Plant Archives Vol. 18 No. 1, 2018 pp. 1175-1183 ***ISSN 0972-5210***

CROPPING SYSTEMS AND THEIR EFFECTIVENESS IN ADAPTATION AND MITIGATION OF CLIMATE CHANGE

Vandna Chhabra[1*], Abdul Haris A.[2], Ved Prakash[#] and Hina Upadhyay[3]

[1*,3] Department of Agronmy, School of Agriculture, Lovely Professional University, Phagwara, -144401 (Punjab)
[2]ICAR CPCRI, RS, Kayamkulam, Kerala-690533
[#] Scientist, ICAR-RCER, Patna, Bihar

Abstract

Increasing trend in concentration of atmospheric green house gases (GHGs) and consequent global warming is alarming, and requires adaptation and mitigation options. Climate-resilient and low-emission future can be built upon a long-term global goal for emission reductions. Reducing CO_2 concentration in the atmosphere by enhancing the rates of removal of the atmospheric CO_2 through carbon sequestration is considered as one of the best climate change mitigation strategy. Plants can sequester carbon through assimilation of carbohydrates in photosynthesis which will be stored in the biomass and will add to different pools of carbon subsequently. Farmers' adaptation to climate change-through changes in farming practices, cropping patterns, and use of new technologies will help to mitigate the adverse impact. The cropping systems and the management practices that could provide C input higher than the above critical level are likely to sustain the SOC level and maintain good soil health in the subtropical regions of the Indian subcontinent. 20 to 25% of soil organic carbon lost within first few decades of cultivation, worldwide estimate of loss is 41 to 55 Gt carbons. Framers being the key stakeholders need to be educated and encouraged for adopting low emission climate resilient agriculture.

Key Words: Adaptation, Carbon sequestration, Climate Change, Cropping system.

Introduction

There has been extensive concern worldwide on population growth, depletion of natural resources and environmental degradation. The world population grew by four times from 1.6 billion to 6.1 billion persons during 1900 to 2000 (United Nations, 2001). India accounts for 18 percent of world population, and is growing at the rate of 1.93 % per annum. Twentieth century is the century of unprecedented population growth, economic development and climate change witnessing changes in land use, degradation of environment and depletion of natural resources. Land use changes accounted for emission of CO_2 @ 1.6 Gt y^{-1} during the decade 1981-90 in tropics (Bhadwal and Singh, 2002). Increase in anthropogenic activities since the advent of industrialisation in the mid-18th century has led to cumulative accumulation of Greenhouse Gases (GHGs) in the earth's atmosphere (IPCC, 2007) and CO_2 emissions are projected to grow 40 to 110% from 2000-2030. The concentration of CO_2 in the atmosphere increased from 280 to 387 ppm in 1750 to 2007 and continues to increase at the rate of 1.5 ppm per year. During the same period, N_2O was increased from 270 to 314 ppb, and CH_4 increased from 700 to 1745 ppb (IPCC, "Climate Change 2001), (IPCC, "Assessment Report," 2007). Actual global emission increased by 1.4% over 2011, reaching a total of 34.5 billion in 2012. Increased concentrations of GHGs and the overall warming of the atmosphere has resulted in changing rainfall patterns, disruption in hydrological cycles, melting of ice caps and glaciers, rise in sea levels, and increase in frequency and intensity of extreme events. These have in turn had serious impact on sustainability of water resources, agriculture, forests and ecosystems, affecting the well being of billions of people on earth. Almost 50% of the Asia's total biodiversity is at risk due to climate change, which refers to any long term substantial deviation from present climate because of variations in weather and climatic elements (Murthy, 2003). Schneider *et al.*, 2007 identified agriculture as a key vulnerable area to climate

***Author for correspondence :** E-mail : vandna.21027@lpu.co.in

change and it will have a negative effect on food production in many countries. A warming climate and decreasing soil moisture can result in production patterns shifting from lower to higher latitude and an increasing demand for water.

Carbon sequestration for green house gas mitigation

Among all the green house gases (CO_2, CH_4, N_2O and CFC *etc*), carbon dioxide is the most important, Carbon dioxide (CO_2) capture and sequestration can significantly reduce emissions from large stationary sources of CO_2, which include coal- and natural-gas-fired power plants, as well as certain industry types such as ethanol and natural gas processing plants so the removal of carbon dioxide from the atmosphere through carbon sequestration and again converting it into soil carbon is a great challenge as well as opportunity to mitigate the adverse impact of climate change. Kumar *et al.*, 2009 suggested the need for the identification of ecosystems with high carbon sink capacity as a mitigation strategy of terrestrial carbon sequestration. Agricultural ecosystems represent an estimated 11% of the earth's land surface and include some of the most productive and carbon-rich soils. As a result, they play a significant role in the storage and release of C within the terrestrial carbon cycle (Lal *et al.*, 1995). Efforts are being done to reduce concentration of CO_2 in the atmosphere by enhancing the rates of its removal through carbon sequestration. Carbon sequestration promotes long term storage of carbon in the terrestrial biosphere, underground or the ocean to reduce carbon dioxide concentration in the atmosphere for improving environmental conditions (Yadav, 2010).

Carbon sequestration, *i.e.* capturing and securing carbon that would otherwise be emitted and remain in the atmosphere might be a suitable alternative to control atmospheric emission of carbon. Sinks of CO_2 may be oceans, consuming 93% of the world's CO_2. Currently, approximately one third of anthropogenic emissions are estimated to be entering the ocean. Geo-sequestration or geological storage, involves injecting carbon dioxide directly into underground geological formations. It is an easily available and technologically feasible method of reducing CO_2 emissions into the atmosphere. Auque *et al.*, 2009 indicated geological storage of carbon dioxide as main strategy to mitigate the impact of the emissions of this gas on global warming. Soil are the largest terrestrial sink for carbon on the planet. Organic matter of plant is sequestered in soil. Soil carbon or organic matter is important because it affects all soil quality functions (Fenton *et al.*, 1999).

Soil is the largest reservoir of terrestrial carbon (C), storing approximately 53% of the terrestrial carbon. Approximately 10% of the CO2 in the atmosphere is cycled through the soil each year (Raich *et al.*, 1995).

More than half of soil carbon is in organic form (soil organic carbon, SOC). Generally, plant biomass (above and below ground residues) is the primary source of carbon input into SOC. When biomass decomposes, it is incorporated into SOC, of which up to 70-80% is defined as humic substance (Gonet SS *et al.*, 1998). Once it is becomes part of SOC, carbon is stored in soil for a long time since humic substances are recalcitrant. Smith *et al.*, 2008 estimated that 89% of global potential for agricultural greenhouse gas mitigation would be through carbon sequestration. Thus, large quantities of carbon from the atmosphere would be removed, and agricultural activity can contribute substantially to cutting greenhouse gas emissions. Soil contains more carbon than in vegetation and the atmosphere combined, but soil organic carbon (humus) levels in many agricultural areas have been severely depleted. Bhattacharyya *et al.*, (2001) reported, agro-ecological regions (AERs) 4 and 13 have highest carbon stock followed by AERs 2, 9 and 15 in India. Almost 80% of the organic carbon is stored in the soil. Through formation of a quick and protective ground cover, cover crops improve SOC content, enhance soil biodiversity, improve soil structure and minimize risks of soil erosion. Changes in agricultural practices for the purpose of increasing SOC can be made either by increasing organic matter inputs to the soil, decreasing decomposition of SOC and oxidation

of SOC, or a combination of both (West To *et al.,* 2002). Understanding the response of soil organic carbon to environmental and management factors is necessary for estimating the potential of soil to sequester atmospheric carbon. Mangroves act as carbon sinks and provide immediate protection to coastal communities from associated storm surges and erosion. Peat bogs contain approximately 25% of the carbon stored in land plants and soil (Chester, 2000). Destruction of bogs causes the stored carbon to be released back into the atmosphere, thereby increasing the potential for climate change. The rate of soil organic carbon sequestration in crop land soil of India are low , but need to be credibly assessed for diverse soil and farming systems (Lal, 2013).

Different System and their potential for sequestration

1. Multiple cropping systems:-

Net GHG emission from agricultural system can be kept low when management is optimized toward better exploitation of the yield potential (Adviento *et al.*, 2007). The great potential of C sequestration in cropland has provided a promising approach to reducing the atmospheric concentration of CO_2 for mitigating climate change. However, this approach depends on cropping systems, which may be defined as an operating system for growers to follow in their practices for crop production. An ideal cropping system for C sequestration should produce and remain the abundant quantity of biomass or organic C in the soil. Diversified cropping systems with better management substantially improved SOC in semiarid-tropical soil of India (Manna *et al.* 2008). Use of approaches like: selection of suitable varieties, change in planting dates and in plant population to maximize crop biomass productivity, planned water and nitrogen management leading to high N use efficiency, residue management and deep tillage help to build-up of soil organic matter. To enhance the efficiency of carbon sequestration in agriculture, cropping systems, crop rotation, intercropping, cover crops, relay cropping, fallowing etc. play a crucial role by affecting crop yield. Cropping system play an important role in greenhouse gas status and improved cropping system can enhance carbon sequestration potential upto 25% studied by Lal *et al.*, 1998. Adopting less intensive tillage system such as no-tillage, strip-tillage, chisel plough and better crop residue cover are effective in reducing CO_2 emission and thus improving soil C sequestration in a corn-soybean rotation (Al-Kaisi and Yin, 2005).

There is great potential of C sequestration in cropland; an ideal cropping system for C sequestration should produce adequate biomass or organic carbon. Potential rate of C sequestration in cropland (Tg C yr^{-1}) is 39-49 for India (Wang *et al.*, 2010), is very low as compared to China (105-198). In the tropics, increasing C inputs to soil through improving the fertility and productivity of cropland and pastures is essential. In a study that surveyed storage and sequestration potential of SOC in China, Pan *et al.*, found a higher topsoil carbon content of paddy soil compared to soils in dry croplands. Several studies in China have also identified paddy soils as one of the most important SOC accumulators (Wu J., 2011). In exclusive systems with vegetated fallow periods, planted fallow and cover crops can increase C levels over the cropping cycle (Andren *et al.*, 2001). The greater efficiency of integrated systems in resource capture and utilization than single-species systems will result in greater net C sequestration. Carbon sequestered in the topsoil in gliricidia-maize was 1.6 times more than in sole-maize at Malawi (Makumba, 2007).

1.1 Crop rotation:-

Crop rotation can improve biomass production and soil C sequestration, especially rotations with legumes and non-legumes. Growing legumes can substantially reduce the nitrogen input as chemical fertilizers, which in turn can reduce the fossil fuel consumption in manufacturing fertilizers (R. P. Zentner *et al.,* 2001, 2004) Conversely, without appropriate crop rotation, soil productivity and biomass production will decrease due to an infestation increase in weeds, diseases, and insects. Crop rotation enhances biomass so also helpful in carbon sequestration and this is observed by Drinkwater *et al.*, (1998) in corn-soybean rotation system where greatest productivity and returned the largest crop residues to the soil was observed as compared to monoculture of corn or soybean. Intercropping can improve the crop productivity due to increased efficiency of utilization of sunlight with an adequate spatial distribution of various plant architectures.

1.2. Intercropping:-

Intercropping like row intercropping, strip intercropping, mixed cropping and relay intercropping, depending mainly on the characteristics of crops in spatial distribution improve the crop productivity due to higher efficiency of utilization of sunlight. For example, row intercropping corn or sorghum with vine crops, such as climbing beans or sweet potato, can improve the productivity of the latter crop since their vines can climb on the former plants to take the advantage of space and sunlight. In which, the former plants usually may be expected to produce optimal yield because of their sacrifices to support the latter plants. Wiley, 1983 observed that In India, sorghum and pigeonpea when intercropped efficiently utilize the time and space for an optimal productivity of both crops. The conversion of long-term arable crop land to agro-horticulture resulted in a significant increase in SOC. it was observed that the cultivation of fruit trees, coconut (*Cocos nucefera* L.) intercropped with guava (*Psidium guajava* L) increased SOC from 3.4 to 7.8 and 2.4 to 6.2 g kg^{-1} or carbon sequestered 877 kg C^{ha-1} y^{-1} and 325 kg C^{ha-1} y^{-1} after 38 and 10 years of cultivation under same agro-ecosystem. In Iowa, a strip cropping system with oats, corn and soybean on ridge-till row showed that net returns with strip intercropping can be increased by 38% compared with same crops in monoculture (Anon, 1990).

Relay intercropping, such as planting soybean into standing winter wheat can efficiently take spatial and time advantages for optimal yield and eliminate the fallow period to conserve the soil and reduce water evaporation (Prochaska., 2003).

1.3. Mixed cropping:-

Mixed cropping is also an effective approach in the intercropping system to optimize the plant production by planting two or more plants in a mixture. The benefits of mixed cropping are to balance the input and output of soil nutrients, suppress weeds and insects, control plant disease, resist climate extremes, for increasing the overall productivity (K.K. Hirst., 2010). In the modern agriculture, such mixed cropping system has to be modified for the convenience of management and harvest with machinery. In addition to grazing pastures, there are a number of successful selections for the mixed cropping system in agriculture, such as wheat and chickpea; soybean and pigeon pea; peanut and sunflower; sorghum and pigeon pea; barley and chickpea; wheat and mustard; and cotton and peanut, etc. (Anon, "Mixed Cropping,").

1.4. Cover Cropping

Growing cover crops is another effective approach to improve C sequestration and SOC storage. Sainju *et al.* 2006 also reported that SOC increased by 6-8% with cover crops at 0 to 10 cm, and by 0.4% with rye in monoculture and 3% with vetch and rye in biculture at 0-30 cm. However, in the tropical or subtropical region, summer cover crops, such as sunn hemp, velvetbean, sorghum sudangrass, are prevailing species grown during the hot and humid summer to cover the bare land conserving soil and water and those summer cover crops, especially sunn hemp can produce as much as 15 Mg ha^{-1} of aboveground biomass and 3.5 Mg ha^{-1} belowground biomass, combined contributes to 8 Mg ha^{-1} of organic C input into the soil within 3 months (Wang *et al.*, 2005). Cover crops are grown to protect the soil from erosion and nutrient loss by either leaching or runoff (Reeves, 1994). The severity of erosion can be reduced by maintaining crop residue on the soil surface (Dickey *et al.*, 1985). The Rodale Institute Farming, 2008 observed that organic wheat/maize/soybean cropping systems with cover crops sequestered almost 1,000 kg C $ha^{-1}yr^{-1}$.

1.5. Ratoon cropping:-

Ratoon cropping has obvious advantages for crop production and soil C sequestration. With these practices, an overall productivity can be enhanced with addition of sufficient biomass to underground and aboveground showing a higher potential for biomass return and soil C sequestration. Ratooning sorghum [*Sorghum bicolour* (L.) Moench] or sugarcane (*Saccharum officinarum* L.) is successful (G. E. Rodolfo and D. L. Plucknett., 1975), and the main crop should be cut at about 2.5-10 cm above the ground level after its maturity. Okra (*Abelmoschus esculentus*) is another ideal ratooning vegetable crop in tropics or subtropics, for which such rationing can be conducted two or three times (Y. Li *et al.*, 2006).

Appropriate cropping practices, such as fertilization to adjust nutrient balance, appropriate water supply, etc., are important factors to optimize biomass production, improve crop growth and development.

2. Agro forestry :

Alternate land use systems, *viz*., agro-forestry, agro-horticulture, and agro-silviculture, are more remunerative for SOC restoration as compared to sole cropping system. Agroforestry is a perfect choice to reduce pressure on forests by increasing tree cover and productivity of wasteland and to prevent and mitigate climate-change effects (Dhyani *et al.*, 2009). The C sequestration potential of tropical agroforestry systems has been estimated to range between 12 and 228 Mg ha^{-1}, and a mean of 95 Mg ha^{-1} (Albrecht and Kandji, 2003). Grassland contribute to soil organic matter, mostly in the form of roots. The amount of carbon stored in the soil system depends on agriculture management systems and practices. Soil C sequestration is a significant mitigation option and pursuing strategies to increase soil C improve soil quality for agricultural productivity and sustainability (Andren *et al.*, 2001). A young forest can also acts as a sink as it absorbs CO_2 at a faster rate. Indian forests and plantations have been able to remove at least 0.125 Gt of CO_2 from the atmosphere (Lal and Singh, 2000). Average sequestration potential in agroforestry has been estimated to be 25 t C ha^{-1} over 96 million ha of land in India and 6-15 t C ha^{-1} over 75.9 Mha in China (Sathaye and Ravindranath, 1998). Tree roots sequestered about 48 Mg C ha^{-1} in 20–200 cm depth of soil at 10 year production system and 68 Mg C ha^{-1} in 20–200 cm depth of soil at 7 year production system, more than in the sole-maize (Makumba *et al*, 2007). Watson *et al.*, (2000) estimated carbon gain of 0.72 Mg C ha^{-1} yr^{-1} on 4000 million ha land under agroforestry, with potential for sequestering 26 Tg C yr^{-1} by 2010 and 45 Tg C yr yr^{-1} by 2040. The Intergovernmental Panel on Climate Change (IPCC) estimated that it may be possible, over the course of the next 50–100 years, to remove between 40 and 80 Pg of the carbon by sequestering it through agroforestry (Houghton , 2003).

3. Farming System:

Integrated crop-livestock systems are one of the most promising approaches of recycling agriculture residues for sustainable development, especially in rainfed area of India (Ramchandra and Samra, 2012). Systems that integrate livestock and crops, employ perennial pastures, and adopt many of the practices used in organic production (e.g., long crop rotations, leguminous crops and cover crops, manure produced by livestock as fertilizer) also have shown potential for improved greenhouse gas balance, reduced pollution, and higher profitability. Further research on these promising approaches will help optimize their benefits and determine their applicability across geographic regions. These systems which aim at a range of resource-saving practices also provide opportunities for deriving maximum benefits from the whole system by exploiting the synergies among different components. Based on the principal of enhancing natural biological processes above and below the ground, the integrated system represents a win-win combination that (a) reduces erosion (b) increases crop yield, soil biological activity and nutrient recycling (c) intensifies land use, improves profits and can therefore help reduce poverty and malnutrition and strengthen environmental sustainability. Under the gradual shrinking of land holdings, it is necessary to integrate land based enterprises like fishery, poultry, duckery, apiary, field and horticultural crops, etc. within the bio-physical and socio-economic environment of the farmers to make farming more profitable and dependable (Behera *et al.*, 2004). In a head-to-head comparison between conventional no-till and organic plowed systems, organic plowed systems sequestered more carbon even though the sampling was restricted to shallow soil, where no-till tends to show carbon accumulation (Teasdale *et al.,* 2007). Although more studies are needed, there are good reasons to believe that organic systems would do at least as well as conventional systems deeper in the soil. Current organic systems typically employ plowing to control weeds, and conventional plowed systems generally sequester more carbon at greater soil depths than no-till (Baker, J.M., *et al.*, 2007).

Management Practices on Carbon Sequestration:

Conventional agriculture normally reduces the SOC of the surface or plough layer. Recommended farming practices involve agricultural intensification on prime agricultural land through use of improved varieties, adoption of appropriate cropping systems that enhance cropping intensity, and elimination of summer fallow. Soil erosion risks are extremely high on ploughed un-cropped land, and accelerated soil erosion accentuates the depletion of SOC pool. Improvements in crop yield through adoption of recommended technology enhance SOC pool and improve soil quality. Conversion of marginal agricultural land to restorative land use reduces soil erosion and increases SOC pool.

1. Tillage:

Tillage is known to decrease soil organic nitrogen (N) and C pools with negative consequences for soil fertility (Kristensen *et al.*, 2003). Although conventional tillage without cover crop and N fertilization reduces soil organic matter level by enhancing C mineralization and limiting C inputs (Dalal and Mayer, 1986; Balesdent *et al.*, 1990; Cambardella and Elliott, 1993), conservation tillage with cover cropping and N fertilization can increase C storage and active C fractions in the surface soil (Jastrow, 1996; Allmaras *et al.*, 2000; Sainju *et al.*, 2002, 2006). Studies suggest that conversion of conventional till (CT) to no-till (NT) can sequester atmospheric CO_2 by 0.1% ha-1 at 0 to 5 cm every year or by a total of 10 tons in 25 to 30 yr (Lal and Kimble, 1997; Paustian *et al.*, 1997). However, SOC below 7.5 cm depth can be higher in tilled areas, depending on the soil texture, due to residue incorporation at greater depths (Jastrow, 1996; Clapp *et al.*, 2000). Similarly, cover cropping and N fertilization can increase C fractions in tilled and non-tilled soils by increasing the amount of crop residue returned to the soil (Kuo *et al.*, 1997). The rate of SOC sequestration by NT can be higher in the subsoil layer .It has been reported that carbon stocks in agricultural soil under tillage decline compared to no-tillage (Duiker and Lal, 1999; Mrabet *et al.*, 2001), and both tillage and burning have been shown to reduce organic matter levels (Chan *et al.*, 1992; Slattery and Surapaneni, 2002). Conservation tillage systems increase SOC level. Conservation tillage when used in conjunction with crop residue mulch and cover crops, improves SOC pool. The benefits of conservation tillage in C sequestration are due both to increase in SOC content and decrease in CO_2 emissions caused by ploughing (Reicosky *et al.*, 1995). Conservation agriculture reduce soil erosion, enhance soil physical and microbial properties, increasing nutrient availability and support the conversion the plant carbon to soil organic matter and humus . Timing and intensity of tillage also must be taken into account in the design of best management practices for maximizing SOC sequestration.

2. Manuring:

Regular application of livestock manure can induce substantial changes in SOC over the course of a few years (Sommerfeldt *et al.,* 1988). Jenkinson (1990) report that after 144 yr of large annual applications of animal manure (35 t ha^{-1} yr^{-1}), SOC content is still increasing at Broadbalk Wheat Experiment. Powlson *et al*, 1998 observed that continuous increase in SOC content at the rate of 35 Mg $ha^{-1}y^{-1}$ even after 150 years of manure application. The organic C concentration in the surface soil (0-15 cm) largely depends on the total input of crop residues remaining on the surface or incorporated into the soil. It decreases soil C greatly to remove crop top from the soil by cleaning up the land (S. Kuo and E. Jellum, 2002). Within a cropping system, SOC increased significantly with N fertilization only in the corn-corn system (Russell *et al.*, 2005). Management practices that optimize cropping systems and N fertilization are believed to offer the greatest potential for increasing SOC storage in agricultural soil (Lal *et al.*, 1999; Lal, 2002). SOC sequestration rates were 50 to 75 g C $m^{-2}y^{-1}$ in well-fertilized soil with optimum cropping systems (Dumanski *et al.*, 1998). The combined use of optimal dose of chemical fertilizers and biofertilizers significantly increased seed and straw yields of pearlmillet and mustard, respectively over other fertility treatments and control. The highly significant and positive correlation of total productivity was observed with pearlmillet-equivalent yield, total organic carbon, very labile carbon and active pool in soil (Khambalkar *et al.*, 2013). Improvements in water use efficiency, through measures such as irrigation system mechanical improvements coupled with a reduction in operating hours; drip irrigation technologies; and center-pivot irrigation systems, can significantly reduce the amount of water and nitrogen applied to the cropping system. This reduces greenhouse emissions of nitrous oxide (N_2O) and water withdrawals. The loss of soil fertility in many developing countries due to continuous nutrient depletion by crops without adequate replenishment poses an immediate threat to food and environmental securities. There is a need to revive the age old practice of application of organic manures to maintain soil fertility and also to supplement many essential plant nutrients for crop productivity. The use of inorganic fertilizers in combination with organic manures has been found more advantageous than either of them alone for sustainable agriculture on long term basis (Narwal and Antil 2005). Integrated nutrient management is followed for enhancing crop productivity of intensive cropping systems, nutrient availability, biological properties and soil carbon pools for long term (Moharana *et al* 2012). Sequestered soil organic carbon (SOC) with a relatively long turnover time is returned to the recalcitrant soil pool thus decreasing the rate of accumulation of atmospheric CO_2 concentration

Carbon sequestration through sustainable intensification of cropping systems, management practices and conservation agriculture is the way forward in a high emission future. Mixed crop rotations, use of cover crop, improve SOC content and enhance aggregation. With better management practices and adopting less intensive tillage systems such as no-tillage, strip-tillage, deep rip, and chisel plow and better crop residue cover are effective in reducing CO_2 emission and thus improving soil C sequestration. It is imperative to supply information to farmers, policy makers and other decision makers on ways to accomplish sustainable agriculture in the changing climatic scenarios around the world.

References

Adviento-Borbe, M. A. A., M. L. Haddix, D.L. Binder, D.T. Walters and A. Dobermann (2007). Soil greenhouse gas fluxes and global warming potential in four high-yielding maize systems. *Global Change Biology,* **13**: 1972-1988.

Albrecht, A. and S. Kandji (2003). Carbon sequestration in tropical agro forestry systems. *Agric. Ecosys. Environ.,* **99**: 15–27.

Al-Kaisi, M.M. and X.H. Yin (2005). Tillage and crop residue effects on soil carbon and carbon dioxide emission in corn-soybean rotations. *Journal of Environmental Quality,* **34**: 437-445.

Allmaras, R.R., H.H. Schomberg, C.J. Douglas, Jr. and T.H. Dao (2000). Soil organic carbon sequestration potential of adopting conservation tillage in U.S. croplands. *J. Soil Water Conserv.,* **55**:365–373.

Andren, O., T. Katterer and R. Hyvonen (2001). Projecting soil fauna influence on long-term soil carbon balances from faunal exclusion experiments. *Applied Soil Ecology,* **18**: 177-186.

Anon, “Strip Intercropping Offers Low-Input Way to Boost Yields,” *Sensible Agriculture*, Mono Publication, May 1990, pp. 7-8.

Anon, “Mixed Cropping,” http://simple.wikipedia.org/ wiki/ Mixed_cropping.html

Auque, L.F., P. Acero, M.J. Gimeno, J.B. Gomez and M.P. Asta (2009). Hydrogeochemical modeling of a thermal system and lessons learned for CO_2 geologic storage. *Chemical Geology,* **268**: 324-336.

Baker, J.M. *et al.* (2007). Tillage and soil carbon sequestration—What do we really know *Agriculture, Ecosystems and Environment,* **118**: 1–5.

Balesdent, J., A. Mariotti and D. Boisgontier (1990). Effect of tillage on soil organic carbon mineralization estimated from C abundance in maize fields. *J. Soil Sci.,* **41**: 587–596.

Bhadwal, S. and R. Singh (2002). Carbon sequestration estimates for forestry options under different land use scenarios in India. *Current Science,* **83(11)**:1380–1386.

Bhattacharyya, T., D.K. Pal, M. Velayutham, P. Chandran and C. Mandal (2001). Total Carbon Stock in Indian Soil: Issues, Priorities and Management. pages 1-46 *In:* Land Resource Management for Food and Environmental Security. Soil Conservation Society of India, New Delhi, India.

Behera, U.K., K.P. Jha and I.C. Mahapatra (2004). Integrated management of available resources of the small and marginal farmers for generation of income and employment in eastern India. *Crop Research,* **27(1)**: 83-89.

Cambardella, C.A. and E.T. Elliott (1993). Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils. *Soil Sci. Soc. Am. J.*, **57**: 1071–1076.

Chan, K.Y., W.P. Roberts and D.P Heenan (1992). Organic carbon and associated soil properties of a red earth after 10 years of rotation under different stubble and tillage practices. *Aust. J. Soil Res.,* **30**: 71–83.

Chester, B. (2000). The case of the missing sink. Mc Gill Reporter.Vol.**32 (15).**

Clapp, C.E., R.R. Allmaras, M.F. Layese, D.R. Linden, and R.H. Dowdy (2000). Soil organic carbon and 13C abundance as related to tillage, crop residue, and nitrogen fertilizer under continuous corn management in Minnesota. *Soil Tillage Res*., **55**: 127–142.

Dalal, R.C. and R.J. Mayer (1986). Long-term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland: II. Total organic carbon and its rate of loss from soil profile. *Aust. J. Soil Res.*, **24**: 281–292.

Dhyani, S.K., Newaj Ram and A.P. Sharma (2009). Agroforestry: its relation with agronomy, challenges and opportunities. *Indian J. Agron*., **54(3)**: 249–266.

Dickey, E.C., D.P. Shelton, P.J. Jasa, and T.R. Peterson (1985). Soil erosion from tillage systems used in soybean and corn residues. *Trans. Am. Soc. Agric. Eng*., **28**:1124-1129.

Drinkwater, L.E., P. Wagoner and M. Sarrantonlo (1998). "Legume- Based Cropping Systems have Reduced Carbon and Nitrogen Losses," *Nature*, **396(6708)** : 262-265.

Duiker, S.W. and R. Lal (1999). Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. *Soil Tillage Res.,* **52**, 73–81.

Dumanski, J., R.L. Desjardins, C. Tarnocai, D. Monreal, E.G. Gregorich,V. Kirkwood, and C.A. Campbell (1998). Possibilities for future carbon sequestration in Canadian agriculture in relation to included oat and alfalfa in the rotation had the greatest land use changes. *Clim. Change,* **40**: 81–103.

Fenton, T.E., J.R. Brown and M.J. Maubach (1999). Effects of long-term cropping on organic matter content of soil: Implication for soil quality. *Soil and Water Con. J.* 95–124.

Gonet, S.S. and D. Bozena (1998). Properties of humic acids developed during humification process of post-harvest plant residues, *Environment International,* **24**: 603-608.

Hirst, K.K., "Mixed Cropping, Agricultural Technique Known as Mixed Cropping," 2009. http://archaeology. about.com/od/historyofagriculture/qt/mixed_cropping.ht ml (access date: 3/28/2010).

Houghton, R. A.2003. Why are estimates of the terrestrial carbon balance so different, *Glob. Chang. Biol*., **9**: 500–509.

IPCC, "Climate Change (2001). The Scientific Basis", Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

IPCC, "Assessment Report," (2007). http://www.ipcc.ch/pdf/assessment report/ar4/syr/ar4_syr_spm.pdf

Jastrow, J.D. (1996). Soil aggregate formation and the accrual of particulate and mineral associated organic matter. *Soil Biol. Biochem*., **28**:665–676.

Jenkinson, D.S. (1990). The turnover of organic carbon and nitrogen in soil. *Philosophical Transactions Royal Society, London,* **B 329:** 361-368.

Jones, R.B., J.W. Wendt, W.T. Bunderson and O.A. Itimu (1996). Leucaena + maize alley cropping in Malawi. Part 1: Effects of N, P, and leaf application on maize yields and soil properties. *Agroforestry Syst*., **33**: 281–294.

Khambalkar, P.A., P.S. Tomar and S.K. Verma (2013). Influence of integrated nutrient management on carbon sequestration and its relationship with productivity of pearlmillet (*Pennisetum glaucum*)-mustard (*Brassica juncea*) cropping sequence. *Indian Journal of Agronomy*, **58(4)**: 480-489.

Kristensen, H.L., Debosz, K., McCarty, G.W. 2003. Short-term effects on mineralization of nitrogen and carbon in soil. *Soil Biol. Biochem.,* **35**: 979–986.

Kumar, G.P., S. Gupta, P.M. Murugan and S.B. Singh (2009). Ethnobotanical studies of Nubra Valley – a cold arid zone of Himalaya. *Ethnobot. Leaf*., **13**: 752–765.

Kuo, S., U.M. Sainju, and E.J. Jellum (1997). Winter cover crop effects on soil organic carbon and carbohydrate. *Soil Sci. Soc. Am. J.,* **61**:145–152.

Kuo, S., and E. Jellum (2002). "Influence of Winter Cover Crop and Residue Management on Soil Nitrogen Availability and Corn," *Agronomy Journal*, **94(3)**: 501-508.

Lal, M. and R. Singh (2000). Carbon sequestration potential of Indian forests. *Environ. Monit. Assess.*, **60**, 315–327.

Lal, R. (1999). Global overview of soil erosion. In: R.S. Baker (ed) "Soil and Water Science: Key to Understanding Our Global Environment." Soil Sci. Soc. Amer. Special Publication No. 41, Madison, WI: 39-51.

Lal, R. (2013). Climate resilient agriculture and soil organic carbon. *Indian Journal of Agronomy*, **58 (4)**: 440-450

Lal, R., J. Kimble, E. Levin, and B.A. Stewart (Eds.) (1995). Advances in soil science: Soil management and greenhouse effect. *Bocan Raton: Lewis Publishers*, P. **93**..

Li Y., W. Klassen, M. Lamberts and T. Olczyk (2006). "Okra Production in Miami-Dade County, Florida," HS-875, 2006. http://edis.ifas.ufl.edu.

Li, Y., W. Klassen, M. Lamberts and T. Olczyk (2006). "Okra Production in Miami-Dade County, Florida," HS-875, . http://edis.ifas.ufl.edu.

Makumba, W., K. Festus and Bert Janssen, and Oene Oenema Akinnifesi (2007). Long-term impact of a gliricidia-maize intercropping system on carbon sequestration in southern

Malawi. *Agriculture, Ecosystems and Environment,* **118**, 237–243.

Manna M.C., A. Swarup, R.H. Wanjari, H.N. Ravankar, B. Mishra, M.N. Saha, Y.V. Singh, D.K. Sahi and P.A. Sarap (2005). Long term effect of fertilizer and manure application on soil organic cabon storage, soil quality and yield sustainability under sub-humid and tropical India. *Field Crops Research,* **93**:264-280.

Murthy, V.R.K. (2003). Crop growth modeling and its applications in agricultural meteorology. *In* Proceedings of a Training Workshop held on 7-11 July 2003 in Dehra Dun India on *Satellite Remote Sensing and GIS Applications in Agricultural Meteorology pp. 235-261.*

Mrabet, R., N. Saber, A. El-Brahli, S. Lahlou and F. Bessam (2001). Total particulate organic matter and structural stability and a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. *Soil Tillage Res*., **57**: 225–235.

Pan, G., L. Li, L. Wu and X. Zhang (2003). Sorae and sequestration potential of topsoil organic carbon in Chaina's paddy sois, *Global Change Biology,* **10**:79-92.

Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 779-810.

Paustian, K., O. Andren, H.H. Janzen, R. Lal, P. Smith, G. Tian, H. Tiessen, M. Van Noordwjik and P.L. Woomer (1997). Agricultural soils as a sink to mitigate CO2 emissions. *Soil Use Manage*., **13**:230–244.

Powlson, D.S., P. Smith, K. Coleman, J.U. Smith, M.J. Glendining, M. KOrschens and U. Franko (1998). A European network of long-term sites for studies on soil organic matter. *Soil &Tillage Res*., **47**: 263-274.

Prochaska, S.C. (2003). "Three-Year Summary of Effect of Modified Relay Intercropping on Wheat Yield in 15-Inch Rows," In: P. Rzewnicki, Ed., *Agronomic Crops Team on-Farm Research Projects*, 2002. Special Circular 190.Wooster, Ohio Agricultural Research and Development Center, The Ohio State University.

Ramchandra, K.S. and J.S. Samra (2012). Integrated crop-livestock production systems for sustainable development of rainfed areas in India. In: Lead papers: 3rd International Agronomy Congress, Nov.26-30, New Delhi, India.

Raich, J.W. and C.S. Potter (1995). Global patterns of carbon dioxide emissions from soils, Global *Biogeochemical Cycles.* **9**:23-36.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.W. Douglas Junior and P.E. Rasmussen (1995). Soil rganic matter changes resulting from tillage and biomass production. *Journal of Soil and water Conservation,* **50:**253-261.

Reeves, D.W. (1994). Cover crops and rotations. In Crops Residue Management. Advances in Soil Science. J.L. Hatfield, and B.A. Stewart (eds.). Lewis Publishers, Boca Raton, FL, pp. 125Y172.

Rodale Institute (2008). Regenerative Organic Farming: A Solution to Global Warming.

Rodolfo, G.E. and D.L. Plucknett (1975). "Ratoon Cropping of Sorghum: II. Effect of Day Length and Temperature on Tillering and Plant Development," Journal series No. **1775,** Hawaii Agricultural Station, University of Hawaii, Honolulu.

www.rodaleinstitute.org/fi les/Rodale_Research_ Paper-07_30_08.pdf.

Russell, A. E., D. A. Laird, T. B. Parkin, and A. P. Mallarino.2005. Impact of Nitrogen Fertilization and Cropping System on Carbon Sequestration in Midwestern Mollisols. *Soil Sci. Soc. Am. J*., **69**:413–422.

Sainju U.M., B.P. Singh, F.W. Wayne and S. Wang (2006). Carbon Supply and Storage in Tilled and Nontilled Soil as Influenced by Cover Crops and Nitrogen Fertilization. *Journal of Environmental Quality,* **35(4)**:1507-1517.

Sainju, U.M., B.P. Singh and W.F. Whitehead (2002). Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. *Soil Tillage Res.,* **63**:167–179.

Sainju, U.M., W.F. Whitehead and B.P. Singh (2003). Cover crops and nitrogen fertilization eff ects on soil aggregation and carbon and nitrogen pools. *Can. J. Soil Sci.,* **83**: 155–165.

Sathaye, J.A. and N.H. Ravandranath (1998). Climate change mitigation in the energy and forestry sectors of developing countries. *Ann. Rev. Energy Environ.,* **23**: 387-437.

Schneider, S.H., S. Semenov, A. Patwardhan, I. Burton, C.H.D. Magadza, M. Oppenheimer, A.B. Pittock, A. Rahman, J.B. Smith, A. Suarez and F. Yamin (2007). Assessing key vulnerabilities and the risk from climate change. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,

Slattery,W.J. and A. Surapaneni (2002). Can organic fertilizers enhance carbon sequestration in soil In: 17th World Congress of Soil Science. 14–21 August 2002, Thailand. Symposium 10, paper no. 1705 11 pp., (http://www.17wcss.ku.ac.th).

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar and J. Smith (1998). Greenhouse gas mitigation in agriculture, *Philosophical Transaction of The Royal Society B: Biological Science,* **363**:789-813.

Spmmerfeldt, T.G, C. Chang and T. Entz (1988). Long-term annual manure applications increase soil organic matter and nitrogen, and decrease carbon to nitrogen ratio. *Soil Science Society of America Journal,* **52:**1668-1672.

Teasdale, J.R. (2007). Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement. *Agronomy Journal,* **99**:1297–1305.

United Nations (2001). Population, Environment and

Development: The Concise Report, New York.

Wang Q., W. Klassen, Y. Li and M. Codallo (2005). Influence of Cover Crops and Irrigation Rates on Tomato Yields and Quality in a Subtropical Region. *Hort. Science*, **40(7)**: 2125-2131.

Wang, Q., Y. Li and A. Alva (2010). Cropping Systems to improve carbon sequestration for mitigation of climate change.. *Journal of Environmental Protection,* **1**: 207-215.

Watson, R.T., I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Vernado and D.J. Dokken (2000eds). Landuse, land use change and forestry, IPCC, special report, Cambridge Univ., Press, New York.

West, T.O. and W.M. Post (2002). Soil organic carbon sequestration rates by tillage's and crop rotation: A Global data analysis. *Soil Science Society of America Journal,* **66**: 1930-1946.

Willy, R.W. (1983). Intercropping Studies with Annual Crops," In: J. Nugent and M.O'Connor, Eds., *Better Crops for Food*, CIBA Foundation Symposium 97, Pitman, London.

Wu, J. (2011). Carbon accumulation in paddy ecosystems in subtropical China: evidence from landscape studies, *European Journal of Soil Science,* **62**:29-34.

Yadav, A.K. (2010). Carbon Sequestration: underexploited environmental benefits of *Tarai* agroforestry Systems. *Report and Opinion*, **2** (11).

Zentner, R.P., C. A. Campbell, V.O. Biederebeck, P.R. Miller, F. Selles and M.R. Fernandez (2001). "In Search of a Suitable Cropping System for the Semi-Arid Canadian Prairies," *Journal of Sustainable Agriculture*, **18(2-3):** 117-136.

Zentner, R.P., C.A. Campbell, V.O. Biederebeck, F. Selles, R. Lemke, P.G. Jefferson and Y. Gan (2004). "Long- Term Assessment of Management of an Annual Legume Green Manure Crop for Fallow Replacement in the Brown Soil Zone," *Canadian Journal of Plant Science*, **83**: 475-482.