Rice-wheat is the most popular cropping system of India as well as of the World, which serves as a source of livelihood for hundreds of millions of people all over the World. Rice-wheat cropping system in Indo-Gangetic plain (IGP) occupies more than 10.5 m ha area. The intensive rice-wheat system also has pronounced effect on greenhouse gas emission. The puddling process (wet cultivation of rice) is being known to liberate considerable amount of GHG, making agriculture main culprit in global warming. The modern/ advanced production practices largely devoid of wet cultivation of rice and non tilled sowing of wheat with residue management have been found to have less such problems. In the ZT system the soil is not disturbed, but only small slit is open to place the seeds in moist zone. Zero-tilled wheat on 1 ha of land in the rice-wheat-cropping systems of the IGP could save 1 million L of irrigation water and 98 L of diesel thereby reducing carbon dioxide emission by 0.25 Mg\textsuperscript{3} While the impact of ZT on N\textsubscript{2}O emission has indicated contrasting results, some time bring lower, equal or higher as compared to the conventional system depending upon the soil type and water management practice\textsuperscript{4}. 

**Impact of GHGs:** The rising concentrations of greenhouse gases (GHGs) of anthropogenic origin in the atmosphere such as carbon dioxide (CO\textsubscript{2}), methane (CH\textsubscript{4}) and nitrous oxide (N\textsubscript{2}O) have increased, since the late 19th century. The current rate of increase in these gases in the atmosphere is unprecedented. Enhanced GHGs contribute to warming of the earth. According to the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change, the three main causes of the increase in greenhouse gases observed over the past 250 years have been fossil fuels, land use, and agriculture. Agriculture occupies 40-50\% of the earth’s land surface and contributes only 10-12\% of total anthropogenic GHG emission. IPCC\textsuperscript{4} reported the contribution to greenhouse gases through different agricultural activities (Fig. 2). The agriculture contributes 47\% and 58\% of total anthropogenic emissions of N\textsubscript{2}O and CH\textsubscript{4}, respectively (Fig.1). Gases like CH\textsubscript{4} and N\textsubscript{2}O have 21 and 310 times the “global warming potential” of CO\textsubscript{2}, respectively. CO\textsubscript{2} has large annual exchanges between the atmosphere and agriculture lands\textsuperscript{5} (Fig.3). Further it was estimated that 47 per cent N\textsubscript{2}O and 58 per cent CH\textsubscript{4} is being emitted by the agriculture sector. The CO\textsubscript{2} emission due to burning of fuel (assuming 2.6 kg CO\textsubscript{2} production/ litre of diesel burnt) during field preparation was 208 kg/ha in farmer’s conventional practice and only 15.6 kg/ha in zero tillage and 36.92 kg/ha in rotary tillage. Even conventional field preparation with drill or bed planter sowing on FIRBs results in reduction of CO\textsubscript{2} emission, which comes to 82.25 and 92.50 per cent for rotary and zero tillage, respectively\textsuperscript{6}.  

**Contribution of different sectors towards emission of greenhouse gases:** The agricultural sector has a major share in the gas emissions and also the land use effect thought to cause climate change. But various other sectors too are equally responsible for green house gas emissions and contribute significantly (IPCC 2007 Fig.1.) In addition to being a significant user of land and consumer of fossil fuel, agriculture contributes directly to greenhouse gas emissions through practices such as rice production and the raising of livestock. According to the Intergovernmental Panel on Climate Change, the three main causes of the increase in greenhouse gases observed
The precipitation has become spatially variable and the intensity and frequency of extreme events have increased. The sea level has also risen at an average annual rate of 1-2 mm during this period (Fig. 4). The continued increase in concentration of GHGs in the atmosphere is likely to lead to climate change resulting in large changes in ecosystems, leading to possible catastrophic disruptions of livelihoods, economic activity, living conditions, and human health.

What is carbon (C) sequestration: Carbon sequestration is defined as the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere. The idea is to:
1. Prevent carbon emissions produced by human activities from reaching the atmosphere by capturing and diverting them to secure storage, or
2. Remove carbon from the atmosphere by various means and store it.

The importance of carbon sequestration: The scientific consensus is that the levels of greenhouse gases in the atmosphere are increasing. These changes in greenhouse gas emissions generally are linked to human activities. The concern is that the mean global level of greenhouse gases in the atmosphere is increasing to a level that can trigger serious climate changes in air temperature and violent weather cycles. Carbon sequestration by agricultural land has generated international interest because of its potential impact on and benefits for agriculture and climate change. Where proper soil and residue management techniques are implemented, agriculture can be one of the many potential solutions to the problem of greenhouse gas emissions. Additionally, agriculture conservation practices such as the use of different cropping and plant residue management as well as organically managed farming, can enhance soil carbon storage. Farmers as well as the soil and environment are likely to receive benefits from 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. The major considerations of the soil C balance and the emission of greenhouse gases from the soil are:
1. the potential increase of CO₂ emissions from soil contributing to the increase of the greenhouse effect.
2. the potential increase in other gas emissions (e.g., N₂O and CH₄) from soil as a consequence of land management practices and fertilizer use.

II. the potential for increasing C (as CO₂) storage into soils, which equals 1.3 - 2.4 - 10⁹ metric tons of carbon per year, and to help reduce future increases of CO₂ in the atmosphere. There are large variety of mitigation options for green house gases being emitted by agricultural activities. Mitigation measures include agronomic measures such as improved crop varieties, fertility management, erosion control, irrigation management and increased use of cover crops and crop rotation. Improved soil management measures including precision nutrient management and minimum tillage will reduce emission and sequester carbon. Efficient residue and carbon management in rice can result in significant reductions of CH₄ emissions. Conversation agriculture can mitigate global warming by organic carbon and nitrogen sequestration in the soil, moderating green house gas emission such as CO₂ and N₂O. In rice production systems, efficient water management can reduce soil CH₄ emissions. It has been reported that rice yields are not affected when irrigation is applied intermittently over continuous flooding, which is the major culprit for CH₄ emission. Management of organic inputs can reduce emission by use of composted rice straw, mulching and removal of rice stubbles from the fields. Soil disturbance stimulate soil carbon losses through enhanced decomposition and erosion. Reduced or no-till agriculture often (but not always) results in soil carbon gain in the surface portions of the soil. Reduced or no-till practice also affects N₂O emission.

Since rice - wheat is the major crop rotation but owing to faulty cultivation practices has been found to contribute to climate change by way of burning of crop residues, release of methan from the rice fields and emission of carbon from the conventional tillage. Thus there is a need to shift from conventional faulty practices to safe practices to reduce the GHG load in the atmosphere. To improve upon the conventional practices alternate advance production technologies in the form of resource conserving technologies (RCTs) and conservation agriculture practices have been developed. An account of these technologies in rice - wheat system has been presented here.

Impact of RCTs/ conservation agriculture on C sequestration and mitigation of GHGs

Conservation tillage: Adoption of zero till practices over an area of 0.5 m ha would produce additional 1 million tons of wheat besides saving in 30-40 million litre of diesel through reduced fuel consumption. Use of zero till drill in one hectare of land would save 60-70 litre of diesel and approximately 1
million litre of irrigation water. Using a conversion factor of 2.6 kg of CO$_2$ per litter of diesel burnt, this represents about a quarter ton less emission per hectare of CO$_2$, the principal contributor to global warming. Adoption of zero till over 5 million hectares would represent a saving of 5 billion cubic metres of water per year. In addition, annual diesel fuel saving would come to 0.5 billion litre (including the pumping) equivalent to a reduction of nearly 1.3 million tons in CO$_2$ emission each year.

**Direct seeded rice:** Direct drill seeding of rice (DSR) is a potential option for reducing methane emission. Methane is emitted from soil when it is continuously submerged such as in case of conventional puddled rice. However, DSR crop does not require continuous soil submergence, thereby either reducing or totally eliminating methane emission when it is grown as an aerobic crop.

**Strategies for mitigating the impact of green house gases:** Green house gases (GHG) emissions can be reduced by managing carbon and nitrogen more efficiently in agricultural eco-systems. Crops and residues from agricultural land can be used as a source of fuel to replace fossil fuel combustion, either directly or after conversion to fuels such as ethanol or diesel. Carbon can be sequestered from the atmosphere and stored in soils or in vegetation, for example in agroforestry systems. In rice crop grown in the upper-IGP, the new
technologies have the capacity to reduce GWP in the range from 0.2% to 203.2% (Table 1). Maximum reduction in GWP has been observed in C sequestration technology where rice straw was used as a construction material. Zero tillage also has a high GWP reduction strength of 83.9%. The calculation of benefit-cost ratio has revealed that in the upper-IGP out of the 14 new technologies, 5 have higher values of benefit-cost ratio than of the conventional practice. Crop diversification has depicted the maximum benefit: cost ratio of 2.52 vis-à-vis of 1.92 in the present practices. In the lower-IGP, reduction in
Table 1. Effect of tillage and crop residue on soil organic carbon by soil depth, Rampur, Chitvan November 2002 to March 2006.

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>Soil organic carbon stock (Mg carbon ha(^{-1}))</th>
<th>Sem</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T0</td>
<td>T1</td>
</tr>
<tr>
<td>0-5</td>
<td>11.8</td>
<td>9.20</td>
</tr>
<tr>
<td>5-10</td>
<td>11.2</td>
<td>9.94</td>
</tr>
<tr>
<td>10-15</td>
<td>11.8</td>
<td>9.5</td>
</tr>
<tr>
<td>15-30</td>
<td>21.6</td>
<td>23.7</td>
</tr>
<tr>
<td>30-50</td>
<td>23.6</td>
<td>23.2</td>
</tr>
<tr>
<td>0-50</td>
<td>82.2</td>
<td>74.8</td>
</tr>
</tbody>
</table>

T0- no till, T1: Conventional till, M0: no crop residue, M1: crop residue at 4 Mg ha\(^{-1}\) for each crop rotation, N1: Recommended practice of N management in rice and wheat N2: leaf color chart based N management in rice and recommend practice in wheat.

Table 2. Effect of tillage management on SOC content of Rampur and Baireni

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>Soil OC (kg cm(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rampur</td>
</tr>
<tr>
<td>0-5</td>
<td>18.81</td>
</tr>
<tr>
<td>5-10</td>
<td>20.16</td>
</tr>
<tr>
<td>15-30</td>
<td>16.87</td>
</tr>
<tr>
<td>30-50</td>
<td>11.81</td>
</tr>
<tr>
<td>LSD</td>
<td>1.57</td>
</tr>
</tbody>
</table>

GWP ranged from 4.77% to 173.89% over the conventional management\(^{13}\).

In sandy loam soil, a study over four years revealed that soil under no till sequestered consistently higher amount of organic carbon than under conventional tillage in upper 15 cm soil depth (Table 1). The rate of carbon sequestration was the highest in the top layer, being 28% higher under ZT than CT\(^{14}\). It was also observed that residue incorporation (M1) and LCC based N management (N\(_2\)) enhanced the soil organic carbon stock over respective control.

Comparisons have also been made between different tillage practices\(^{15}\) and a higher soil organic carbon (SOC) content was in ZT tillage treatments as compared to other treatments (Fig. 5).
A study has been carried out at two study locations, and it was observed that with or without crop residue application, SOC content in no tillage treatment was the highest in top 0-5 cm soil depth followed by 5-10 cm, 10-15 cm, 15-30 & 30 - 50 (Table 2). The SOC content from 0-5 cm, 5-10 cm, 10-15 cm soil depths by conventional tillage plot were consistent, however they were significantly higher than SOC content below 15 cm soil depth at both the location. Soil organic carbon sequestration study up to 50 cm soil depth from surface showed that no tillage soil sequestrate significantly higher amount of SOC than CT.

The magnitude of C sequestered also varied with the kind of crop rotation (Table 3). Spring wheat - fallow rotation had lower carbon in soil than annual rotation with two crops. Lower soil layer (7.6 -15.2 cm) retained more Carbon as compared to surface layer (0-7.6 cm). Manipulation in tillage did bring variation in amount of Carbon sequestered. NT and minimum tillage (MT) did not differ with CT in spring wheat - fallow rotation. In annual rotation, ZT and MT were significantly better than CT. Nitrogen dose at higher rates failed to increase the quantity of carbon in the soil as well as sub-surface layer.

In a study carried out for 5 years at Tunisia under two tillage system, it has been reported that the soil organic carbon content was significantly higher under no tillage than in conventional tillage (Fig. 6). The SOC stored was approximately 1 t C ha⁻¹ yr⁻¹. The increase could be due to the carbon restitution which is more important in NT than in CT. In a comparative study between three tillage practices viz., no tillage, minimum tillage and conventional tillage, it was observed that SOC was significantly influenced by soil tillage treatments (Fig. 7) and recorded higher value of SOC in NT than MT and CT at top layer (0-11 cm soil layer), but the reverse trend was found at deeper layer (22-33 cm depth).

A relationship between CH₄ and N₂O fluxes in all the rice paddy fields has also been studied. The sum of annual CO₂ equivalent emission of CH₄ and N₂O was a little bit higher in continuation of no-tilled direct seeding cultivation (ND) than in conventional tilled transplanting cultivation (TT) but not significantly different between ND and TT, possibly due to the long-term continuation of ND, although the emission of CH₄ was much lower in ND than in TT during a few or several years after TT was converted to ND. The averaged annual emission ratio of N₂O to the sum of CH₄ and N₂O on the CO₂ equivalent basis was 9.0, 7.3, and 1.8% in ND, TD and TT, respectively. The highest ratio in ND was caused by sporadic enhancements of N₂O flux in fallow seasons due to an organic matter layer only formed on the surface soil of ND. As a result, the N fertilizer-induced emission factor of N₂O in a three-year average was 0.48 and 2.5% in TT and ND, respectively. During fallow and no-flooded seasons, the CO₂ flux from the surface soil to the atmosphere was higher in ND than in TT. An annual NEE in TD was estimated to be -294 and -311 g CO₂ m⁻² year⁻¹ in 1998 and 1999, respectively. The organic matter layer formed on topsoil increased with the continuation of ND, and the carbon sequestration rate to the surface soil was 86.2 g C m⁻² year⁻¹.
equal to approximately 30% of the total annual CO$_2$ equivalent emission rate of CH$_4$ and N$_2$O. According to the carbon neutral principle, the annual net CO$_2$ emission in ND was -268 g CO$_2$ m$^{-2}$ year$^{-1}$ by adding the CO$_2$ emission through the slow decomposition of soil organic matter to the carbon sequestration rate. Hence, the total CO$_2$ equivalent greenhouse gas emission (the sum of CH$_4$, N$_2$O, and CO$_2$) in ND was 811 and 648 g CO$_2$ m$^{-2}$ year$^{-1}$ in 1998 and 1999, respectively, and which were lower by 20% than those in TT, mainly due to carbon sequestration to soils in ND. The conversion to TD or TT from ND with the continuation for 8 years, by incorporating the surface organic matter into the ploughed layer, did not show any increase in the emission of CH$_4$ or N$_2$O during the following two years. A possible and effective option for mitigation of greenhouse gas emissions in ND is that ND fields should be converted to TT or TD fields after the continuation of ND for 4-5 years.

**Conclusion:** Rice and wheat being the staple food crops are indispensable, thus are likely to continue as an integral part of World agriculture inspite of having numerous limitations. The available literature suggests that the unhealthy consequences from these crops or crop rotations can be mitigated or overcome through the approaches of RCTs and conservation agriculture principles. These technologies besides being soil and environmental friendly have the potential to stabilize the productivity of these crops under all kind of growing situations, even under resource poor conditions. Moisture conservation, erosion control and energy saving are the added advantages lies with these practices. Now there is a need to translate these technologies into reality by way of making local (site specific) refinements according to the growing conditions and resources base of the area and stakeholder.

**REFERENCES**