Climate Change and Carbon Sequestration

Ch. Srinivasarao, Sumanta Kundu and Pravin B. Thakur

ICAR-Central Research Institute for Dryland Agriculture, Santoshnagar, Saidabad, Hyderabad-500059, Telangana, India

Corresponding Author

Ch. Srinivasarao
e-mail: cherukumalli2011@gmail.com

Article History

Article ID: IJEP54
Received in 6th August, 2015
Received in revised form 15th August, 2015
Accepted in final form 22nd August, 2015

Abstract

Industrial revolution has led footprints towards changes in atmospheric composition since its initiation. The Earth's average surface temperature increased by 0.74°C in the late 19th century, and is projected to increase by >1.5°C (IPCC Fifth Assessment Report). In the scenarios of higher rates of emissions, temperature is likely to exceed 2°C and could be as much as 4°C at the end of 21st century. Climatic vulnerability includes increased frequency of extreme events such as cyclones, floods, cold-hot waves and droughts. Temperature increase is associated with a rise in greenhouse gases, deforestation, agriculture and industrial processes. CO_2, methane (CH_4) and nitrous oxide (N_2O) are the prime GHGs which are associated with agriculture. Indian agriculture, on which about 60% of the populations are dependent for livelihood may have impacted directly or indirectly by abrupt climate change. On the other hand Soil organic matter (SOM) in soils is a strong determinant of soil quality and controls the physico-chemical and biological soil processes. A warming climate and decreasing soil moisture limits the soil functions. One of the important climate smart agricultural practices is reduction of CO_2 emission by restoring soil organic carbon (SOC) pool and improving soil quality which can address both the problems of food security and climate change.

Keywords: climate change, carbon sequestration, global warming, GHGs

1. Introduction

Industrial revolution has led footprints towards changes in atmospheric composition since its initiation. The Earth's average surface temperature increased by 0.74 °C in the late 19th century, and is projected to increase by > 1.5 °C (IPCC Fifth Assessment Report). In the scenarios of higher rates of emissions, temperature is likely to exceed 2 °C and could be as much as 4 °C at the end of 21st century (IPCC, 2013). Temperature increase is associated with a rise in greenhouse gases (GHGs) such as carbon dioxide (CO_2) and other hydro fluorocarbons (HFCs), per-fluorocarbons (PFCs), and sulfur hexafluoride (SF6) emitting from the burning of fossil fuels, deforestation, agriculture and industrial processes. IPCC (2007) projected temperature increase in India of 0.5−1.2 °C by 2020, 0.88−3.16 °C by 2050 and 1.56−5.44 °C by 2080. The corresponding CO_2 concentrations are expected to be 393, 543 and 789 ppm in 2020, 2050 and 2080, respectively.

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the prime GHGs which are associated with agriculture. Indian agriculture, on which about 60% of the populations are dependent for livelihood may have impacted directly or indirectly by abrupt climate change. Climatic vulnerability includes increased frequency of extreme events such as cyclones, floods, cold-hot waves and droughts. Melting of the Himalayan glaciers which are the major source of water for the main rivers could affect the availability of water in case of global warming. These changes could raise sea-levels and threats for coastlines and habitations. Climate change is expected beneficial as well as harmful concern for agriculture and allied sectors. Some research indicates that warmer temperatures extends the plant growth period. Increased CO_2 in the atmosphere results in higher yields because photosynthesis is the largest Carbon (C) transfer process, through assimilation of atmospheric CO_2 in the green biomass. It has been observed a strong response in terms of increased total and root biomass of pulse crops with the elevated CO_2 (Vanaja et al., 2006). On the other hand, changing climate was projected to reduce grain yield of rainy season sorghum (*Sorghum bicolor*) by 2−14% by 2020, with worsening yields by 2050 and 2080. Reduction in wheat yield is projected to be high in the most favorable and high yielding areas of Indo-Gangetic Plains (IGP) due to terminal heat stress. A meta-analysis of data of 52 studies have projected that 16% and 11% change in mean yield of maize (*Zea mays*) and for sorghum, respectively in South Asia by 2050s (IPCC, 2013). Thus, agriculture in India must adapt to changing climate through improved and innovative systems of soil and water management, use of improved cultivars and crops, new technologies, and by upgrading infrastructure and diversifying land use system. Otherwise, this change in climate will impact on food and water security.

2. Carbon Sequestration

Soil organic matter (SOM) in soils is a strong determinant of soil quality and controls the physico-chemical and biological soil processes. A warming climate and decreasing soil moisture limits the soil functions. One of the important climate smart agricultural practices is reduction of CO_2 emission by restoring soil organic carbon (SOC) pool and improving soil quality which can address both the problems of food security and climate change. Most agricultural soils in India are reported for their low SOC stocks. Changing and uncertain climate may further exacerbate risks of soil degradation by accelerated erosion, secondary salinization, depletion of SOC stock, elemental imbalance and the overall decline in soil quality and productivity. Current database shows that around 121 M ha land has been degraded in the country, of which 68% is due to water erosion, 20% by chemical and 10% by wind erosion. In rainfed situation, long fallow periods, uneven distribution of rainfall, and mono-cropping are the main factors responsible for broader yield gaps. Therefore, maintaining SOC concentration above the threshold level is essential to climate resilient agriculture.

3. Carbon Sequestration Potential In Major Crop Production Systems of India

3.1. Rainfed production systems

Several experiments were conducted at dry land centers under All India Coordinated Research Project on Dryland Agriculture, AICRPDA in diverse soil and climatic conditions, *viz.,* Anantapur and Bengaluru (Alfisol), Solapur and Indore (Vertisol), Sardar Krushinagar (Entisol), and Varanasi (Inceptisol). Seven rainfed long term cropping system experiments involving major crops of the region has been assessed for C sequestration including groundnut (*Arachis hypogeae*), fingermillet (*Eleucine coracana*), winter sorghum (*Sorghum bicolor*), pearlmillet (*Pennisetum glaucum*), clusterbean (*Cyamopsis tetragonoloba*), castor (*Ricinus communis*), soybean (*Glycine max*), safflower (*Carthamus tinctorius*), lentil (*Lens esculenta*) and upland rice (*Oryza sativa*). Diverse nutrient management treatments assessed included cattle manure, green leaf manure, crop residues and inorganic fertilizers.

The average SOC sequestration rate (kg C $ha^{-1}year^{-1}$) measured with different management treatments were :(1) 570 for 50% RDF+4 Mg ha^{-1} GNS, (2) 570-720 for 10 Mg ha^{-1} FYM+100% NPK, (3) 650 for 25 kg N ha^{-1} (sorghum residue)+25 kg N (*Leucaena* clippings), (4) 240 for 50% RDN (Fertilizer)+50% RDN (FYM), (5) 790 for 6 Mg ha^{-1} FYM +20 kg N+13 kg P, and (6) 320 for 100% organic (FYM).The level of increase in yield (Mg ha^{-1}) over control was : (1) from 0.78 to 1.03 in groundnut with 50% RDF+4 Mg ha^{-1} FYM, (2) 0.40 to 1.34 and 0.82 to 3.96 in groundnut and fingermillet, respectively, through 10 Mg ha^{-1} FYM+100% NPK in groundnut-fingermillet rotation, (3) 0.84 to 3.28 in fingermillet through 10 Mg ha^{-1} FYM+100% NPK, (4) 0.61 to 1.19 in sorghum through 25 kg N ha^{-1} (*Leucaena* clippings)+25 kg N ha^{-1} (urea), (5) 0.43 to 0.81, 0.32 to 0.58 and 0.44 to 0.83 in pearmillet, clusterbean and castor, respectively, through 50% RDN (Fertilizer)+50% RDN (FYM), (6) 1.04 to 2.10 and 0.63 to 1.49 in soybean and safflower, respectively, through 6 Mg ha^{-1} FYM+20 kg N+13 kg P ha^{-1}, and (7) 1.08 to 1.95 and 0.48 to 1.04 in rice and lentil, respectively, through 50% N (FYM)+50% RDF treatment (Srinivasarao et al., 2013, 2014) .

4. Irrigated Production Systems

In irrigated rice-wheat system of Punjab, Benbi et al. (2009) reported that after 25 years (1981-2006) of intensive cropping, concentration of SOC increased from 2.9 g kg^{-1} (1981) to 4.0 g kg^{-1} (2006) in the surface layer (0-20 cm depth). Under irrigated conditions, intensive crop cultivation produce large amount of biomass which accumulated in the soils. Integrated nutrient management practices (INM) significantly increased total organic carbon (TOC) (11.48 g kg^{-1}) and Walkley and Black C (7.86 g kg^{-1}) in the sub-soil in FYM-treated plots in soil test crop response (STCR) -based approach in long term (6-year) pearl millet (*Pennisetum glaucum*)–wheat system in sub-tropical India. Whereas, labile organic C (1.36 g kg^{-1}) and the microbial biomass C (MBC) (273 mg kg^{-1}) were more in FYM + NPK than the control treatment, and the change of SOC stock was low (Mohrana et al., 2012). A 20-year meta-analysis of a no-till system in IGP showed that the associated GHGs emitted were 3% less than those under conventional tillage rice–wheat systems C sequestration potential is estimated to be 44.1.Tg C in no-till. Even if, implementation of no-till in maize–wheat and cotton–wheat cropping systems would sequester an additional 6.6 Tg C. (Grace et al., 2012).

5. Requirement of Critical Carbon Input to Maintain SOC Stock in the Soil at Its Antecedent Level

It is generally recognized that greater C inputs increases C sequestration in soils. Soil C inputs are mainly affected by the type of plants grown, amount of dry matter the crop accumulated in soils during the crop growing season, environmental factors which govern crop production. Among the major rainfed production systems of India, the critical level of C input requirements for maintaining SOC at the antecedent level ranged from 1 to 3.5 Mg C ha^{-1} $year^{-1}$ and differed among soil type and production system (Srinivasarao et al., 2013). The required critical C input for groundnut, fingermillet, groundnut-fingermillet, sorghum, permillet, soybean and rice cropping systems are 1.12, 1.13, 1.62, 1.10, 3.30, 3.47 and 2.47 Mg C ha^{-1} $year^{-1}$, respectively (Srinivasarao et al., 2013). These critical C inputs values across the seven rainfed production systems are low because, it might be due to initial SOC concentration in these soils was low. Likewise critical C input requirement is 2.92 Mg C $ha^{-1}year^{-1}$ for rice based system (Mandal et al., 2007), 3.56 Mg ha^{-1} $year^{-1}$ for irrigated rice–wheat systems (Majumder et al., 2008) under sub-tropical condition, 3.1 Mg ha^{-1} $year^{-1}$ in Davis, California, USA in a Mediterranean-type climate (Kong et al., 2005).

6. Productivity Enhancement Due to Increase in SOC Stock at Root Zone

Increase in agronomic productivity through increase SOC stock at root zone was evaluated in major production systems. Result showed that the rate of increase (Mg C ha^{-1} $year^{-1}$) of the SOC stock at the root zone led to a significant increase in yield (kg ha^{-1}) in several rainfed crops. These increases were 13,101, 90, 170, 145, 18 and 160 for groundnut, fingermillet, sorghum, pearlmillet, soybean, lentil and rice, respectively (Srinivasarao et al., 2014). It has also been reported that an increase in SOC stock by 1 Mg ha^{-1} increased grain yield by 27 kg ha^{-1} in wheat (*Triticum aestivum*) in North Dakota, United States (Lal,2006), 40 kg ha^{-1} in wheat in the semi-arid pampas of Argentina (Diaz-Zorita et al., 2002), 6 kg ha^{-1} in wheat and 3 kg ha^{-1}in maize (*Zea mays*) in alluvial soils of northern India (Kanchikerimath and Singh, 2001), 17 kg ha^{-1} in maize in Thailand (Petchawee and Chaitep, 1995), and 10 kg ha^{-1} in maize and 1 kg ha^{-1} in cowpea (*Vigna unguiculata*) in western Nigeria (Lal, 1981). Adoption of recommended management practices (RMPs) which could increase SOC stock by 1 Mg $ha^{-1}$$year^{-1}$ can increase food grain production by 32 million Mg $year^{-1}$ in developing countries (Lal, 2006).

7. Strategies to Increase Carbon Sequestration

The strategies for a positive C balance are termed as recommended management practices (RMPs) in comparison with traditional practices in agriculture. These RMPs are the conversion, conservation, alters cropping systems, improved varieties with high biomass production, recycling organic waste, judicious use of chemical fertilizers and use of bio-amendment, improved soil and water management for irrigation and drainage (Fig 1). These practices contributes not only towards soil conservation and water quality goals but also enhance the amount of SOC and reduce CO_2 emissions (Follett et al., 2009) as well as maintain a steady state of SOC for longer term (Govaerts et al., 2009). Conservation agriculture (CA) has gaining importance day by day as a technology in the context of increased climatic vulnerability. It has also been recognizing about C storage and sustainable ecosystem services. CA is based on three main principles (zero or no tillage, permanent organic residue cover on soils and associated crop rotation). Experts have different opinion about C sequestration under CA system (Srinivasarao et al. 2015a). Though, adoption of CA worldwide shows a positive C balance in soils (West and Post 2002, Goaverts ,2009) according to many case studies. It has been estimated that conversion of all cropland to CA globally could sequestered 25 Gt C for the next 50 years. This might mitigate C emission to 1833 Mt CO_2 eq $year^{-1}$ (Baker et al., 2007). Applications of bio-char or charcoal also have higher GHG mitigation potential than other practice. Many studies suggest that bio-char is as an effective soil amendment for improving soil conditions and increasing C sequestration (Sohi et al., 2010)

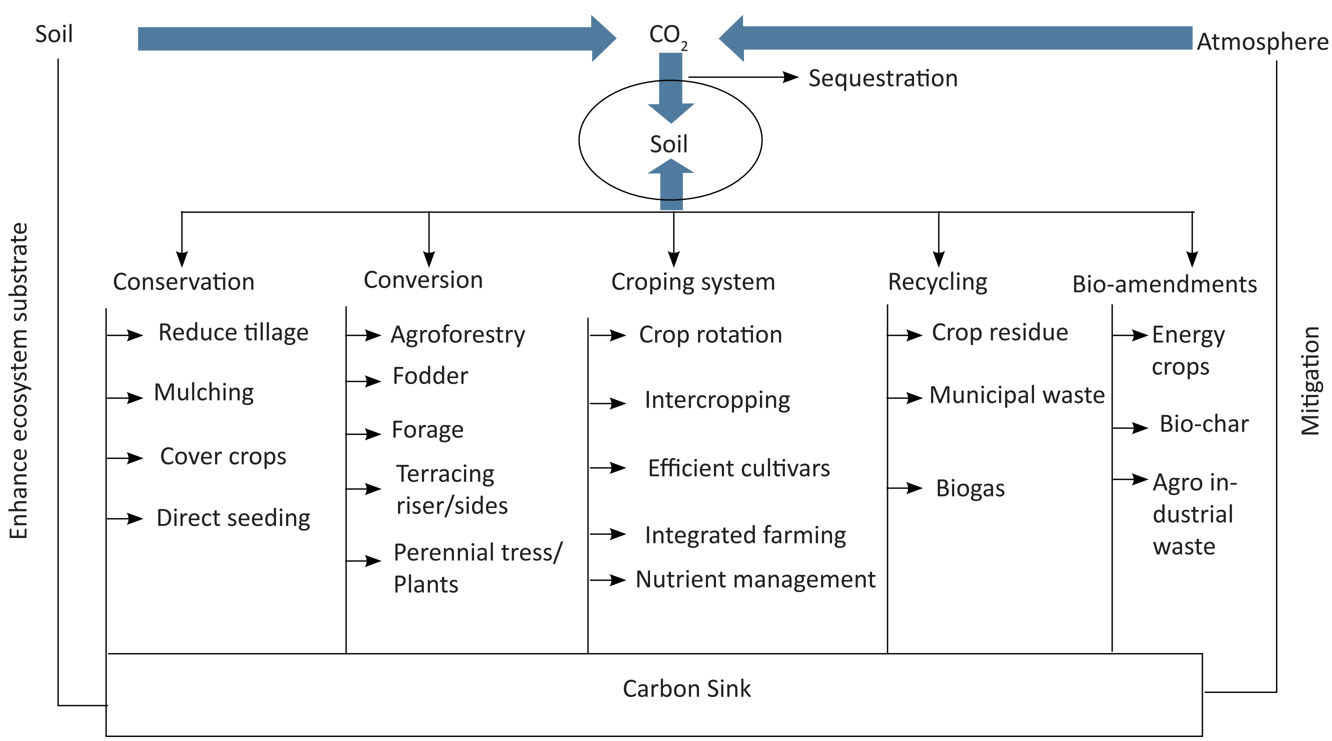

Figure 1: Carbon management options in climate smart agriculture for mitigation (Srinivasarao et al. 2015b)

8. Conclusion

Agriculture in India shows its low productivity is both the cause and the effect of the climate change. Moreover, the atmospheric concentration of CO_2 at 400 ppm in 2014 is increasing the risk of global warming. Most soils under rainfed agriculture are severely depleted their soil organic carbon and nutrient pools because of intensive farming practices. Consequently soils are compelling to degradation. Thus, restoring the soil and ecosystem carbon pools through recommended management practices is important for enhancing agronomic productivity, mitigating climate change by off-setting emissions, and adapting to climate change by reducing risks of intermittent drought.

9. Further Research

1. For increasing C sequestration, adoption of recommended management practices by the resource poor farmers to small scale farming managers are essential to restore degraded lands. These practices include use of crop residues as mulch, crop rotations, reduced tillage, and use of integrated nutrient management, strategies for recycling bio-solids and other co-products.

2. There are numerous competing uses of crop residues. It has been estimated that 560 Mt crop residue are available in the country. Thus interventions are needed that would promote the efficient use of crop residues without affecting crop livestock systems, animal manure and other by-products as soil amendments on small scale farming level.

3. Additional basic research involving well designed long term field experiments on major soil groups of principal eco-regions of India is essential to evaluate the threshold value of SOC in the root zone.

4. Developing mechanisms of payments to farmers for environmental services as alternative financing for agriculture transition.

5. Emerging carbon market and payment for emissions removals or reductions have attracted much interest and anticipate such financing as a source for selected agricultural activities and products.

10. References

Baker, J. M., Ochsner, T.E., Venterea, R.T., Griffis, T.J., 2007. Tillage and soil carbon sequestration – what do we really know? Agriculture Ecosystem and Environment 118, 1–5.

Benbi, D.K., Brar, J.S., 2009. A 25-year record of carbon sequestration and soil properties in intensive agriculture. Agronomy for Sustainable Development 29, 257–265.

Diaz-zorita, M., Gustavo, A., D., Grove J. H., 2002. A review of no-till system, soil management for sustainable crop production in the sub-humid, semi-arid Pampas of Argentina. Soil Tillage and Research 65, 1-18.

Follett, R.F., Varvel, G.E., Kimble, J., Vogel, K.P., 2009. No-till corn after brome grass: effect on soil C soil C and soil aggregates. Agronomy Journal 101, 261–268.

Govaerts, B., Verhulst, N., Navarrete, C., Sayre, A., Dixon, K.D., Dendooven, J.L., 2009. Conservation agriculture and soil carbon sequestration: between myth and farmer reality. Critical Review in Plant Sciences 28, 97–122.

Grace, P.R., Antle, J., Aggarwal, P.K., Ogle, S., Paustian, K., Basso, B., 2012. Soil carbon sequestration and associated economic cost for farming systems of the Indo-Gangetic Plain: A meta-analysis. Agriculture Ecosystem and Environment 146, 137–146.

IPCC, 2013. Climate Change, 2013. The Physical Science Basis. In Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. Eds., 1535. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2007. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Climate Change, 2007. Impacts, Adaptation and Vulnerability. Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. Eds. Pp 976. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

Kanchikerimath, M., Singh, D., 2001. Soil organic matter, biological properties after 26 years of maize-wheat-cowpea cropping as affected by manure, fertilization in a Cambisol in semiarid region of India. Agriculture Ecosystem and Environment 86, 155.

Kong, A.Y.Y., Six, J., Bryant, D.C., Denison, R.F., van Kessel, C., 2005. The relationship between carbon input, aggregation, and soil organic carbon stabilization in sustainable cropping systems. Soil Science Society of America Journal 69, 1078–1085.

Lal, R., 1981. Soil erosion problem on Alfisol in Western Nigeria, VI. Effect of erosion on experimental plots. Geoderma 25, 215-230.

Lal, R., 2006. Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural soil. Land Degradation Development 17, 197–209.

Majumder, B., Mandal, B., Bandyopadhyay, P. K., Gangopadhyay, A., Mani, P. K., Kundu, A.L., Majumder, D., 2008. Organic amendments influence soil organic carbon pools and crop productivity in a 19 years old rice-wheat agro-ecosystems. Soil Science Society of America Journal 72, 775–785.

Mandal, B., Majumder, B., Bandopadhyay, P.K., 2007. The potential of cropping systems and soil amendments for carbon sequestration in soils under long-term experiments in subtropical India. Global Change Biology 13, 357–369.

Moharana, P.C., Sharma, B.M., Biswas, D.R., Dwivedi B.S., Singh, R.V., 2012. Long-term effect of nutrient management on soil fertility and soil organic carbon pools under a 6-year-old pearl millet–wheat cropping system in an Inceptisol of subtropical India. Field Crops Research 136, 32–41.

Petchawee, S., Chaitep, W., 1995. Inorganic matter management in upland systems in Thailand, Australian Centre for International Agricultural Research, Canberra, Australia, 21–26.

Sohi, S.P., Krull, E., Lopez-Capel, E., Bol, R., 2010., A review of biochar and its use and function in soil. In: Advances in Agronomy, 47-82, Publisher Elsevier Academic Press Inc., ISSN 0065-2213, San Diego, CA-92101-4495, USA.

Srinivasarao, Ch., Lal, R., Kundu, S., Prasad, Babu, M. B. B., Venkateswarlu, B., Singh, A.K., 2014. Soil carbon sequestration in rainfed production systems in the semiarid tropics of India. Science for Total Environment 487, 587–603.

Srinivasarao, Ch., Lal, R., Kundu, S., Thakur, P.B., 2015a. Conservation Agriculture and Soil Carbon Sequestration. *In:* Conservation Agriculture (Eds. M. Farooq and K. H. M. Siddique) Part V. Publisher Springer International, Switzerland. pp 479-524. DOI: 10.1007/978-3-319-11620–4_19.

Srinivasarao, Ch., Lal, R., Subba Rao A., Kundu, S., Sahrawat K. L., Thakur, P. B., Srinivas, K., 2015b. Carbon management and climate resilient agriculture. Indian Society of Agronomy In press.

Srinivasarao, Ch., Venkateswarlu, B., Lal, R., Singh, A.,K., Kundu, S., 2013. Sustainable management of soils of dryland ecosystems of India for enhancing agronomic productivity, sequestering carbon. In: Advances in Agronomy. (Sparks, D. L., Eds.). 253-329. Academic Press Burlington.

Vanaja, M., Maheswari, M., Ratnakumar, P., Ramakrishna, Y.S.,2006. Monitoring and controlling of CO_2 concentration in open top chambers for better understanding of plants response to elevated CO_2 levels. Indian Journal Radio Space Physics 35, 193–197.

West, T.A., Post, W. M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Science Society of America Journal 66, 1903–1946.