Chapter 7

Effects of Different Tillage Methods, Nitrogen Fertilizer and Stubble Mulching on Soil Carbon, Emission of CO_2, N_2O and Future Strategies

Sikander Khan Tanveer, Xiaoxia Wen,
Muhammad Asif and Yuncheg Liao

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1. Introduction

The basic reasons of greenhouse effect are the greenhouse gases which emits and absorbs the radiations. The main greenhouse gases include CO_2, Methane and Nitrous oxide which are playing a major role in global warming.

CO_2 is mainly emitted by the burning of coal, natural gas and wood etc. Before the Industrial revolution its concentration in the atmosphere was about 280 ppm but due to the burning of fossil fuels now its concentration is about 397 ppm. The concentration of CO_2, in the atmosphere is about 0.039 percent by volume and it is used by the plants for the process of photosynthesis.

Nitrous Oxide is also a major greenhouse gas. In the atmosphere from N_2O, Nitric oxide (NO) is produced, which after combination with O_2, reacts with Ozone. Global warming potential of this gas is 298 times more than the global warming potential of CO_2. In agriculture the main source of N_2O is the use N fertilizers, which is used for the production of crops. It is also produced from the animal wastes. In the atmosphere annually about 5.7 Tg N_2O-N yr^{-1}, N_2O is produced and agricultural soils provide about 3.5 Tg N_2O-N yr^{-1}, which is produced from the soils by the process of Nitrification and Dinitrification. Its emission from the soil is affected by many factors including temperature, moisture, PH, soil organic matter and soil kind etc.

The soil contains carbon in the organic and as well as in the inorganic form. Soil organic carbon is mainly present in the soil organic matter in the form of "C". and its availability in any soil mainly depends upon the soil kind, its texture, vegetation and management processes. Management of SOC is very important for the maintenance of healthy soils because its loss leads to soil infertility. SOC can be helpful in mitigating the effects of elevated CO_2 in the atmosphere, because change in land management practices can be helpful in sequestering the C from the atmosphere.

Tillage is a group of field operations and it is defined as the mechanical manipulation of the soil for improving its physical condition suitable for plant growth. The main aims of the tillage are production of a suitable tilth or soil structure, control of weeds; manage soil moisture, incorporation of organic matter, managing water and air in the soil and establishment of a surface layer which prevents the soil from wind and water erosion. A wide range of implements are used for tillage operations which vary from country to country. Different tillage implements have been designed and are used for various operations depending on the soil, type of operations, agro climatic conditions and soil conditions. Primary tillage implements include Moldboard plough, Disc plough, Chisel plough, Sub Soiler and Rotavator and secondary tillage implements include Harrows, Field cultivators and Rollers while due to recent technological developments along with economic pressures, Minimum and Zero tillage is also being practiced on large scale in the world.

Soil is the medium in which crops grow and it is one of the most precious natural resources of earth. Its maintenance for the coming generations is the responsibility of all human beings. However the urge for the production of more food, feed, fiber and fuel, especially in the form of emission of Greenhouse gases is causing irreparable damages to our environment.

2. Background

Long term records indicate increasing trends in the growth of anthropogenic greenhouse gas emissions, particularly in the last decades (IPCC, 2001). The greenhouse gases mainly include CO_2, CH_4 and N_2O having the contributions of about 60%, 20% and 6% while the potential of N_2O in warming the atmosphere is greater than 290~310 times than CO_2 and 10 times than CH_4. The concentrations of CO_2 and N_2O currently in the atmosphere are about 397 ppmv and 314 ppbv, respectively.

The emission of greenhouse gases from the soils is not clear (Le Mer J., and Roger, 2001). It has also been reported that the addition of anthropogenic greenhouse gases in to the atmosphere has been previously underestimated (Mosier A.R., et al 1998) because these gases may diffuse directly from the soil or indirectly in the atmosphere through subsurface drainage after leaching (Sawamoto T. et al. 2003).

Agricultural productivity lead to the emission of several greenhouse gases (CO_2, CH_4 and N_2O), that differ with regards on their ability to absorb the long wave radiation, and depending on their specific radiation forcing and residence time in the atmosphere. The relative ability of gases, also called global warming potential (GWP), is computed relative to carbon dioxide. The GWP is 1 for Carbon dioxide, 21 for Methane, 310 for Nitrous Oxide, 1800 for O_3 and 4000 – 6000 for CFCs (IPCC, 1995) The rate of increase in CO_2 was 1.6 ppmv per year from 1990 to 1999 (http:// www. CO_2 Science.Org/) and N_2O was 0.8 ppbv per year in the 1990s, respectively

(IPCC, 2001). According to OECD (2000), the total emission of CO_2, CH_4 and N_2O (As CO_2 equivalent) was 14142 million tons for the period from 1995 to 1997. OECD (2000) also reported that agriculture is responsible for about 1% of CO_2 emissions, about 40% of CH_4 and 60% of N_2O, so it is clear that agriculture is also playing an important role in the emission of green house gases.

Watson et al., (1995) reported that emissions of carbon dioxide (CO_2) and nitrous oxide (N_2O) are major sources of atmospheric green house gases generated from the upland agro-ecosystems. It was estimated that 90% of N_2O and 20% of CO_2 in the atmosphere come from agricultural production (Bouwman, 1990).

The global soil carbon (C) pool of 2300 Pg includes about 1550 Pg of soil Organic Carbon (SOC) and 750 Pg of soil inorganic carbon (SIC) both to 1- m depth (Batjes,1996). The soil carbon pool is three times the size of the atmospheric pool (770 Pg) and 3.8 times the size of the biotic pool (610 Pg). The SOC pool to 1-m depth ranges from 30 tons/ha in arid climates to 800 tons /ha in organic soils in cold regions and a predominant range of 50 to 150 tons/ha. The SOC pool represents a dynamic equilibrium of gains and losses. Conversion of natural to agricultural systems causes depletion of the SOC pool by as much as 60% in soils of temperate regions and 75% or more in cultivated soils of the tropics. The depletion is exacerbated when the out put of C exceeds the input and when soil degradation is severe. Some soils have lost as much as 20 to 80 tons C/ha. Severe depletion of the SOC pool degrades soil quality, reduces biomass productivity and adversely impacts water quality and the depletion may be exacerbated by projected global warming. Terrestrial ecosystems contributed to the atmospheric C enrichment during both the preindustrial and industrial areas. During the preindustrial era, the total carbon emission from terrestrial ecosystem was supposedly about twice (320 Gt or 0.04 Gt C/year for 7800 years) that of the industrial era (160 Gt or 0.8 Gt C/year for 200 years). Between 1850 and 1998, the emission from fossil fuel combustion was 270 (+ or -) 30 Gt from soil of which about one–third is attributed to soil degradation and accelerated erosion and two thirds to mineralization. The estimates of historic SOC loss range widely, from 44 to 537 Gt, with a common range of 55 to 78 Gt. The soil C can be sequestered through judicious land use and recommended management practices, which are cost effective and environmental friendly. SOC sequestration in agricultural soils and restored ecosystems depend on soil texture, profile characteristics and climate. It ranges from 0 to 150 kg C/ha per year in dry and warm regions and 100 to 1000 kg C/ha per year in humid and cool climates. Soil management techniques and land use patterns play an important role in the removal as well as store of carbon from the ecosystem and the soil management techniques are the suitable ways to reduce the CO_2 emission from the soil (IPCC, 2000; Lal, 2004). The conclusion by the intergovernmental panel on climate change (IPCC) “that there has been a discernible human influence on global climate (IPCC, 2001) is one more call for action on the reduction of green house gas (GHG) emissions. Worldwide about one fifth of the annual anthropogenic (GHG) emission comes from the agricultural sector (excluding forest conversion), producing about 5%, 70% and 50% of anthropogenic emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), and 50% methane (CH_4) (Cole et al., 1996).

Nitrous Oxide (N_2O) is a natural trace gas occurring in the atmosphere that causes global warming and stratospheric ozone depletion. The concentration of atmospheric N_2O has increased up to 16% over the last 250 years at a rate of 0.25% per year (IPCC, 2007) and agricultural soils account for approximately 42% of anthropogenic N_2O emissions (IPCC,2007) and nitrogen fertilization is considered as a primary source of N_2O emissions from agricultural soils (Mosier et al., 1998; Mosier and Kroeze,2000). The annual global emission of N_2O from soils is estimated to be 10.2 Tg N or about 58% of all emissions (Mosier A.R., et al 1998).

Use of nitrogen fertilizers increased at the rate of 6-7% per year during the 1990s (Mosier, 2004). According to FAO (2008) during 2008 to 2012 on world level the demand for nitrogen fertilizers on annual basis will increase at the rate of 1.4% and about 69% of this growth will take place in Asia. It has been reported by many researchers (e.g. Hatano R., and Sawamoto T, (1991), Kaiser E, A., and Ruser R, (2000), and Mosier A.R., and Delgado J.A., (1997) that N_2O emission increases with increasing nitrogen fertilization. Nitrogen fertilizer is one most important mineral fertilizer, both in the amount of plant nutrient used in agriculture and in energy requirements. Its principal products include Ammonia, Urea, Ammonium Nitrate, Urea/ Ammonium nitrate solution, Di-Ammonium Phosphate and Ammonium Sulphate. Nitrogen fertilizers are energy–intensive. For example one kilogram of nutrient-N requires about 77.5 MJ for its manufacture, packing, transportation, distribution, and application (Stout, 1990). For its production manufacturer requires pure gaseous nitrogen and hydrogen. AS compared to hydrogen, pure gaseous nitrogen is simple and inexpensive. Natural gas and coal are the main sources of hydrogen for fertilizer production (Helsel, 1992). In addition to this, in some developing countries transportation routes can be very energy demanding.

N_2O emission is affected by many factors but the most important of these are tillage and fertilization. Increased N_2O emission from No-tilled soils as compared to the tilled soils have been reported by many researchers (Aulakh M.S. etal,1984, Jacinthe P.A., and Dick W.A., 1997, Lal R. et al. 1995, Mackenzie A.F., and Fan M.X., Cadrin F., 1997 and Mummey D.L.,etal, 1997). However Grandy et al. (2006) reported that N_2O emissions were similar between NT and CT systems. Lemake et al. (1999) observed lower N_2O emissions from NT compared to CT in some north-central Alberta soils. Similarly Hao et al. (2001) observed decline in N_2O emissions when crop residue was retained, especially in plots tilled in autumn after crop harvest. Mc Swiney and Robertson (2005) and Wanger Riddle et al. (2007) have reported that fertilizer application rates influence the N_2O fluxes. They also reported that the best management practices can be helpful in reducing the emission of N_2O.

Nitrous oxide (N_2O) is a major green house gas (GHG), although its emission is numerically smaller as compared with the other greenhouse gases (Isermann,1994), but global warming potential (GWP) of it is about 296 times higher than that from Carbon dioxide (CO_2). It is reported that arable soils are responsible for about 57% of the annual N_2O emissions in the world (Moiser et al.,1998).Effects of seasons (Van Kessel et al. 1993; Nyborg et al.1997 and Aulakh et al.1982), nitrogen fertilizers (Mc Kenney etal.1980; Eichner 1990), manure or legumes (Aulakh etal.1991; Laidlaw 1993) on emission of N_2O have also been reported.

Low fertilizer use efficiency is mainly due to the inexpert use of fertilizer and it is associated with the water and air pollution. These kinds of symptoms are common in many countries, where due to leaching and volatilization important fertilizer losses are taking place (FAO, 2000). In such regions the extra use of fertilizers can be reduced by adopting the more efficient

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methods of fertilizers applications, use of fertilizers at the proper timings to meet the nutrient demand of the crop, nitrification inhibitors, controlled release fertilizers, optimization of tillage, irrigation and drainage and ultimately the use of precision farming can be helpful in saving the extra use of fertilizers (Viek and Fillery, 1984; IPCC, 1996). Higher productivity can be achieved at a given level of fertilizer use with improved crop and fertilizers management. However, there are many constraints including economic, educational and social in improving the fertilizer productivity.

Conventional tillage increases the CO_2 in the atmosphere by promoting the loss of soil organic matter, while instead of conventional tillage, conservation tillage increases soil organic matter (SOM) with the passage of time (Dao, 1998) and available water content and soil aggregation (Pare etal.,1999). A lot number of researchers (La Scala Jr et al (2001), Lipiec J., and Hatano R., (2004), Reicosky D.C et al (1997), and Sanchez M.L et al (2002)) have reported that emission of CO_2 is lower in no-till or reduced tillage as compared to the conventional tillage. On the other side more carbon sequestration is in the soil which is under no-till or reduced tillage as compared to the soil under conventional tillage (Ball B.C et al (1999) and McConkey Liang B.C et al (2002)). Wilson H.M and M.M. Al-Kaisi (2010) reported 23% less emission of CO_2 from the soil fertilized with 270 kg N/ha as compared to the soils fertilized with 0 and 135 kg N/ha in a continuous corn and a corn-soybean rotation. Similarly Burton et al. (2004) found that N fertilized plots averaged 15% less soil CO_2 emissions than unfertilized plots.

Campbell et al. (2001), reported that without adequate fertility from Conservation to No-tillage may not always result in an increase in soil N or C. The contribution of CO_2 in the total atmospheric greenhouse effect is about 60% (Rastogi M., et al 2002). Conversions of native soils for agricultural use have contributed a large to the emission of CO_2 in to the atmosphere (Paustian K., et al, 1998).

Agriculture seems to have potential to make an important contribution to the mitigation of global climate change. Lal et al. (1998) estimated that changes in global agricultural practices can be able to sequester over about 200 million metric tons of carbon (Mt C) per year. Changes in agronomic practices in United States are thought to have the potential to offset nearly 10% of its total carbon emissions (FAO, 2001).The International Panel on Climate Change (IPCC, 2000) quotes figures showing that alone conservation tillage can be able to store more than a ton of carbon per hectare per year, while other researchers have provided the figures that range from a low of 3 to a high of 500 kg C per hectare per year (Uri, 2001; Follet, 2001).

Uri, (2001) and West and Marland, (2002), reported that No-till cultivation that appears to bring about carbon benefits as compared to the different kinds of tillage systems, but it increases cost of production (because more chemical inputs are required) and often reduces yields (Lerohl and Van Kooten,1995).

It is generally acknowledged that soil carbon will be increased by the adapting of No (Zero) tillage as compared to the Conventional (Intensive) tillage practices (Kern and Johnson, 1993; IPCC, 2000; Uri, 2001). The relationship between NT and carbon storage is complex one. A lot number of researchers have examined the effects of crop type, fertilizers and rotation (Campbell et al., 2001), climate and soil texture (Tobert et al., 1998; Six et al., 1999) and time (Ding et al., 2002) on carbon storage potential.

The way by which Conventional Tillage (CT) might store more carbon than No Tillage (NT) is not clear (Angers et al., 1997). Conventional tillage increases CO_2 respiration as the soil is plowed (Lupwayi et al., 1999), but it appears that due to plowing organic matter is pushed more deeply in to the soil, which in future facilitates the adsorption and stabilization of more organic material into the soil, as compared to the way in which straw and residue remain concentrated on top of the ground (Paustian et al., 1997).

Tillage often decreases soil organic matter (Gebhart et al., 1994) and it increases the flux of CO_2 from the soils (Reicosky and Lindstrom, 1993) through enhanced biological oxidation of soil carbon by increasing subsequent microbial activity as a result of residue incorporation (Reicosky et al., 1995).

In the tropics the conversion of native ecosystems to agricultural use is believed to be the largest non- fossil fuel source of CO_2 input to the atmosphere. The production of more fertilizers increases the CO_2 emission, but its use reduces the need of further expansion into forested areas and may allow land to set aside for revegetation or reforestation. In addition to it modern cultivation practices and injudicious use of mineral fertilizers are further deteriorating our soil fertility. The intensive management of agricultural soils has resulted in the depletion of soil carbon (C) stocks and has increased atmospheric carbon dioxide (CO_2) levels. Lal and Bruce (1999) and Lal, 2003, 2004 reported that conservation tillage can increase the amount of C sequestered in agricultural soils. A review of soil organic carbon (SOC) studies from West and Post (2002) concluded that on an average conservation tillage could sequester 0.60+ 0.14 t C per ha per year. It has also been reported by several recent published studies that conventional or reduced tillage systems have little to no difference in soil organic carbon (SOC), (Dolan et al.,2006; Venterea et al; 2006; Baker et al., 2007; Blanco- Canqui and Lal, 2008).

A number of studies have reported that conservation tillage systems have higher N_2O emissions when compared to the conventional tilled systems (Robertson et al., 2000; Mummey et al., 1998; Ball et al., 1999).

The use of organic waste can be helpful in improving the crop productivity, improving the soil health, reduce the waste disposal problem and the betterment of environment. In some areas of the world wheat and maize straw are produced in such a huge quantity that their disposal is a big problem. Though a large portion of them is used as animal feed or for making compost but a large portion of it is being burnt which is a big threat to the environment. Therefore possible use of crop residues into the farm soil must be explored.

Researchers have also debated about the burning of crop residues as compared to their burning on the carbon flux. Clapp et al. (2000) and Duiker and Lal (2000) favor the leaving the straw, where as Sanford et al. (1982) found that straw limits the yields. Dalal (1989) reported that burning of residues contribute to carbon sequestration at depths as low as 0.9- 1.2 m.

Javed et al. (2009), reported that N addition with straw increases the CO_2 flux and sequestrates the soil C by mitigating the global carbon budget. Since SOC storage is highly dynamic in gain and loss of soil organic matter (SOM), manure abandonment and straw removal led to loss of soil organic carbon (SOC) (Qiu et al., 2004; Tang et al., 2006). Field practices with low carbon inputs to arable soils, removal of crop straw and manure abandonment have depleted SOC contents (Wang et al., 2008). The loss of SOC has bad affects on biological, physical and chemical properties (Kumar and Goh 2003). Returning crop straw to the soil can enhance the crop yield by affecting the microbial processes and nutrient availability (Olivier et al., 2000). Increase of SOC storage in crop land improves soil productivity and is good for healthy environment (Lal, 2004). Sequestration of atmospheric CO_2 will be significantly improved, if large quantities of crop residues and organic manures are returned to the soil (Lal, 2004 & Lal, 2002). Increase in SOC storage in crop land improves soil productivity and improves the environmental health. Thus can be recognized as win-win strategy (Lal, 2004).

Increase in soil organic matter works as a sink for atmospheric CO_2 and thus reduces the adverse effects of global warming (Lal, 2004). Addition of straw evolutes CO_2, affects microbial activity for decomposition, recycles available nutrients and restores soil organic carbon (SOC) (Henriksen and Breland, 1999; Hadas et al., 2004).

Wu et al. (2003). reported that 57% of cultivated soils in China have experienced losses in soil organic carbon (SOC) due to the injudicious use chemical fertilizers and intensive cultivation along with less use of organic manures and crop straw since the introduction of synthetic fertilizers in 1950s.

The burning or discarding of the crops straw has caused a decline in soil organic matter (SOM), reduction in microbial activity and is causing pollution by discharging CO_2 into the atmosphere. Michellon and Parret, (1994) reported that the use of crop residue can be helpful in the reduction of chemical fertilizer use. While Boyer et al., (1996) reported that the use of crop residues can be helpful in the restoration of soil fertility. Lal et al. (1998) recommended the rate of residue for cool and humid areas about 400-800 kg/ha/year, while about 200-400 kg for warm and dry areas.

Kumar and Goh, 2000 reviewed the effects of crop residues and management practices on the soil quality, soil nitrogen dynamics recovery and as well as on crop yields. They reported that residues of cultivated crops are a significant factor for crop production through their effects on soil health as well as on soil and water quality. Unger et al. (1988), reviewed the role of surface residues on water conservation and they reported that surface residues enhance water infiltrations. Dao, (1993) and Hatfield & Pruger, (1996), reported that surface mulch helps in reducing water losses from the soil and promotes biological activity which enhances nitrogen mineralization especially in the surface layers. Leak (2003) reported that rotations increase microbial diversity. Jacinthe P.A et al. (2002) reported that carbon sequestration can be enhanced by the crop residue management.

3. Future strategies

Many crop management and soil management practices in the future can be helpful in the reduction of emission of greenhouse gases along with the maintenance of soil fertility, few of them include

1. Adaptation of tillage systems that are helpful in the reduction of emission of greenhouse gases, and can be helpful in the increasing the soil fertility.
2. Selection of more better cropping systems which are more environmental friendly and give maximum crops productions.
3. Judicious and timely use of nitrogenous fertilizers
4. Use of crop residues and animal manures
5. Use of crop rotations
6. Reduce the soil erosion

In future from the less available land resources, only the better crop production practices will be helpful to feed the burgeoning population. Instead of traditional tillage practices, use of productive but more sustainable environmental friendly management practices will resolve this problem. Crop and soil management practices that maintain soil health and reduce farmers cost are essential in this regard. Minimum soil disturbance, soil cover (mulch) combined with judicious use of fertilizers will be helpful in getting the maximum yields of crops and maintenance of healthy environment.

Author details

Sikander Khan Tanveer[1], Xiaoxia Wen[1], Muhammad Asif[2] and Yuncheg Liao[1*]

*Address all correspondence to: yunchengliao@163.com or yunchengliao@nwsuaf.edu.cn

1 College of Agronomy, Northwest A&F University Yangling, Shaanxi, China

2 Agriculture, Food and Nutritional Science, 4-10 Agriculture/Forestry Centre, Univ. of Alberta, Edmonton, Canada

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