22 Conservation Agriculture for Carbon Sequestration and Mitigation of Climate Change

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Abstract

Climate change is expected to intensify existing problems and create new combinations of risks, particularly in India. The situation is made worst due to factors such as widespread poverty, malnutrition, overdependence on rainfed agriculture, inequitable land distribution, limited access to capital and technology, and long-term change in weather. By lessening the severity of key damages to the agricultural sector, the adoption of conservation agriculture (CA) is the key sustainable measure. CA is an approach to farming that seeks to increase food security, alleviate poverty, conserve biodiversity, and safeguard ecosystem services. CA practices can also contribute to making agricultural systems more resilient to climate change. In many cases, CA has been proven to reduce farming systems' greenhouse gas (GHG) emissions and enhance their role as carbon (C) sinks. CA systems influence several ecosystem services in various types of environments while improving agricultural sustainability and soil health through climate change mitigation and biodiversity conservation. The increasing temperature and climate change have warned agriculture production and threatened the food security with variable rainfall and other abnormal climatic conditions. Extreme weather conditions such as irregular rainfall amount and distribution, droughts, floods, etc. are likely to continue to increase with serious impacts on agricultural productivity in the future. At the same time, CA could be an effective

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adaptation option under these situations as it protects natural biodiversity, strengthening the ability of the agroecosystem to respond to these stresses, minimizing environmental pollution, reducing the incidence of insect pests, diseases, and weed problems, securing food supply opportunities, and also providing producers with alternative means of generating income.

Keywords

Carbon sequestration · Climate change · Conservation agriculture

22.1 Introduction

Conservation agriculture (CA) is a resource-saving farming production system to increase crop production and attain high productivity while sustaining the natural resources with the incorporation of three related principles, besides other good crop production principles and practices of pest management and plant nutrition. It is a process of environment protection, mitigating and adapting climate change, and sustainable land and agriculture management (Kassam 2019; FAO 2020). FAO describes conservation agriculture (CA) as a resource-saving agricultural production concept based on enhancing the above and below the ground biological and natural and processes. Minimum tillage and soil disturbance, permanent soil cover with crop residues and live mulches, and crop rotation and intercropping are the three key principles of the CA system (FAO 2020). In recent times, CA is becoming increasingly popular due to the compound benefits it delivers like enhanced production efficiency, crop and soil productivity, protection of soil from erosion, and climate change mitigation (Busari et al. 2015; Ngoc et al. 2018); enhances infiltration and increases soil water content (Kassam et al. 2009; Blanco-Canqui and Ruis 2018; Zhang and Han 2019); and prevents the growth and infestation of predaceous nematodes while increasing and fastening the multiplication of all soil micro- and macroorganisms (Henneron et al. 2015).

CA systems influence several ecosystem services in various types of environments while improving agricultural sustainability and soil health through climate change mitigation and biodiversity conservation (Ghosh et al. 2019). CA system is also reported to reduce blast disease in rice (Lakhran et al. 2017). Ella et al. (2016) reported that besides increasing soil organic carbon (SOC), CA systems also increased residual water content in upland crop production systems in the Philippines. CA can act as a strategy to reduce GHG emissions and to mitigate climate change. The different CA practices introduce the changes in C dynamics of soils and lead to increase in soil carbon status. In CA practice, the tillage operations are reduced extremely or completely abandoned, which slows the process of organic matter mineralization in soil (Sommer et al. 2011; Alvaro-Fuentes et al. 2012; Almagro and Martinez-Mena 2014). Also reduced or no-tillage operations are energy-saving; hence, they save energy, fuel, and time and reduce GHG emission (West and Marland 2002; Ogle et al. 2019).

22.2 Climate Change, Agriculture, and Conservation Agriculture

According to the United Nations Framework Convention on Climate Change (UNFCCC), climate change is the occurrences of several alterations or changes in the present climate witnessed over comparable periods attributed to direct or indirect human activities leading to the altered composition of the earth atmosphere and can be connected to the natural discrepancy of the climatic parameters (González-Sánchez et al. 2017). The earth's average temperature has been witnessed an increase of 1.3 °C in the last 57 years, while the average earth's surface temperature in Southern Asia and India has marked an increase of 1.2 and 1.1 °C, respectively (FAOSTAT 2020, Fig. 22.1a). By the end of the twenty-first century, the temperature in India is likely to increase by 1–5 °C (IPCC 2007; Intergovernmental Panel on Climate Change 2014; Basha et al. 2017; Joshi et al. 2018). The increasing temperature and climate change have warned agriculture production and threatened food security with variable rainfall and other abnormal climatic conditions. Extreme weather conditions such as irregular rainfall, droughts, floods, sharp changes in maximum and minimum temperatures, etc. are likely to continue to increase with serious impacts on agricultural productivity. Countries like India are more vulnerable to the effects of climate change. Climate change may affect the distribution of plant species (Sharma et al. 2010) and may also increase the incidence of pests and diseases (Harrington et al. 2001; Samways 2005; Diffenbaugh et al. 2008; Bale and Hayward 2010; Danielle 2018). The changing climate scenarios may have some

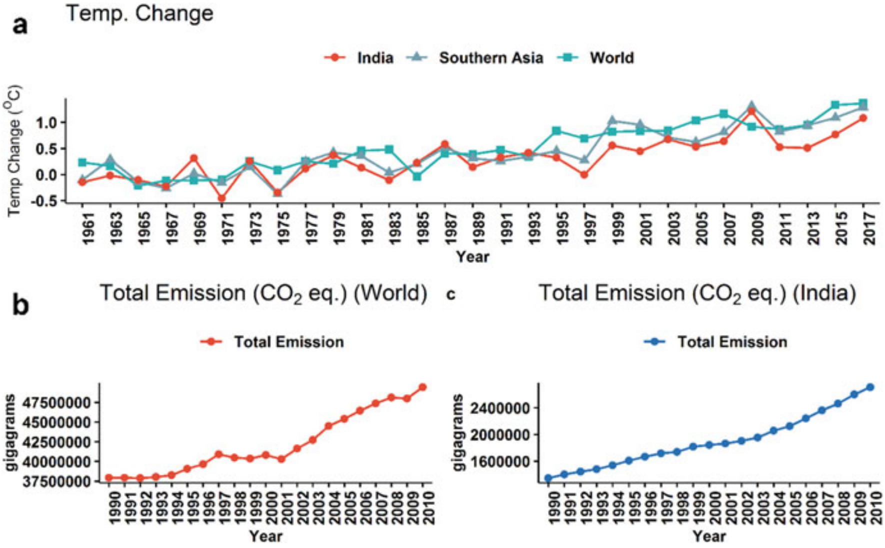

Fig. 22.1 Change in the average temperature of the world, Southern Asia, and India (**a**); trend in total emission (CO_2 eq.) of greenhouse gases (GHGs) by all sectors in the world (**b**); and India (**c**). (Source: FAOSTAT 2020)

positive effects on crops; for example, increase in CO_2 concentration may increase the photosynthetic activity in plants as a result of CO_2 fertilization effect and leads to higher productivity in some crops (Allen Jr et al. 1995; Singh 2007; Degener 2015; Lone et al. 2017). Temperature rise may result in the introduction of new crops in cold areas. However, the negative impacts of changing climatic scenarios are more serious and threatening. These negative impacts may further increase the incidence of weeds, pests, and diseases, thermal stress in plants due to ambient temperature, damage in vernalization, frequencies of droughts and floods, salinity and erosion problems, etc. These negative impacts of climate change may pose a serious problem in the agriculture production system with a decline in productivity under the arena of the ever-increasing population (Mall et al. 2006; Gornall et al. 2010).

Lead by the several anthropogenic activities, a notable gain in the atmospheric concentration of greenhouse gases (GHGs), *viz*., carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), has been witnessed during the last couple of centuries. Carbon (C) is the source of origin of GHG emission, and these GHGs are responsible for global warming (Ritchie and Roser 2020). In the last several years (1990–2010), the total GHG emission (CO_2 eq. of CO_2, CH_4, and N_2O) has noticed a worldwide increase from 38 million gigagrams to 49 million gigagrams (Fig. 22.1b); as far as the total GHG emission (CO_2 eq.) from India is concerned, it was 1.35 million gigagrams in 1990 and increased to 2.70 million gigagrams in 2010 (Fig. 22.1c), indicating a twofold increase within a period of 20 years (FAOSTAT 2020).

Among all the sectors responsible for GHG emission, the contribution of agriculture is about 10% of total GHG emission (CO_2 eq.) worldwide, whereas it is 23% of total GHG emission in India. The share of different sectors in total greenhouse gas emission (CO_2 eq.) in the world (left) and India is depicted in Fig. 22.2. The energy sector contributes nearly half of the total GHG emission. The global GHG emission from the agriculture sector has increased from 2.75 million gigagrams in 1961 to 5.41 million gigagrams in 2017. In India, the GHG emission from the agriculture sector was 0.34 million gigagrams in 1961, which has turned up to 0.63 million gigagrams in 2017 (Fig. 22.3). In 1750, the concentration of CO_2, CH_4, and N_2O in the atmosphere was 280 ppm, 715 ppb, and 270 ppb, respectively, which increased to 405 ppm, 1850 ppb, and 330 ppb, respectively, in 2017 (EEA 2019).

The two GHGs produced by the agriculture sector are CH_4 and N_2O contributing 55% and 45% of emissions, respectively. With respect to global warming potential, CO_2 and CH_4 are having a global warming potential (GWP) of 25 and 298 times that of CO_2 (IPCC 2007). GWP is a measure of how much heat the emission of 1ton greenhouse gas traps in the atmosphere over a given period of time (usually 100 years' time slice), relative to the emissions of 1 ton CO_2. Since agricultural activities contribute 45% of N_2O emission of total GHG emission and the GWP of this gas is 298 times greater than CO_2, a very small emission of this gas may have a huge effect on climate change. Soil microbial processes like nitrification and denitrification are responsible for the transformation of elemental soil N to N_2O and large-scale emission of this GHG emission. Rice cultivation, due to its significant contribution to methane (CH_4) and N_2O emission and global warming, appealed a

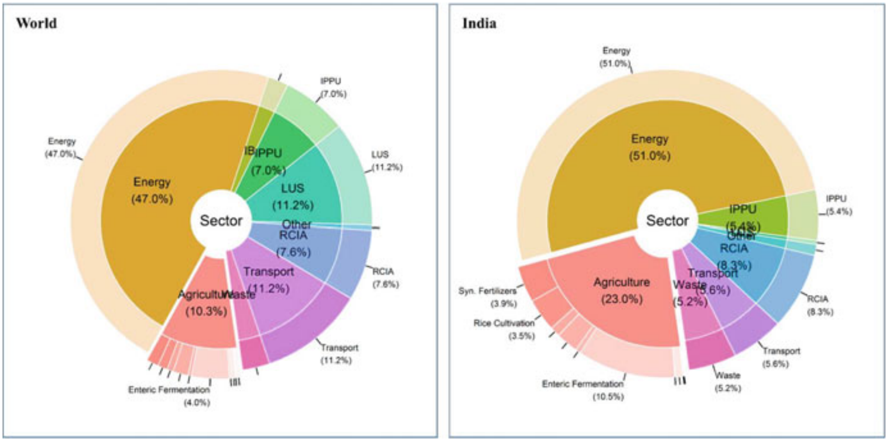

Fig. 22.2 Share of different sectors in total greenhouse gas emission (CO_2 eq.) in the world (left) and India (right). Energy includes energy, manufacturing and construction industries, and fugitive emissions. *RCIA* residential, commercial, institutional, and AFF, *IPPU* industrial processes and product use, *LUS* land use sources, *IB* international bunkers. Data is based on the year 2010. (Source*:* FAOSTAT 2020)

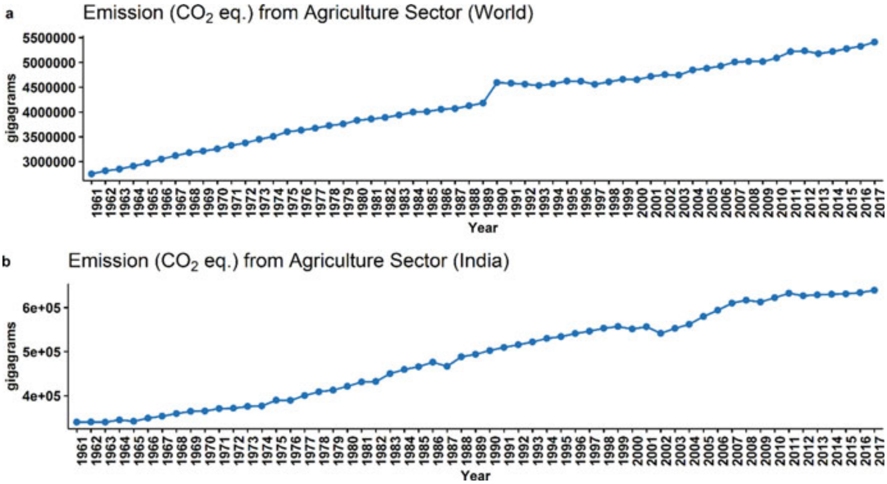

Fig. 22.3 Trends in total emission (CO_2 eq.) of GHGs from the agriculture sector in (**a**) the world and (**b**) India. (Source: FAOSTAT 2020)

large interest (Jat et al. 2016). The methane emission from rice cultivation is due to the presence of methanogenic bacteria in the methane anaerobic soils of flooded paddy fields and the enteric fermentation [digestive systems of ruminant livestock (e.g., cattle, sheep, goats, horses)] being two important sources of methane emission; the other sources like manure decomposition and crop residue decomposition under wet conditions also contribute in methane emission from the agriculture sector.

Other sources of CH_4 from agriculture are from the decomposition of animal manure, especially when stored in lagoons, and from crop residues when decomposing under very wet conditions. In contrast, in the well-aerated soils with high organic matter content, crop residues on the surface may absorb methane from the atmosphere.

On one hand, agricultural activities are considered to be the cause of climate change; on the other hand, they are also affected by it. However, if well managed, the use of less productive factors in agriculture can reduce CO_2 emissions, and this can mitigate the effects of climate change caused by agriculture (Gornall et al. 2010; Liu et al. 2016). If we include the total anthropogenic emission from the agriculture sector with the emission from deforestation due to agriculture area expansion, the share of agriculture in global GHG emission may reach 30% (IPCC 2007). However, agriculture can mitigate about 5.5–6 Gt of CO_2 eq. per year, and a large portion of this potential can be covered through carbon sequestration. Conservation agriculture (CA) can act as a strategy to reduce GHG emissions and to mitigate climate change. The different CA practices introduce the changes in C dynamics of soils and lead to increase in SOC status. In CA practice, the tillage operations are reduced extremely or completely abandoned, which slows the process of mineralization of organic matter in soil. Also, reduced or no-tillage operations are energy-saving; hence, they save energy, fuel, and time and reduce GHG emission (Kassam et al. 2012; Carbonell-Bojollo et al. 2019).

22.3 Conservation Agriculture and C Sequestration

Several CA practices comprising zero tillage has been reported to increase the soil organic carbon (SOC) concentration in the upper soil layers; however, it is not always true in all cases, but increase in SOC content is important for climate change (Shi et al. 2012; Powlson et al. 2014; Williams et al. 2018). However, it is also not true that management practices resulting in increased CO_2 concentration always lead to climate change mitigation (Powlson et al. 2016). As GHG emission from agricultural activities adds a large contribution to global emission, currently, carbon (C) sequestration is considered as the most practical option with respect to reduction in GHG emission and mitigation of climate change (Kimble et al. 2002).

The process of transfer of CO_2 from the atmosphere to the soil system in the form of long-lasting pools of C is defined as carbon sequestration (Yu et al. 2015). Organic and inorganic forms of C pools in soil are the most long-standing global C sequestration forms. Soil organic C sequestration in the form of plant biomass offers a counterbalanced approach for climate change mitigation and also important for improving the physical, chemical, and biological soil conditions, enhancing soil fertility, and cherishing soil biodiversity while checking soil erosion (Ngoc et al. 2018). Increased SOC levels improve and maintain the productivity and sustainability of agricultural production systems, prevent surface runoff and check soil erosion, and improve the overall soil quality as a result of increased microbial activity (Lal 2015). Besides these benefits, it provides a number of significant off-farm paybacks to the public. These off-farm advantages may include enhanced wildlife habitat and protection of water bodies from sediment runoff from cultivated fields.

The amount of SOC added in the soil profile, enumerated as a function of C input from crop residue addition, bulk density, and protection by aggregates relative to soil particles fraction, SOC concentration, and depth, is considered as SOC accumulation. Encouragement of C sequestration in soil is greatly considered as a potent approach of the reduction of GHG emission and climate change mitigation (González-Sánchez et al. 2017). Several factors, viz., C input, tillage, crop rotation, climate, and fertilization, greatly affect the rate of SOC sequestration. Han et al. (2016) stated that increased C inputs are the most efficient way to uplift SOC sequestration. In the coarse soil textures or soils with rapid decomposition rates of OM with low inherent soil organic matter, the addition of C in soil surface is a typical key of CA practices—even though it is sometimes likely to attain momentous SOC sequestration with increased deepness in some soils (Fisher et al. 1994). As SOC symbolizes the key C sink in terrestrial environments, C sequestration in soil by increasing SOC is considered a unique approach for climate change mitigation (Wang et al. 2015).

22.3.1 Zero Tillage for C Sequestration

Tillage systems which exclude regular soil disturbances and physical manipulation of soil, maintain a permanent surface cover with crop residues, and adopt crop rotations have been found to increase SOM level and carbon sequestration in various types of soils under different climate regimes (Kassam et al. 2012). The systems of conservation tillage are often claimed to improve SOC stocks, increase soil C sequestration, and mitigate the GHG emission related to agricultural operations. Scientific evidences suggested that zero-tillage practices may lead to increased C sequestration and climate change mitigation as it slows down the decomposition rate of organic C present in soil and helps in stabilizing in added organic C, but frequently, the impact of SOC is considered as a matter of depth reallocation instead of the net accumulation (Powlson et al. 2016).

In the Indo-Gangetic Plains (IGP), the rate of SOC increase under zero or reduced tillage (0.3 Mg C ha^{-1} year^{-1}) is consistent, while in Sub-Saharan Africa (SSA), the rate of increase of SOC stock has a great variability between 0 and 1 Mg C ha^{-1} year^{-1} (Mangalassery et al. 2015). This suggested that the adoption of zero or reduced tillage may have some potential value as a strategy of climate change mitigation approach; however, the impact may differ greatly within regions. Powlson et al. (2014) opined that the extent of impact is less than as often claimed. In Central Morocco, the no tillage (NT) was introduced in wheat-based systems for two different soils (cambisols and vertisols), and after the 5 years' study, the system of NT was recorded to have 2% and 10% increase in SOC content, respectively, in both soils, when compared to the conventional tillage (CT) (Moussadek et al. 2014). In the rainfed lands of China, the transformation of conventional tillage into conservation tillage improved the carbon sink from 0.84 Mg C ha^{-1} $year^{-1}$ to 2.69 Mg C ha^{-1} $year^{-1}$ (Lu et al. 2018). From all the examples given above, it is clearly indicated that CA practices like zero tillage have in themselves some potential of climate change mitigation by increasing the SOC stocks on a long-term basis.

22.3.2 Cover Management for C Sequestration

Leaving crop residues on the soil surface to maintain a permanent soil cover is another important principle of CA. However, in developing countries, crop residues are used for livestock feed and for fuel purposes, so using the crop residues on surface soil as a cover has the cost of fuel and livestock feed. Plants absorb CO_2 from the atmosphere, and through the photosynthesis process, it is stored in plant tissues biomass, and on the decomposition, the stored C is returned to the soil as soil C pool. This is the principle process of transferring C from the atmosphere to the soil by photosynthesis (Kell 2011).

In general agreement, cover crops have the potential to sequester C, but the magnitude is still debated. The magnitude of C sequestration potential of cover crops may differ with plant species, climate, soil type, and management practices. It is estimated that cover crops can sequester 0.22 t $acre^{-1}$ $year^{-1}$ of C in cultivated soils (Ruis and Blanco-Canqui 2017). Besides having several benefits such as the ability to reduce erosion, capacity to fix atmospheric nitrogen, and improving soil health, in recent time, cover crops are gaining importance with increase in adoption coordinated benefits with the alertness of climate change as the adaption and mitigation strategy, which is an additional yet important advantage of cover crops but not listed under traditional benefits from cover crops (Kaye and Quemada 2017). Several models and meta-analysis studies established the fact that while acting as a cover to the soil surface, cover crops enhance C sequestration with significant variability across sites; beneficial impacts of cover crops increase with crop rotation, zero tillage, and optimum use of N inputs (McDaniel et al. 2014). Carbon sequestration by cover crops gets influenced by reduced rates of soil erosion with dependency on decomposition balance.

Another way to maintain permanent soil cover under the CA system is the retention of crop residues on the surface soil. When these residues were applied alone, the increase in SOC was very small (0.2 Mg C ha^{-1} $year^{-1}$), but when residue retention was combined with zero tillage, the increase in SOC was to 0.45 Mg C ha^{-1} $year^{-1}$. Similarly, in temperate regions, the effect of cereal straw incorporation for 25 years continuously was found nonsignificant indicating the importance of climatic features for residue decomposition and SOC accumulation for surface application of residues than for incorporated (Powlson et al. 2016). It is expected that in tropical regions, the rates of SOC accumulation are lower due to the faster decomposition of organic matter under high temperatures (Krishna and Mohan 2017). Even if the SOC buildup under residue retention or incorporation is smaller, constituting a very limited climate mitigation potential, it provides a genuine climate change mitigation over the practice of residues burning after the harvest of rice and wheat in many parts of India, where the carbon present in residues emitted back into the atmosphere during the burning (Singh and Sidhu 2014; Bhuvaneshwari et al. 2019).

22.3.3 Crop Diversification and Carbon Sequestration

One aspect of CA which has genuine potential for climate change mitigation and C sequestration but often overlooked is crop diversification. Besides increasing soil organic C pools, crop diversification can benefit farmers with the monetary value of additional crops (Powlson et al. 2016). Crops which profuse growth to cover the soil surface mimic the natural vegetative conditions and produce the comparable SOC pools (Sa and Lal 2009). The continuous mass and energy flow provided by the crops in a diversified crop system stimulates the soil biodiversity and changes in SOC pools.

In CA systems, certain crop diversification strategies lead to increased C sequestration through the higher rates of photosynthesis. Increased rates of C sequestration were reported when legumes were intercropped between the rows of cereals (Thierfelder et al. 2013) or when an extra crop was incorporated between the period of two crops where the field otherwise would be fallow (Ghosh et al. 2012). Replacement of one of the crops in crop systems with others may also increase C inputs in soil. The amount of increased C inputs may depend on total biomass, the proportion of above- and belowground biomass produced by the replacement crop, and the rate of decomposition of the replacement crop as it is affected by the composition of the replacement crop. Powlson et al. (2016) reviewed that the SOC accumulation rates under CA-based crop diversification were to the tune of 0.5 Mg C ha^{-1} year^{-1} in IGPs.

22.4 Conservation Agriculture for Climate Change Mitigation

CA is an approach to farming that seeks to increase food security, alleviate poverty, conserve biodiversity, and safeguard ecosystem services. CA practices can also contribute to making agricultural systems more resilient to climate change and weather aberration. In many cases, CA has been proven to reduce farming systems' greenhouse gas (GHG) emissions and enhance their role as C sinks.

22.4.1 Zero Tillage

Tillage practices contribute to mitigation and adaptation strategies to climate change in different ways. Conventional tillage (CT) is known for stimulating the mineralization process of SOC, using energy for operations, and creating soil erosion problems and hardpans (Rusu 2014). CT practices that consist of reduced and zero or no tillage have the potential to reverse these negative effects, but sometimes these practices may also be associated with reduced yields. Different agriculture practices contribute to GHG emission through the alteration of the soil microenvironment. For instance, tillage operations break down the soil aggregates, which leads to a rapid SOM decomposition and limits C and N concentration (Alvaro-Fuentes et al. 2008). In contrast, no tillage enhances the soil macroaggregate stability leading to reduced heterotrophic respiration and depresses CO_2 emission. In maize monoculture, the reduced soil disturbance added with residue retention was associated with the increased C pools in macroaggregates in a surface soil layer and declined CO_2 emission compared over CT with no surface residue retention (Fuentes et al. 2012).

Shallower depth tillage with lower intensity compared to the conventional plowing in combination with crop rotation, weeding, and green manuring in an organic farming system is referred to as organic reduced tillage systems. In a study on organic reduced tillage system following 13 years, effects of system were of minor importance in relation to N_2O and CH_4 emissions when compared to plowing in slurry fertilized plots, and after single tillage, the N_2O fluxes in the reduced system were higher. Further, with slight effects on CH_4 uptake, fertilization with manure compost increased N_2O emission compared to fertilization with slurry indicating the importance of the combination of reduced tillage (RT) and manure application in climate change mitigation compared to the traditional plowing system (Krauss et al. 2017).

Reduction in CH_4 oxidation with tillage was assumed due to the disturbances in the methanotrophic microbes, alteration in gas diffusion, or damage to methane forming microbes due to soil structure disruption as a result of tillage. In conflict, some studies found that CH_4 uptake may increase under no-tillage (NT) treatment as NT improves soil structure, which may be a cause to improve oxygen and CH_4 flow between atmosphere and soil (Ussiri et al. 2009). Compared to the normal tillage system, some studies reported comparable or even reduced CH_4 changes under RT or NT systems (Omonode et al. 2007). Different tillage systems and their effect on CH_4 uptake may have not been thoroughly assessed; however, several reports advocated higher uptake with RT/NT management.

After the transfiguration from conventional tillage to reduced/no tillage, N_2O emission increased in the first 10 years and then decreased or may not vary generally (van Kessel et al. 2013). Identifying the soil aeration as a factor, Rochette (2008) claimed higher N_2O emission in poorly aerated soils under NT compared to CT, but the reverse was found in soils with good aeration. In some situations, NT may result in increased N_2O emission, but this case is not very common. In this regard, evidences are lacking to draw strong conclusions. However, this is a vital issue as a very small rise in N_2O emission will counterbalance a considerable gain in SOC; every one kg extra emitted N_2O ha^{-1} is responsible to counterbalance 0.13 Mg C ha^{-1} sequestered (Grandy et al. 2006).

Under the rice-wheat crop system, two studies in almost similar conditions showed contradictory results. Bhatia et al. (2010) reported a marginal increase in N_2O emission with zero tillage (ZT), while Pandey et al. (2012) reported decreased N_2O emission in ZT. In a study in China with the wheat-maize crop system under high rates of N fertilizer application, NT combined with straw retention resulted in decreased N_2O emission, but the yield was equal or increased with CT with no straw retention (Huang et al. 2015). In a study in China with a wheat-maize system in an environment similar to the IGP, there was a degree of helpful synergy between CA practices and N_2O emissions. In a situation with high rates of N fertilizer, a combination of no-till and straw retention led to a decreased N_2O emission but equal or increased crop yields compared to CT with straw removed (Huang et al. 2015). By contrast, no N_2O emission differences were detected between traditional hand plowing and direct-seeded mulch-based system under an intercropped maize soybean system in Madagascar (Chapuis-Lardy et al. 2009).

22.4.2 Permanent Soil Cover and GHG Emission

Besides tillage, crop residue retention on the soil surface can greatly influence the CH_4 and N_2O emission by altering surface soil properties such as moisture, porosity, and temperature (Yao et al. 2009). Global annual production of crop residues has extended around 4 billion metric tons. These residues can play a beneficial role in C sequestration if retained on the soil surface. However, it is also possible that beneficial effects of residue retention may be offset by increased emission of N_2O. A meta-analysis by Chen et al. (2013) suggested that residue retention did not help in the reduction of N_2O emission. However, the residue impacts on N_2O emission were subjected to soil properties, especially soil moisture content and soil texture.

In another study, Sapkota et al. (2015) could not trace detectable level of CH_4 emission under zero-tillage rice crop both with and without residue retention due to the arrested methanogenesis process under higher redox potential of soil. Wang et al. (2016) found that the practice of removing cane debris from the soil surface reduced N_2O releases by 24–30%, representative of the promoting effects of trash removal on N_2O emissions. Due to the lack of synchronization between demand and supply, more than 60% of applied nitrogen is lost, which in turn may lead to increased cultivation cost, natural contamination, and reduced N use efficiency (Kumar et al. 2019). Nitrogen fertilization is considered responsible for 60% of nitrous oxide (N_2O) anthropogenic emissions.

Cover crops are a good option for both soil and water nitrate concentrate reduction, and in turn they are expected to reduce the mobility of N_2O between soil and the environment. The application of N inputs immediately after harvesting of legume crop leads to high nitrification and denitrification rates, which raises N_2O losses; however, the magnitude of losses is depended on the crop type (Sainju 2017). Kaye and Quemada (2017) assumed that cover crops do not have any effect on CH_4 flux from soil. According to them, cover crops were not good enough for the mitigation of GHG emission as the global widespread adoption of cover cropping system is estimated to mitigate only 10% of GHG emissions from agriculture. However, the mitigation potential of maintaining a cover by growing cover crops is comparable to other practices such as zero tillage; it can be a beneficial management practice to stable the yield levels and minimize N losses under climate change situations.

22.4.3 Crop Diversification

Introduction of new crops or cropping systems on a farm refers to crop diversification. It is the practice of changing the existing cropping pattern with the addition of a new crop. Crop diversification helps farmers to increase the income sources and the variety of potential foods. Crop diversification also plays an important role in climate risk management under resource-limited areas. Crop diversification is becoming increasingly popular around the world because of the advantages it provides like gain in production stability (Mhango et al. 2013), suppression of weeds and plant diseases (Kutcher et al. 2013), increased monetary returns, enhanced ecosystem productivity (Gan et al. 2015), and reduced C footprint (Yang et al. 2014). Due to the possible impacts of climate change on agriculture production, consideration of diversified cropping is more insistent.

A more viable tactics in crop diversification is the addition of grain legumes as these crops have the ability to fix atmospheric nitrogen and reduce dependence on synthetic N fertilizers and the higher rate of residue decomposition due to the narrow C:N ratio. Besides increasing the soil N availability, the legume residues also increase the pace of SOM decomposition known as the "priming effect" (Kuzyakov 2010). However, this priming effect may influence the N_2O flux between soil and atmosphere; hence, good synchrony between soil available N and applied N is suggested to prevent N losses via leaching and denitrification process. Management practices such as crop rotation with legumes and CA can alter the GHG emission (Guardia et al. 2016). Many studies have reported legumes as an N_2O mitigation approach as legumes reduced the quantity of fertilizer N added. However, legumes are also reported to produce N_2O via N release from root exudates and crop residue decomposition after crop harvest (Tellez-Rio et al. 2015).

Residue management practices and the soil and environmental condition influence the N_2O flux resulting from legume crops in crop diversification. A high variability of N_2O fluxes (0.03–7.09 kg N_2O–N ha^{-1} $year^{-1}$) has been reported by previous studies (Jensen et al. 2012). A study in China showed that the rice-rice-potato system with straw mulching produced the highest CH_4 emission during both early and late seasons of rice growing. When compared to the rice-rice system with winter fallow, the total N_2O emission was increased by 0.013 g m^{-2} in the rice-rice-rapeseed system and 0.045 g m^{-2} in the rice-rice-potato system with straw mulching indicating that crop diversification had no beneficial effect on reducing N_2O emission when introduced with straw mulching (Tang et al. 2015). Weller et al. (2015) reported that diversification from flooded crop systems to non-flooded crop systems leads to changes in the pattern of N_2O and CH_4 emissions. Flooded crop systems had high CH_4 emissions, while upland crop systems had high N_2O emissions; however, the GWP of non-flooded crops was lower compared to flooded rice. Weller et al. (2016) conveyed that N_2O emission was increased by two- to threefold in diversified crop systems but the large reduction in CH_4 emission resulted in a significant reduction in annual GWP compared to the traditional double-rice cropping system.

22.5 Conclusions

Conservation agriculture involves minimum soil disturbance, continuous ground cover, and diversified crop rotations or mixtures. CA production systems have the potential to improve soil quality if appropriate cropping systems are developed. Sequestering organic C in soil, creating a nutrient-rich environment for the proliferation of plants, and allowing water to pass through and conserved are some critical soil functions that can be enhanced with CA systems. Conservation tillage, increased cropping system complexity, cover cropping, animal manure application, optimum fertilization, and rotation of crops with pastures are effective strategies to enhance SOC sequestration. CA has the potential to contribute to soil C sequestration and reduced greenhouse gas emission. However, all circumstances are not perfect always. CA practices can reasonably be regarded as contributing to climate change adaptation and to sustainable intensification, whether or not they consistently deliver increased crop yields in every season.

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