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Conservation agriculture: An option to mitigate the adverse effect of climate change: A review

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Abstract

Agriculture is a primary occupation and has been more intensified to feed the growing population. Changing climatic conditions by and large affected the soil microbial communities and their interaction with crop plants (Meena *et al*., 2017). Practicing agriculture in such a way so as to cause minimum damage to the environment is being advocated on a large scale world-wide, i.e. conservation agriculture. Conservation tillage, the most important aspect of conservation agriculture, is a deliberate effort to take care of the soil health and the environment. In the changing climate and resource fatigue scenario, conservation agriculture approaches endorse the potential for creating a healthy soil environment by conserving natural flora and maintaining microbial ecosystems, thus paving the way for sustainable agricultural production systems. Conservation tillage practices such as no-tillage (NT) have potential to increase C sequestration in agricultural soils but patterns of N2O and CH4 emissions associated with NT practices are variable (David *et al*., 2013). A long term study (2006–2009) revealed that double no-till practice in rice-based system is cost-effective, restored soil organic carbon (70.75%), favoured biological activity (46.7%), conserved water and produced yield (49%) higher than conventional tillage (Ghosh *et al*., 2010). Therefore it can be concluded that practicing conservation practices can play a significant role in SOC sequestration. CA sequesters maximum soil organic carbon near soil surface layer. Use of crop residue mulch, efficient crop rotation and no till farming and efficient use of agricultural inputs help to conserve moisture, better soil aggregates, reduce soil erosion and ultimately enhances carbon sequestration. Thus sequestering carbon in soil by conservation agriculture can mitigate the effect climate change as a win-win strategy.

Keywords: Conservation, agriculture, mitigate, climate, review

Introduction

Agriculture is the backbone of the economy of Jammu and Kashmir with over 65% of its population depending upon agriculture and allied sectors. Jammu region of the State has maximum cropping intensity (176.8%) followed by Kashmir (123%) and Ladakh (106%) (Raina *et al*. 2018). The large agro-climatic diversity and variations at macro and micro levels, speaks volumes about the huge agricultural potential in the State and is conducive for cultivation of diversified farming systems. The topography causes lot of hurdles to the people for agriculture inputs

Jammu & Kashmir is situated between 32^0 17' and 37^0 5' N latitudes and 72^0 40' and 80^0 30' E longitudes geographical area of 2.22 lakh square kilometres (Lohan and Sharma 2012). It is surrounded on north by China, on east by Tibet, on south by Himachal Pradesh and Punjab and on west by Pakistan. The state is fundamentally divided into three provinces namely as Jammu, Kashmir and Ladakh having their own typical and distinct geographical peculiarities for their respective agro-climatic zones which in turn determine their cropping patterns and productivity of crops (Raina *et al*. 2018). The state consists of 22 districts with 10 districts of Kashmir valley having by and large a temperate like climate with a landscape dominated by peripheral mountain forests, large natural lakes, Jhelum river waterways, *karewaas* and arable terraced fields.

The Jammu region on the other hand encompasses sub-tropical foothills and plains, temperate Pirpanjal mountains and semi-temperate foothills and mid-hills. Whereas, the Ladakh region is mainly cold arid where tundras dominate and crop culture is localized in the areas fed by small glacial streams. There are many low lying valleys in the state like that of Jhelum valley, Tawi Valley, Chenab Valley, Poonch Valley, Sind Valley and Liddar Valley, but the main Valley is the value of Kashmir which is 100 kms wide and 15520.3 sq. kms in area.

The average height of valley is about 1700 metres above sea level (Raina 2002). The important rivers of this state are Indus, Chenab and Jhelum. There is great diversification in climate of the state due to altitude and latitude variations along with modified climatic conditions created by localized topographies. The climate of the state therefore, varies from sub-tropical in Jammu plains to semi-arctic cold in Ladakh with Kashmir and Jammu mountainous tracts having temperate like climatic conditions. Leh is the coldest and Jammu is the hottest region of the state. Likewise, the annual rainfall also varies from region to region with the lowest annual rainfall of about 93 mm in Leh, 651 mm in Srinagar and 1,116 mm in Jammu (Raina *et al* 2018).

The net sown area (7.52 lakh hectares) in the state is about 35% as against national average of 46% (Dar *et al*. 2017). Out of total net sown area about 70% is under food grains and about 13% is under fruit cultivation. The major challenge for agriculture production is scarcity of irrigation water and only 30% of the cultivated area is under irrigation. Hilly terrain puts limits to mechanical farming and transportation of products, especially horticulture produce. The soils of Jammu & Kashmir are generally loamy with little clay contents comprising of illite type of clay rich in potassium naturally. Fragile soils in hilly areas are susceptible to erosion and mainly a single cropping season is available in temperate and high altitude areas.

What is climate change?

Climate change occurs when changes in Earth's climate system result in new weather patterns that last for at least a few decades, and maybe for millions of years. The climate system comprises five interacting parts, the atmosphere (air), hydrosphere (water), cryosphere (ice and permafrost), biosphere (living things), and lithosphere (earth's crust and upper mantle). The climate system receives nearly all of its energy from the sun, with a relatively tiny amount from earth's interior. The climate system also gives off energy to outer space. The balance of incoming and outgoing energy, and the passage of the energy through the climate system, determines Earth's energy budget. When the incoming energy is greater than the outgoing energy, earth's energy budget is positive and the climate system is warming. If more energy goes out, the energy budget is negative and earth experiences cooling.

As this energy moves through Earth's climate system, it creates Earth's weather and long-term averages of weather are called "climate". Changes in the long term average are called "climate change". Such changes can be the result of "internal variability", when natural processes inherent to the various parts of the climate system alter Earth's energy budget. Examples include cyclical ocean patterns such as the well-known El Niño–Southern Oscillation and less familiar Pacific decadal oscillation and Atlantic multidecadal oscillation. Climate change can also result from "external forcing", when events outside of the climate system's five parts nonetheless produce changes within the system. Examples include changes in solar output and volcanism.

Human activities can also change earth's climate, and are presently driving climate change through global warming.[1] There is no general agreement in scientific, media or policy documents as to the precise term to be used to refer to anthropogenic forced change; either "global warming" or "climate change" may be used [2] The first describes the average effect on a global scale, whilst the second describes how different geographical regions are affected differently.

The field of climatology incorporates many disparate fields of research. For ancient periods of climate change, researchers rely on evidence preserved in climate proxies, such as ice cores, [3] ancient tree rings, geologic records of changes in sea level, and glacial geology. Physical evidence of current climate change covers many independent lines of evidence, a few of which are temperature records, the disappearance of ice, and extreme weather events.

Impacts of climate change

Glaciers

Glaciers are considered among the most sensitive indicators of climate change. Their size is determined by a mass balance between snow input and melt output. As temperatures warm, glaciers retreat unless snow precipitation increases to make up for the additional melt; the converse is also true.

Glaciers grow and shrink due both to natural variability and external forcings. Variability in temperature, precipitation, and englacial and subglacial hydrology can strongly determine the evolution of a glacier in a particular season. Therefore, one must average over a decadal or longer time-scale and/or over many individual glaciers to smooth out the local short-term variability and obtain a glacier history that is related to climate.

A world glacier inventory has been compiled since the 1970s, initially based mainly on aerial photographs and maps but now relying more on satellites. This compilation tracks more than 100,000 glaciers covering a total area of approximately 240,000 km², and preliminary estimates indicate that the remaining ice cover is around 445,000 km². The World Glacier Monitoring Service collects data annually on glacier retreat and glacier mass balance. From this data, glaciers worldwide have been found to be shrinking significantly, with strong glacier retreats in the 1940s, stable or growing conditions during the 1920s and 1970s, and again retreating from the mid-1980s to the present.

The most significant climate processes since the middle to late Pliocene (approximately 3 million years ago) are the glacial and interglacial cycles. The present interglacial period (the Holocene) has lasted about 11,700 years. Shaped by orbital variations, responses such as the rise and fall of continental ice sheets and significant sea-level changes helped create the climate. Other changes, including Heinrich events, Dansgaard–Oeschger events and the Younger Dryas, however, illustrate how glacial variations may also influence climate without the orbital forcing.

Glaciers leave behind moraines that contain a wealth of material-including organic matter, quartz, and potassium that may be dated-recording the periods in which a glacier advanced and retreated. Similarly, by tephrochronological techniques, the lack of glacier cover can be identified by the presence of soil or volcanic tephra horizons whose date of deposit may also be ascertained.

Data from NASA's Grace satellites show that the land ice sheets in both Antarctica (upper chart) and Greenland (lower) have been losing mass since 2002. Both ice sheets have seen an acceleration of ice mass loss since 2009.

Arctic sea ice decline

The decline in Arctic sea ice, both in extent and thickness, over the last several decades is further evidence for rapid climate change. Sea ice is frozen seawater that floats on the ocean surface. It covers millions of square kilometers in the polar regions, varying with the seasons. In the Arctic, some sea ice remains year after year, whereas almost all Southern Ocean or Antarctic sea ice melts away and reforms annually. Satellite observations show that Arctic sea ice is now declining at a rate of 13.2 percent per decade, relative to the 1981 to 2010 average. The 2007 Arctic summer sea ice retreat was unprecedented. Decades of shrinking and thinning in a warm climate has put the Arctic sea ice in a precarious position, it is now vulnerable to atmospheric anomalies. "Both extent and volume anomaly fluctuate little from January to July and then decrease steeply in August and September". This decrease is because of lessened ice production as a result of the unusually high SAT. During the Arctic summer, a slower rate of sea ice production is the same as a faster rate of sea ice melting.

Vegetation

A change in the type, distribution and coverage of vegetation may occur given a change in the climate. Some changes in climate may result in increased precipitation and warmth, resulting in improved plant growth and the subsequent sequestration of airborne CO_2. The effects are expected to affect the rate of many natural cycles like plant litter decomposition rates. A gradual increase in warmth in a region will lead to earlier flowering and fruiting times, driving a change in the timing of life cycles of dependent organisms. Conversely, cold will cause plant bio-cycles to lag. Larger, faster or more radical changes, however, may result in vegetation stress, rapid plant loss and desertification in certain circumstances. An example of this occurred during the Carboniferous Rainforest Collapse (CRC), an extinction event 300 million years ago. At this time vast rainforests covered the equatorial region of Europe and America. Climate change devastated these tropical rainforests, abruptly fragmenting the habitat into isolated 'islands' and causing the extinction of many plant and animal species. Such stress can alter the growth rate of trees, which allows scientists to infer climate trends by analyzing the growth rate of tree rings. This branch of climate science is called dendroclimatology, and is one of the many ways they research climate trends prior to written records.

Forest genetic resources

Even though this is a field with many uncertainties, it is expected that over the next 50 years climate changes will have an effect on the diversity of forest genetic resources and thereby on the distribution of forest tree species and the composition of forests. Diversity of forest genetic resources enables the potential for a species (or a population) to adapt to climatic changes and related future challenges such as temperature changes, drought, pests, diseases and forest fire. However, species are not naturally capable to adapt in the pace of which the climate is changing and the increasing temperatures will most likely facilitate the spread of pests and diseases, creating an additional threat to forest trees and their populations. To inhibit these problems human interventions, such as transfer of forest reproductive material, may be needed.

Pollen analysis

Palynology is the study of contemporary and fossil palynomorphs, including pollen. Palynology is used to infer the geographical distribution of plant species, which vary under different climate conditions. Different groups of plants have pollen with distinctive shapes and surface textures, and since the outer surface of pollen is composed of a very resilient material, they resist decay. Changes in the type of pollen found in different layers of sediment in lakes, bogs, or river deltas indicate changes in plant communities. These changes are often a sign of a changing climate. As an example, palynological studies have been used to track changing vegetation patterns throughout the Quaternary glaciations and especially since the last glacial maximum.

Animals

Remains of beetles are common in freshwater and land sediments. Different species of beetles tend to be found under different climatic conditions. Given the extensive lineage of beetles whose genetic makeup has not altered significantly over the millennia, knowledge of the present climatic range of the different species, and the age of the sediments in which remains are found, past climatic conditions may be inferred. The studies of the impact in vertebrates are few mainly from developing countries, where there are the fewest studies; between 1970 and 2012, vertebrates declined by 58 percent, with freshwater, marine, and terrestrial populations declining by 81, 36, and 35 percent, respectively.

Similarly, the historical abundance of various fish species has been found to have a substantial relationship with observed climatic conditions. Changes in the primary productivity of autotrophs in the oceans can affect marine food webs.

Human impacts

According to the IPCC, human-caused global warming is driving climate changes impacting both human and natural systems on all continents and across the oceans. Human-caused global warming results from the increased use of fossil fuels in transportation, manufacturing and communications. Internet induced climate change is newest contributor to human-induced climate change. Some of the impacts include the altering of ecosystems (with a few extinctions), threat to food production and water supplies due to extreme weather, and the dislocation of human communities due to sea level rise and other climate factors. Taken together these hazards also exacerbate other stressors such as poverty. Possible societal responses include efforts to prevent additional climate change, adapting to unavoidable climate change, and possible future climate engineering.

Climate Change Scenarios in India

- Temperature increased 0.68 ^{0}C in the last century, to increase 1.4-5.8 ^{0}C by 2100
- Rainfall to increase 10% by 2050 with an increased variability causing frequent floods and droughts
- Sea level risen 10-25 cm, to rise 50 cm by 2100
- Retreating glaciers in the Himalayas
- Shortened *rabi* season
- More incidences of diseases and pests

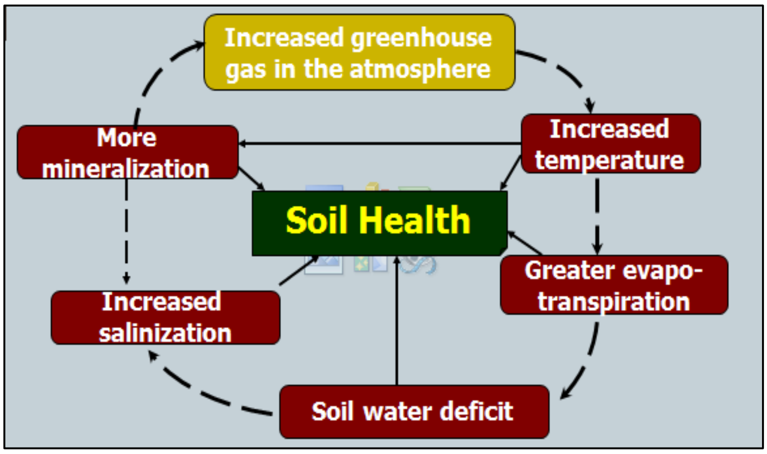
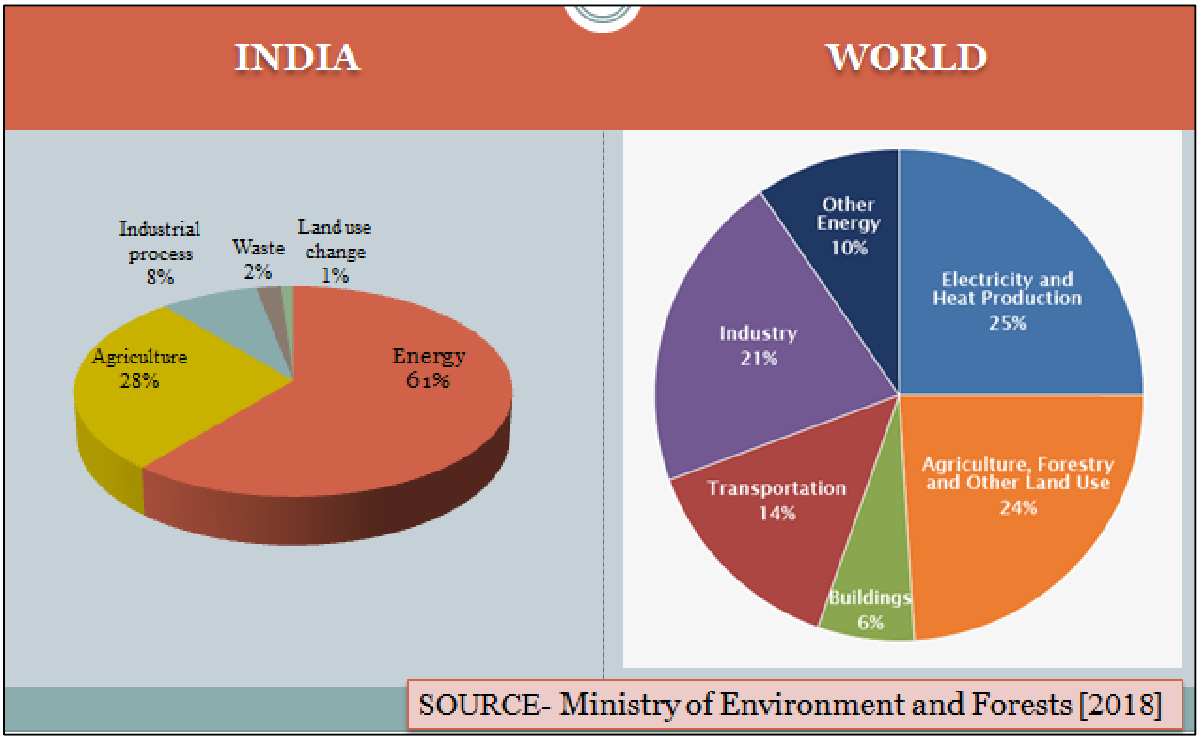
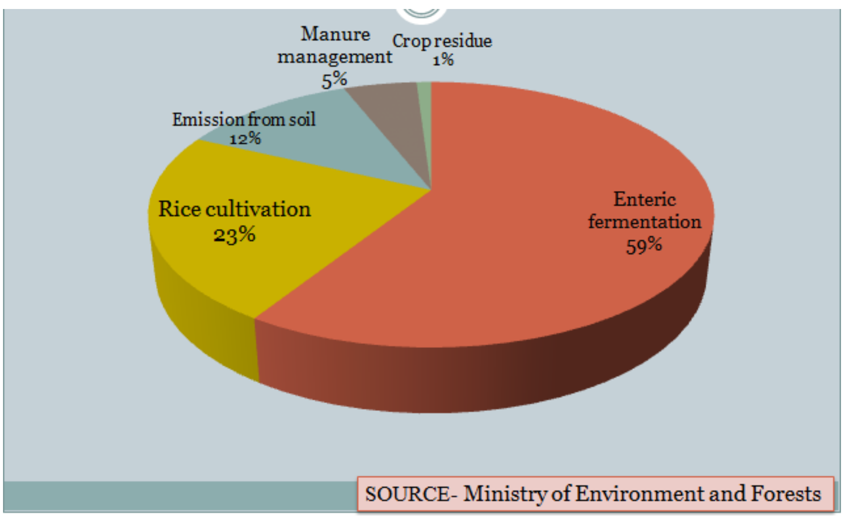


Fig 1: Contribution of major sector to emission of green house gases



SOURCE- Ministry of Environment and Forests [2018]

Fig 2: The relative contribution of sub sector of agriculture to emission of GHGs in India



SOURCE- Ministry of Environment and Forests

Impact of climate change on agriculture

The principal barrier to food security is currently food access. Sufficient food is produced globally to feed the current world population, yet more than 10% are undernourished. Climate change is likely to contribute substantially to food insecurity in the future, by increasing food prices, and reducing food production. Food may become more expensive as climate change mitigation efforts increase energy prices. Water required for food production may become more scarce due to increased crop water use and drought. Competition for land may increase as certain areas become climatically unsuitable for production. In addition, extreme weather events, associated with climate change may cause sudden reductions in agricultural productivity, leading to rapid price increases. For example, heat waves in the summer of 2010 led to yield losses in key production areas including: Russia, Ukraine and Kazakhstan, and contributed to a dramatic increase in the price of staple foods. These rising prices forced growing numbers of local people into poverty, providing a sobering demonstration of how the influence of climate change can result in food insecurity.

The consensus of the Intergovernmental Panel for Climate Change (IPCC) is that substantial climate change has already occurred since the 1950s, and that it's likely the global mean surface air temperature will increase by 0.4 to 2.6°C in the second half of this century (depending on future greenhouse gas emissions). Agriculture, and the wider food production system, is already a major source of greenhouse gas emissions. Future intensification of agriculture to compensate for reduced production (partly caused by climate change) alongside an increasing demand for animal products, could further increase these emissions. It's estimated that the demand for livestock products will grow by +70% between 2005 and 2050.

While gradual increases in temperature and carbon dioxide may result in more favourable conditions that could increase the yields of some crops, in some regions, these potential yield increases are likely to be restricted by extreme events, particularly extreme heat and drought, during crop flowering. Crop production is projected to decrease in many areas during the 21st century because of climatic changes. Average crop yield projections across all emission scenarios, regions, and with- or without- adaptation by farmers, showing an increasing trend towards widespread yield decreases.

What is conservation Agriculture

"Also called as resource efficient or resource effective agriculture"

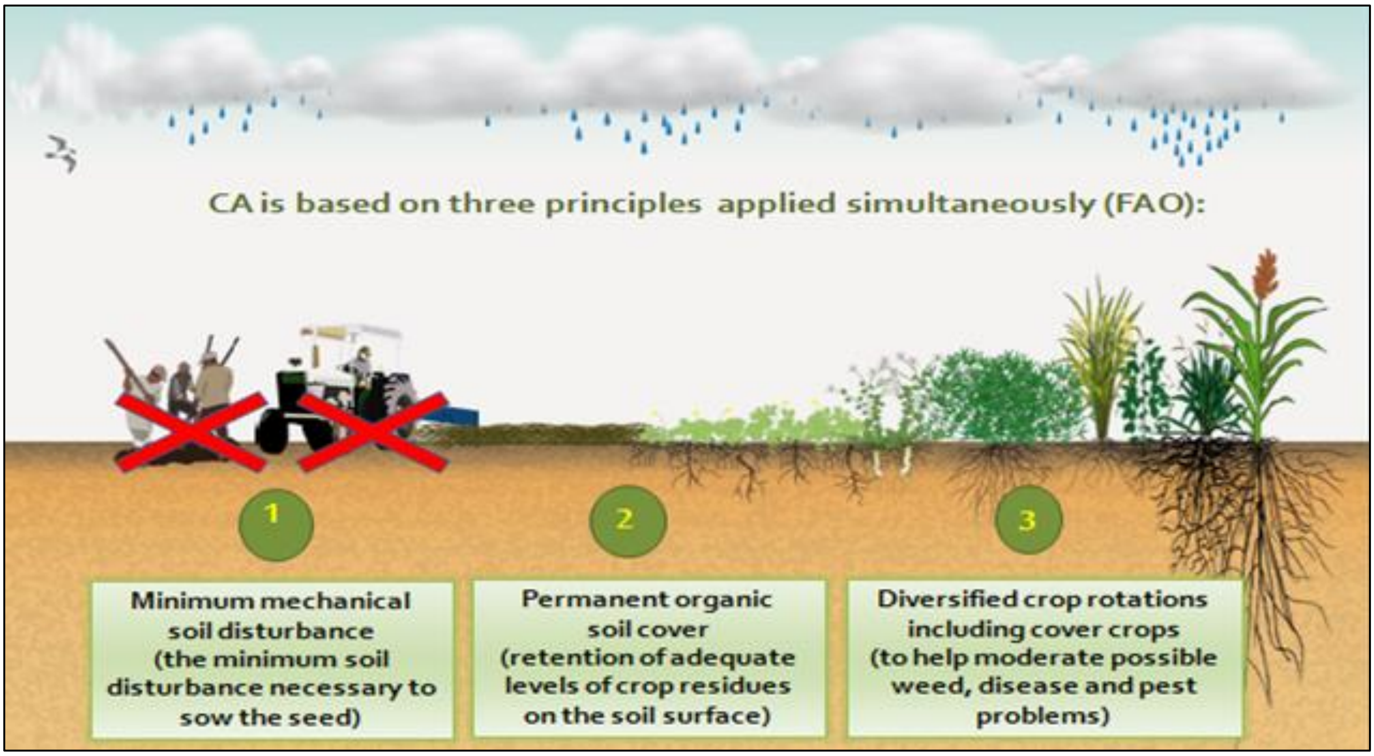
- Conservation Agriculture is scientific practice of agriculture utilizing resource efficient/conservation technologies to save and conserve the natural resources, increase the production and productivity with concurrently conserving the environment. (FAO)

Conservation agriculture and its relevance in Jammu and Kashmir

Conservation agriculture (CA) refers to the system of raising crops without tilling the soil while retaining the crop residues on the soil surface. It can also be refers as resource efficient/resource effective agriculture. CA achieves sustainable and profitable agriculture and subsequently, improved livelihoods of farmers through the application of three CA principles; minimal soil disturbance, permanent soil cover, and crop rotation. CA aims to conserve, improve and make more efficient use of natural resources by practicing integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. CA practices are precise land levelling by laser leveller to save water, direct sowing or drilling/no-tillage/reduced tillage for timely sowing, surface retention of crop residues and establishment of annual and perennial crops to add organic matter to the soil and avoid burning of straw, thus, pollution is reduced. The soil is thus protected from rainfall erosion and water runoff. The soil aggregates, organic matter and fertility level increase, soil compaction is reduced and use of fossil fuels and GHGs emissions are also reduced. CA allows for the management of soil and water for agricultural production without excessively disturbing them. The degradation of natural resources leading to increased cost of production, unsustainable resource use, environmental pollution and health of ecosystems. Therefore, it is very important that CA practices are adopted in different agro-ecological regions without delay. CA can be seen as a new way forward, for conserving resources and enhancing productivity to achieve goals of sustainable agriculture, which demands a strong knowledge base and a combination of institutional and technological innovation. Hence, it is being promoted in Jammu and Kashmir especially in following regions:

- Most of the rice farmers in Jammu and Kashmir practice conventional transplanting method which requires large quantity of water for puddling and transplanting operations that are labour intensive, time consuming and costly. Thus direct seeding can be an alternate option for rice cultivation.
- Wheat in the R. S. Pura belt after Basmati rice is sown late, often linked to late maturing Basmati rice (including Basmati 370, Ranveer Basmati etc) and zero tillage potentially would alleviate this by allowing for timelier wheat establishment.
- As soils under CA have high water infiltration capacities reducing surface runoff and thus soil erosion significantly reduced. To protect the soil form water erosion CA can be a viable option under hills of Jammu and Kashmir besides of increasing organic matter in soil due to surface decomposition of crop residue. Enhancing water conservation through mulching, crop residue retention, zero-tillage & crop rotation etc. *Zero tillage* allows significant amount of crop residues to remain on the *soil* surface, protecting it from water *erosion*.
- For the farmer, conservation farming is mostly attractive because it allows a reduction of the production costs, reduction of time and labour, particularly at times of peak demand such as land preparation and planting and in mechanized systems it reduces the costs of investment and maintenance of machinery in the long term.

Principles of conservation agriculture

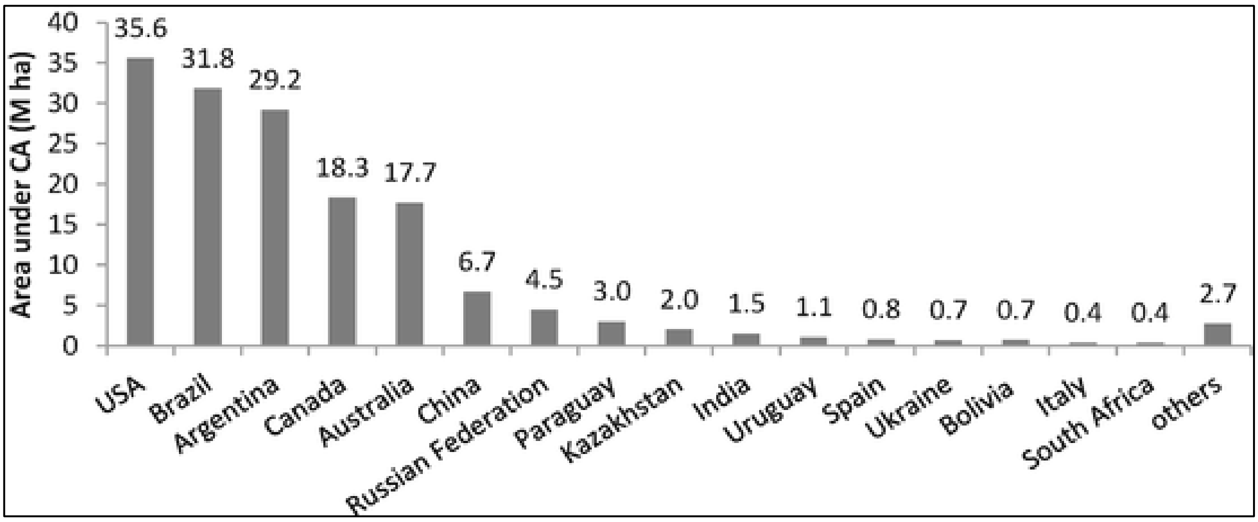


Conservation agriculture systems utilize soils for the production of crops with the aim of reducing excessive mixing of the soil and maintaining crop residues on the soil surface in order to minimize damage to the environment.

The 3 principles of CA are

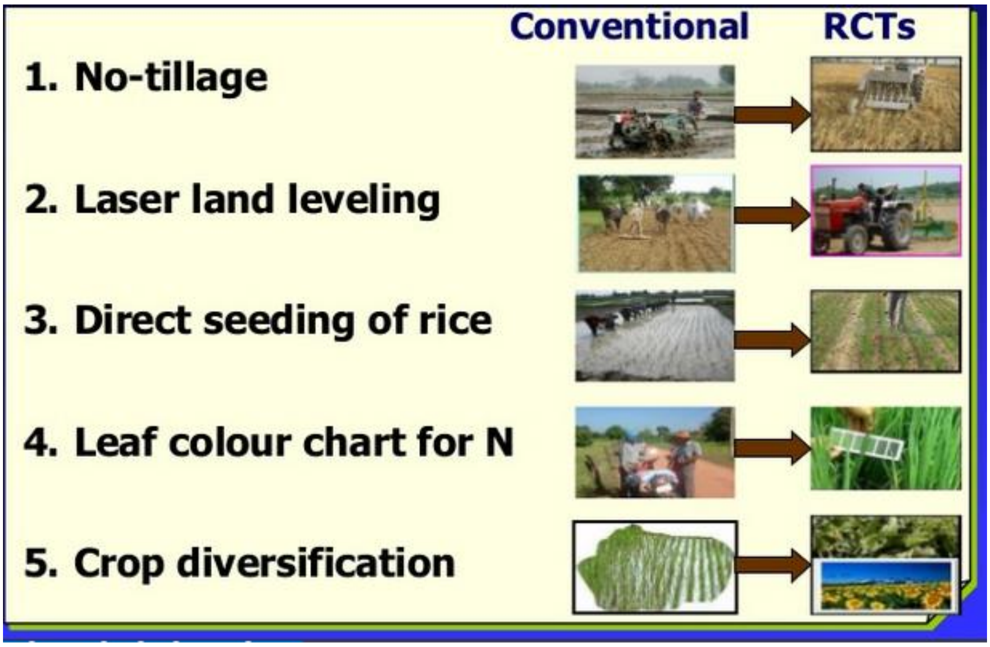
- **Minimum tillage and soil disturbance:** Direct planting involves growing crops with minimum soil disturbance since the harvest of the previous crop. Direct planting can be used with all annual and perennial crops and vegetables. Conservation agriculture can be done manually (i.e. likoti) or mechanically(i.e. animal or tractors drawn conservation agriculture planters).
- **Permanent soil cover with crop residues and live mulches:** Mulch is any organic material (such as decaying leaves, bark, or compost)spread over the soil and around a crop to enrich and insulate the soil. Live mulches are crops intercropped for purposes of providing soil cover. Crop residue or live cover protect the soil from direct impact of erosive raindrops; conserves the soil by reducing evaporation and suppresses weed growth.
- **Crop rotation and intercropping:** Crop rotation means that different crops are alternated in the same field, preferably cereals (maize and wheat) followed by legumes (beans).

World Scenario



In India, it is being cultivated in an area of about 1.5 -2 mha (WCCA report, 2017)

Resource conservation technologies (RCTs)



Conventional RCTs

1. No-tillage
2. Laser land leveling
3. Direct seeding of rice
4. Leaf colour chart for N
5. Crop diversification

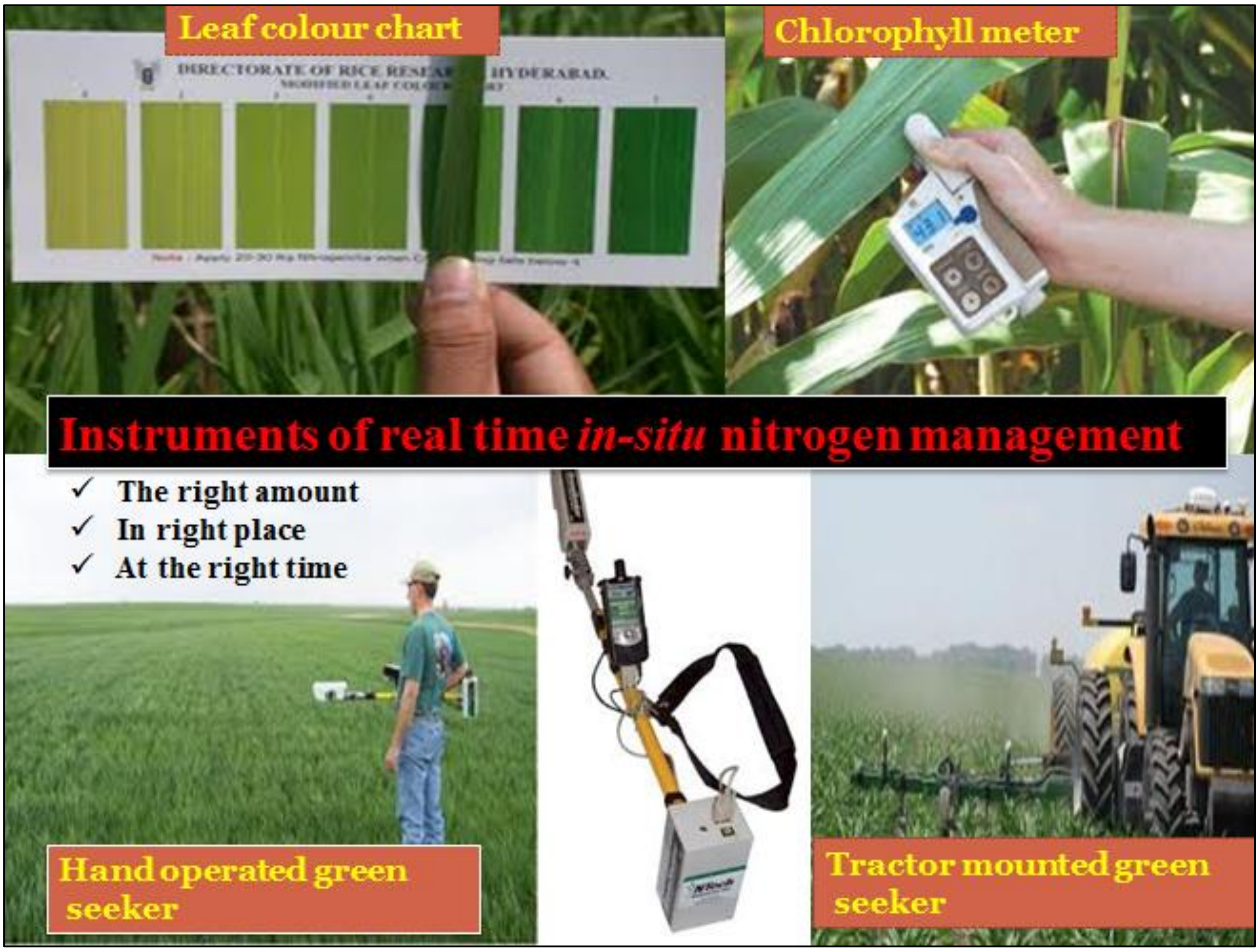


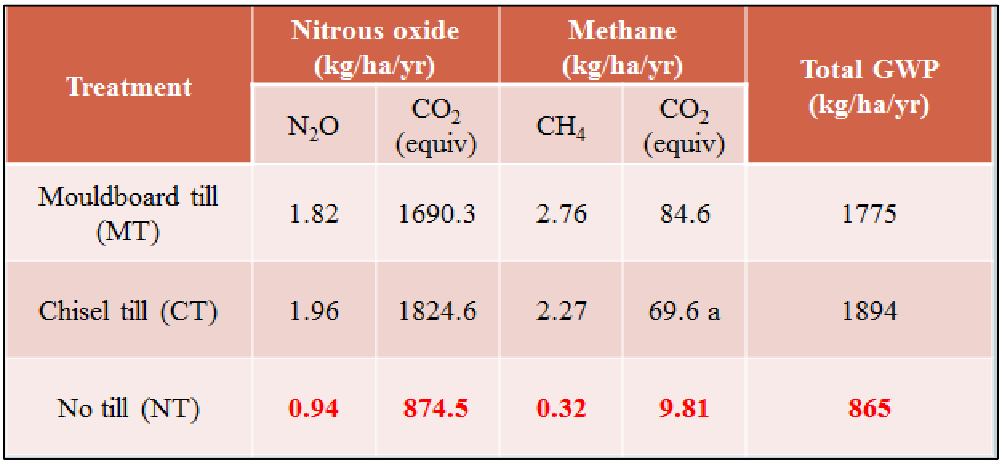
Table 1: Comparative performance of Conservation tillage methods with conventional tillage method

Particular	No-tillage seeding	Strip tillage seeding	Seeding with roto–till drill	Conventional tillage (3 passes + leveling)
Time required (h/ha)	3.23 (70.15)*	4.17(61.46)	3.45(68.1)	10.82
Fuel used (l/ha)	11.30 (67.36)	17.80(49.45)	13.80(60.14)	34.62
Operational energy (MJ/ha)	648.96 (67.16)	1001.76(49.31)	783.60(60.34)	1976.11
Cost of operation (Rs/ha)	639.54 (66.39)	979.95(48.50)	807.30(57.58)	1903.04

In India, zero-till drills, strip till drills, roto till drills are used for direct drilling of wheat after paddy. Comparative study of zero till, strip trill and roto-till was carried out and their performance was compared with conventional tillage. In no-till plots, fuel consumption was found to be 11.30 l/ha as compared to 34.62 l/ha by conventional method resulting in fuel saving of 24 l/ha. There was 67% saving in fuel due to no-tillage as compared to conventional method. Jat (2007) for rice-wheat system reported that the crop yield was comparable under flat bed and raised bed sown wheat and paddy and was equal to the yield obtained by conventional method.

For promotion and adoption of conservation agriculture (CA) on large scale, research is being carried out in India by Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs) and CIMMYT's Rice- wheat consortium. A good number of machines such as no- till drill, strip till drill, raised bed planter, laser land leveler, straw cutter cum incorporator, straw baler, farm residue collector, straw combine have been developed and are being propagated (Tandon 2008). Lal (2004) [2] reported that, conversion of conventional tillage to minimum tillage or no tillage practices can lead to drastic reductions in C emissions.

Table 2: Effects of urban waste compost (C), manure (M) and (N) on corn dry matter, height, leaf area and leaf number

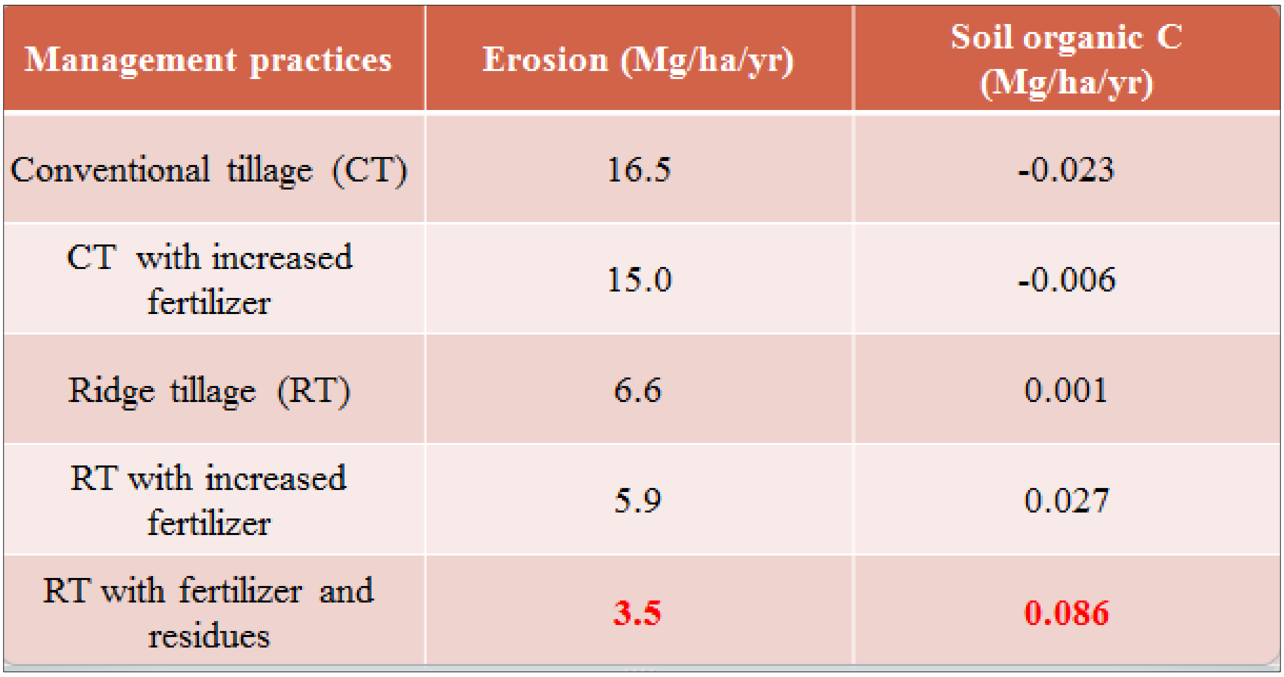


Treatment	Nitrous oxide (kg/ha/yr)		Methane (kg/ha/yr)		Total GWP (kg/ha/yr)
	N_2O	CO_2 (equiv)	CH_4	CO_2 (equiv)	
Mouldboard till (MT)	1.82	1690.3	2.76	84.6	1775
Chisel till (CT)	1.96	1824.6	2.27	69.6 a	1894
No till (NT)	**0.94**	**874.5**	**0.32**	**9.81**	**865**

David *et al.*, (2009) [2] to evaluate the effects of tillage practices on N2O and CH4 emissions in long-term continuous corn (Zea mays) plots. The study was conducted on continuous corn experimental plots established in 1962 on a Crosby silt loam (fine, mixed, mesic Aeric Ochraqualf) in Ohio. The experimental design consisted of NT, chisel till (CT) and moldboard plow till (MT) treatments arranged in a randomized block design with four replications. Overall, all treatments caused net release of N2O. The annual N_2O flux was significantly more from CT (1.96 kg N2ON ha–1 year–1) and MT (1.82 kg N_2O-N ha–1 year–1) than NT (0.94 kg N2O-N ha–1 year–1) treatment. The N_2O emitted were equivalent to 1690, 1825 and 875 kg CO2E ha–1 year–1 for CT, MT and NT, respectively. Net N_2O emission and GWP from NT were 48 and 52%, lower than those from MT and CT, respectively, after 43 years of tillage and continuous corn practice. However, a slight increase in N2O emissions was predicted for eastern Canada, mainly due to higher soil moisture content which increases denitrification rates. Their prediction is consistent with the observation by Six *et al.* (2004) that in humid climates newly converted NT practice systems have higher N2O emissions for the first 10 years, while a long-term NT adoption (>10 years) reduces N2O emission.

Net annual efflux of CH4 occurred under CT (2.27 kg CH4-C ha–1 year–1) and MT (2.76 kg CH4-C ha–1 year–1), but net uptake was observed under NT (_0.32 kg CH4-C ha–1 year–1). The data showed that long-term tillage management practices over the past 43 years had significant impact on CH4 uptake by an Alfisol. soil tillage can significantly reduce CH4 uptake rates in cultivated soils due to disturbance of the methane-oxidizing microbes. The increase in CH4 uptake under NT could be attributed to greater pore continuity which enhances gas diffusivity, increase the rate of supply of atmospheric CH4, and presence of ecological niches for methanotrophic bacteria in NT.

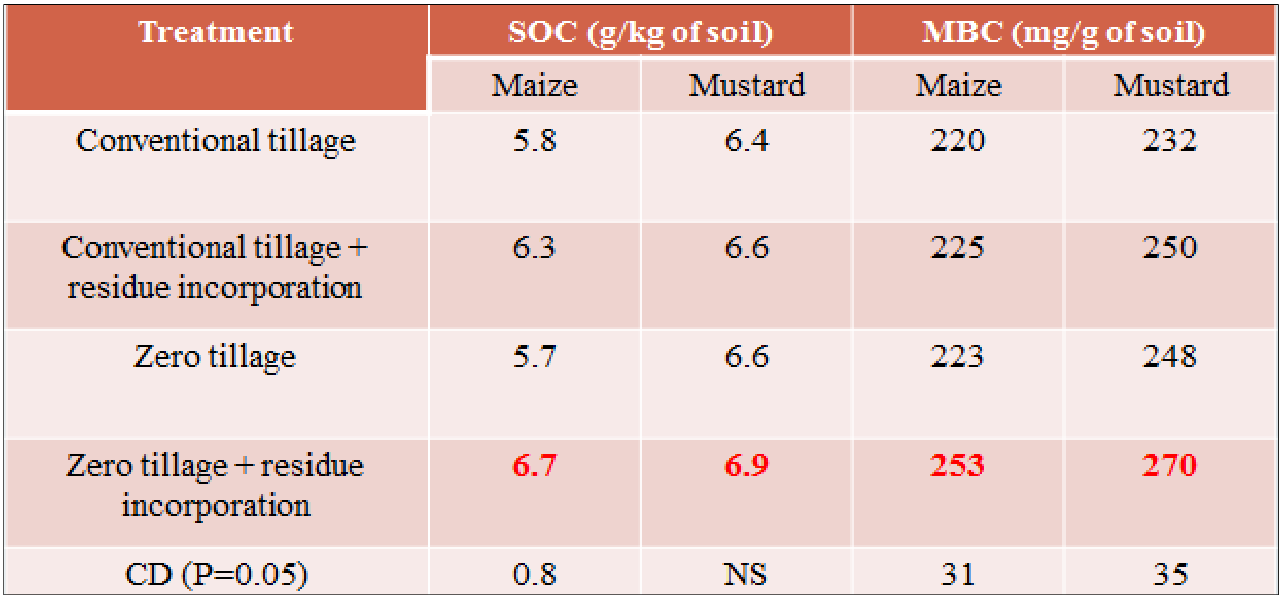
Table 3: Effect of management practices on soil erosion and SOC sequestration



Management practices	Erosion (Mg/ha/yr)	Soil organic C (Mg/ha/yr)
Conventional tillage (CT)	16.5	-0.023
CT with increased fertilizer	15.0	-0.006
Ridge tillage (RT)	6.6	0.001
RT with increased fertilizer	5.9	0.027
RT with fertilizer and residues	**3.5**	**0.086**

Doraswamy *et al*., (2008) used a combination of high- and low-resolution imagery to develop a land use classification for an area of 64 km2 near Omarobougou, Mali. Field sizes were generally small (10–50 ha), and the primary cultivation systems are conventional tillage and ridge tillage, where tillage is performed by a combination of hand tools and animal-drawn plows. Based on land use classification, climate variables, soil texture, in situ soil carbon concentrations, and crop growth characteristics. Ridge tillage with increased fertilizer and residue management significantly increased the simulated amount of carbon sequestered in the slow and passive soil organic matter pools for all four crops. Ridge tillage with increased fertilizer also increased the amount of carbon sequestration for maize, millet, and sorghum, but not as much as including residue management. Increasing crop biomass with either ridge tillage (improved water relations) or conventional tillage with increased fertilizer without ridge tillage allowed about equal inputs to the soil and thus about equal amounts of soil carbon sequestered for maize, sorghum, and millet as model output did not show significant differences in carbon mineralization between these two management systems. Soils with conventional tillage, without additional fertilizer, are expected to continue to lose soil organic carbon for all four crops and consequent reduction in biomass yields. Whereas the SOC content has year-to-year variation due to differences in annual precipitation over the 25 years of the simulations, conventional tillage losses averaged about 20 kg C ha–1 year–1. These losses can be considered the baseline for carbon sequestration credits, which may help fund any additional fertilizer and alternative fuel sources.

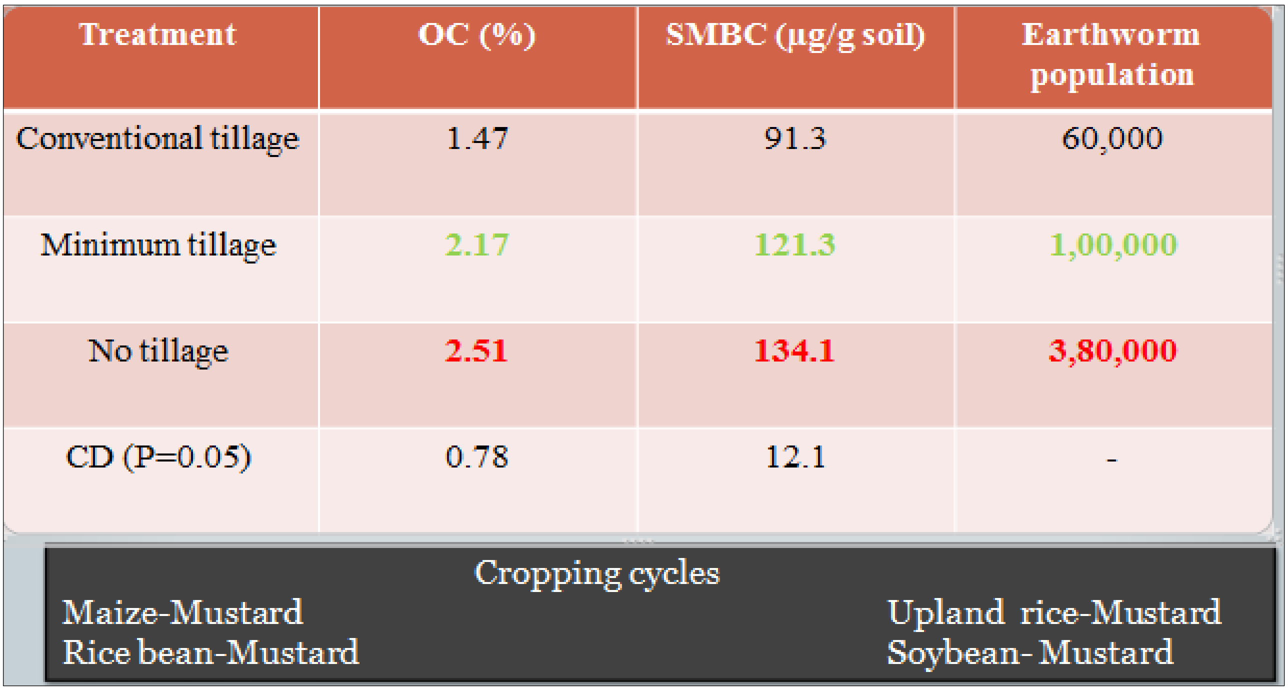
Table 4: Effect of tillage and residue management on soil organic carbon (SOC) and microbial biomass carbon (MBC)



Treatment	SOC (g/kg of soil)		MBC (mg/g of soil)	
	Maize	Mustard	Maize	Mustard
Conventional tillage	5.8	6.4	220	232
Conventional tillage + residue incorporation	6.3	6.6	225	250
Zero tillage	5.7	6.6	223	248
Zero tillage + residue incorporation	**6.7**	**6.9**	**253**	**270**
CD (P=0.05)	0.8	NS	31	35

Field experiments were carried out on a sandy loam (Typic Haplustept) soil in semi-arid climate of New Delhi to evaluate the effect of tillage (conventional and zero) and residue management (incorporation, retention and removal) on soil physical properties *vis-à-vis* plant growth after 3 years of continuous maize (*Zea mays* L.)–Indian mustard [*Brassica juncea* (L.) Czern. & Coss.] sequence. Maize (July–October) and mustard (October–November) were grown with conventional (disc plowing, followed by 2 cultivators) and zero tillage (no plowing) and crop residues were applied at sowing @ 3 tonnes/ha for maize and 2 tonnes/ha for mustard. Residue incorporation significantly ($P<0.05$) lowered the bulk density of surface (0–0.15 m) soil layer. Zero tillage with residue retention recorded significantly higher soil organic carbon and microbial biomass carbon, and also mean weight diameter and geometric mean diameter of soil aggregates. Zero tillage resulted in higher infiltration rates, initial as well as steady state (0.120 and 0.029 m/hr where residue retained; 0.108 and 0.028 m/ hr where residue removed). Seedling emergence rates were faster in zero-tilled plots without residue for maize and mustard crops, but the quick emergence could not be effectively transformed in producing more biomass or yield. Increase in leaf area was faster under conventionally-tilled plots with residue incorporation, and the peak leaf area index was also the maximum (3.37 and 5.60 in maize and mustard, respectively). Biomass at maturity differed significantly between conventional and zero tillage, but no difference was observed between residue management practices within same tillage system. Root weight density in maize was significantly higher in conventional tillage with residue incorporation, though at deeper depths, the differences were mostly insignificant. In mustard also, maximum root weight was obtained under conventional tillage with residue incorporation. Although zero tillage optimized water use by 14 and 12% in maize and mustard, respectively as compared to conventional tillage, maximum water-use efficiency was obtained in conventional tillage with residue incorporation, mainly because of maximum yield in maize (2.93 tonnes/ ha) and mustard (1.83 tonnes/ha) obtained under the treatment. In maize, soil organic carbon and microbial biomass carbon were significantly increased in the zero tillage + residue retention than conventional tillage in the surface (0– 0.15 m layer)

Table 5: Organic carbon and biological activity under different tillage practices



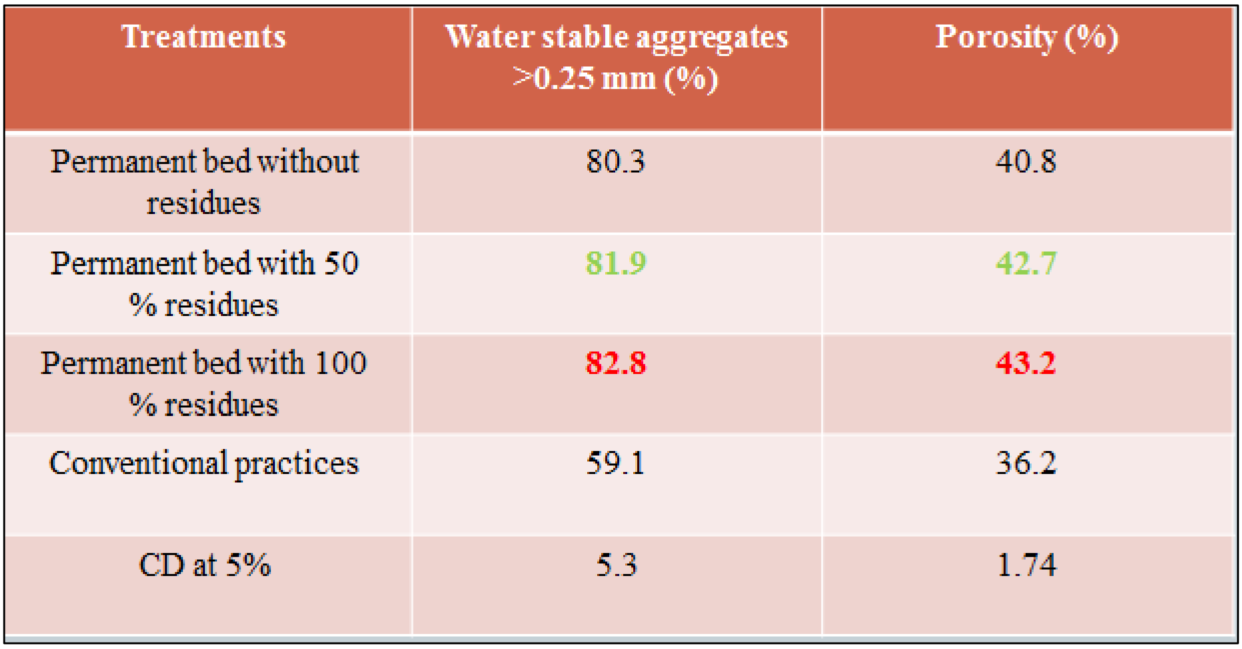
Treatment	OC (%)	SMBC (µg/g soil)	Earthworm population
Conventional tillage	1.47	91.3	60,000
Minimum tillage	2.17	121.3	1,00,000
No tillage	2.51	134.1	3,80,000
CD (P=0.05)	0.78	12.1	-

Cropping cycles

Maize-Mustard
Rice bean-Mustard
Upland rice-Mustard
Soybean- Mustard

Studies conducted by Gosh, *et al*., (2010) [5] on conservation tillage and residue management in different land situation were conducted during 2006–2009 and they are highlighted in this article. In terrace upland, growing mustard completely on residual moisture following upland rice/maize was possible when it is practised under conservation tillage (crop residue of all crops, including weed biomass incorporated). Similarly, in valley upland, growing second crop of pea in rice fallow is possible if two-thirds or half of rice residues are retained on the soil surface under zero tillage. A long term study (2006–2009) revealed that double no-till practice in rice-based system is cost-effective, restored soil organic carbon (70.75%), favoured biological activity (46.7%), conserved water and produced yield (49%) higher than conventional tillage. Therefore, conservation tillage practised in terrace upland, valley upland and low-land situations ensured double cropping, improved farm income and livelihood in rainfed NE India. Significant difference in SOC was found among the tillage treatments. After four years, zero tillage (double no-till) recorded the highest SOC. Kuswantha *et al*.and Barman reported that SOC and total N were highest in zero tillage and residue-retained treatments, and lowest in conventional tillage and residue-removed treatments. In the present study, no-till also recorded higher soil microbial biomass carbon (SMBC), dehydrogenase activity and earthworm population, which in turn resulted in good growth and higher yield. When zero tillage was combined with residue on soil surface, C-sequestration was higher than conventional tillage, which favoured greater earthworm population in the field.

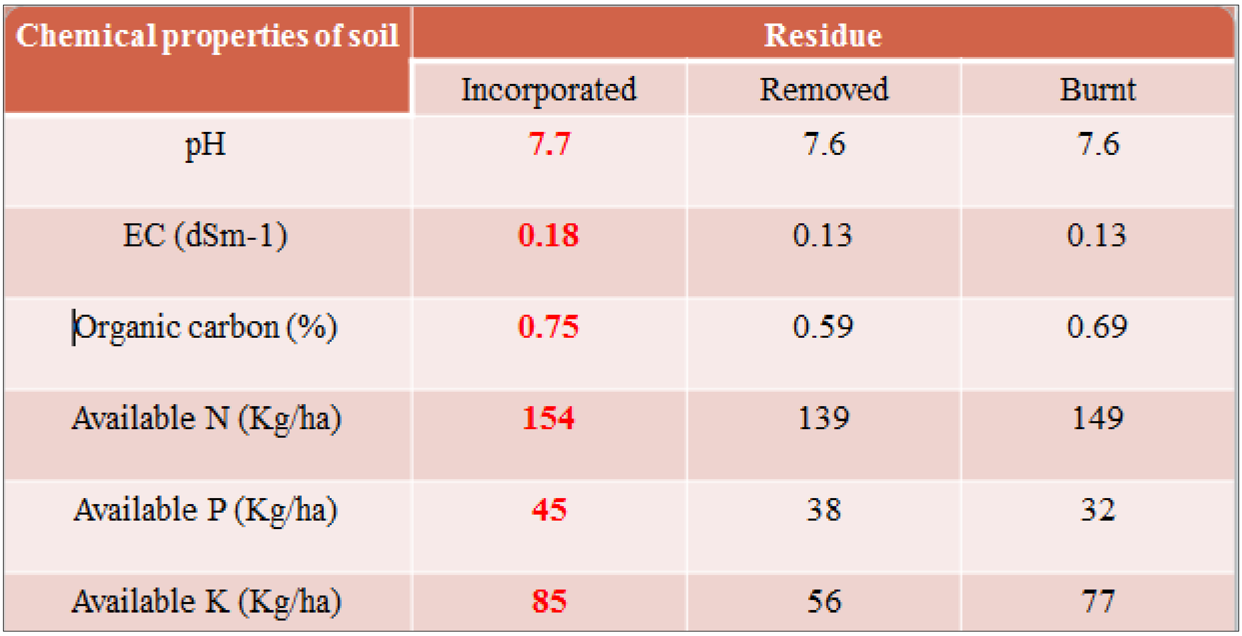
Table 6: Effect of Residue Retained on Water Stability of and porosity under Maize-Wheat Cropping System



Treatments	Water stable aggregates >0.25 mm (%)	Porosity (%)
Permanent bed without residues	80.3	40.8
Permanent bed with 50 % residues	81.9	42.7
Permanent bed with 100 % residues	82.8	43.2
Conventional practices	59.1	36.2
CD at 5%	5.3	1.74

Conservation agriculture in its version of permanent raised bed planting with crop residue retention has been proposed as an alternative wheat production system of western Uttar Pradesh. Therefore the present work was undertaken by Naresh *et al.*, (2012) [8] during 2008-2011 to compare permanent and tilled raised beds with different residue management under irrigated conditions. Permanent beds with residue retention resulted in increased crop yield of 11-17% in maize and 12-15% in wheat over conventional practices. In permanent raised beds with retained plot over without residue plot the savings in water use were 11.2% to 21.5% in maize and 12.3% to 19.7% in wheat as compared to conventional practices of seeding. Permanent raised beds with full residue retention increased soil organic matter content 1.6 times in the 0–5 cm layer and had significantly higher mean weight diameter and aggregate stability compared to conventionally tilled flat beds. The residues lying on the soil surface in conservation agriculture protect the soil from raindrop impact. No protection occurs in conventional tillage, which increases susceptibility to further disruption. Moreover, during tillage a redistribution of the soil organic matter takes place. Small changes in soil organic carbon can influence the stability of macro aggregates. Permanent raised bed planting practices have been developed to reduce production costs while conserving resources and sustaining the environment and numerous benefits have been observed in comparison with other planting systems. Less is known, however, about how residue management, partial or completely retained, or tillage practices, i.e., permanent raised beds versus conventional tillage in which raised beds are formed each year, affect physical and chemical soil quality. Crop yields on beds with straw retention, rose by about 11-17% for maize and 12-15% for wheat over a 3-year cycle compared with conventional tillage on the flat beds. Conservation agriculture improved soil aggregation compared to conventional tillage systems without retention of sufficient crop residues. Infiltration is generally higher and runoff reduced in permanent raised beds with residue retention compared to conventional tillage with residue removal due to the presence of the crop residue cover that prevents surface crust formation and reduces the runoff velocity, giving the water more time to infiltrate.

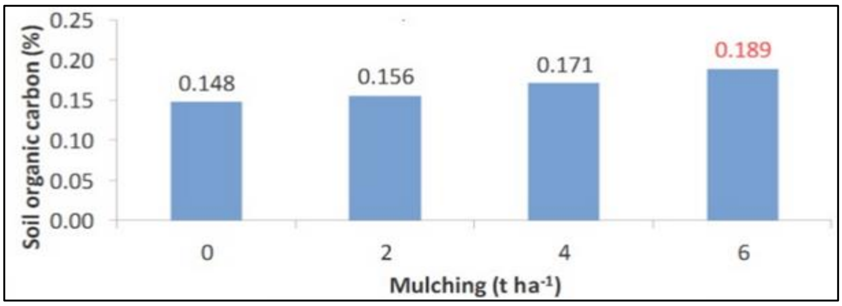
Table 7: Effect of different residue management systems in soil



Chemical properties of soil	Residue		
	Incorporated	Removed	Burnt
pH	7.7	7.6	7.6
EC (dSm-1)	0.18	0.13	0.13
Organic carbon (%)	0.75	0.59	0.69
Available N (Kg/ha)	154	139	149
Available P (Kg/ha)	45	38	32
Available K (Kg/ha)	85	56	77

Rice residues are important natural resources, and recycling of these residues improves the soil physical, chemical and biological properties. Management of rice straw is a major challenge as it is considered to be a poor feed for the animals due to high silica content. This paper by Mandal *et al.*, (2004) [6] reviews the potential of rice residues and its management options, residue effects on soil properties and crop productivity. On the basis of reported research results by different researchers, an analysis has been made. A rice-wheat sequence that yields 7 t ha^{-1} of rice and 4 t ha^{-1} of wheat removes more than N 300, P 30 and K 300 kg ha^{-1} from the soil; the residues of rice and wheat amount to as much as 7-10 t ha^{-1} yr^{-1}. South Asian farmers need to manage 5-7 t ha^{-1} of rice residues and overcome the problems for planting wheat. Management options are: burning, incorporation, surface retention and mulching, and baling and removing the straw. Despite some advantages like killing of deleterious pests and clearing the piles before wheat planting, burning results huge losses of N (up to 80%), P (25%), K (21%) and S (4-60%), air pollution (@ CO2 13 t ha$_{-1}$) depriving soils of organic matter (SOM). This loss of SOM is one of the recognized threats to sustainability. Incorporation leads to build up of SOM, soil N, P and K. The major disadvantage of incorporation is the immobilization of inorganic N. However, N at 15-20 kg ha^{-1} as starter dose with straw incorporation increases yield of wheat and rice compared to burning. Surface retention of residues increases soil NO_3^- by 46%, N uptake by 29%, and yield by 37% compared to burning. Residue management practices affect soil physical properties *viz.* soil moisture, temperature, aggregate formation, bulk density and hydraulic conductivity. Soil temperature is influenced through the change in radiant energy balance and insulation. Rice crop residues are highly siliceous, and have the potential of transforming electrochemical properties of acidic soils that reduces P fixation; improving base retention and increasing the soil pH. Rice straw incorporation coupled with organic manure increases grain yield of wheat and improves soil physical condition. Residue incorporation results more microbial activity than residue removal or burning. Thus, if residues are managed properly, then it can warrant the improvements in soil properties and the sustainability in crop productivity.

Research results show that a continuous recycling of crop residues for 7 years in rice-wheat markedly influenced the soil properties. The organic-C status of the soils was significantly increased when crop residues were incorporated. Similar was the trend in the available and total forms of NPK in soil. The increase in nutrient status of soil may be ascribed to the average addition of 6 t ha^{-1} yr^{-1} of wheat straw and 12 t ha^{-1} of rice straw for seven years.

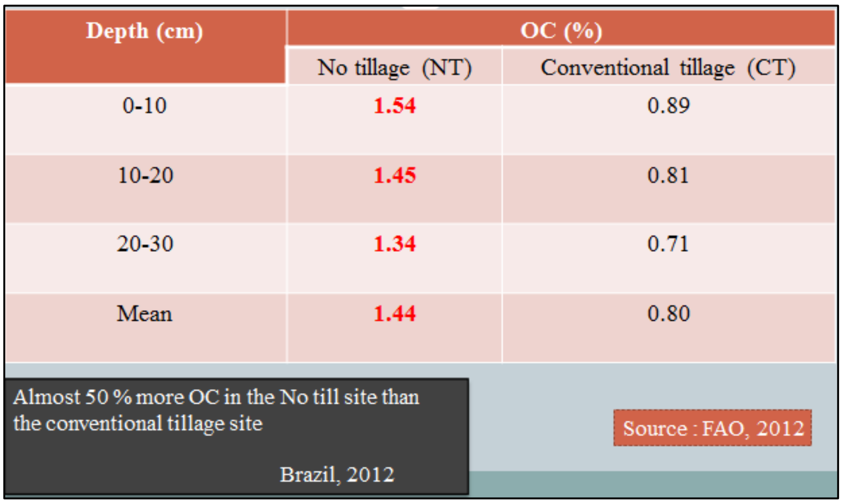


Graph 1: Mulch effect on soil organic carbon (%)

Continuous cultivation with a rice (*Oryza sativa* L.)–wheat cropping system in north-western India has led to an irrigation water crisis due to excessive withdrawal of underground water. Large scale on-farm burning of surplus rice residue by the farmers has also caused intense air pollution. Retaining rice residue as surface mulch as an alternative to burning could be useful for soil moisture conservation, reducing air pollution and improving soil organic matter level. A field experiment was conducted by Ram *et al*., (2013) [11] for three years (2008–09, 2009–10 and 2010–11) to study the effect of four irrigation treatments with irrigations applied at critical growth stages and four rates of rice straw mulching on the grain yield and water use efficiency of wheat in North-west India. The irrigation treatments were irrigations at crown root initiation (CRI) and boot stage (I2); CRI, tillering, and boot stage (I3); irrigations at CRI, tillering, boot stage, and milk stage (I4); and irrigations as CRI, tillering, jointing, boot stage, and milk stage (I5). Mulch application included no mulch (M0) and 2 (M2), 4 (M4), and 6 (M6) t ha−1. Significant irrigation × mulch interaction effects were observed on grain yield during 2008–09. Rice straw mulching decreased the maximum soil temperature by 2.0–3.3 ◦C recorded during the emergence of the wheat crop in different years. Mulching at different rates reduced the mean weed dry matter by 12.5–52.7% compared with the no mulch treatment, and increased growth and yield attributes of wheat crop in different years. WUE increased as mulching increased for the I2, I3, and I4 treatments, but not for the I5 treatment. The increase in water use efficiency with the I5 treatment compared to no mulch was observed at the M2 treatment only and no further increase occurred thereafter. After three years of experimentation straw mulching decreased soil bulk density and increased organic carbon content in the 0–15 cm soil layer. It may be concluded from this study that under limited irrigation water conditions, rice straw mulching will be beneficial in increasing yield, soil organic carbon and water use efficiency in wheat.

Irrigation did not have significant effect on soil bulk density and soil organic carbon content (data not reported). Straw mulch significantly decreased the bulk density (from 1.47 g cm−3 in M0 treatment to 1.37 g cm−3 in M6 treatment) in the surface 0–15 cm soil layer and increased the soil organic carbon content. Gła and Kulig (2008) reported that the bulk density in the upper soil layer (0–10 cm) decreased with mulch residues and reached the similar value as those obtained at conventional tillage (1.25 g cm−3). Soil organic carbon increased from 0.148% in no mulch to 0.189% with the M6 treatment continuously for three years. Straw mulch is an excellent source of carbon, which on decomposition becomes a part of soil organic matter. There are several reports in the literature showing significant increase in soil organic and decrease in bulk density in the surface soil layer.

Table 8: Soil organic carbon for the 12 years of NT and CT sites

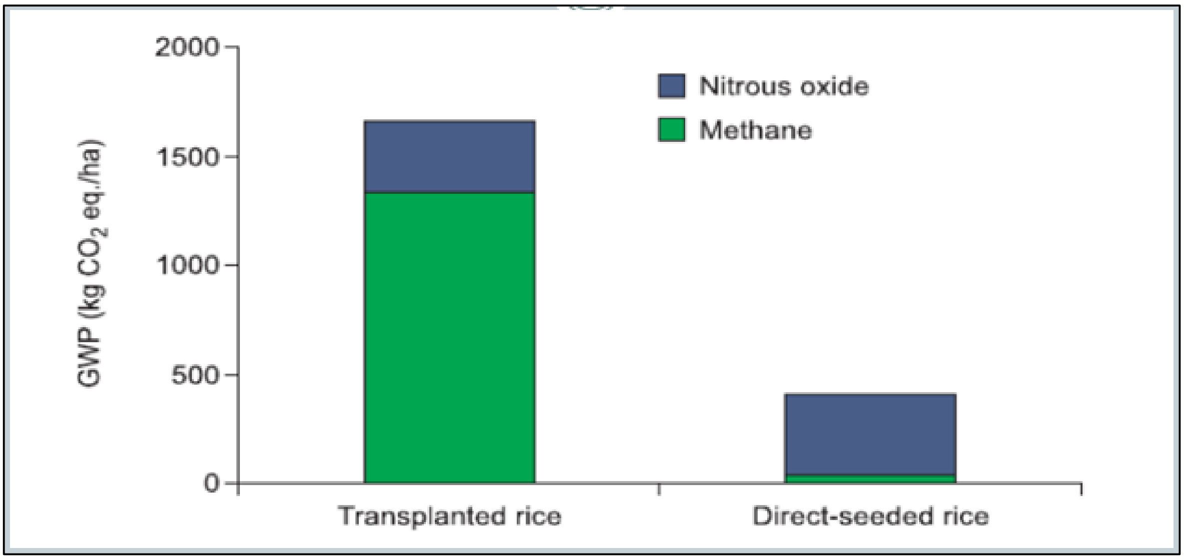


Depth (cm)	OC (%)	
	No tillage (NT)	Conventional tillage (CT)
0-10	1.54	0.89
10-20	1.45	0.81
20-30	1.34	0.71
Mean	1.44	0.80

Almost 50 % more OC in the No till site than the conventional tillage site

Brazil, 2012

Source : FAO, 2012



Graph 2: Global warming potential of transplanted and direct seeded rice

Biogas technology, besides supplying energy and manure, provides an excellent opportunity for mitigation of GHG emission and reducing global warming through substituting firewood for cooking, kerosene for lighting and cooking and chemical fertilizers (Pathak *et al*., 2009). The global warming mitigation potential of a family size biogas plant is about 10 t CO2 eq. yr–1. Presently 3.83 million biogas plants are operating in the country, which can mitigate global warming by 38 Mt CO2 eq. yr–1. If all the collectible cattle dung (225 Mt) produced in the country is used, 51.2 million family size biogas plants can be supported which will have a mitigation potential of 512 Mt of CO2 eq. yr–1 and can earn substantially through carbon credit under the clean development mechanism. The reduction in global warming, therefore, should encourage policy makers to promote this technology to combat climate change. Integration of carbon revenues will help the farmers to develop biogas as a profitable venture.

Table 9: Effect of rotation and treatments on organic carbon content

Rotation	Treatment	% Organic C	% organic matter	% C change#
Corn	None	1.74	2.99	- 45.6
	MLP*	2.09	3.59	- 34.7
Corn-oat	None	2.14	3.68	- 33.1
	MLP	2.44	4.2	- 23.6
Corn-oats-clover	None	2.28	3.92	- 28.7
	MLP	3.35	5.76	+ 4.0
Sod		3.2	5.5	0.0

Conservation tillage practices can minimize the rapid breakdown of plant residues, reduce CO2 emission, and reduce the production of inorganic dissolved nitrogen (i.e., nitrate and ammonium) in soil. When conventional tillage is converted to conservation tillage, both CO2 emission from soil and N-uptake by crops are reduced. Reduction in CO2 emission from soils enhances soil organic carbon (SOC) content, but reduction in N-uptake decreases residue production and hence, organic C storage in soils. Also, it was found that reducing tillage significantly decreases SOC loss from soils with high organic matter content. The Morrow plots at the University of Illinois were established in 1876 to study the effects of crop rotations and fertilization on yield. Crop sequences, in a single replication, were continuous corn, corn-oats rotation, and corn-oats-clover rotation, with and without lime, manure, and rock phosphate (Stauffer *et al*., 1940). The results show that continuous corn plots with no fertilizer decreased soil organic matter (SOM) content by 45.6% in 55 years as compared with the adjacent sod. Neither the cropping system nor the soil treatment had much effect on soil organic carbon below 9 inches.

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