soil organic matter) may significantly affect the carbon and nitrogen balance and, thus, the greenhouse gas emissions and removal from these lands. The actual magnitude of human-induced emissions and removals from lands with organic and wet soils depends on numerous variables, including soil type, type of land use/conversion, wetland type, wetland size, management practice, vegetation composition, water table depth, growing season length, salinity, precipitation and temperature (IPCC 2011).

Soil C sequestration is a strategy to achieve food security through improvement in soil quality. It is a by-product of the inevitable necessity of adopting RMPs for enhancing crop yields on a global scale. While reducing the rate of enrichment of atmospheric concentration of CO_2, soil C sequestration improves and sustains biomass/agronomic productivity. It has the potential to offset fossil-fuel emissions by 0.4 to 1.2 Gt C/year, or 5 to 15% of the global emissions. Soil organic carbon is an extremely valuable natural resource. Irrespective of the climate debate, the SOC stock must be restored, enhanced and improved. AC-management policy that includes regulation-based trading soil C must be developed. Likewise, a wide spread adoption of RMPs by resource poor farmers of the tropics is urgently warranted. The soil C sequestration potential of this win-win strategy is finite and realizable over a short period of 20 to 50 years. Yet, the close link between soil C sequestration and world food security on the one hand and climate change on the other can neither be over emphasized nor ignored (Lal R. 2004; Kumhar *et al.*, 2019b) [54, 52].

Sustainable use of soil, water and other non-renewable resources implies: (i) an efficient use of all off-farm input, (ii) minimal leakage or losses through leaching, volatilization and erosion, (iii) maintenance or enhancement of soil quality and (iv) minimal risks of environmental degradation such as pollution of water and emission of GHGs into the atmosphere. Land use and land cover change and agricultural practices contribute about 20% of the global annual emission of carbon dioxide (CO_2) (IPCC, 2001) [76].

With reference to C emissions, agricultural practices may be grouped into primary, secondary and tertiary sources (Gifford, 1984) [22]. Primary sources of C emissions are either due to mobile operations (*e.g.* tillage, sowing, harvesting and transport) or stationary operations (*e.g.* pumping water, grain drying). Secondary sources of C emission comprise manufacturing, packaging, storing fertilizers and pesticides. Tertiary sources of C emission include acquisition of raw materials and fabrication of equipment and farm buildings, etc. Therefore, reducing emissions implies enhancing use efficiency of all these inputs by decreasing losses, and using other C-efficient alternatives (Lal R. 2004) [54].

A careful assessment is needed to reduce their use and to enhance use efficiency of these practices. Conversion of till to no-till, using integrated nutrient management and integrated pest management practices and enhancing water use efficiency by adopting drip irrigation and sub-irrigation practices can save C emission and at the same time increase soil C pool. Adopting a holistic approach to the management of soil and water resources, which decreases losses, improves efficiency and enhances agronomic productivity per unit consumption of C-based input is an important strategy. The sustainability of a production system can be assessed by evaluating temporal changes in C output to C input ratio or the net C output to C input ratio. The objective of sustainable management is to enhance the ecosystem C pool by increasing output, improving use efficiency of C-based input and decreasing losses. (Lal R. 2004) [54].

SOC sequestration by RMPs, with specific references to crop rotations and tillage practices, cover crops, ley farming and agroforestry, use of manure and bio solids, N fertilization, precision farming and irrigation. Key to enhancing soil quality and achieving food security lies in managing agricultural ecosystems using ecological principles which lead to enhancement of SOC pool and sustainable management of soil and water resources (Marek K. Jarecki& Rattan Lal 2003) [53].

Technological options for SOC sequestration on agricultural soils include adoption of conservation tillage, use of manures and compost as per integrated nutrient management and precision farming strategies, conversion of monoculture to complex diverse cropping systems, meadow-based rotations and winter cover crops and establishing perennial vegetation on contours and steep slopes. While improving soil quality, biomass productivity and enhanced environment quality, the strategy of SOC sequestration also buys us time during which the non-carbon fuel alternatives can take effect.

The projected climate change may also have a drastic impact on soil quality, growing season duration and biomass productivity. Land use and management practices to sequester SOC include afforestation with appropriate species, soil management on cropland, pasture management on grazing land and restoration of degraded soils and ecosystems through afforestation and conversion to other restorative land uses recommended soil management practices including application of biosolids (e.g., manure, sludge), which enhance activity of soil macro-fauna (*e.g.* termites), use of vegetative mulches, water harvesting and judicious irrigation systems. Recommended practices for managing grazing lands include controlled grazing at an optimal stocking rate, fire management and growing improved species (Lal R, 2004) [54].

A considerable part of the depleted SOC pool can be restored through conversion of marginal lands into restorative land uses, adoption of conservation tillage with cover crops and crop residue mulch, nutrient cycling including the use of compost and manure and other systems of sustainable management of soil and water resources.

Factors affecting depletion of soil carbon pool

Depletion of the SOC pool has major adverse economic and ecological consequences, because the SOC pool serves numerous on-site and off-site functions of value to human society and wellbeing. Principal on-site functions of the SOC pool are (R. Lal. 2004) [54].

1. Source and sink of principal plant nutrients (*e.g.* N, P, S, Zn and Mo);
2. Source of charge density and responsible for ion exchange;
3. Absorbent of water at low moisture potentials leading to increase in plant available water capacity;
4. Promoter of soil aggregation that improves soil tilth;
5. Cause of high water infiltration capacity and low losses due to surface runoff;
6. Substrate for energy for soil biota leading to an increase in soil biodiversity;
7. Source of strength for soil aggregates leading to reduction in susceptibility to erosion;
8. Cause of high nutrient and water use efficiency because of reduction in losses by drainage, evaporation and volatilization;
9. Buffer against sudden fluctuations in soil reaction (pH) due to the application of agricultural chemicals; and
10. Moderator of soil temperature through its effect on soil colour and albedo.

Important RMP for enhancing SOC include conservation tillage, mulch farming, cover crops, and integrated nutrient management including use of manure and compost and agroforestry. Restoration of degraded/decertified soils and ecosystems is an important strategy. The rate of SOC sequestration, ranging from 100 to 1000 kg/ha year, depends on climate, soil type and site-specific management. Soil carbon plays vital roles in ecosystem services, such as maintaining biodiversity, regulating climate and adjusting water circulation (Nahlik and Fennessy, 2016) [67]. Soil carbon pool sizes have also been documented to increase with stand age regionally (Kang *et al.*, 2018) [39].

Terms

Cropland management is the system of practices on land on which agricultural crops are grown and on land that is set aside or temporarily not being used for crop production.“Grazing land management” is the system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced.

Soil quality is defined as the “fitness for use” (Larson and Pierce 1991) [58] and “capacity of the soil to function” (Karlen *et al*., 1997) [41].

Soil health is defined as soil’s capacity, as a biologically active entity, within natural and managed landscapes, to sustain multiple ecosystem services, including net primary productivity (NPP), food and nutritional security, biodiversity, water purification, renewability, C sequestration, air quality, atmospheric chemistry and elemental cycling for human well- being and nature conservancy (Lal R., 2016) [11].

Short-lived climate forcers (SLCF) are also referred to as short-lived climate pollutants (SLCP). They are referred to as near-term climate forcers (NTCF) which are a set of compounds whose impact on climate occurs primarily within the first decade after their emission. This set of compounds includes methane, which is also a well-mixed greenhouse gas, ozone and aerosols, or their precursors and some halogenated species that are not well-mixed greenhouse gases. (IPCC, 2018) [34].

Biomass is defined as the dry mass of the live plant material produced as a result of photosynthesis including shoots and roots.

Radiative forcing is defined as the change in net irradiance (w/m^2) at the tropopause after allowing the stratospheric temperatures to readjust to radiative equilibrium (Ramaswamy, 2001) [76].

Conclusion

There is a need for a quick and clear understanding of impact of climate change on agricultural crops for making sound action plan because perennial grass based farming systems have high potential for sequestering carbon for mitigation of climate change. Mitigation of CO_2 emission from agriculture can be achieved by increasing C sequestration in soil, which implies storage of C as soil organic matter.

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