TNA Guidebook Series

Technologies for Climate Change Mitigation

– Agriculture Sector –

UNEP RISØ CENTRE

ENERGY, CLIMATE AND SUSTAINABLE DEVELOPMENT

Technologies for Climate Change Mitigation

– Agriculture Sector –

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Disclaimer:

This Guidebook is intended to help developing country governments, agricultural experts, and stakeholders who are carrying out technology needs assessment and technology action plans for greenhouse gas mitigation in agriculture sector. The findings, suggestions, and conclusions presented in this publication are entirely those of the authors and should not be attributed in any manner to the Global Environment Facility (GEF) which funded the production of this publication.

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Abbreviations and Acronyms

ACCase	Acetyl Co-A carboxylase
ACT	Africa Conservation Tillage Network
AM	Arbuscular mycorrhizal
AWD	Alternate wetting and drying
BCR	Benefit-cost ratio
C	Carbon
C/N	Carbon-nitrogen ratio
CBM	Coal bed methane
CE	CO_2 equivalent
CFC	Chlorofluorocarbon
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon Dioxide equivalent
CTFR	Concentrate to forage ratios
DAT	Days after transplanting
DCD	Dicyandiamide
DDT	(2, 2-dichlorodiphenyltrichloroethane)
DM	Dry matter
DS	Dry season
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FCM	Fat corrected milk
FRB	Ferric iron reducing bacteria
FYM	Farm yard manure
GHG	Greenhouse gas
GM	Genetically modified
GWP	Global warming potential
IRRI	International Rice Research Institute

K	Potassium
LECA	Lightweight expanded clay aggregate
MOP	Muriate of potash
MSW	Municipal solid waste
N	Nitrogen
N_2O	Nitrous oxide
NH_4^+-N	Ammonical form of Nitrogen
NH_4NO_3	Amonium nitrate
NO_3^-	Nitrate
NPK	Nitrogen, Phosphorous, Potassium
NPV	Net present value
P	Phosphorous
PB	Price of biochar
ppbv	Parts per billion (by volume)
ppmv	Parts per million (by volume)
PV	Present value
RMB	Renminbi (Official currency of China, also CNY)
SBT butanoate	S. benzylisothiouronium butanoate
SOC	Soil Organic Carbon
SRB	Sulfate-reducing bacteria
TNA	Technology Needs Assessment
WS	Wet season

Conversions

GWP (Global Warming Potential)*		
Gas	**GWP**	**Name of unit**
CO_2	1	CO_2e (unit of mass of CO_2)
CH_4	25	CO_2e (unit of mass of CO_2)
N_2O	298	CO_2e (unit of mass of CO_2)

(*) The values presented above are as per IPCC WG I, fourth assessment report Forster et al., (2007).
The values as per UNFCCC for CO_2, CH_4 and N_20 are still 1, 21 and 310 respectively.

SI Units		
Physical quantity	**Name of unit**	**Symbol**
Length	metre	m
Mass	kilogram	kg
Time	second	s
Thermodynamic temperature	kelvin	K
Volume	litre	L
Amount of substance	mole	mol

SI (decimal prefixes)					
Fraction	**Prefix**	**Symbol**	**Multiple**	**Prefix**	**Symbol**
10^{-1}	deci	d	10	Deca	da
10^{-2}	centi	c	10^{2}	hector	h
10^{-3}	milli	m	10^{3}	Kilo	k
10^{-6}	micro	μ	10^{6}	Mega	M
10^{-9}	nano	n	10^{9}	Giga	G
10^{-12}	pico	p	10^{12}	Tera	T
10^{-15}	femto	f	10^{15}	Peta	P
			10^{18}	Eta	E

Decimal fractions and multiples of SI units that have special names			
Physical Quantity	**Name of SI Unit**	**Symbol for SI Unit**	**Definition of unit**
Area	hectare	ha	10^4 m^2
Mass	tonne	t	10^3 kg

Non-SI units	
ppmv	Parts per million (10^6) by volume
ppbv	Parts per billion (10^9) by volume
acre	A measure of land. One acre is equivalent to 0.405 hectares

Preface

Agriculture today contributes about 13 percent of greenhouse gas emissions – a significant part of the overall total. Agricultural emissions are expected to increase given the growing demand for food, fuel, fibre, and other materials supplied by agriculture. New technologies and agricultural practices, however, hold the promise of reducing GHG emissions from the sector.

This guidebook describes crop and livestock management technologies and practices that contribute to climate change mitigation while improving crop productivity, reducing reliance on synthetic fertilizers, and lowering water consumption. It is co-authored by internationally recognised experts in the areas of crops, livestock, emissions, and economics, and we are grateful for their efforts in producing this cross disciplinary work.

This publication is part of a technical guidebook series produced by the UNEP Risø Centre on Energy, Climate and Sustainable Development (URC) as part of the Technology Needs Assessment (TNA) project (http://tech-action.org) that is assisting developing countries in identifying and analysing the priority technology needs for mitigating and adapting to climate change. The TNA process involves different stakeholders in a consultative process, enabling all stakeholders to understand their technology needs in a cohesive manner, and prepare Technology Action Plans (TAPs) accordingly.

The TNA project is funded by the Global Environment Facility (GEF) and is being implemented by UNEP and the URC in 36 developing countries.

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1. Introduction and Outline of the Guidebook

This guidebook supports developing countries to select technologies that can help mitigate greenhouse gas (GHG) emissions from the agriculture sector and promote a sustainable agriculture sector. The GHG emissions from agriculture are mainly due to three gases: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). There are six broad mitigation measures that can contribute to mitigation of these gases from the agriculture sector (Smith et. al., 2008).

1. Cropland management
2. Livestock management
3. Manure/bio-solid management
4. Bioenergy
5. Grazing land management/pasture improvement
6. Management of organic soils and restoration of degraded lands.

We have added a seventh measure: the concept of organic agriculture, which encompasses the other six measures. These seven measures contribute to mitigation of the three key greenhouse gases in three ways:

1. By reducing emissions of CH_4 and N_20 from agriculture
2. By enhancing removal of atmospheric greenhouse gases
3. By avoiding emissions of fossil fuels which are inputs for agriculture.

This guidebook focuses on measures 1 to 4 and organic agriculture. These measures can each be divided into activities which are exemplified through a number of technologies (see Table 1.1). Table 1.1 follows a classification provided by Smith et. al., 2008. The various technologies discussed in the guidebook are then mapped according to this classification and in terms of the gases mitigated by each technology. This is to provide an overall perspective to the reader.

Table 1.1 Measures and activities for mitigating GHG emissions from agriculture (*)

Mitigation measure	Activity	Technology examples discussed	Mitigation effects		
			CO_2	CH_4	N_2O
Cropland management	Agronomy	Agricultural biotechnology	√	√	
		Cover crop technology	√		
	Nutrient management	Fertiliser management technologies	√		√
		Using mycorrhiza	√		
	Tillage/residue management	Zero-tillage, Conservation tillage	√		?
		Biochar	√		
	Water management	Sprinkler and drip irrigation, Fog and rainwater harvesting (provided in the Guidebook for Adaptation Technologies)	?		√
	Rice management	Fertiliser and manure management		√	
		Mid-season water drainage		√	√
		Alternate wetting and drying		√	
		Potassium fertiliser application		√	
		Nitrification inhibitors		√	
		Agriculture biotechnology		√	
		Methane mitigation using reduced tillage		√	
		Chemical fertiliser amendment		√	
		Direct seeding technology		√	
		Amendment in methanogenic activity using electron acceptors		√	
	Agro-forestry	Agro-forestry	√		?
Livestock management	Improved feeding practices	Feed optimisation		√	
		Extension of ammoniated straw and sillage		√	
	Specific agents and dietary additives	GM rumen bacteria to produce lower methane		√	
	Longer term structural and management changes and animal breeding	Animal species and performance		√	

Mitigation measure	Activity	Technology examples discussed	Mitigation effects		
			CO_2	CH_4	N_2O
Manure/ bio-solid management	Improved storage and handling	Covering manure storage facilities		√	?
	Anaerobic decay of agriculture waste (anaerobic digestion)	Crop residue management		√	?
		Biogas digester with methane recovery		√	?
Bioenergy	Energy crops, solid, liquid, biogas, residues	Agriculture for bio-fuel production	√		?
		Micro-algae (also to make bio-diesel)	√		
Integrated and other technologies	Organic agriculture		√	√	√

(*) The mitigation measures and activities based on Smith et. al., 2008.
√ means the technology has a positive contribution to mitigation
? means that mitigation impact is not clear

Chapter 2 provides an overview of CO_2, CH_4 and N_2O emissions from agriculture and the strategies that are available for mitigation of these gases.

Chapters 3 to Chapter 7 cover different mitigation technologies. A listing of the technologies covered is provided in Table 1.1., including:

- A technical description
- Advantages and disadvantages
- Economics and mitigation potential
- Examples citing locations of its application
- Barriers the technology faces.

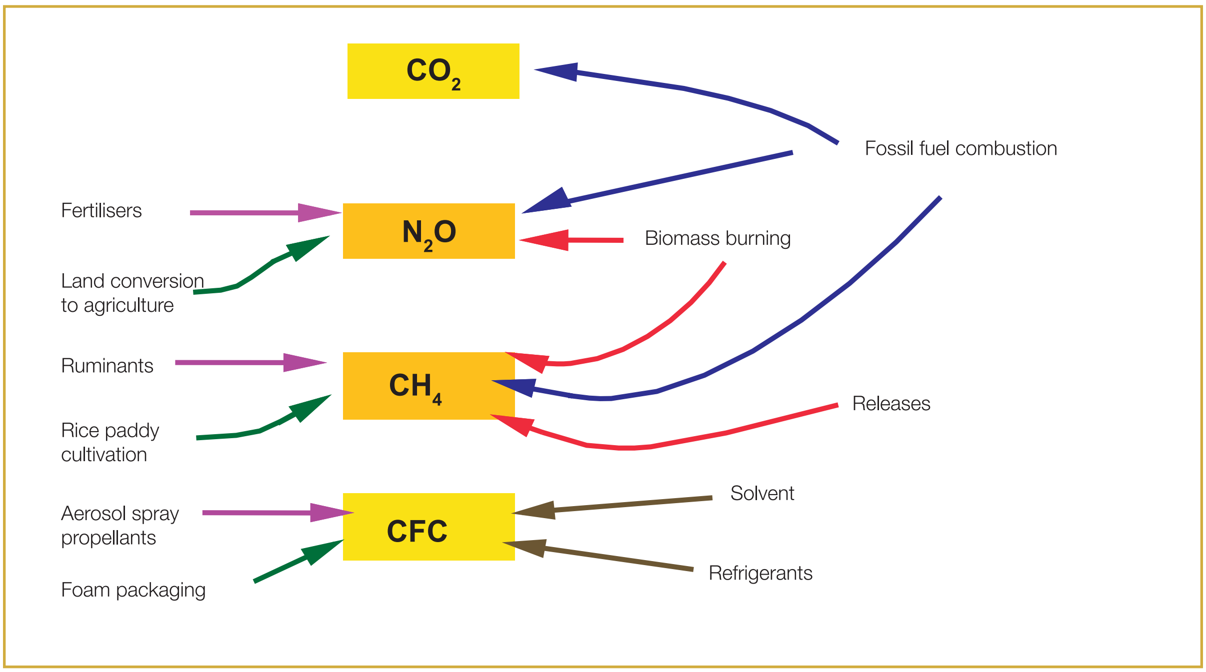
This guidebook covers both technologies that are mature and ready to use and those that have potential for the future. However, they require research at global and local levels.

Chapter 8 emphasises the need to address barriers, co-benefits, climate mitigation financing and the adaption of technologies to local conditions, including conducting necessary research.

2. Greenhouse Gases and Agriculture

Agriculture is our primary source of food, and it is particularly sensitive to climate change. Anthropogenic activities like fossil fuel burning for power generation, industrial manufacturing and transportation, agricultural activities such as rice production, synthetic fertiliser use, livestock rearing, change in land use patterns such as deforestation as well as waste disposal have contributed to the increased atmospheric concentration of greenhouse gases (Figure 2.1). This increase is an important contributor to climate change leading to increased global temperature and other stresses (Houghton et al., 1996).

Figure 2.1 Various greenhouse gases and their anthropogenic sources



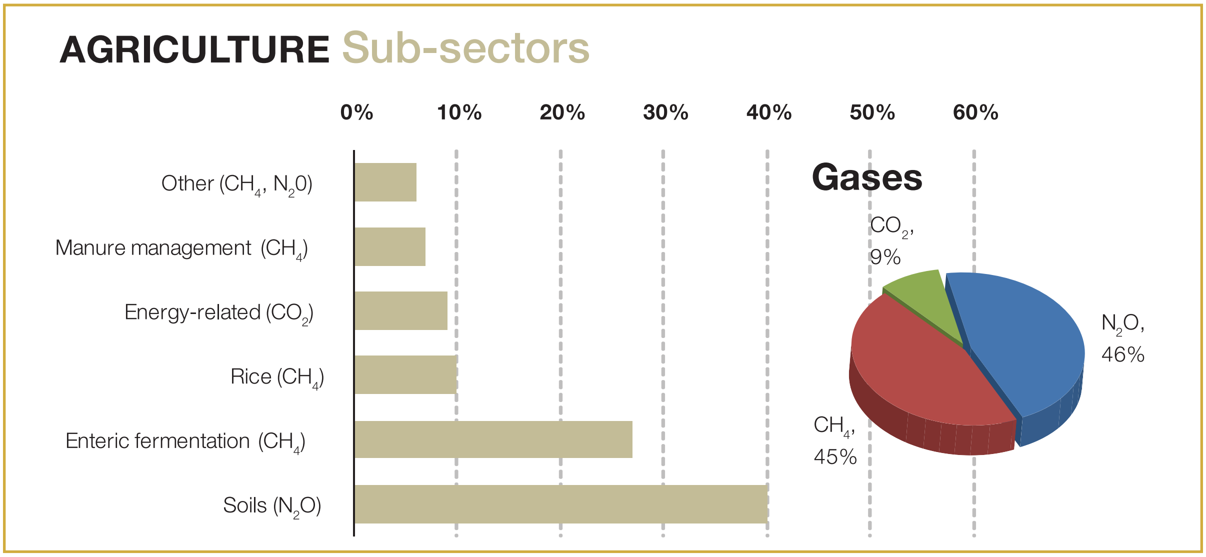
Source: Uprety et al., 1996

2.1 Contribution to emissions

The agriculture sector accounts for about 13 per cent (Barker et al., 2007) of global anthropogenic greenhouse gas emissions, i.e., between 5 and 6 giga tonnes (Gt) of CO_2 equivalents (CO_2e) per year. This is predicted to rise almost 40 per cent by 2030 largely due to increasing demand from a growing population and changing consumption patterns for food, including increasing demand for ruminant meats (Smith et al., 2007). The sector emits about 3.3Gts of methane (CH_4), 2.8Gt of nitrous oxide (N_2O) and 0.04Gt of carbon dioxide (CO_2) in terms of CO_2e annually. Over half of the global nitrous oxide and methane emissions come from the agriculture sector (Figure 2.2). The relative global warming potential (i.e., relative amount of warming compared to the same mass of CO_2) of N_2O is 298 (CO_2e) and that of CH_4 is 25 (CO_2e)

compared to 1(CO_2e) of CO_2 (Forster et al., 2007). Nitrous oxide is emitted mainly from inorganic fertiliser and manure application to soils. Methane is emitted largely from livestock (fermentation in digestion), rice production, and manure handling. Carbon dioxide is released mainly from microbial decay of plant litter and soil organic matter, as well as from burning of plant residues (Smith, 2004).

Figure 2.2 Greenhouse gas emissions from agriculture



Source: Kasterine and Vanzetti (2010)

The CO_2, CH_4, and N_2O concentrations were 280 ppm, 715 ppb, and 270 ppb, respectively in 1750 A.D. By 2005 these values rose to 379 ppm, 1774 ppb, and 319 ppb, respectively (IPCC, 2007). The ice-core record for CO_2, CH_4 and N_2O confirmed that their concentrations in the atmosphere are higher than at any time in the last 65,000 years (Long et al., 2004). The total quantity of the atmospheric greenhouse gases (CO_2, CH_4 and N_2O) has increased exponentially from 3.08 to 6.51 billion tonnes between 1961 and 2005, along with the rise in world population. Thus, there is a positive relation between population and emissions of N_2O and CH_4 for countries including India and Brazil (Vanbeek et al., 2010). Crop production during this period increased from 1.8 to 4.8 billion tonnes per annum. Global cropland expanded from 960 Mha to 1,208 Mha. Total crop production increased from 1.84 tonnes/hectare to 3.96 tonnes/hectare. This increase in agricultural production due to addition of N-fertilisers resulted in 1.4-1.7Gt of GHG emissions i.e., 10-12% of total anthropogenic emissions including 0.76Gt CO_2e N_2O and 0.90Gt CO_2e CH_4, representing 58% and 47% of agricultural emissions respectively.

2.2 Mitigation

The agriculture sector also contributes significantly to GHG mitigation by acting as GHG sink for 10% of emissions. Agriculture creates a reduction in global GHG emissions by approximately 32% by absorbing CO_2 emissions, 42% by carbon offsets through biofuel production, 15% by reducing methane emissions and 10% from reducing emissions of N_2O (IPCC, 2007).

Mitigation could be accomplished through intensification and extensification of agriculture. Intensification may increase emission of GHGs per hectare due to high input of fertilisers, extensive mechanised tilling of soil, heavy use of pesticides and use of inorganic fertilisers. However, it could reduce total land requirement and total agricultural emissions, i.e., a reduced carbon footprint per kg of product. Extensification creates a reduction in emission per hectare due to less use of fertilisers, labour, capital and less mechanisation but total land requirement may increase slightly.

Emission strategies are generally grouped as: (1) enhancement of sinks for CO_2 sequestration (2) emission reduction from agriculture, and (3) avoidance of emissions via replacement products or land use change prevention. Schneider and Kumar (2008) interpreted sinks as reversals of past agricultural emissions which include carbon sequestration in soils and the increase in biomass productivity by altering management and land use changes. The potential emission reductions from agriculture include lower CH_4 emissions from rice fields, ruminants animals and manure; lower N_2O emissions from changes in fertiliser use and manure management and lower CO_2 emission by reduced fossil fuel consumption in agriculture. The avoidance of emissions by using replacement products includes: prevention of deforestation, substitution of fossil fuels by biomass-based energy (e.g., ethanol, biodiesel) and use of biomaterial to replace GHG emitting products (e.g., bamboo in place of aluminium).

However, these strategies should be applied with consideration of local conditions. If agricultural land is used for energy crop plantations, wetland restoration, and afforestation, it will lead to the reduction in land for crop production and food security. Wetland restoration may sequester a large amount of CO_2, but it will also contribute to higher methane emissions. Energy crops act as beneficial carbon offsets, but they can also lead to undesirable nitrous oxide emissions (Crutzen et al., 2008). Use of excess N-fertiliser required for the production of an energy crop can result in more emissions of nitrous oxide. This may contribute more to the global warming by emitting N_2O than cooling by saving on fossil fuels. However, crops with less nitrogen demand such as grasses and woody species may have positive climate impacts i.e., net reduction in equivalent GHG emissions.

Developing technologies for GHG mitigation and harnessing them to adapt to agricultural systems will require innovations in policy and institutions as well. Mitigation technologies are not likely to be cheap or easy but the cost and complexities of mitigation likely will be less than the losses caused by climate change.

GHG mitigation options in agriculture which also support food production include:

a) Increase in carbon storage due to improved cropping and grazing land management.

b) Reduction in methane emissions caused by using improved rice cultivation techniques and diet management of livestock.

c) Reduction in nitrous oxide emissions by improved N-fertiliser application technologies.

These mitigation technologies can be classified into three categories:

1. Reductions in greenhouse gas emissions:

By managing the flow of carbon and nitrogen in agro-ecosystems through:

a) Practices that add N more efficiently to crops to reduce N_2O emissions.

b) Management of livestock and their feed to reduce CH_4 emissions.

c) Nutrient and water management in rice cultivation to enhance carbon sequestration and to control CH_4 emissions.

2. Enhancing removal of atmospheric greenhouse gases:

By sequestering carbon:

a) By any practice that increases crop productivity, such as improved varieties, thereby requiring less land for cultivation while at the same time providing larger amounts of plant residues for C sequestration.

b) About 90% of mitigation could be accomplished from sink enlargement by taking carbon for the development of grains and converting the CO_2 to food components through source sink balancing.

c) Using agro-forestry ecosystems to increase photosynthetic storage of carbon.

d) Removal of CH_4 from the atmosphere on agricultural lands by oxidation. The oxidation of atmospheric methane is stimulated by soil methanotrophs. Generally, it is predominant with the type II methanotrophs such as TRF35. However, the mechanism of atmospheric methane oxidation is not fully known. The CH_4 oxidation rate was most closely related to soil moisture as well as to the methanotrophic community structure and nitrate-N, extractable carbon and total carbon concentration.

3. Avoiding emissions:

By substituting fossil fuels with bio-fuels such as ethanol and bio-diesel.

2.2.1 CO_2 mitigation

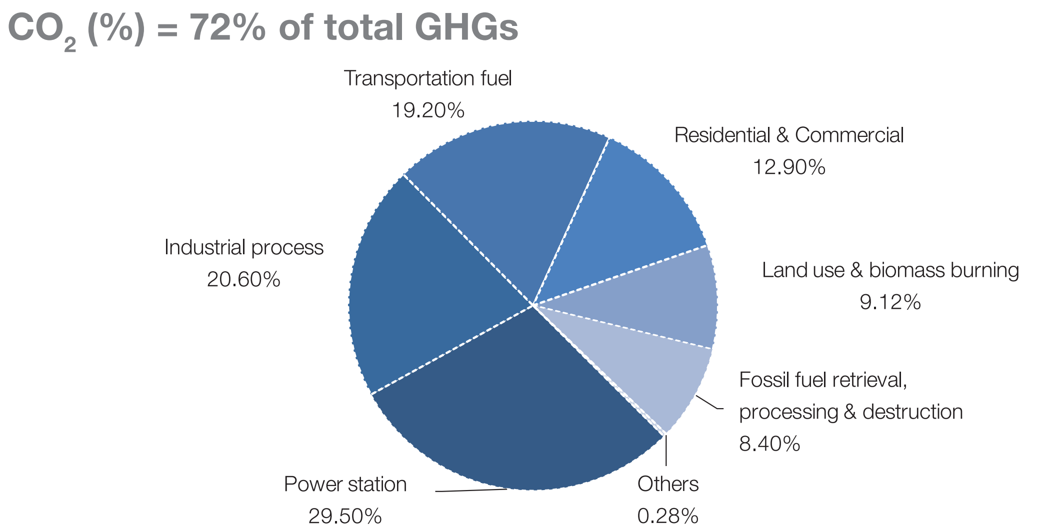
Carbon dioxide contributes around 72% of total greenhouse gas emissions (Houghton et al., 1996). Fossil fuel burning in power stations is the largest source category (29.50%) of CO_2 emissions. Other source categories are industrial processes (20.60%); transport fuel (19.20%); residential and commercial activity (12.90%); land use change and biomass burning (9.12%); fossil fuel retrieval, processing and destruction (8.40%). (Raupach et al., 2007) see Figure 2.3.

Anthropogenic activities such as fossil fuel burning and deforestation lead to an increase in the concentration of atmospheric CO_2 at the rate of 1.8 ppmv per year, which is expected to reach 550 ppmv by 2050 (IPCC, 2007). At present the atmospheric concentration of CO_2 is higher than it was at any time in the past 65,000 years (IPCC, 2007). Fossil fuel burning contributes 5.7Gt, deforestation adds 2.3Gt of CO_2 in the atmosphere, contributing about 8.0Gt carbon per year in all. Soil organic carbon (SOC) has reduced by 50% over the past 40 years from its initial value due to climate change induced degradation of soil (Lal, 2004). The declining SOC has become severe in the past few years, and is closely associated with loss of productivity of several agricultural crops. Therefore, carbon needs to be conserved in soil with minimum release of CO_2 to the atmosphere.

Carbon sequestration mitigation technologies for CO_2

Carbon sequestration in biological systems is commonly considered an approach to conserving carbon. There are other technologies that convert atmospheric CO_2 to other chemicals like methanol and similar organic substrates. However, carbon sequestration in the agricultural system is related to the productivity of crop plants and is considered one of the best ways to store carbon in the biological system. It is defined as the storage of carbon in a stable solid form through direct or indirect fixation of

Figure 2.3 Percentage contributions of various sectors to carbon dioxide (CO_2) emissions



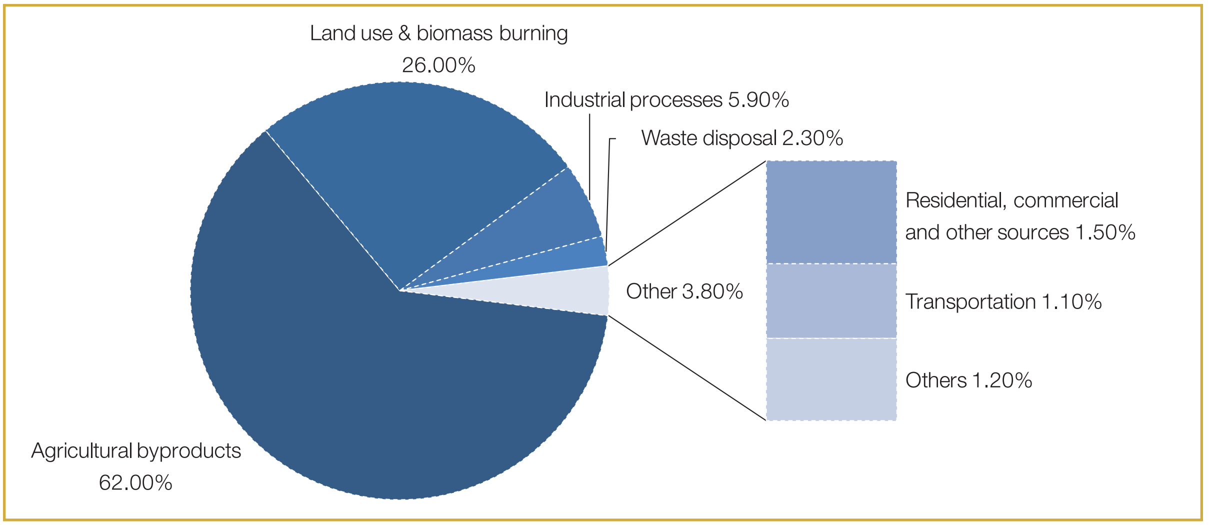
Source: IPCC, Summary for policy makers in climate change, 2007

atmospheric carbon dioxide. CO_2 sequestration for carbon capture is a scientific and technical approach to mitigate CO_2 into the atmosphere. In the global carbon cycle, carbon continuously moves between the soil and the atmosphere. It moves into the soil via photosynthesis in plant leaves and plant derived organic matter (CO_2 influx), and it moves out via respiration of plant roots and soil microorganisms during the decomposition of the organic matter (CO_2 out flux). According to Conant et al. (2001), conversion of cropland to fallow land sequesters 0.1 to 1 metric tonnes C $ha^{-1}yr^{-1}$, depending on the type of biome, with maximum sequestration happening in native grassland and woodland. Other management practices include fertilisation which can sequester 0.3 metric tonnes C $ha^{-1}yr^{-1}$; and irrigation which can sequester 0.2 metric tonnes C $ha^{-1}yr^{-1}$, Conant et al. (2001). Barker et al. (2007) estimated that 89 per cent of the potential for GHG mitigation in the agriculture sector could be achieved through carbon sequestration while the remaining 11 per cent of the mitigation potential is achievable through reducing nitrous oxide and methane emissions.

2.2.2 N_2O mitigation

Agriculture is the major contributor of nitrous oxide (N_2O) emissions to the atmosphere. The percentage of global N_2O emissions attributed to agricultural byproducts including different types of fertilisers, their application technology, and land use is 62%. Biomass burning contributes 26%; industrial processes add 5.9%; waste disposal adds 2.3%; residential, commercial, and other sources contribute 1.5% and transportation adds 1.1% (Figure 2.4). Emissions of N_2O from soil are caused by microbial metabolism of nitrogen through nitrification (oxidative path) and denitrification (reductive path). N_2O with 319 ppbv atmospheric concentration accounts for 7.9% of total greenhouse gases (IPCC, 2007). The global N_2O emissions from agriculture mainly come from agricultural soil management, manure management, and non-crop systems in the rhizosphere (Table 2.1).

Figure 2.4 Percentage contributions of various sectors (source categories) nitrous oxide (N_2O) emissions



Source: IPCC, Summary for policy makers in climate change, 2007

Table 2.1 Annual global N_2O emissions from agriculture

Emission source	Global N_2O emissions (Gg N_2O)
Agricultural soil management	3900 (62%)
Manure management	300 (4.8%)
Indirect emissions from non-crop systems	2100 (33%)
Total	**6300**

Source: Mosier et al., 1998

Urea and ammonium nitrate (NH_4NO_3) are widely used fertilisers with annual consumption rates of 28 and 17 million tonnes of nitrogen, respectively. Temperate regions consume 61% of the total globally used N fertilisers, whereas the sub-tropical and tropical regions use only 29% and 9%, respectively. Emissions of N_2O were significantly higher from soil fertilised with urea compared to ammonium nitrate. Ammonium nitrate was beneficial in reducing the volatility of NH_3 and the emission of N_2O (Mc Taggart et al., 1994).

Most cropped soils emit N_2O at 1.5% of their nitrogen input (Paustian et al., 2004). Decreasing N inputs decrease N_2O emissions. Only half of the N input is captured in crop biomass, and the remainder is lost from the system by leaching and gaseous losses. Any practice that tightens the coupling between soil nitrogen release and crop growth will enhance nutrient use efficiency and diminish the need for exogenous N and decrease N_2O flux. Any practice that conserves N within the system can also reduce N_2O emissions.

The control of N_2O emissions at the farm level could be categorised into:

a) Structural measures

b) Technological measures

c) Management measures.

Structural measures, such as decreasing the volume of production and number of animals via quotas are effective but are very expensive. For example, structural measures followed by The Netherlands Government (buy out of animal rights and lowering the milk quota) decreased national N_2O emissions by 10% (Kuikman et al., 2003). Technological measures, such as type of housing system, manure application technique, manure treatment, fertiliser type, additions to animal feed, and refinement of fertiliser applications can also help reduce GHG emissions. For example, Kimura et al (1992) suggested that foliar application of N fertilisers ($(NH_4)_2SO_4$) decreases CH_4 emissions by 5-25%. Management measures directed towards N-use efficiency focus on improving resource use efficiency (energy, water, feed and nutrients). The most promising measures for decreasing N_2O emissions include adjustment of grazing system, changes in crop rotations, and changing permanent grassland into temporal grassland,. Kuikman et al (2003) reported that the implementation of manure policy will increase N-use efficiency at farm level by a factor of two within five years which may decrease N_2O emissions by approximately 30% in The Netherlands (Table 2.2).

Table 2.2 Emissions of N_2O (Gg N_2O) in The Netherlands

Sources of emissions of N_2O	1990	1997	2000	2010
1. Direct N_2O from agriculture soil	13.0	17.1	15.4	11.9
2. Animal production (grazing and storage)	3.8	3.5	2.5	2.6
3. Indirect N_2O for agriculture soil	4.7	4.7	4.7	4.7
Total	**21.5**	**25.3**	**22.6**	**19.2**

Source: Olivier et al., 2003

The Netherlands study demonstrated that:

1. Inorganic fertiliser in grasslands results in lower emission of N_2O than cattle slurry.
2. Applying fertiliser in small doses reduces the emission of N_2O from grasslands.
3. Split application of fertiliser decreases the emission of N_2O from the field.
4. Broadcast application at one time reduces N_2O emissions compared to the application of fertilisers at 5-10 cm depth.

Mitigation technologies

Velthof et al (2002; 2003) and Groenigen et al (2004) described various mitigation technologies for nitrous oxide emissions from agriculture:

1. Soil nitrogen tests can reduce over-fertilisation resulting into lower N_2O emissions.
2. Fertilisation timing: fertilisation in synchrony with active crop growth reduces the loss of N_2O to the atmosphere.

3. Fertiliser placement: accurate fertiliser placement in the rhizosphere can increase nitrogen use efficiency. It also reduces N_2O emissions. It is economic and saves on a large amount of N fertilisers, which would otherwise be wasted.

4. Nitrification and urease inhibitors: nitrogen as ammonia must be nitrified to NO_3 before it is available for denitrification. Inhibitors delay transformation of NH_4 to NO_3 and urea to ammonia to match crop demand.

5. Cover crops: cover crops can prevent losses of residual soil nitrogen and reduce N_2O emissions.

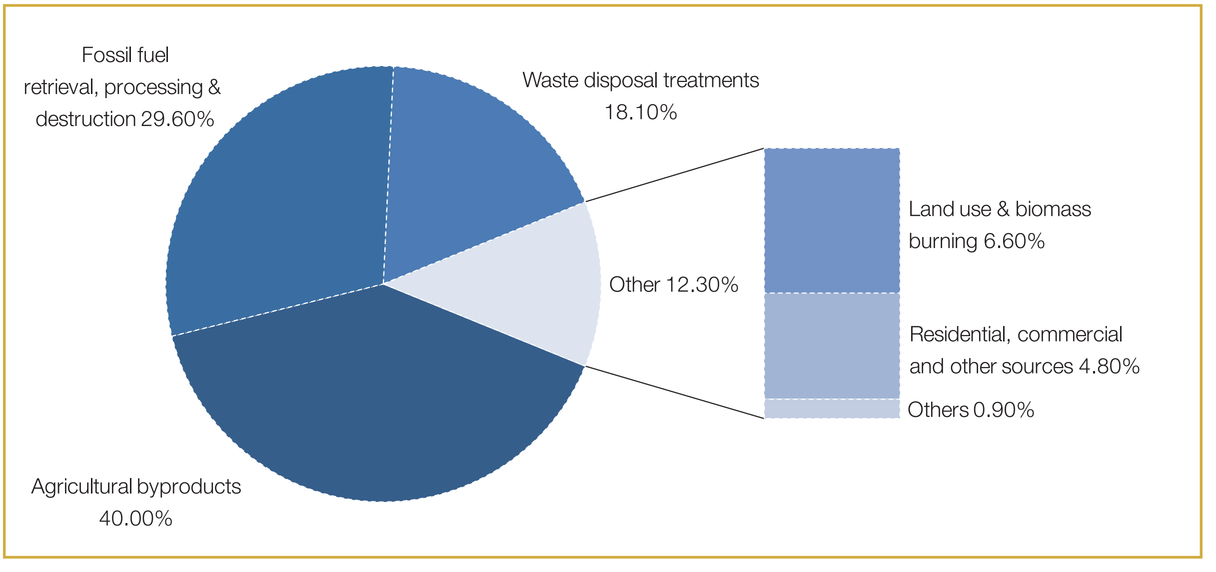
6. Storing animal waste anaerobically minimises N_2O losses to the atmosphere, and mitigates post storage emissions.

7. Indirect emission from non-agricultural crop land: planting trees near (river banks) riparian zones reduces N_2O emissions.

2.2.3 CH_4 mitigation

Methane comprises 18% of total greenhouse gas emissions. It has been attributed to agricultural byproducts (40%); fossil fuel retrieval, processing and destruction (29.60%); waste disposal treatments (18.10%); land use and biomass burning (6.60%); residential and commercial sources (4.80%); and other sources (0.90%) (Figure 2.5).

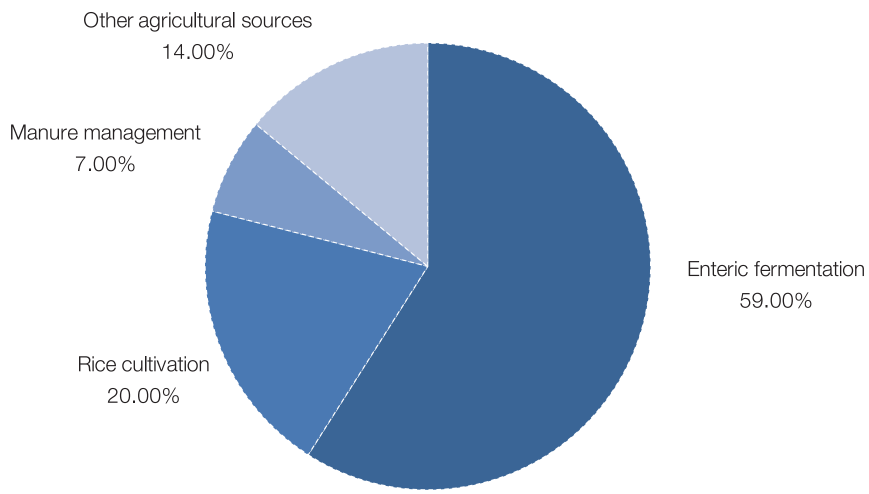
Figure 2.5 Percentage contribution of various sectors to methane (CH_4) emissions



Source: IPCC, Summary for policy makers in climate change, 2007

Methane is a significant contributor to climate change, with the bulk of methane emissions coming from the agriculture sector. Methane is 21 times stronger than CO_2 in terms of trapping heat in the atmosphere. Emissions of methane are increasing with time. For example, in 2000, methane emissions amounted to 6.0Gt, or 15% of the total GHG emissions, compared to 5.8Gt CO_2e a decade earlier (US EPA, 2006a). Methane is produced when organic materials decompose in oxygen-deprived conditions. These conditions are mainly produced by: enteric fermentative digestion by ruminant livestock (such as cattle), from stored manure, and from rice produced under flood-irrigation conditions. Out of these, enteric fermentation is the main source, accounting for 58% of agricultural methane emissions in 2000. Fermentation of micro flora causes 2 to 12 per cent of the total methane emissions. Ruminants (cattle, sheep, and goats) are major methane emitters. Their husbandry covers an area of 3,432 million hectares. These animals carry bacteria in their rumen that make plant material digestible but unfortunately this fermentative process creates methane emissions (Figure 2.6).

Figure 2.6 Worldwide methane emissions from agricultural sources (2005)



Source: US EPA, 2006

Methane emission sources

1. **Domestic livestock** (enteric fermentation and manure management)

   A large amount of methane is produced during digestive processes in which carbohydrates are broken down by microorganisms into simple molecules for absorption into the blood stream of ruminant animals (e.g., cattle and sheep).

2. **Rice cultivation** (flooded rice fields)

   Methane emissions occur as a result of anaerobic decomposition of organic material in flooded rice fields. This gas escapes into the atmosphere primarily by diffusive transport through the rice plant during growing season. Upland rice, which is not flooded does not produce a significant quantity of CH_4.

3. **Prescribed burning of savannas**

   Savannas are burned every 1 to 4 years on an average. The burning of savannas results in instantaneous emissions of CO_2, as well as CO, CH_4, N_2O and oxides of nitrogen. CO_2 released to the atmosphere is reabsorbed during the next vegetative growth period.

4. **Burning of agricultural residue in the field** also contributes significantly to the emission of methane.

2.3 Conclusion

There are significant opportunities for GHG mitigation in agriculture. However, there are many barriers to be overcome. Many studies (Smith et al., 2005) have shown that actual GHG mitigation levels are far below the technical potential for these measures. The gap between technical potential and realised greenhouse gas mitigation occurs due to barriers to implementation, including climate and non-climate policy and institutional, social, educational and economic constraints. The total biophysical potential of approximately 5,500-6,000 Mt CO_2e yr^{-1} are unlikely to ever be be realised due to these constraints. However, with appropriate policies, education and incentives it may be possible for agriculture to make a significant contribution to climate mitigation by 2030 (Smith et al., 2008). The technologies available for mitigation are at different stages of development and a lot of research development work is required to make these technologies commercially viable and usable. These technological improvements could potentially counteract the negative impacts of climate change in cropland and grassland soil carbon stock, pointing to technological improvement as a key factor in future mitigation of GHGs.

3. Cropland Management

Croplands offer many opportunities for reducing emissions (Table 1.1). Mitigation practices in cropland involve:

- Agronomy
- Nutrient management
- Tillage/residue management
- Water management
- Rice management
- Agro-forestry
- Land use change.

3.1 Agronomy

Improvements in agronomic practices generally have the goal to increase yields. Then humans or livestock usually consume these yields, and subsequently their respiration returns the CO_2 to the atmosphere relatively quickly. However, in many cases the improvements have not greatly changed the harvest index of the crops meaning that greater amounts of residue carbon are generated, which can lead to increased carbon storage in the soil (Lal et al., 1998b; Smith et. al., 2008). One example is using biotechnology to produce improved crop varieties with greater insect and/or disease resistance resulting in greater yields and in corresponding increases in residues available for sequestration. A second way would be to improve the digestibility of pasture species using gene modification (GM) technology to reduce methane emissions from ruminants and nitrous oxide emissions from animal excreta. A third method to reduce emissions is adopting cropping systems which reduce reliance on pesticides, nitrogenous fertilisers, and other inputs that require fossil fuels to be manufactured. A good example of this is the use of rotations with legume crops. A fourth method is to provide temporary cover between agricultural crops. Besides adding carbon to soil, temporary cover crops also take up unused nitrogen, thereby reducing N_2O emissions.

3.1.1 Agricultural biotechnology to produce crop varieties with enhanced carbon sequestration

i. Technology definition

This biological approach uses traditional plant breeding and newer biotechnological methods to select and tailor crop varieties with greater carbon sequestration capacity.

ii. Technology description

Agricultural biotechnology stands out as a promising tool for the development of traits and varieties that help to mitigate and adapt to climate change. GM crops with pest resistance (Bt) and herbicide tolerance and conventionally bred varieties using marker selection in tissue culture have benefited agriculture by improving productivity and disease resistance. Had productivity not been maintained or increased by such GM crops, more land would have to be cultivated, and it is likely such land would come from forest or other more natural ecosystems with sequestered carbon that would be released when tilled for growing crops. There are three ways that a GM crop can reduce GHG emissions: (1) increasing productivity and the amount of residue carbon that can be sequestered, (2) herbicide-resistance crops enable greater use of no-till which helps preserve carbon sequestration, and (3) because of enabled no-till, the amount of fossil fuel use by tractors and other implements is reduced because no-till involves fewer passes of equipment across the field.

iii. Advantages and disadvantages

Advantages

1. A big advantage of biotechnology is that, besides increasing carbon sequestration, it can help to improve the productivity of crop plants.
2. By selecting cultivars that are more responsive to elevated CO_2 and more resistant to heat stress, crops will be better adapted to future climatic conditions.

Disadvantages

1. The method generally requires several years and generations of plants to implement because yield and carbon sequestration are dependent on many abiotic and biotic factors. The pace of variety development may be slower than changes in atmospheric CO_2 and climate.
2. Whole new research programs are needed for identifying varieties and traits responsive to the increases in atmospheric CO_2 and global warming and their interactions on the productivity, grain quality, water relations, and pest resistance of crops, and such research is expensive (e.g., Ainsworth et al., 2008).
3. To be successful, selection needs germplasm that differs in many traits, and there may not be enough range in variation of crucial traits needed to adapt to climate change.
4. Many varietal crosses require the use of growth chambers or greenhouses with potted plants, which makes it difficult to predict responses under field conditions.

iv. Economics and mitigation potential

Varieties with increased yield for whatever reason improve the profitability of farmers. Many commercial seed companies are hugely successful. Therefore, the economics of using improved varieties, whether by traditional plant selection or by biotechnology, have been very positive, and it is very likely that they will continue to be positive with future climate change. As mentioned above, besides benefiting agriculture by improving productivity and disease resistance, improved plant varieties have decreased GHG emissions by reducing demand for cultivated land and fossil-fuel-based inputs. GM crops conserve over 14,200 million kg of CO_2 – the equivalent of removing over 6 million cars from circulation in 2007 alone (Brookes and Barfoot, 2009).

v. Examples/locations where presently practiced

Traditional plant selection is used worldwide to improve plant varieties, often with the aim of matching them to local growing conditions. Newer biotechnology requires specialised equipment and laboratories as well as more trained personnel, therefore it tends to be a technology that is confined to more developed countries. Because of the high cost of facilities that can produce conditions with elevated CO_2 and temperature as expected with global change, relatively few field experiments have been conducted (e.g., Ainsworth et al., 2008), and they have tended to be in developed countries, with China and India as exceptions. Approximately 250 million acres of biotechnology engineered maize, canola, cotton, soybeans, papaya, sugarbeets, sweetcorn and squash crops have increased global farmer profits by about $27 billion, reduced pesticides application by 224 million kg, reduced environmental impacts of pesticides by 14% and reduced GHG emissions by 960 million kg of CO_2 (Brookes and Barefoot, 2009). On the basis of above advantages of GM crops, several companies such as Monsanto, Syngenta and Pioneer-DuPont have started to use these germplasms in their research and development pipelines.

vi. Barriers to dissemination

Crop varieties that have been created by traditional plant selection methods have no barriers to dissemination, and they are accepted worldwide. On the other hand, plant varieties resulting from GM crops have faced stiff opposition from consumers in several parts of the world, most notably in Europe. Moreover, the resultant seeds are often relatively expensive so they may not be available to the poorest farmers.

3.1.2 Cover crop technology

i. Technology definition

Cover crops are fast growing crops such as winter rye and clovers that are planted between periods of regular crop cultivation. By covering the soil surface, they protect the soil from erosion, and if leguminous, they fix nitrogen. Later, when ploughed under, they provide humus and carbon to the soil, as well as nitrogen for the subsequent crop.

ii. Technology description

Cover cropping is an effective method of reducing emissions of CO_2. These crops grow over entire land areas or in localized spots such as grassed waterways, field margins, and shelterbelts. Compared to leaving fields fallow, they reduce emissions and can sequester carbon during periods when primary crops are not grown. Cover crops are usually an option on surplus agricultural land or on cropland of marginal productivity.

iii. Advantages and disadvantages

Advantages

1. A primary advantage is that by increasing plant residues and roots, cover crops can sequester carbon during times when the soil surface would normally be bare and emitting carbon due to soil respiration.
2. Cover crops can alleviate nutrient deficiencies and reduce artificial fertiliser use by nitrogen fixing, if leguminous. This will save fossil fuel used in fertiliser manufacture, although more nitrogen in the soil can increase N_2O emissions.
3. Cover crops reduce soil erosion as well as rainfall runoff by improving water infiltration and water adsorption in the soil matrix.
4. Cover crops can also reduce use of pesticides and herbicides for the associated cash crop by suppressing weed growth and providing a substantial habitat for beneficial arthropods.

Disadvantages

1. There are costs associated with planting and terminating cover crops.
2. If not terminated properly, cover crops may act like weeds and compete with the following cash crops for light, nutrients and water.
3. The residues from cover crops can potentially interfere with post-emergence herbicides, which results in the escape of weeds.
4. In some cases, the additional water requirement of the cover crops may make this practice economically and environmentally less viable.

iv. Economics and mitigation potential

Lu et al. (2000) present several examples showing that the growing of cover crops is profitable. In one experiment hairy vetch was grown during the off-season for a main crop of corn. The costs of fertiliser and of hairy vetch seed required for the no-till zero-tillage cover crop systems were \$117.08 and \$16.62 ha^{-1} yr^{-1}, respectively, while the cost of fertiliser for conventional no tillage system was \$174.97 ha^{-1} yr^{-1}. The cover crop system produced average corn yield of 7.86 Mt ha^{-1} in a no-tillage conventional system. The average gross margin (profit) was \$238.28 ha^{-1} yr^{-1} in cover crop system and \$233.27 ha^{-1} yr^{-1} in conventional no tillage system.

Cover crops can also increase soil carbon sequestration. Lal (1998; Table 13) lists carbon sequestration rates from 0.28 to 2.60 Mg ha^{-1} yr^{-1} from growing cover crops on an eroded Alfisol in western Nigeria.

v. Examples/locations where presently practiced

Cover crops are grown all over the world. However, adoption is limited because of the many concerns of growers and the specificity of profitable cropping systems as discussed in the next section.

vi. Barriers to dissemination

Lack of knowledge, incorrect choice of cover crop, and the economic costs of planting and terminating cover crops are all concerns of growers, and they have led to the slow adoption of this practice. If land is fallow for portions of the year, cover crops should be considered. However, they need to be selected on the basis of the growing season, protection capacity, nitrogen fixing capability, and economic feasibility. They vary from region to region, cropping system to cropping system, and crop season to crop season. Therefore, local research must be conducted in order to obtain the knowledge needed to use this practice reliably.

3.2 Nutrient management

3.2.1 Management of nitrogenous fertilisers

i. Technology definition

Efficient use of nitrogenous fertilisers can reduce N_2O emissions from agricultural fields. In addition, by reducing the quantity of synthetic fertilisers required, improved management can also reduce CO_2 emissions associated with their manufacture. In this section a variety of fertiliser management technologies are discussed in brief, followed by a discussion on their relative advantages and disadvantages.

ii. Technology description

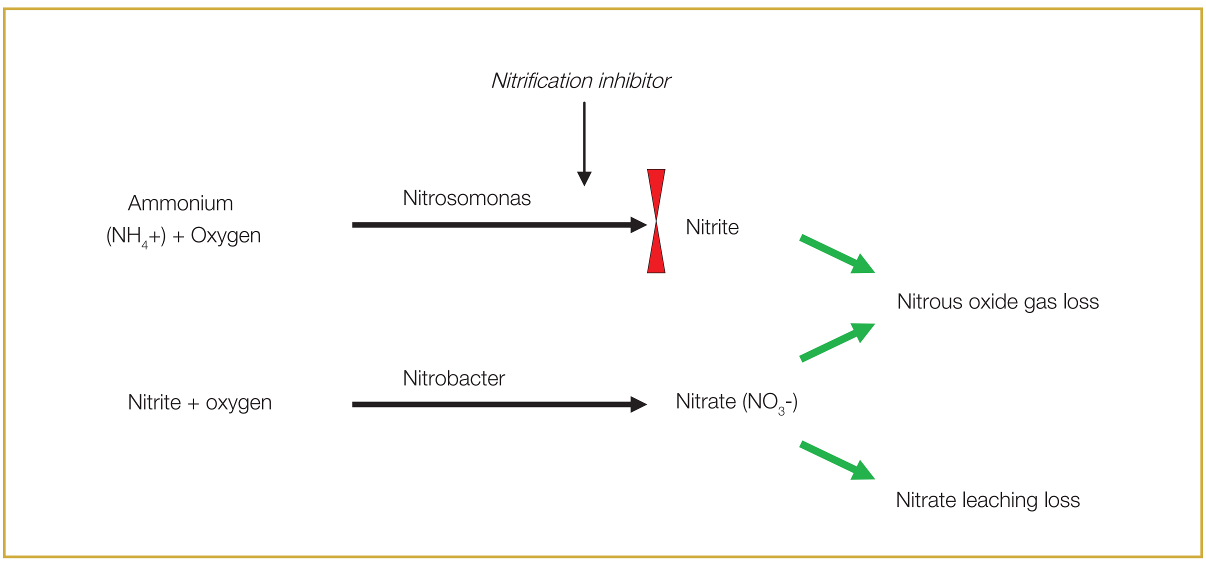
Nitrous oxide mitigation in organic agriculture

Organic agriculture reduces emission of N_2O due to the ban on the use of mineral nitrogen and the reduction in livestock units per hectare. A diversified crop rotation with green manure in organic farming improves soil structure and diminishes emissions of N_2O, although the nitrogen provided by the green manure does contribute to N_2O emissions. Soils in organic farming are more aerated and have significantly lower mobile nitrogen concentrations, which reduces emissions of N_2O. Since organic crop systems are limited by the availability of N, they aim to balance their N inputs and outputs and their N use efficiency. Thus, their emissions are lower than those of conventional farming systems per unit of land area. However, with lower yields from organic farming, the emissions per unit of produce could be the same or higher. (Petersen et al., 2006).

Mitigation using nitrification inhibitors

Emission of N_2O can be reduced by using nitrification inhibitors which slow the microbial processes that lead to N_2O formation (Figure 3.1; Robertson, 2004). The use of nitrification inhibitors such as: S. benzylisothiouronium butanoate (SBT butanoate) and S. benzylisothiouronium fluroate (SBT fluroate) increased yield of crop plants (Table 3.1), reduced emissions of N_2O by 4-5%, and, because N_2O is a more potent greenhouse gas than CO_2, reduced global warming potential by 8.9-19.5% compared to urea treatment alone, thereby helping to mitigate N_2O emission (Bhatia et al., 2010).

Figure 3.1 Nitrification inhibitors (e.g., DCD) reduce the activity of nitrifying bacteria



Source: Rys, unknown

Nitrification and urease inhibitors can reduce the loss of N as N_2O. The application of dicyandiamide (DCD) and Nitrapyrin to grassland reduced the emission of N_2O from NH_4^+ based fertilisers by 64% and 52% respectively (McTaggart et al., 1994).

Table 3.1 Summary of corn yield responses from nitrification inhibitors added to ammoniacal fertilisers applied at varying times in several regions of the United States

Region	Time of application	% of studies with yield increase	% yield increase[1]
Southeast (GA, MD, NC, SC, TN)	Autumn	17	14
	Spring	43	15
Eastern Cornbelt (IL, IN, OH, KY)	Autumn	69	9
	Spring	51	3
	Spring (no-till)	82	13
Northern Cornbelt (MI, MN, WI) Not irrigated Spring 17 12	Autumn	25	5
	Spring	17	12
Western Cornbelt (KS, MN, NE) irrigated coarse-textured soils	Spring	52	30
Western Cornbelt (KS, NE) irrigated medium- and fine-textured soils	Spring	10	5

[1] Average increases obtained in experiments where NI addition gave significant yield increases
Source: From Nelson and Huber, 2001 (data taken from a variety of research progress reports and published materials).

Slow release fertiliser application and manipulation technologies

Fertiliser application technology significantly influences nitrous oxide emissions. The various parameters of this technology are described below:

a) The use of slow release fertilisers offers a cost effective mitigation option. Slow release of urea and NH_4 based fertilisers can be achieved by using various coatings, chemical modifications, and changing the size of fertiliser granules (Figure 3.2). For example, increasing the size of urea granules from conventional 0.01g to 1g decreased nitrification rates and was shown to be more effective than adding the nitrification inhibitor DCD (Skiba et al., 1997).

Figure 3.2 Minimum fertiliser application with larger granule size

Source: Travis Lybbert & Daniel Sumner (2010)

b) A combination of increasing the size of pellet to 1g and adding DCD led to very slow nitrification rates, with 30% of the original N application still present 8 weeks after fertiliser application (Goose and Johnson, 1993).

c) Global warming potential (GWP) due to N_2O reduced from 231kg CO_2e ha^{-1} on urea application to 200kg CO_2e ha^{-1} under urea and SBT fluroate treatment under conventional tillage, whereas under zero-tillage it was reduced from 260kg CO_2e ha^{-1} with urea alone to 210kg CO_2e ha^{-1} with SBT fluroate (Bhatia et al., 2010). These reductions in global warming potential were 13.5% and 19.5% due to SBT fluroate compared to urea alone under conventional and zero-tillage, respectively.

Nitrogen management technology

Fertiliser nitrogen management practices significantly influence the emissions of nitrous oxide in agriculture. These practices are fertiliser type, timing, placement, and rate of fertiliser application, as well as coordinating the time of application with irrigation and rainfall events. Each direct nitrogen management practice influences nitrous oxide emissions.

Type of fertiliser: Nitrous oxide production can be affected by the form of fertiliser applied. Venterea et al (2005) observed that plots amended with anhydrous ammonia emit N_2O at rates 2-4 times greater than from those amended with urea, ammonium nitrate, or broadcast urea. Tenuta and Beauchamp (2003) found that the relative magnitude of total emissions was greater from urea than from ammonium sulphate, which in turn was greater than that from calcium ammonium nitrate. Bouwman et al (2002a) found that nitrate-based fertiliser resulted in significantly lower emissions of N_2O than ammonium-based fertiliser. Snyder et al., (2007) demonstrated that slow, control release and stabilised N fertiliser can enhance crop productivity and minimize the N_2O emissions. Emissions of N_2O were significantly higher from a soil fertilised with urea compared to NH_4NO_3 (Mc Taggart et al., 1994). NH_4NO_3 was beneficial in reducing the volatilisation of NH_3 and the emission of N_2O. Another compound, NH_4HCO_3, when used as basal fertiliser, contributed less to N_2O in contrast to urea.

Fertiliser N timing: Synchronous timing of N fertiliser application with N demand from plants is an important factor in determining the emissions of N_2O from row crop cultivation. Crop nitrogen intake capacity is generally low at the beginning of the growing season, increasing rapidly during vegetative growth and dropping sharply as the crop nears maturity. Prior to spring crop planting results in increased soil N with poor plant N uptake, and therefore, it results in increased N_2O emissions. About 30% of the US area cropped to corn is fertilised in autumn (CAST, 2004). Therefore, large emissions of N_2O could potentially be avoided by fertilising in spring rather than autumn. Hultgreen and Leduc (2003) showed that emissions of N_2O were lower following spring N fertiliser application compared to autumn application.

Fertiliser N placement: Placement of N fertiliser into the soil near the zone of active root uptake may reduce surface N loss and increase plant N use resulting in a reduction in N_2O emissions (CAST, 2004). Liu et al (2006) found that injection of liquid urea, ammonium nitrate at a deeper level in soil profile (10-15cm) resulted in 40-70% lower emission of N_2O compared to shallow injection (5cm) or surface application. Hultgreen and Leduc (2003) reported that the N_2O emissions were reduced when urea was broadcast in mid-row rather than side-banded.

Fertiliser N rate: The emission of N_2O correlates well with fertiliser N rate (Drury et al., 2008). Millar et al (2010) also report that increasing the amount of N applied to soil resulted in increasing emissions of N_2O.

Global warming potential in a no-N treatment of conventional transplanted rice was 1,419kg CO_2e ha^{-1}, whereas GWP under traditional nutrient application of NPK was 6,730kg CO_2e ha^{-1} (Pathak, 2010). The loss in yield was not significant.

Miller et al (2010) suggested that the incentive for nitrous oxide emission reduction by application of lower nitrogen application rates within a profitable range ultimately could be financially remunerated through a carbon or nutrient market. That would bring economic and environmental advantages to compensate for lost productivity benefits due to the use of higher nitrogen application rates.

Coordination with irrigation and rainfall events: application of fertiliser immediately after rain will increase N use efficiency of plants and mitigate N_2O emissions. Losses of N through leaching, volatilisation, and denitrification in a farmer's rice field (which had received 67.5kg N ha^{-1} after rain) decreased up to 40.5kg N ha^{-1} compared to total amount of loss which was 80.3kg N ha^{-1} with the farmer's practice of alternate flooding. The exception was when there were mid-season drainage or alternate flooding and drainage cycles, in which case it increased (Pathak, 2010). The N management regime also reduced global warming potential (GWP) by 1 to 9%.

iii. Advantages and disadvantages

Advantages

Improved nitrogen fertiliser management has many environmental benefits such as:

1. Reductions in N_2O emissions can be achieved by relatively simple adjustments in the farming practices, such as using fertiliser in larger granules and applying it in more frequent, smaller applications, yet high productivity can be maintained.
2. Increase in farm N use efficiency will reduce leaching of NO_3^- to ground water.
3. Making crops more N-use efficient will decrease the need for inorganic N fertilisers and thereby reduce emissions from fossil fuel associated with their manufacture.

Disadvantages

1. The use of chemical inhibitors of N_2O emissions may leave unacceptable residues, and they may not be effective in certain types of soil.
2. The present prices of chemical inhibitors of N_2O emission are quite high, so they aren't affordable to many farmers, and they are not commercially available in many regions.

iv. Economics and mitigation potential

As presented above in the individual sections, the several N management approaches have a high potential for reducing greenhouse gas emissions. However, costs for nitrification inhibitors are high, and reducing rates of N applications can have negative impacts on productivity. On the other hand, relatively simple changes, such as increasing particle size of the fertilisers and changing the timing of applications can minimise emissions with little or no additional cost or loss of productivity.

v. Examples/locations where presently practiced

Nitrogen fertilisation is a significant input cost for farmers worldwide, and therefore, some of the approaches, such as split applications of fertiliser to better match plant uptake needs, are in common use. On the other hand, chemical inhibitors are relatively expensive, so they are less widely used, but nevertheless have gained some acceptance as suggested by the number of positive yield studies in the United States (Table 3.1).

vi. Barriers to dissemination

Besides costs, lack of knowledge and education are barriers. Research is needed to determine the best management practices for specific crops and local conditions.

3.2.2 Mitigation of CO_2 by mycorrhiza

i. Technology definition

Mycorrhiza assist plants in obtaining soil nutrients. Therefore, any resulting stimulations in plant growth provide additional plant residue, which in turn can lead to increased carbon storage in the soil (Lal et al., 1998b; Smith et. al., 2008). However, mycorrhiza can also promote carbon sequestration through a second mechanism. Mycorrhizae release glomalin, which is a glycoprotein that serves as gluing agent that facilitates soil aggregate formation, improvement of soil physical properties, and sequestration of carbon in the soil (Rillig, 2004; Subramanian et al., 2009). The stability of soil aggregates is highly correlated with the length of mycorrhizal hypha in the soil (Jastrow et al., 1998).

ii. Technology description

One of the prime factors associated with enhancing soil carbon sequestration is the release of glomalin in mycorrhizal systems. Specific mycorrhizae: *Glomus intraradices, Glomus mosseae, Glomus fascicullatum, Glomus margarita,* and *Glomus pellucida,* have been reported to enhance soil carbon due to the release of glomalin. Glomalin is a glycoprotein that serves as gluing agent that facilitates soil aggregate formation and improves soil physical properties (Rillig, 2004). Glomalin secretion helps to conserve soil carbon besides increasing microbial biomass. Subramanian et al (2009) reported that glomalin is composed of 45% carbon, like most organic compounds, and it is considered to be a major compound that is a store of carbon in soil carbon sequestration. Since glomalin is a reservoir of carbon, examining it helps explain amounts of C sequestration in a maize-mycorrhizal system. Arbuscular mycorrhizal (AM) fungi release glomalin which stores about 30-40% carbon in the form of carbohydrates and proteins. It is a super glue that helps store carbon, nutrients, and beneficial microorganisms, as well as being involved in stabilising soil aggregates. It also offers protection against biotic and abiotic stress conditions that could decrease crop growth and therefore reduce carbon sequestration Subramanian et al., (2009).

Mycorrhizal inoculation resulted in colonisation of roots irrespective of fertility gradients and crop growth stages (Subramanian et al., 2009). The un-inoculated treatments registered less than 5% colonisation shortly after planting, but the percentage of colonisation tended to increase significantly with the advancement of plant growth. The glomalin content of the soil substantially increased with mycorrhizal association, suggesting that mycorrhiza plays a vital role in conserving the carbon in a long-lived pool, which prevents loss of carbon to the atmosphere while sustaining soil fertility. Although soil glomalin concentration was not affected by chemical fertiliser levels, combined application of fertiliser and rice straw significantly increased soil glomalin concentration, which result into the greater soil organic carbon conservation (Subramanian et al., 2009).

Mycorrhizal plants are generally photosynthetically more active and capable of converting more atmospheric CO_2 into assimilates in the plants (Subramanian et al., 2009). Mycorrhizal symbiosis utilises at least 10% of the host plant's photosynthetic carbon which helps the microbial activity in the rhizosphere and contributes to the enhancement of active carbon pool in the soil. Shoot and root biomass of *Glomus intraradices* mycorrhiza inoculated maize plants were significantly increased about 29% in comparison with un-inoculated plants with there being more enhancement when soil zinc levels were low (Subramanian et al., 2009). Thus, arbuscular mycorrhizal fungi that form symbiotic relationship with more than 90% of terrestrial plant species are helpful in storing carbon in living soil pools. However, the degree of dependence on mycorrhizae varies with plant species, particularly root morphology, as well as soil and climate (Muchovej, 2001). Crops with thick roots, poorly branched, and with few root hairs are more dependent on mycorrhizae including onions, grapes, citrus, cassava, coffee, and tropical legumes.

iii. Advantages and disadvantages

Advantages

1. Mycorrhizal inoculated plants produce larger biomass as a direct consequence of improved photosynthetic activities, and they can translocate 20-30% of assimilated carbon to the rhizosphere (underground).

2. Glomalin concentrations in the soil can be significantly enhanced by the mycorrhizal inoculation resulting in more durable soil carbon sequestration, as well as more stable soil aggregates with improved soil physical properties.

Disadvantages

1. Indigenous mycorrhizal fungal inoculation is not very effective and causes inhibitory effects when inorganic fertiliser is applied to the soil without any integration of organic manures.

2. Cultures of arbuscular mycorrhizae for inoculation of agricultural crops require a host plant and therefore are difficult to grow. However, they are beginning to become commercially available, at least in the United States (Muchovej, 2001).

iv. Economics and mitigation potential

The potential for use is very high, especially to remove the need for phosphorous fertiliser in developing countries, and therefore the mitigation potential to reduce GHG emissions is also high.

v. Examples/locations where presently practiced

Inoculation with ectomycorrhizae is common in the forest industry, but the necessity for more-difficult-to-produce arbuscular mycorrhizae has slowed penetration into agriculture. Nevertheless, practical applications include transplant media that have been treated to remove soil pathogens, re-vegetation of eroded or mined areas, and in arid and semi-arid regions (Muchovej, 2001).

vi. Barriers to dissemination

In many parts of the world, phosphate fertilisers are relatively inexpensive, and therefore farmers do not have a great incentive to inoculate with mycorrhizae. Where phosphate fertilisers are relatively expensive or unavailable, the lack of commercial inoculums and the difficulty of culturing one's own are significant barriers, although commercial sources are becoming available.

3.3 Tillage/residue management

Tillage of the soil stimulates microbial decomposition of soil organic matter, which results in emissions of CO_2 to the atmosphere. Therefore, minimising the amount of tillage promotes sequestration of carbon in the soil. In the last decades advancements in weed control methods and farm machinery now allow many crops to be grown with minimum tillage (Smith et al., 2008). Some examples are provided below.

3.3.1 Conservation tillage CO_2 mitigation technology

1. Technology definition

Conventional tillage is the traditional method of farming in which soil is prepared for planting by completely inverting it with a tractor-pulled plough, followed by subsequent additional tillage to smooth the soil surface for crop cultivation. In contrast, conservation tillage is a tillage system that conserves soil, water and energy resources through the reduction of tillage intensity and retention of crop residue. Conservation tillage involves the planting, growing and harvesting of crops with limited disturbance to the soil surface.

ii. Technology description

Conservation tillage is any method of soil cultivation that leaves the previous year's crop residue (such as corn stalks or wheat stubble) on fields before and after planting the next crop to reduce soil erosion and runoff, as well as other benefits such as carbon sequestration (MDA, 2011). With this technique, at least 30% of the soil surface is covered with crop residue/organic residue following planting (Dinnes, 2004). It also features non-inversion of the soil. This type of soil tillage is characterised by tillage depth and the percentage of surface area disturbed. For example, to plant the crop in Figure 3.3, the planter was adjusted to place the seed 50mm deep and provide a layer of fine tilth 18mm deep across the planted row areas in order to incorporate Treflan, which was sprayed in front of the machine. This was all completed at 20km/h (www.specialtynotill.com.au/). Conservation tillage methods include zero-till, strip-till, ridge-till and mulch-till. Zero-tillage is the extreme form of conservation tillage resulting in minimal disturbance to the soil surface.

Figure 3.3 Zero-till farming system

Source: Wikicommons http://commons.wikimedia.org/wiki/File:Mais_Direktsaat008.jpg?uselang=en-gb

Zero-till involves planting crops directly into residue that hasn't been tilled at all (MDA, 2011). Zero tillage technology is generally used in large-scale agricultural crop cultivation systems because large machines are required for planting (Fig. 3.4). For smaller-scale farms, no adequate machines are available for sowing, although very small scale farmers may do so by hand (Fig. 3.5). In zero-tillage, crops are planted with minimum disturbance to the soil by planting the seeds in an un-ploughed field with no other land preparation. A typical zero-tillage machine is a heavy implement that can sow seed in slits 2-3cm wide and 4-7cm deep and also apply fertiliser in one operation (CIMMYT, 2010). The machine contains an inverted T-type furrow opener to open the slits (Fig. 3.4). The seed and fertiliser are placed in corresponding boxes and dropped into the slits automatically. The depth of the slits may be controlled by a hydraulic mechanism from the tractor.

Figure 3.4 Photograph showing zero-tillage sowing implement

Source: Travis Lybbert & Daniel Sumner (2010)

Figure 3.5 Zero-till maize cultivation after rice harvesting

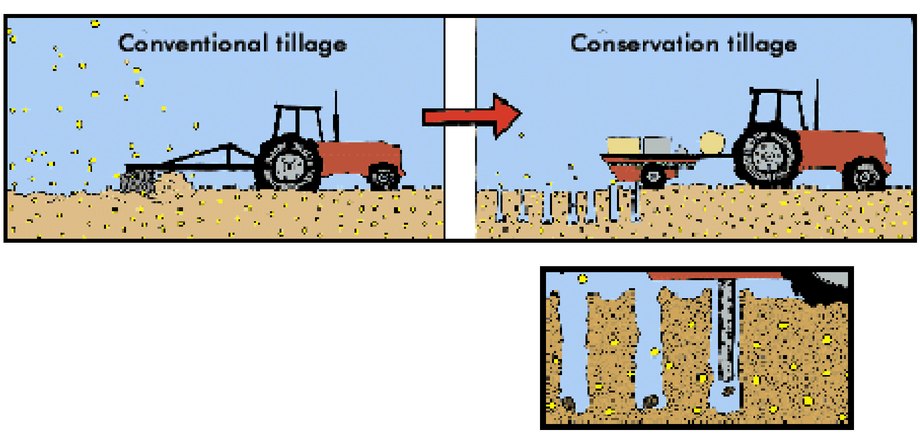
Source: NAIP (ICAR), Annual Report 2009, CRIDA, Hyderabad, India

Features of zero-tillage include:

- Crop residues are distributed evenly and left on the soil surface
- No implements are used (a) to turn the soil over, (b) to cultivate the crops or (c) to incorporate the crop residues into the soil
- Weeds and cover crops are controlled by a pre-planting application of non-pollutant desiccant herbicides
- A specialised planter is used to cut crop residues on the soil surface and insert the seeds and fertilisers into the soil with minimum disturbance. Generally seed sowing is done when soil moisture content is adequate for seed germination but not so high that the large tractor and planter would compact the soil
- Weed control is also accomplished with pre- and post-emergence herbicides
- Crop rotation is fundamental to zero-tillage because it helps to minimise weed, insect, and disease populations that increase when the same crop is grown year after year on the same ground
- Most experiments with zero-tillage have had increased yields, but in the wetter areas, it took many years to see the crop yields stabilise or increase. However, in drier areas where moisture is the major limiting factor, the effects on yield were seen even in the first year (Kimble et al., 2007)
- Zero-tillage causes stratification of soil organic carbon content with relatively higher concentration in the surface and lower in the subsoil compared to plow-based methods of seedbed preparation. The ratio of soil organic carbon content for zero-tillage to plow-till system remains 2.5 for 0-5cm depth, 1.5 for 5-10cm depth and 1.1 for 10-15cm depth (Lal et al., 1998b).

Strip-tillage involves tilling the soil only in narrow strips with the rest of the field left untilled (strip-till) (MDA, 2011).

Figure 3.6 Ridge-till farming system



Source: Why Files (2011)

Ridge-till involves planting seeds in the valleys between carefully molded ridges of soil (Figure 3.6). The previous crop's residue is cleared off ridge-tops into adjacent furrows to make way for the new crop being planted on ridges. Maintaining the ridges is essential and requires modified or specialised equipment (MDA, 2011).

Figure 3.7 Mulch-till farming system

Source: NRCS (Unknown)

Mulch-till (Figure 3.7) is another reduced tillage system in which residue is partially incorporated using chisels, sweeps, field cultivators, or similar farming implements that leaves at least one third of the soil surface covered with crop residue (MDA, 2011).

Each conservation tillage method requires its own type of specialised or modified equipment and adaptations in management.

iii. Advantages and disadvantages

Advantages

1. Increases the ability of soil to store or sequester carbon while simultaneously enriching the soil.
2. Improves soil water infiltration, thereby reducing erosion and water and nitrate runoff.
3. Improves the stabilisation of soil surface to wind erosion and the release of dust and other airborne particulates.
4. Reduces leaching of nutrients due to greater amounts of soil organic matter to provide binding sites.
5. Decreases evaporation and increases soil moisture retention, which can increase yields in drought years (Suddick et al., 2010).
6. Reduces the number of passages of equipment across the field, thereby reducing the cost of fossil fuel and the associated carbon emissions to the atmosphere.

7. Reduces the loss of pesticides and other applied chemicals. This is because higher infiltration rates with more surface residue results in less runoff moisture holding capacity due to higher soil organic matter that results in less leaching.

Disadvantages

1. Adoption of reduced tillage in humid, cool soils would primarily affect the distribution of SOC in the profile, unless carbon inputs were increased (Lal et al., 1998b).

2. Specialised, expensive equipment is required, or much hand labour in the case of very small scale growers.

3. Requires more herbicides and pesticides than standard conventional practices to control weeds and other pests.

4. Due to the large size of the original soil carbon pools, the contribution of conservation tillage can appear to be small, and a significant amount of time is required to detect changes.

5. Sizable amounts of non-CO_2 greenhouse gases (N_2O and CH_4) can be emitted under conservation tillage compared to the amount of carbon stored, so that the benefits of conservation tillage in storing carbon can be outweighed by disadvantages from other GHG emissions.

iv. Economics and mitigation potential

1. Less labour time and cost are required under a reduced tillage system due to fewer tillage trips and cultivation operations for seedbed preparation. The savings range from $2.47/ha to $19.13/ha (Kimble et al., 2007).

2. A large number of studies have estimated the potential fuel cost savings as a result of reducing tillage. They range between $3.58/ha and $28.29/ha (Kimble et al., 2007).

3. Generally, reduced tillage systems have lower machinery repair and maintenance costs due to less use of tillage implements (Kimble et al., 2007).

4. Zero-tillage technology reduces costs of field preparation up to US$70 (Rs. 3200) per hectare (Verma and Singh, 2009), and it also saves time and labour (up to 10-20%). A saving of fuel consumption by 26.5-43.7 litres per hectare (Verma and Singh, 2009) results in reduced fuel cost and reduced carbon emitted to the atmosphere.

5. Zero-tillage can save farmers around 1 million litres of water per hectare (100mm) compared with conventional practices due to the mulch on the soil surface which reduces evapotranspiration (Rehman, 2007).

6. Zero-tillage increases soil carbon from 0.1 to 0.7 metric tonnes $ha^{-1}yr^{-1}$ (Paustion et al., 1995) under sub-tropical conditions.

v. Examples/locations where presently practiced

According to Brown (2008), zero-till is widely used in five countries in particular: 15 million hectares in the United States, 24 million hectares in Brazil, 18 million hectares in Argentina, and 13 million hectares in Canada. Australia has 9 million hectares under zero-till, making a total of 79 million hectares for these five countries with the most hectareage. Worldwide, the use of zero-till is increasing. In 1999 it was used on 45 million hectares and by 2005 it had more than doubled to reach 95 million hectares. Using the latter figures, all other countries than those in the top five accounted for only 17% of the total.

For conservation tillage in general, in the developing world, it has been most successful in Brazil and Argentina (Abrol et al., 2005). In these countries, 45-60% of all agricultural land is said to be managed by conservation agriculture systems. In the 2001-2002 season, conservation agriculture practices are estimated to have been used on more than 9 million hectares in Argentina and 13 million hectares in Brazil. In Africa, the Africa Conservation Tillage Network (ACT) was established in 1998 to promote conservation agriculture as a sustainable means to alleviate poverty, make more effective use of natural and human resources, and reduce environmental degradation (Abrol et al. 2005).

vi. Barriers to dissemination

The largest barrier is the weight and cost of the specialised planters required to penetrate the soil covered with the previous crop. The use of these planters is mainly restricted to richer countries where the fields are relatively large. For growers with small farms in poor countries, the large amount of hand labour required is a barrier.

3.3.2 Biochar – a potential technique for carbon sequestration

i. Technology definition

Crop residues can be carbonised by partial combustion to a highly stable carbon compound known as ‘biochar’ or biomass-derived black carbon. The main quality of biochar is its carbon-rich fine-grained, highly porous structure and increased surface area that makes it an ideal soil amendment for carbon sequestration (Lehmann, 2007; Newsletter, CRIDA, 2010).

ii. Technology description

Biochar can be used to improve agriculture and the environment in several ways, and its stability in soil and superior nutrient retention properties make it an ideal soil amendment to increase crop yield. Biochar applications to soil sequester carbon and reduce emissions of non-CO_2 greenhouse gases. It also provides habitat for micro-organisms, which can increase soil microbial diversity. Biochar also acts as a soil conditioner that enhances plant growth, retains nutrients, and improves soil properties (Lehman and Rondon, 2005; Lehman et al., 2006; Glaser et al., 2002).

A low-cost charring kiln has been developed to produce biochar from cotton, maize, and castor bean stalks on a small scale to study the production of biochar at different loading rates and partial combustion periods (Lehman et al., 2006). When biomass is exposed to moderate temperatures, between about 400 and 500°C (a low-temperature pyrolysis) under complete or partial exclusion of oxygen, biomass undergoes exothermic processes and releases gases, heat and biochar. The gases can be captured and burned to provide energy for the pyrolysis (Czernik and Bridgwater, 2004). Such pyrolysis produces biochar, a carbon-rich, fine-grained, porous substance and solid byproduct, similar in its appearance to charcoal, which, when returned to soil, creates a range of environmental benefits, such as enhanced soil carbon sequestration and soil fertility improvement (Lehmann, 2007). This is a novel approach to sequester carbon in terrestrial ecosystems that creates environmental benefits and produces several useful products in the process of its manufacture.

iii Advantages and disadvantages

Advantages

1. Substantial amounts of carbon can be sequestered in a very stable form.
2. Addition of biochar to soil has been associated with enhanced nutrient use efficiency, water holding capacity, and microbial activity.
3. In the process of manufacturing biochar, both heat and gases can be captured to produce energy carriers such as electricity, hydrogen, or bio-oil. Further, other valuable co-products including wood flavoring and adhesives can also be obtained as a byproduct of biochar (Czernik and Bridgwater, 2004).

Disadvantages

1. Biochar applications sometimes disturb the physical and chemical balances of nutrients in the rhizosphere.
2. Biochar generally helps the growth of undesirable weeds.
3. Biochar manufacturing is relatively expensive.

iv. Economics and mitigation potential

The rice-wheat cropping system in the Indo-Gangetic plains of India produces substantial quantities of crop residues, and if these residues can be pyrolysed, 50% of the carbon in biomass is returned to the soil as biochar This would increase soil fertility and crop yields, while sequestering carbon. In addition, pyrolysis of plant materials with applications of biochar to soil can actually result in a net carbon reduction from the atmosphere of 20%, making it a carbon sequestering process (Lehmann, 2007). It has been projected that about 309 million tonnes of biochar could be produced annually, the application of which might offset about 50% of carbon emissions (292 teragram C yr^{-1}) from fossil fuel (Lal, 2005).

Galinato et al. (2011), has examined the potential economic returns to farmers if they utilise biochar as a substitute for agricultural lime under three price scenarios: (1) $350.74/MT, (2) $114.05/MT, and (3) $87/MT (Table 3.2).

v. Examples/locations where presently practiced

At this time, amending soil with biochar is mostly experimental and not widely practiced.

vi. Barriers to dissemination

Because it is a relatively new approach, considerable research is needed to verify that it works well under the many combinations of soil, climate, and cropping systems. Farmers and energy producers needs to be educated on the C sequestration properties of the biochar as well as its positive impact on soil characters. Lower cost pyrolyzers needs to be structurally designed and their production to be increased to make them easily available to the farmers. Suitable sites for steady and reliable supplies of biomass may not be generally available. Efforts should be made to make biochar application as a viable C sequestration procedure eligible for higher carbon credits.

Table 3.2 Comparison of profits from winter wheat production[a] (US$ per hectare), with and without biochar application

Scenario	Revenue	CO_2 offset value[b]	Total cost	Cost of ag lime[c]	Cost of biocharc	Profit[d]
Without biochar or agricultural lime application	$1,099	–	$1,038	–	–	$61
With ag lime application	$1,741	–	$1,038	$334	–	$369
With biochar application, when offset price is $1/MT CO_2 and the price of biochar (PB) is						
PB1=$350.74/MT	$1,741	$226	$1,038	–	$26,842	-$25,913
PB2=$114.05/MT	$1,741	$226	$1,038	–	$8,728	-$7799
PB3=$87/MT	$1,741	$226	$1,038	–	$6,658	-$5729
With biochar application, when offset price is $31/MT CO_2 and the price of biochar (PB) is						
PB1=$350.74/MT	$1,741	$6,995	$1,038	–	$26,842	-$19,144
PB2=$114.05/MT	$1,741	$6,995	$1,038	–	$8,728	-$1030
PB3=$87/MT	$1,741	$6,995	$1,038	–	$6,658	$1,040

Explanations:
Figures for the revenue, CO_2 offset value, cost and profit are rounded to the nearest whole number.
[a] *The assumed base soil pH is 4.5. Biochar or agricultural lime application is intended to raise the assumed soil pH to 6.*
[b] *CO_2 offset value = 225.66 MT of CO_2 offset per ha from avoided emissions of lime and biochar C sequestration times the price of CO_2 offset ($1 or $31/MT CO_2).*
[c] *Excludes the cost of applying lime or biochar to agricultural land (machinery and labour cost).*
[d] *Profit = Revenue √ CO_2 offset value – Total Cost – Ag Lime Cost – Biochar Cost. All are in US$ per hectare.*
Source: Galinato et. al., 2011

3.4 Irrigation

i. Technology definition

CO_2 emissions can be reduced with effective irrigation by increasing yields and crop residues which can enhance carbon sequestration. (Smith et. al., 2008).

ii Technology description

Irrigation is sufficiently common that little description is required. Suffice as to say that all types of irrigation, such as flood, sprinkler, surface and sub-surface drip, can all enhance crop yields with subsequent increases in crop residues and enhanced carbon sequestration. Eighteen per cent of cropped areas are currently irrigated. If additional areas can be put under irrigation, then additional carbon sequestration can occur. Three prominent technologies in this area are:

- Sprinkler and drip irrigation
- Fog harvesting
- Rainwater harvesting.

These three technologies are covered in Section 4.2 as part of TNA Guidebooks on adaptation (http://tech-action.org/Guidebooks/TNA_Guidebook_AdaptationAgriculture.pdf).

3.5 Management of rice production systems

Rice cultivation is responsible for 10% of GHG emissions from agriculture (Figure 2.2). In developing countries, the share of rice in GHG emissions from agriculture is even higher, e.g., it was 16% in 1994 (UNFCCC). A variety of technologies are presented here for reducing emissions from rice cultivation.

3.5.1 Fertiliser, manure, and straw management mitigation technology

i. Technology definition

Fertiliser and manure management in rice fields are important methane mitigation technologies. The fertiliser management mitigation option includes changes in: fertiliser types; fertiliser nutrient ratios; the rates and timing of applications; and use of nitrification inhibitors to reduce methane emissions by affecting methanogenesis in rice fields.

ii. Technology description

Nitrification inhibitors are known to inhibit methane oxidation (Bronson and Mosier, 1994). Lindau et al. (1993) reported that some nitrification inhibitors can mitigate methane emissions from rice fields as well. They are, therefore, dual-purpose technologies for both N_2O and CH_4 mitigation. In a micro-plot study with dry-seeded, flooded rice, application of nitrification inhibitors, nitrapyrin and wax-coated calcium carbide in particular, retarded methane emission significantly (Keerthisinghe et al., 1993). The decrease in methane emission in plots treated with wax-coated calcium carbide was attributed to the slow release of acetylene, a known inhibitor of methanogenesis (Bronson and Mosier, 1991).

The use of the nitrification inhibitors such as Nimin or placement of urea super-granule in flooded rice fields can be considered as suitable options for mitigation of methane emissions from rice fields without affecting grain yields where flood waters are deep (30cm) but not shallow (5cm) (Table 3.3, Table 3.4). These measures not only improve N-use efficiency in lowland rice cultivation but also reduce methane emissions from deep-flooded rice fields.

Deep (30 cm) flooded conditions

Generally the depth of flood water under low land conditions in India, Bangladesh, and China is close to 30cm. Under rain-fed lowland conditions, where the depth of flood water remained 30 ± 10cm, prilled urea and nitrification inhibitor, Nimin (Neem triterpenes) 1:100 ratio (nitrification inhibitor: urea (w/w)) were applied at an uniform rate of 60kg N/ha (Rath et al., 1999). The prilled urea or the mixture of prilled urea and Nimin was broadcast to the pre-flooded field plants just before transplanting, as practiced by most farmers in rain-fed lowland rice. Urea granules (about 1gm/granule) were placed manually between the rows of rice plants at less than 5cm depth in reduced soil zones just before transplanting.

Shallow (5 cm) flooded conditions

Under shallow irrigated rice field conditions with a flood water depth of 4-6cm, prilled urea; green manure *(Sesbania rostrata)* and prilled urea in combination with green manure were applied to provide 60kg N ha^{-1}

(Rath et al., 1999). Prilled urea was given (broadcasted) just before transplanting. Green manure *(Sesbania rostrata)* was grown in a nearby plot, uprooted, cut into 5-10cm pieces, and incorporated into the soil. In the treatment receiving green manure alone, the manure was applied at a rate to provide 60kg N/ha (dry weight basis). In the treatment receiving prilled urea + green manure, the required quantity of green manure to provide 30kg N/ha was first incorporated in the soil for seven days before transplanting, and prilled urea at 30 kg N/ha was applied on the day of transplanting to provide a total of 60kg N/ha.

Methane emissions were lowest in plots treated with a mixture of prilled urea and Nimin, a nitrification inhibitor which inhibits the autotrophic oxidation of NH_4^+ to NO_2. Lindau et al., (1993) reported that these nitrification inhibitors can significantly mitigate methane emissions from rice fields. In a micro plot study with dry seeded flooded rice, application of nitrification inhibitors, in particular nitrapyrin and wax coated calcium carbide, retarded methane emissions considerably. The decrease in methane emissions in plots treated with wax coated calcium carbide was attributed to a direct result of the slow release of acetylene, a known inhibitor of methanogenesis. Lindau et al., (1993) also reported that nitrification inhibitors such as encapsulated calcium carbide and dicyandiamide and SO inf$_4$ sup^{2-} containing compounds [$(NH_4)_2SO_4$ and Na_2SO_4] had mitigating effects on CH_4 emissions from flooded rice cultivation.

Table 3.3 Methane efflux from deep (30cm) flooded lowland rice plots planted to cv. Gayatri, as influenced by fertiliser management

Treatment	Methane efflux* (mg m^{-2} h^{-1})				
	Days after transplanting (DAT)				
	30	50	70	85	100
Control	8.3[a]	21.0[a]	39.9[a]	90.7[a]	70.6[a]
Prilled urea	5.7[a]	13.1[a]	26.8[a]	67.2[ab]	62.8[a]
Prilled urea + Nimin	5.2[a]	17.7[a]	27.1[a]	48.0[c]	50.0[b]
Urea super-granule	6.1[a]	13.2[a]	30.7[a]	58.4[c]	52.6[b]

** Mean of four replicate observations. In a column, means followed by a common letter are not significantly different at the 5% level by DMRT*
Source: Rath et al., 1999

Table 3.4 Plant biomass production and the cumulative methane efflux from shallow (5cm) irrigated and rain-fed deep (30cm) flooded lowland rice fields planted with cv. Gayatri

Treatment	Plant biomass production (t ha^{-1})		Cummulative methane emission (g m^{-2})
	Straw yield	Grain yield	
Deep (30 cm) flooded field plots			
Control	8.38	5.04	347.5
Prilled urea	8.48	5.52	307.5
Prilled Urea + Nimin	10.07	5.48	255.0
Urea supergranule	10.97	6.22	295.0
Shallow (5cm) field plots			
Control	5.87	4.10	38.8
Prilled urea	7.37	4.90	73.8
Prilled urea + Nimin	8.51	5.60	70.0
Urea supergranule	8.19	5.80	116.3

Source: Rath et al., 1999

The effectiveness of treatments for inhibiting CH_4 production in order from most to least effective are; sodium azide > dicyandiamide (DCD) > pyridine > aminopurine > ammonium thiosulfate > thiourea. Inhibition of CH_4 production in DCD amended soils was related to a high redox potential, low pH, low Fe^{2+}, lower mineral carbon content, and low population of methanogenic bacteria.

Several benzene-ring compounds (Patel et al., 1991) and N-containing compounds (Bollag and Czlonkowski, 1973) are also known to suppress methanogenesis in pure cultures and in soils. Chemicals known to inhibit CH_4 production as well as CH_4 oxidation include: DDT (2, 2-dichlorodiphenyltrichloroethane) (McBride and Wolfe 1971) and the nitrification inhibitor, acetylene (Sprott et al., 1982). Availability of these specific and general inhibitors of microorganisms holds promise for their use with chemical fertilisers or other agrochemicals to mitigate CH_4 emissions from rice soils.

This opens up the possibilities of developing suitable management schedules for regulating methane emissions from flooded rice paddies

The mineral N fertilisers generally reduce NH_4 emissions to varying degrees. In contrast, incorporation of organic sources, for instance green manure and rice straw, in soils can stimulate methane emission (Denier van der Gon and Neue, 1995). However, when compared to burning of the straw, incorporation of rice straw before a wheat crop in Haryana (India) or vegetable crops in the Philippines and China has resulted in significant reductions of methane emissions (Wassmann and Pathak, 2007). Average methane emissions were reduced by approximately 0.4 t CE ha^{-1} compared to straw burning. However, the cost of field operations and the detrimental effects on upland crops make this option costly. Two other options of straw management are: sequestration of straw in the form of construction material and feeding raw straw to animals. These options are being used in China, where high rice production results in a large amounts of rice straw. The prices in China are US$5.98 and US$6.86 per t CE, which is only half of the price in the Philippines and Haryana (India). However, in all these three cases, straw management options have a relatively high reduction potential that collectively accounts for 1.34, 1.87 and 1.36 t CE ha^{-1} in the Philippines, India, and China, respectively. Another option is composting the straw before application, which can reduce CH_4 emissions under continuous flooding by 58% compared to fresh straw under continuous flooding with no significant effect on yield (Wassmann et al., 2000).

iii. Advantages and disadvantages

Advantages

1. Nitrogen fertiliser is needed for rice to reach its potential yield. These N treatments can supply the N while at the same time increasing C sequestration from the increased productivity.
2. Nitrification inhibitors can effectively improve fertiliser use efficiency while providing immediate and large reductions of methane emissions for a long period of time.

Disadvantages

1. To reach its maximum potential, the particular fertilisers and a supply of manure must be available at or just before transplanting time.
2. Nitrification inhibitors are expensive, may leave unacceptable residues in the soil, are only effective in certain soils, and may be lost by volatilisation.

iv. Economics and mitigation potential

Pathak et al. (2011) have presented annual cost, returns and wheat equivalent yield in the recommended N, P and K (NPK) as well as recommended N, P and K plus farmyard manure (NPK+FYM) in various long-term experiments carried out in different states of India using different cropping systems (Table 3.5). Their calculations show, for example, that the rice-wheat rotation in Haryana is far more productive and profitable than the other rotations, which would increase C sequestration at the same time. The addition of farmyard manure increased productivity in two-thirds of the cases, but decreased it in about one-third of the cases, so local adjustments would have to be made for the crop rotation in use.

Table 3.5 Annual cost, return and wheat equivalent yield in the NPK and NPK+FYM treatments in various long-term experiments.

Years[a]	Cropping system[b]	State	NPK treatment				NPK+FYM treatment			
			WEY[c] (Mg/ha)	Cost (US$)	Return (US$)	Benefit/ cost	WEY[c] (Mg/ha)	Cost (US$)	Return (US$)	Benefit/ cost
8	A	Meghalaya	4.6	660	1062	1.6	7.1	694	1634	2.4
28	B	West Bengal	9.2	915	2106	2.3	7.8	951	1783	1.9
20	A	West Bengal	4.1	789	940	1.2	5.0	815	1157	1.4
13	C	West Bengal	6.6	932	1504	1.6	8.1	957	1864	1.9
20	D	West Bengal	3.4	660	783	1.2	3.9	694	889	1.3
12	A	Uttar Pradesh	7.6	679	1738	2.6	7.6	696	1740	2.5
14	A	Uttar Pradesh	7.1	679	1628	2.4	6.2	704	1434	2.0
8	A	Bihar	6.0	679	1385	2.0	7.0	736	1600	2.2
14	A	Uttar Pradesh	7.4	679	1706	2.5	7.2	704	1662	2.4
14	A	Uttarakhand	8.1	679	1851	2.7	7.6	702	1736	2.5
15	A	Punjab	6.5	545	1496	2.8	7.6	562	1749	3.1
10	A	Haryana	7.4	475	1711	3.6	8.2	511	1892	3.7
10	E	Orissa	6.9	581	1592	2.7	7.5	598	1723	2.9

[a] *Duration of the experiment.*
[b] *A Rice-Wheat, B Rice–Wheat–Jute, C Rice–Mustard–Sesame, D Rice–Berseem, E Rice–Rice.*
[c] *Wheat equivalent yield.*
Source: Pathak et al. (2011)

Setyanto et al., (1997) reported that methane emissions from mineral fertilisers such as tablet urea, prilled urea, $(NH_4)_2SO_4$ were affected by the method of application, i.e., those methods that involved incorporation of the fertiliser into the soil had lower methane emissions. The use of ammonium sulfate as N-fertiliser to replace urea also resulted in a 5-25% decrease in CH_4 emissions.

As per Wassmann and Pathak (2007), the relative costs for mitigation through nitrification inhibitor were US$6.4, US$5.5 and US$9.8 per t CO_2e saved in Ilocos Norte province (Philippines), Zhejiang province (China), and Haryana state (India) respectively. In Ilocos Norte and Zhejiang the reduction potential was ca. 0.7t CO_2e/ha whereas this option only yields marginal emission savings (0.13t CO_2e/ha) in Haryana.

If incentives are given in terms of C credits for mitigating global warming potential and subsidies for reducing N loss, farmers will adopt these technologies such as conservation tillage, soil test based N use, and more precise placement of fertilisers on a large scale in South Asia (Ladha et al., 2009).

v. Examples/locations where presently practiced

Some of the states in India practice this technology as indicated in Table 3.5. At this point, nitrification inhibitors are mostly experimental and not widely practiced in rice production.

vi. Barriers to dissemination

Farmers would need to be educated about the proper types and amounts of fertiliser and manure to apply which would vary with location and cropping systems. Greater knowledge about the cost versus effectiveness of nitrification inhibitors compared to other mitigation options are needed for the many possible conditions, and then educating growers about their use is needed.

3.5.2 Water management: mid-season drainage technology

i. Technology definition

Mid-season drainage involves the removal of surface flood water from the rice crop for about seven days towards the end of tillering. The duration of the dry period must be long enough for rice plant to experience visible moisture stress.

ii. Technology description

Mid-season drainage aerates the soil, interfering with anaerobic conditions and thereby interrupting CH_4 production. Mid-season drainage of a rice crop involves withholding flood irrigation water for a period until the rice shows symptoms of stress. It involves ridge and furrow cultivation technology, where some moisture still exists in the soil even after the toe furrow is drained. It is essential to check when the crop has used most of the available water. The degree of soil cracking will depend on the soil type and on the spatial distribution of the rice cultivars. The cumulative evapotranspiration of the crop varies from 77-100mm during the time water is removed depending on crop vigour and soil types. The field is then re-flooded as quickly as possible. It is necessary to cover the soil surface with water so that the plants start recovery. Water depth then can be gradually increased to that required for protection of the developing plant canopy from damaging high temperatures during anthesis.

Mid-season drainage reduces methane emissions of paddy fields, with reductions ranging from 7 to 95% (Table 3.6).

Table 3.6 Reductions in methane emissions due to various water management practices compared to continuous flooding (with organic amendments). WS = wet season, DS = dry season

Mitigation practices	Seasonal emissions (kg ha^{-1})	Relative reduction (%)	Experiment
Mid-season drainage	385	23**	Beijing 1995
	312	44 ns	Hangzhou 1995
	51	43**	Maligaya 1997 DS
	25	7 ns	Maligaya 1997 WS
Alternate flooding/drainage	216	61**	Hangzhou 1995
	207	59**	Beijing 1995
Mid-season drainage and no organic matter	26	95**	Beijing 1995
	239	57**	Hangzhou 1995

*** Statistically significant*
ns Statistically not significant
Source: modified from Wassman et al. (2000)

However, rice is also a significant anthropogenic source of N_2O. Mid-season drainage or reduced water use creates unsaturated soils conditions, which may promote N_2O production. Mid-season drainage is an effective option for mitigating net global warming potential although 15-20% of the benefit gained by decreasing methane emission was offset by increasing N_2O emissions. Little N_2O emission occurred when fields were continuously flooded (Zou et al., 2005). Mid-season drainage, however, caused intense emissions of N_2O, which contributed greatly to the seasonal amount. After the midseason drainage, on the other hand, no recognizable N_2O was observed when the field was frequently waterlogged by the intermittent irrigation. In contrast, large N_2O emissions were observed when the field was moist but not waterlogged by the intermittent irrigation. Thus, N_2O emissions during intermittent irrigation periods depended strongly on whether or not waterlogging was present in the fields. Different water regimes cause changes to N_2O emissions from rice paddies (Zou et al., 2005).

iii. Advantages and disadvantages

Advantages

1. Methane emission reductions associated with mid-season drainage in rice field range from about 7 to 95% (Table 3.6) with little effect on rice grain yield.

2. Draining stimulates root development and accelerates decomposition of organic materials in the soil making more mineralised nitrogen available for plant uptake.

3. Mid-season drainage saves water, which could be used for other purposes.

4. Mid-season drainage inhibits ineffective tillers and improves root activities.

Disadvantages

1. Drainage has the unintended effect of increasing nitrous oxide emissions. However, mid-season drainage can help mitigation of N_2O if a field was frequently water logged by intermittent irrigation.
2. Intermittent drying or drainage of soil is not feasible on terraced rice fields because drying could cause cracking of the soil leading to water losses, or in extreme cases, complete collapse of the terraced construction.
3. Field drainage also induces weeds and thereby reduces the rice grain yield.
4. Mid-season drainage delays the development of crop. Flowering is generally delayed by 3-4 days and harvest/maturity may be delayed by 7-10 days.
5. Mid-season drainage may increase plant height, and this will make the crop more prone to lodging especially when grain yield is high.

iv. Economics and mitigation potential

According to Wassmann and Pathak (2007), mid-season drainage a profitable mitigation technology due to low labour cost and low yield risk. The cost of the technology was around US$20 per t CO_2e saved. Nelson et al., (2009) observed that by one mid-season drying, net revenue dropped less than 5% while GHG emissions dropped by almost 75 million metric tons of CO_2e (approximately 4,000 tonnes CO_2e ha^{-1}).

The technologies of conservation tillage, mid-season drainage and alternate flooding reduced GHG emissions without extra expenditure. Higher net return with these technologies suggests the tremendous potential scope of their adoption by farmers.

Water management is often considered a good strategy to mitigate methane emissions from rice fields. Water saving technologies can reduce methane emissions in a given area of rice land. The saved water will then be used to irrigate more land and new crops in future seasons. Rice is grown on more than 140 million hectares worldwide. Ninety per cent of rice fields are temporarily flooded, providing scope for better water management to reduce water consumption, related energy and electricity consumption, and fertiliser consumptions. These reductions would result in methane mitigation and could then be included for claiming carbon credits.

v. Examples/locations where presently practiced

Mid-season drainage (a common irrigation practice adopted by major rice growing regions of China and Japan) and intermittent irrigation (common in north-west India) greatly reduce methane emissions. Field drying at the mid tillering stage reduced methane emissions by 15-80% compared to continuous flooding without significantly affecting rice yield.

vi. Barriers to dissemination

Farmers fear potential adverse effects on yield both from observing the visible stress and from the delay in harvest time. They need to be educated on the benefits that outweigh the potential losses. A large part of the benefits are towards GHG mitigation, which do not accrue any financial return to the farmers.

3.5.3 Water management: alternate wetting and drying (AWD) technology

i. Technology definition

The International Rice Research Institute (IRRI) in the Philippines has developed a new mitigation technology for methane known as alternate wetting and drying (AWD) (IRRI, 2009). AWD is a water-saving and methane mitigation technology that lowland (paddy) rice farmers can use to reduce their water consumption in irrigated fields. Rice fields using this technology are alternately flooded and dried. The number of days of drying the soil in AWD can vary according to the type of soil and the cultivar from 1 day to more than 10 days.

Figure 3.8 Alternate wetting and drying (AWD) technology for methane mitigation. The water table level has been lowered to the stress stage (15cm depth) so that it is time to flood the field again.

Source: IRRI, 2009.

ii. Technology description

AWD is also called controlled irrigation or intermittent irrigation. The number of days of non-flooded soil can vary from 1 to more than 10 days. A practical way to implement AWD technology is by monitoring the depth of the water table in the field using a simple perforated field water tube. When the water level is 15cm below the surface of the soil, it is time to flood the soil to a depth of around 5cm at the time of flowering, from 1 week before to 1 week after the maximum flowering. The water in the rice field needs to be kept at 5cm depth to avoid any water stress that would result in severe loss in rice grain yield. The threshold of water level at 15cm is called 'safe AWD', as this will not cause any yield decline because the roots of the rice plants will still be able to take up water from the saturated soil and move it to root zone. The field water tube used in this technology will help to measure the water level in the field so that incipient water stress in the rice plants can be anticipated (Fig 3.8). Thus, this alternate wetting and drying technology will not only save water but can greatly reduce emissions of methane. Water-saving technologies such as alternate wetting and drying reduce the amount of time rice fields are flooded and can reduce the production of methane by about 60% (Table 3.6) or even up to 90% (IRRI, 2009).

Starting from about 15 days after transplanting, farmers using AWD stop irrigating until the water table goes 15 cm below the ground level. A 20cm hole is dug in the rice field, and a perforated plastic pipe is installed to monitor the level of the water table after each irrigation. This practice is continued until flowering starts. At that time, it is necessary to keep 2-4cm of standing water from flowering to dough stage.

iii. Advantages and disadvantages

Advantages

1. Large reductions in methane emissions are possible compared to continuous flooding (Table 3.6).
2. It will help the economic use of water during rice cultivation.
3. The drying phase of rhizosphere will help root growth and its sustainability for water transport to rice plants even under low soil moisture conditions.
4. Farmers will be able to know the status of water of their rice growing fields and would be able to balance irrigation with achieving minimum methane emissions.
5. The savings of irrigation water will have impact on environment because of reduced withdrawal of ground water and a reduction in consumption of diesel for water pumps.
6. Protection of water levels of ground water may also reduce arsenic contamination in rice grain and straw.

Disadvantages

1. Occasionally, rice productivity is reduced using AWD technology if moisture stress condition is induced. However, the reduction of yield was less compared to the yield reduction due to the direct moisture stress effect.
2. N_2O emissions are increased.

iv. Economics and mitigation potential

AWD technology can reduce the number of irrigations significantly compared to farmer's practice, thereby lowering irrigation water consumption by 25 per cent, reducing diesel fuel consumption for pumping water by 30 liters per hectare, and producing 500kg more rice grain yield per hectare.

The cost of AWD was found to be US$20 per t CO_2e saved in Haryana, India, whereas in Ilocos Norte, Philippines and Zhejiang, China, this cost became greater than US$45 per t CO_2e saved (Wassmann and Pathak, 2007).

The visible success of AWD has dispelled the concept of yield losses under moisture stress condition in non-flooded rice fields. Adoption of AWD technology reduced water use and methane emissions, and it increased rice productivity. It can reduce methane emissions by 50% as compared to rice produced under continuous flooding.

v. Examples/locations where presently practiced

This technology is very common in countries such as China, India and the Philippines (IRRI, 2002).

vi. Barriers to dissemination

The practice requires that the irrigation systems must accommodate precise control of the timing of the irrigations and the depths of water in the paddies. Therefore, farmers need to be trained in its use. The benefits towards GHG mitigation do not accrue any financial return to the farmers.

3.5.4 Potassium fertiliser application technology

i. Technology definition

Fertilisation with muriate of potash (MOP) can significantly reduce emissions of methane from flooded soils planted with rice.

ii. Technology description

Potassium applications to rice field soils prevent a drop in redox potential and reduce the contents of active reducing substances and Fe^{2+} contents. Potassium amendments also inhibit methanogenic bacteria and stimulate methanotrophic bacterial populations. In addition to producing higher rice biomass (both above and below ground) and grain yield, potassium amendments can effectively reduce CH_4 emission from flooded soil, and this could be developed into an effective mitigation option especially in potassium deficient soils (Babu et al., 2006) (Table 3.7).

iii. Advantages and disadvantages

Advantages

1. Chemical fertilisers mitigate methane emissions more quickly compared to the slow processes of organic amendments.
2. Chemical fertilisers also fulfill the nutrient requirements of crops, thus helping in sustaining productivity while mitigating methane emissions.
3. Chemical fertilisers sometimes improve soil health if used with care to maintain nutrient balance in soil.

Disadvantages

1. The potassium fertiliser must be precisely applied in order to avoid negative effects on field fertility.
2. Chemical fertilisers that are applied in excess to the normal ratio generally change the nutrient composition of the soil besides affecting their physical structure. This affects adversely both methane oxidation and methanogenesis.

Table 3.7 Effect of K fertilisation on methane emissions from a rice field

K level	Biomass ($g\ m^{-2}$)		Cumulative CH_4 ($kg\ ha^{-1}$)	Kg CH_4 Mg^{-1} grain yield
	Above ground	Under ground		
Control (K_0)	1419.21a	189.6 4a	125.34	25.32
K_{30}	1562.90ab	252.23bc	63.81	11.00
K_{60}	1557.65ab	236.32b	82.03	14.34
K_{120}	1671.0b	287.03c	64.43	10.70

*Note: The K levels were 0, 30, 60, and 120. In a column, means followed by a common letter are not significantly different (P<0.05) by Duncan's multiple range test. * Grain yield is a mean of four replicate observations.*
Source: Babu et al. (2006)

iv. Economics and mitigation potential

In potassium deficient soils, applications of potassium fertiliser generally increase yields significantly; the value of the increase in yield exceeds the costs of the fertiliser treatments. Therefore, under these conditions, the reduction in methane emissions is an added benefit whose mitigation cost is effectively zero. In addition, K fertilisation can reduce methane emissions by half (Table 3.7).

v. Examples/locations where presently practiced

It is standard practice to fertilise with additional potassium fertiliser on potassium-deficient paddy soils, at least in more developed countries. In less developed countries, it is not as prevalent due to less awareness about usage, cost and availability of fertiliser inputs.

vii. Barriers to dissemination

As mentioned above, fertiliser costs can be an issue, as well as the need to provide education about their appropriate and precise use.

3.5.5 Agricultural biotechnology as a mitigation option

i. Technology definition

The biotechnology approach for methane mitigation technology involves identification of rice cultivars which emit less methane. It also involves the tailoring of plants which translocate less photosynthate to the roots and more to reproductive parts.

ii. Technology description

To identify the use of rice cultivars with reduced methane emissions, Wang et al., (2000) demonstrated that rice cultivars with small root systems, high root oxidative activity, high harvest index, and productive tillers are likely to produce less methane than other cultivars. They have identified cultivar Zhongzhou (modern japonica) as less methane-emitting compared to Jingyou (japonica hybrid) and Zhonghua (tall japonica). Parashar and Bhattacharya (2002) identified Annada rice variety (commonly used in Andhra Pradesh, a major rice growing region in India) as high yielding, with comparatively low methane emissions. Although low methane-emitting rice cultivars have been identified, methane emission reductions due to cultivar selection have been shown to be less significant than those identified due to modifying water management regimes or adding organic amendments. In addition, the rice yield of low methane-emitting cultivars needs to be evaluated. If the low emitting rice cultivars produce less rice, then more rice would need to be cultivated to meet demand, and as a result, overall methane emissions may increase.

Methane emissions can be reduced by selecting rice cultivars like ‘Luit’ which transport a large portion of their photosynthates to panicle growth and grain development (high harvest index). Varieties like ‘Disang’ should be avoided which use their photosynthates for the development of vegetative parts such as roots, leaf sheaths, culm etc. (low harvest index) that later on contribute to the emission of methane (Das and Baruah, 2008).

Methane emissions can also be reduced by selecting cultivars like ‘Prafulla’ and ‘Gitesh’ which have slower transport of methane due to smaller cross-sectional areas of their medullary cavities. Das and

Barauh, (2008) recorded a positive correlation between methane flux and the size of medullary cavity. They observed that the rice varieties 'Basumuthi' and 'Bogajoha' with larger sizes of medullary cavities had greater cross-sectional areas with higher methane diffusion pathways. Uprety et al., (2011) reported that methane concentration in the medullary cavities of rice plants are about 2,900 times higher than that of ambient air.

Important plant anatomical parameters such as leaf number, tiller number and plant biomass, which regulate the emission of methane, are identified. Modification of these anatomical traits, as well as possible changes in physiological processes, can help rice breeders develop new low methane-emitting genetic lines of rice and developing site-specific technology packages, ascertaining synergies with productivity and accounting for methane emissions.

iii. Advantages and disadvantages

Advantages

1. Farmers have exclusive choice of designing and selecting low methane emitting rice cultivars with high yield without altering the farming operations.

Disadvantages

1. Methane emissions are not normally measured by rice breeders, so this would require additional effort, although if some anatomical traits are sufficiently well correlated with methane emissions, then the extra effort might be minimal.
2. The degree to which emissions can be lowered using this approach may not be large.
3. Varieties with the low-emissions trait may be lower yielding.
4. Considerable time is required to develop new varieties.

iv. Economics and mitigation potential

If varieties can be developed that significantly reduce methane emissions without sacrificing yield, then this approach could be easily implemented, and the potential mitigation reduction could be high.

v. Examples/locations where presently practiced

This approach is just starting, and it has not advanced beyond preliminary experiments.

vi. Barriers to dissemination

The barrier for the biotechnological approach is the positive correlation between methane emission and yield. However, the barriers can be disseminated by selecting correlation breaker varieties.

3.5.6 Methane mitigation using reduced tillage technology

i. Technology definition

Similar to conservation tillage discussed in section 3.3.1 for upland crops, reduced tillage technology for paddy rice involves planting or transplanting directly into the soil with minimal prior tillage in the residues of the preceding crop.

ii. Technology description

Methane emissions at the tilling stage of rice field preparation account for more than 80% of total annual emissions (US EPA, 2008). Wet-land tillage compared to dry-land zero-tillage results in an earlier onset of methanogenesis and, therefore, contributes to greater methane production during the growing season. Zero-tillage results in the lowest methane emissions and is a practice which utilises crop residues in place of compost or mulch. This is often done by hand transplanting, but mechanical rice transplanters that can transplant small seedlings into flooded soil are becoming popular in developed countries like Japan and South Korea (e.g., http://en.wikipedia.org/wiki/Rice_transplanter). Following about a week after an herbicide application, broadcasting of pre-germinated seeds into the flood water is also done (Huang et al., 2012).

iii. Advantages and disadvantages

Advantages

1. Less labour required.
2. Farmers do not require as much time for the preparation of the field for the next crop.
3. As less time is required for field preparation, water can be conserved or alternatively, the plant growth period can be lengthened, allowing the use of longer-season varieties with higher yield potential.
4. Methane mitigation through reduced tillage provides protection of the soil and improves its condition.

Disadvantages

1. Rice cultivation under reduced tillage makes it vulnerable to harmful pests such as the stem borer which survive on the unincorporated residue or stubble.
2. Deploying new machinery for reduced tillage and training to farmers is a long-term endeavor and involves considerable expenditure.
3. Minimum tillage practices require increased use of herbicides and are, therefore, less acceptable.
4. Lower germination with reduced tillage necessitates higher seeding rates and therefore higher seed costs.

iv. Economics and mitigation potential

Tilling causes 80% of methane emission, therefore, reduced tillage improves the mitigation potential of methane. However, the high cost of mechanical transplanters restricts deployment, although use of herbicides and broadcasting of pre-germinated seed greatly improves the economic gains for small farmers.

v. Examples/locations where presently practiced

Zero-till for paddy rice production is not widely practiced.

vi. Barriers to dissemination

As discussed previously for upland crops, zero-till with its more costly machinery has become prevalent only in richer countries whose farmers can afford equipment like mechanical transplanters. However, use of herbicides has enabled broadcasting of pre-germinated seed, but lack of familiarity with reduced tillage techniques is a major constraint for small, poor farmers.

3.5.7 Direct seeding technology

i. Technology definition

Pre-germinated seeds or seedlings are directly planted in soil or broadcast in flooded field under this technology.

ii. Technology description

Direct seeding of pre-germinated rice has resulted in to the reduced methane emissions due to a shorter flooding period and decreased soil disturbance compared to transplanting rice seedlings. Ko and Kang (2000) demonstrated that in South Korea, where the common cultural practice is to transplant 30-day-old seedlings, that significant reductions in methane emissions could be achieved by direct seeding on wet soil (8%) and on dry soil (33%) with no significant effect on yields in either case. Similarly, Metra-Corton et al., (2000) showed that direct seeding resulted in a 16-54% reduction in methane emissions compared to that of transplanted rice seedlings. For six different cases, Wassman et al. (2000) reported a 16-92% reductions in methane emissions with direct seeding compared to transplants, for six rice cultivars, however, a yield reductions of 4-36% was also observed. Subsequently, Huang et al. (2012) found no significant effect on yield over six growing seasons, when a treatment of no-tillage + herbicide + broadcast of pre-germinated seeds on flooded field was compared to conventional tillage + later flooding + transplants, but at the end of the fifth year, increased in organic carbon in the top 5cm of soil was approximately matched by reductions in carbon at deeper depths.

iii. Advantages and disadvantages

Advantages

1. Direct planting is faster and less labour-intensive than transplanting.
2. It reduces land preparation time.

Disadvantages

1. Yields reduced in some instances (e.g., Hossain et al., 2002; Wassman et al., 2000)
2. More lodging of rice plants (De Datta, 1986).

iv. Economics and mitigation potential

According to Wassmann and Pathak (2007), costs of emissions saving through direct seeding was found to be more than US$35 per tCO_2e saved.

Weerakoon et al. (2011) surveyed Sri Lankan farmers and presented the cost of cultivation for direct wet-seeded rice in three scenarios: dry zone irrigated, intermediate zone irrigated and wet zone rain fed (Table 3.8). They found that under irrigated conditions direct seeding was profitable, whereas under rain fed conditions, gross returns were about half than under irrigation, and the direct seeded cropping system was not profitable.

Table 3.8 Economics of wet-seeded rice in Sri Lanka

Region	Total Input Costs (US $/hectare)	Gross Returns (US $/hectare)	Profit (US $/h
Dry zone irrigated	523	865	342
Intermediate zone irrigated	551	731	181
Wet zone rain fed	538	426	-112

Source :Weerakoon et al. (2011).

vi. Examples/locations where presently practiced

Transplanting is the most common method for paddy rice production in Asia, whereas direct seeding is common in Australia and the United States (IRRI, http://www.knowledgebank.irri.org/ericeproduction/II.3_Direct_seeding.htm).

vii. Barriers to dissemination

In Asia, it is traditional to use transplants, so there is resistance to change to direct seeding. However, before habits can change, it must be consistently demonstrated that yields will not be significantly decreased by direct seeding.

3.5.8 Chemical fertiliser amendment technology

i. Technology definition

Emissions of GHGs are affected by the amounts and types of fertilisers applied, so judicious choice of fertiliser application rates and fertiliser types can reduce emissions.

ii. Technology description

The source, mode, and rate of application of mineral fertilisers influence CH_4 production and emission from flooded rice paddies. CH_4 emissions from rice fields were decreased by 18% due to chemical fertiliser amendments (Minami, 1995).

Increases in rice production in south Asia have been attributed to increased nitrogen use (EPA, 1991). Increased nitrogen use may also have an additional benefit of lowering methane emissions. Incorporating urea into soil has been shown to reduce methane emissions (EPA, 1991). However, surface-applied urea resulted in 20% more emissions compared to an unfertilised field. The use of sulfate-based fertiliser has also being linked to methane emission reductions. Metra-Corton et al., (2000) reported that ammonium sulfate reduced methane emissions by 25-36% in rice fields. Applying phospho-gypsum (calcium sulfate dihydride) in combination with urea reduced methane emissions by more than 70%. Application of sulfate-containing fertilisers reduced methane emissions from flooded rice fields (Adhya et al., 1998). In contrast, incorporation of organic sources, for instance green manure and rice straw, in soils stimulates methane emission (Denier van der Gon and Neue, 1995).

Foliar application of nitrogenous fertiliser is another potential mitigation practice for reducing CH_4 emissions from rice soils (Kimura et al., 1992). Adhya et al., (1998) demonstrated a large inhibition of CH_4 production and emission by an application of single superphosphate and a smaller inhibition by an application of rock phosphate. They attributed this inhibitory effect to the high PO_4^{2-} content of the P fertilisers. Nitrification inhibitors (thiourea, sodium thio sulphate and dicyandiamide) inhibited the CH_4 emission activity of flooded rice field soil (Bronson and Mosier 1994).

Rath et al., (1999) found that the subsurface application of urea super granules was marginally effective in reducing the CH_4 flux relative to that in untreated control plots. Bronson and Mosier (1994) reported that N fertilisers inhibit methanotrophic microorganisms in soils. Generally, fertilisers with an ammonical form of N (NH_4^+-N) increase CH_4 emissions.

In principle, three different causes have been suggested for the inhibitory effect of nitrogenous fertilisers, especially NH_4^+-N fertilisers, on CH_4 oxidation which results in increased emissions of CH_4:

1. An immediate inhibition of the methanotrophic enzyme system (Bedard and Knowles, 1989).
2. Secondary inhibition through the NO_2^- production from methanotrophic NH_4^+ oxidation (Megraw and Knowles, 1987).
3. Dynamic alteration of microbial communities of soil (Powlson et al., 1997).

iii. Advantages and disadvantages

Advantages

1. Crop growth and yields are stimulated while emissions are reduced compared to fertilisers without mitigation potential.

Disadvantages

1. Fertilisers with higher mitigation potential may cost more.
2. Economics and mitigation potential

According to Wassmann and Pathak (2007), rice production without organic amendments demonstrated the technical feasibility of reducing emissions at relatively low costs. The addition of phosphogypsum is an efficient strategy to reduce emissions. Its actual costs varied from US$ 1.5 to 2.5 per t CO_2e saved in the Philippines and China, respectively, and the reduction potential is approximately 1 t CO_2e ha^{-1}. However, the relative cost for phosphogypsum application in Haryana (India) was higher (US$5 per t CO_2e saved), and the reduction potential was 0.29t CO_2e ha^{-1}.

iv. Examples/locations where presently practiced

Nitrogen fertiliser is commonly used worldwide. However, deliberate selection of the type of fertilisers to use based on GHG emissions potential is not commonly done.

v. Barriers to dissemination

Site-specific research needs to be done to establish which fertilisers are cost effective with regard to both yield enhancement and GHG mitigation potential. This information also needs to be provided to growers.

3.5.9 Change to methanogenic activity using electron acceptors

i. Technology definition

Addition of electron acceptors, such as ferrihydrite, to paddy fields can stimulate microbial populations that compete with and slow the activity of methanogens, thereby reducing emissions of methane.

ii. Technology description

According to Lueders and Friedrich (2002), methane emissions from paddy fields can be reduced by the addition of electron acceptors to stimulate microbial populations that compete with methanogens. Under ferrihydrite amendment, acetate was consumed efficiently (<60 µM), and a rapid but incomplete inhibition of methanogenesis occurred after three days.

Methanogenesis can be suppressed by the supplementation of alternative electron acceptors such as Fe (III) or sulfate, when electron donors for respiratory processes become limiting (Achtnich et al., 1995). This mitigation strategy is based on the thermodynamic theory which predicts that the energetically more favorable electron acceptor will be utilised first under substrate limiting conditions (Zehnder and Stumm, 1988). Microorganisms which can reduce the energetically more favorable electron acceptor (e.g., nitrate, Fe (III), sulfate) will outcompete those using a less favorable electron acceptor (e.g., CO_2).

Functional shifts can occur within a rice field soil microbial community by supplementing alternative electron acceptors in the form of ferrihydrite and gypsum, and thereby respiratory processes other than methanogenesis are promoted. Under gypsum addition, hydrogen was rapidly consumed to low levels (~0.4 Pa), indicating the presence of a competitive population of hydrogenotrophic sulfate-reducing bacteria (SRB). This was paralleled by a suppressed activity of the hydrogenotrophic RC-I methanogens as indicated by the lowest SSU rRNA quantities. Full inhibition of methanogenesis only became apparent when acetate was depleted to non-permissive thresholds (<5 µM) after 10 days.

The enhanced activity of FRB (Ferric iron reducing bacteria) and SRB (sulfate reducing bacteria) resulted in almost complete inhibition of methanogenesis under conditions of limiting substrate and non-limiting electron acceptor availability. Considering the electron uptake potential of eight electrons per CO_2 and SO_4^{2}, and one electron per Fe^{3+}, only the amount of sulfate reduced perfectly matched the quantity of methane which was not produced under inhibition. FRB also participate in the oxidation of electron donors other than acetate and H_2, thus limits its properties of reduction in methanogenesis. This may be another reason for the lower efficiency of inhibition of methanogenesis under ferrihydrite amendment. It was also demonstrated by Lueders & Friedrich (2002) that although the mitigating agent such as gypsum is added in the soil about one-tenth that of the ferrihydrite amendment, but still the mitigation effects were comparable: 69% and 85% methane reduction, respectively.

iii. Advantages and disadvantages

Advantages

1. Methane emissions can be reduced.

Disadvantages

1. The approach is still at the experimental stage.

iv. Economics and mitigation potential

The economics and mitigation potential have not yet been established.

v. Examples/locations where presently practiced

Addition of alternative electron acceptors is experimental and not yet a field practice.

vi. Barriers to dissemination

More research needs to be done to determine the cost effectiveness of this approach, as well as its consequences on yield and the environment.

3.5.10 Summary and potential of various mitigation technologies to reduce emissions from rice

Optimising irrigation patterns by adding drainage periods in the field, or early mid season drainage reduced CH_4 emissions by 7-80% compared to flooded conditions. Using composted rather than fresh rice straw reduced emissions by 58-63%. Such large reductions and relative ease of implementation suggest that these are the best methane mitigation technologies for farmers (Wassman et al. 2000). The reductions of 16-22% in CH_4 emissions suggest it would also be a good practice if associated yield reductions can be overcome by higher seeding rates or other means. Compared to prilled urea as the sole N source, ammonium sulphate could reduce CH_4 emissions by 10-67%. Methane can be reduced by fallow incorporation (11%) and mulching (11%) of rice straw as well as addition of phosphogypsum (9-73%) in all rice ecosystems. Nitrification inhibitors can repress methane emissions from flooded soils (Bronson and Mosier, 1991). Methane emissions were lowest in plots treated with a mixture of prilled urea and Nimin, a nitrification inhibitor which inhibits the autotrophic oxidation of NH_4^+ to NO_2^- (Sahrawat and Parmar, 1975). Removal of a surface peat layer (soil with a high percentage of organic material) of soil before irrigation reduces the emission of methane significantly. This practice (peat soil technology) has been recently reported by the Russian scientists (Sirin et al. 2010).

Incorporation of rice straw in soil generally increases CH_4 emissions. However, it can be a disposal problem, and compared to burning it, incorporation of rice straw before a wheat crop in Haryana (India) or vegetable crops in the Philippines and China resulted in significant reductions of approximately 0.4 t CE ha^{-1} in methane emissions (Wassmann and Pathak, 2007). However, the field operations and its detrimental effects on upland crops make this option costly. Mixing of straw in construction material or feeding it to animals is additional options.

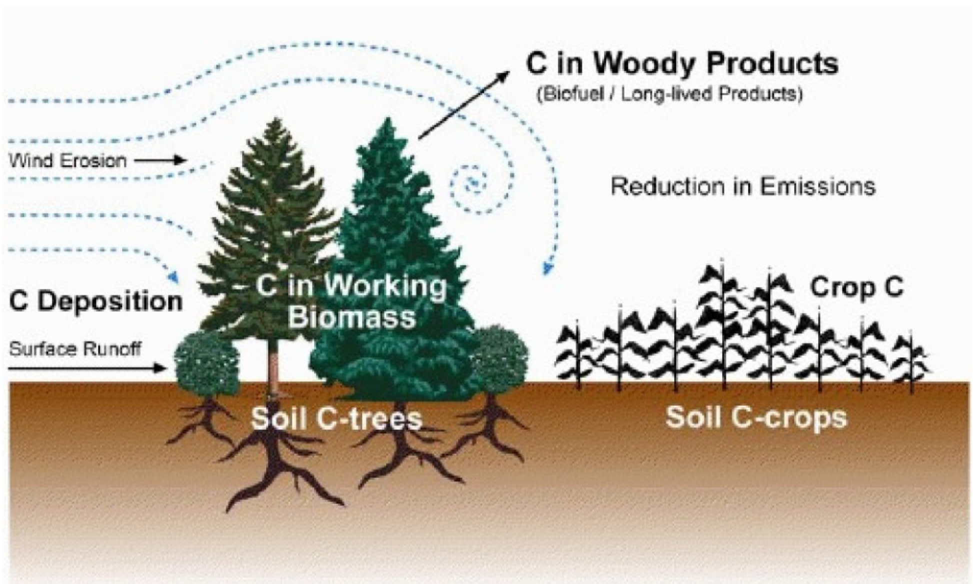
Mitigation potential exists through the use of new rice cultivars with lower emissions, but they have a higher seed cost (Pathak and Wassmann, 2007). The use of such cultivars is only promising under conditions where the existing methane emissions are high, i.e., in China and the Philippines. The challenge for rice research is to develop technologies that increase rice productivity and at the same time reduce GHG emissions.

3.6 Agro-forestry

Improved grazing, cropland management, and agro-forestry offer greater potential for carbon sequestration (UNFCCC, 2008a). Terrestrial sequestration is based on the fact that plants take CO_2 out of the atmosphere through photosynthesis and store it as organic carbon in above-ground biomass (trees and other plants) and in the soil through root growth and the incorporation of organic matter (Figure 3.9).

Thus, the process of carbon loss through land use change can be reversed, at least partially, through improved land use and management practices. In addition to afforestation, changes in agricultural land management, such as the adoption of tillage practices that reduce soil disturbance and incorporate crop residues into the soil, can remove carbon from the atmosphere and store it in the soil as long as those land use and management practices are maintained. Agro-forestry systems will vary by region. However, crops and forests together will elevate the carbon conserving capacity of the agro-ecosystem of a region.

Figure 3.9 Agro-forestry and carbon sequestration



Source: IGUTEK (2011)

i. Technology definition

Agro-forestry, as defined by the World Agro-forestry Centre, is “a dynamic, ecologically based, natural resources management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic, and environmental benefits for land users at all levels”. On the other hand, the Association for Temperate Agro-forestry describes it as “an intensive land management system that optimises the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock” (IGUTEK, 2011).

ii. Technology description

Agro-forestry is one of the important terrestrial carbon sequestration systems. It involves a mixture of trees, agricultural crops, and pastures to exploit the ecological and economic interaction of an agro-ecosystem. Agro-ecosystems play a central role in the global carbon cycle and contain approximately 12% of world terrestrial carbon (Dixon, 1995). Increased C sequestration by agro-forests is an important element of a comprehensive strategy to reduce GHG emissions. According to Richards and Stokes (2004), forest land can fix about 250 million metric tonnes of carbon each year (12% of total CO_2 emissions), crop land can sequester about 4-11% of atmospheric C/yr, and grazing land can sequester about 5% of atmospheric C/yr in the USA. The system of planting trees in strategic locations on farms to compensate for the lost carbon due to cutting of trees for agriculture is called agro-forestry. It has the biggest potential for increasing agricultural carbon sequestration in tropical countries (Youkhana and Idol, 2009).

Figure 3.10 Agroforestry in Burkina Faso with Borassus akeassii, Maize and Faidherbia albida

Source: Marco Schidt http://commons.wikimedia.org/wiki/File:Faidherbia_albida.JPG?uselang=en-gb

Increasing agroforestry may involve practices that increase emissions of GHGs including shifting cultivation, pasture maintenance by burning, paddy cultivation, N fertilisation, and animal production. On the other hand, several studies have shown that including trees in agricultural landscapes often improves the productivity of systems while providing opportunities to create C sinks (Albrecht and Kandj, 2003). The trees play various functions, including shading crops, erosion control, and nutrient cycling. Shading crops and the rhizosphere by the trees would significantly reduce evapotranspiration (ET) of the cropped area although overall ET of crops plus trees may increase. The soil organic carbon content increases at the rate of 50kg ha^{-1} yr^{-1} in the top 10cm depth of an improved forestry plantation of *Cassia siamia* where the high rate of litter fall under Cassia (5 to 7 Mg ha^{-1} yr^{-1}) helps to maintain high soil organic carbon content (Lal et al., 1998b).

Bamboo is an especially effective agro-forest sink of CO_2 with a C sequestration rate as high as 47% amounting to 12-17 t CO_2 per hectare per annum. It also generates 35 per cent more oxygen than other timber species (Aggarwal, 2007). Additionally, bamboo plantations generate income, provide a livelihood for forest dependent people. Degraded lands can be used for plantations of fast growing clones of bamboo species up to an altitude of 1,800m. Bamboo grows much faster than other trees with some species growing up to 150ft in just six weeks, occasionally more than 4ft per day. Bamboo is a pioneering plant that can also grow in over grazed soil using poor agricultural techniques (Aggarwal, 2007).

iii. Advantages and disadvantages

Advantages

1. Trees act as a buffer against storms to prevent crop destruction.
2. Dry land forests apparently manage to sequester carbon by reducing respiration rates and growing rapidly in early spring to take advantage of temperatures most favorable for growth (Rotenberg and Yakir, 2010).
3. Trees send their roots considerably deeper than crops, thereby placing organic matter at deeper depths in the soil where tillage won't accelerate its decomposition and the release of CO_2. In some instances trees have extracted water from deeper depths which has become redistributed at shallower depths with positive effects on the growth of understory plants. In other cases of negative effects have also been reported, so the phenomenon remains controversial (Prieto, et al., 2012). While such redistributions could be ecologically important, allowing some species to survive that would otherwise perish, it is less clear that the amounts of water involved would enable significant increases in the yield of agronomic crops.
4. Leaf litter generates compost and serves as mulch that reduces runoff from rainfall. It also slows soil water loss from evaporation into the atmosphere.
5. Agro-forestry trees also improve land cover in agricultural fields in addition to providing carbon inputs (root biomass, litter and pruning) to the soil. These often reduce soil erosion, which is a crucial process in soil carbon dynamics.
6. Carbon sequestration continues beyond harvest if boles, stems, or branches are processed into durable products that do not decompose and release CO_2.
7. An agro-forestry induced micro-climate improves quality and increases the yield of some crops, although it is difficult to provide an estimation of the yield increase (Ebeling and Yasue, 2008).
8. Increasing soil carbon greatly benefits agricultural productivity and sustainability.
9. Cost of carbon sequestration through agro-forestry appears to be much lower than through other CO_2 mitigating options (Albrecht and Kandji, 2003).

Disadvantages

1. This technology involves a very slow process of marginal carbon conservation.
2. Soil carbon increases only in drier sites and actually decreases in wetter sites of agro-forestry regions (Jackson et al., 2002). As a result, the net carbon balance was marginally positive for the dry sites but negative for the wet sites.
3. Under dry environments, the tree-crop competition for water usually results in low crop yields, which makes this technology unattractive for dryland farmers. Under dryland conditions, trees with their effective rooting systems take more water compared to crops with relatively less effective rooting systems, so the crops are more vulnerable to water stress with consequent lower yields (Schroeder, 1995).
4. Various species of damaging insects, pests, and diseases have been associated with dead or dying trees. These are a major threat to the development of agro-forestry in the tropics.

5. Emissions of other greenhouse gases such as N_2O and CH_4 in the atmosphere may increase, which reduces overall mitigation potential.

iv. Economics and mitigation potential

According to Lal et al. (1998a), a small agro-forestry enterprise following nutrient recapitalisation had a cost of $87 per tonne of carbon sequestered in East African Highlands. Sudha et al. (2007) carried out a cost-benefit analysis of baseline (chili crops – best alternative to agro-forestry and the dominant pre-plantation crop) and agro-forestry (Eucalyptus clones) scenarios in the Khammam district, India. Costs and benefits under both the scenarios can be seen in Table 3.9.

Table 3.9 Costs and benefits under baseline and project scenarios for the period 2006–2035

	Baseline scenario[a]	Project scenario
Present Value (PV) of cost (US$/ha)	297	108
PV of benefit (US$/ha)	423	235
Net Present Value (NPV) of benefit (US$/ha/year)	126	178
Benefit–cost ratio	1.42	2.18

[a] *The best alternative to plantations (chilli crop) has been used for the baseline scenario.*

Note: Present value (PV) is the value on a given date of a payment or series of payments made at other times. While net present value (NPV) of a time series is defined as the sum of the present values of the individual cash flows (both incoming and outgoing) of the same entity.
Source: Sudha et. al., 2007

Takimoto et al. (2008) experimented with two types of agro-forestry systems (live fence and fodder bank) at the Segou region, Mali. The live fence treatment showed US $96 net present value (NPV), 1.53 benefit cost ratio (BCR) and 25.5% internal rate of return (IRR), while fodder bank project showed $159 NPV, 1.67 BCR and 29.5% IRR.

Promotion of agro-forestry can reduce the amount of carbon emitted to the atmosphere annually by 700,000 million tonnes (Rabindra Nath and Sudha, 2004). This can happen due to controlled grazing, fire management, use of fertilisers, improved cultivars, and re-vegetation of reclaimed lands.

According to Rottenberg and Yakir (2010), agro-forestry in semi-arid regions can sequester as much carbon as forests in temperate regions. Every tonne of carbon added to and stored in plants or soils removes 3.6 tonnes of CO_2 from the atmosphere.

v. Examples/locations where presently practiced

Agro-forestry is practiced to some extent all over the world. It is especially used for crops that benefit from the quality improvements associated with shading. However, the other benefits, including carbon sequestration, are being more recognised, and agro-forestry appears to be growing in popularity. One such system with high yield 2-year clonal eucalyptus crop and annual wheat intercrop polyculture developed at Punjab in India is shown in Figure 3.11.

Figure 3.11 Agro-forestry system in Punjab, India

High yield 2 year old **clonal *Eucalyptus*** crop & annual **wheat intercrop** polyculture managed as an agro-forestry system. (Jalandhar, Punjab, India)

Source: GIT forestry 2008

vi. Barriers to dissemination

Light is a limiting factor for crop production in agroforestry system, and most crops yield less when shaded with higher plants. Therefore, unless the several advantages such as quality improvement and carbon sequestration can overcome the yield depression, agro-forestry is not likely to become widespread. In addition, most farmers have the equipment to accommodate only a few similar crops. Adapting to growing both small stature and large stature tree crops presents a greater challenge for them.

4. Livestock Management

Livestock farming was responsible for over one-third of global methane emissions in 2005 and for two-thirds of total agricultural methane emissions (Figure 2.6). While a number of methane mitigation strategies exist, there has been limited experience to date in the implementation of policies to encourage the adoption of such strategies.

Mitigation technologies

Mitigation options for enteric methane fall into three general categories:

1. Improved feeding practices. Feed conversion efficiency can be enhanced by increasing the energy content and digestibility of feedstuffs so that less feed is converted to methane and more is utilised as product output.
2. Use of specific agent and feed additives. Methane emissions can be reduced by substituting concentrates for forage in animal diets, by adding oils or oilseeds to the diet and by improving pasture quality. Natural or synthetic dietary additives (such as growth hormone bovine somatotropin (bST) and antibiotics) can assist animals to use more of the potential energy available in their feed and to suppress methanogenesis.
3. Changes in animal management and breeding (IPCC, 2007a). Increasing animal productivity through breeding and improved management can also reduce methane emitted per unit of output. For example, if meat-producing animals reach slaughter weight at a younger age, lifetime methane emissions can be reduced.

Reductions in total emissions are dependent on a sufficient decrease in total animal numbers. Such a reduction may be an approach to methane mitigation if coupled with improved animal productivity so that milk and meat outputs may still increase to meet consumer demands.

4.1 Improved feeding practices

4.1.1 Reducing enteric CH_4 emission by extension of ammoniated straw and silage

i. Technology definition

Straw ammonisation: a process by which low-value forage such as corn stalks, rice straw, wheat straw, and straw of other crops is ammoniated. Adding liquid ammonia, urea, or ammonium bicarbonate as ammonia sources result in the straw lignin being completely degraded, while the nutrients are enhanced. It is made more easily digestible by rumen microorganisms, which increases the digestibility of forage.

Straw silage: It refers to forage that is prepared through the fermentation of chopped fresh green fodder, forage grass, and all kinds of vines and other materials by lactobacillus in the anaerobic conditions of an airproof silage container (tower or silo).

ii. Technology description

a) Straw ammonisation

The cellulose part of the straw can be digested and utilised by ruminant animals, while the lignin part cannot be digested. The main function of ammonisation is to generate ammonolysis reaction using ammonia and straw, by damaging the ester bonds between lignin and polysaccharide, so that it can contact with digestive enzymes more easily, with an improvement in digestibility of straw. The digestibility and feed intake of ammoniated straw can be increased by approximately 20%, and the content of crude protein in ammoniated straw can be increased by two to three times (Guo, 1996).

Straw ammonisation mainly includes the following procedures:

Selection of raw materials
all kinds of crop straw with good quality, no mould, and a water content of no more than 13%, such as straw, corn stalks, and wheat straw and other agricultural by-products such as rice husk and cotton seed hull can be used as the raw materials for ammonisation.

Ammonia source and its dosage
Ammonia source includes liquid ammonia, urea, and ammonium bicarbonate, of which urea is the most commonly used. The dosages of urea and ammonium bicarbonate are about 3-5% and 8-12%, respectively.

Ammonisation container
Containers can be: a cement ammonisation pond (cellarage), plastic (Figure 4.1), water tank, basin, etc.

Ammonisation method
According to the ammonia source used, the ammonisation method is divided into liquid ammonia treatment method, urea treatment method, ammonia water treatment method, ammonium bicarbonate treatment method, urea and lime treatment method, and so on, of which urea treatment method is promoted with the fastest speed by China and other developing countries (See figure 4.1). The urea treatment method is more flexible, and it can be carried out in stacking, ammonisation furnace, and other ammonisation containers.

Ammonisation time
The length of ammonisation time is closely related to the ambient temperature, which is generally 2-3 weeks in summer, 3-6 weeks in spring and autumn, and 8 weeks or longer in winter. It is stored in a bag at the temperature of 20-30°C for 7-14 days, however it takes only 5-7 days when the atmospheric temperature is higher than 30°C.

The preservation and utilisation of ammoniated straw
Ammoniated straw can be stored in the stack or other containers for more than six months. If the straw is treated with urea or other ammonia sources, the moisture content of straw is relatively high. It should be taken out from the ammonisation container according to the desired feed quantity before feeding, and

then dried in a well-ventilated place for 10-24 hours to let the remaining ammonia volatise. It cannot be fed until there is no ammonia odor to irritate eyes and noses, but it should not be over dried to avoid adverse influence on the ammonisation effect. The ammonisation container should be resealed each time material is taken out.

Figure 4.1 Process of straw ammonisation

Source: http://www.hbav.gov.cn/structure/zwxx/hygz/qszw_679_1.htm

b) Straw silage

To make straw silage, fresh plants are tightly packed in the airtight container, and the sugar contained in the raw materials is converted into organic acids (mainly lactic acid) via the anaerobic fermentation of microorganisms (mainly lactobacillus). When the lactic acid in the silage material reaches a certain concentration (pH lower than 4.2), the activities of other micro-organisms are inhibited and the nutrients in the materials are prevented from being broken down or destroyed by micro-organisms. For this reason the nutrients in the forage can be retained. A great deal of heat is produced during the process of lactic fermentation. When the temperature of silage material rises to 50°C, the activities of lactobacillus stop, and the fermentation is over. As the forage for silage is stored under airtight conditions with no microbial activities, it can remain unchanged for a long time.

Straw silage production mainly includes the following procedures:

Selection of silage materials
Forage for silage can come from a wide variety of sources. Generally gramineous crops, leguminous crops, root tubers, stem tubers, aquatic feeds, and leaves can all be used for silage. Currently the most frequently used material is silage corn (with ears), followed by the snapped corn, sorghum stalks, fresh sweet potato vines, wild grass, and alfalfa.

Timely harvest
Corn stalks are reaped for silage when wax ripe and yellow-green leaves both account for half.the stalk itself. The method of reaping vines before frost and harvesting sweet potatoes after frost should be adopted for the silage of sweet potato vines. Gramineous and leguminous forage grass should be reaped at the heading and full flower stage, respectively, and then they are mixed into the green corn stalks with the proportion of 1:2 for silage.

Regulation of moisture content

If the harvested silage materials have high moisture content, they can be appropriately dried in the field for 2-6 hours after being harvested to reduce the water content to 65%-70%. If the crop straw has low moisture content, they can be added with water or mixed and filled with the newly-cut green materials to adjust the moisture content.

Silage container

It mainly includes silage tower, silage trench, silage pillar, silage bag, or bale silage. Silage sites should be chosen in high and dry places with good drainage and convenience to prepare and access silage (See Figure 4.2).

Chopping

After the forage is transported to the selected place, it must be promptly chopped by the chaff cutter. The chopping length depends on the type of forage. Generally, green corn stalk is chopped to 1.5-2.5cm and fresh sweet potato vine to 2-4cm. The shorter the cutting length is, the tighter it can be compressed when filling, which is more conducive to eliminating air. This will also shorten the period of aerobic activities of microorganisms during the silage process to ensure the formation of an anaerobic environment.

Filling and compaction

The silage materials should be chopped and filled at any time, and compacted well at a depth increment of 20-30cm. If the compaction is interrupted for a long period due to other reasons, the upper layer should be compacted for a second time when it is refilled to prevent the forage from rebounding. The function of compaction is to exhaust air and create the fermentation conditions for anaerobic lactobacillus for silage. The tighter the silage materials are filled, the more thoroughly the air is removed, and the better the quality of silage is. The filling and compaction time should be short, which is generally less than three days.

Sealing and management

The silage material should be stacked 50-60cm higher than the pillar (tank) mouth and covered with a layer of plastic film. Then it is covered and compacted with earth to form the steamed bun appearance. The soil sealing is about 40-50cm thick. There may be cracks that form about one week after storage, and they should be repaired quickly to prevent the leakage of water and gas. Sinking usually stops at the tenth day after storage. Then the cellar can be earthed up so that the pillar top is 30-40cm above the ground. The pillar top should be reworked into the shape of steamed bun, and then finished with plaster. In addition, we should prevent trampling by livestock, control rodents, and resist water filtration.

Figure 4.2 Plastic silage bags

Source: Authors

iii. Advantages and disadvantages

Advantages of straw ammonisation

1. Saving grain, and reducing the dependence of animal husbandry on grain.
2. Improving palatability and the feed intake of forage by livestock.
3. Increasing the digestibility of organic matters in forage by 10%-12% and doubling the content of crude protein.
4. The materials are easily accessed with simple methods.
5. Reducing feeding costs and increasing economic benefits.

Disadvantage of straw ammonisation

1. The ammonia utilisation efficiency is as low as approximately 50%. The surplus ammonia is discharged into the environment after the ammonisation facilities are opened, which causes environmental pollution and threatens the health of animals and human beings.

Advantages of straw silage

1. Minimal loss of nutrients (generally by less than 10%), and effectively maintains the freshness of green feed.
2. Fragrant, soft, and juicy, and therefore, highly palatable to livestock.
3. Expands the application scope of feed sources.
4. Easy to store in large quantities for a long time, as an economical and safe approach for silage.
5. Less restricted by climate and season during storage.
6. The preparation process of silage can kill pathogenic insects, weed seeds, etc.
7. Improved feed digestibility and reduced methane emissions.

Disadvantage of straw silage

1. The straw silage production process needs to be done quickly.
2. The high degree of mechanisation requires a high investment cost.

iv. Economics and mitigation potential

Methane emissions of ruminant animals are produced through the normal fermentation of the feed taken by animals in the digestive tract. The energy loss in the form of methane by ruminant animals accounts for about 2%-15% of the total energy intake (IPCC, 2000). Generally, the amount of methane emissions by a single animal increases with the weight of the animal. Higher level methane emission are observed under greater the feed intake and with lower feed digestibility. Therefore, the improvement of feed quality and animal productivity is an effective approach to reduce methane emissions of ruminant animals (Dong, et al., 2008).

Straw ammonisation and silage can significantly improve the digestibility of forage. One experiment indicated that the feed intake was increased by 53% and 32.8%. In addition, the average daily weight gain was increased by 126% and 97.4%, by feeding the beef cattle with ammoniated straw and silage, respectively, than those by feeding dry corn stalks (Wang, et al., 2008). Dong, et al. (2004) calculated and compared methane emissions of ruminant animals after the straw was treated with ammonisation and silage technology using the IPCC method, The results showed that the methane emissions were reduced by 16%-30% by feeding treated straw than by feeding dry straw. Methane emissions of beef cattle that were fed dry corn stalks and corn stalk silage were 229L/d and 196L/d, respectively, under the conditions of identical energy intake level and the same ratio of fine feed to coarse feed; the methane emissions of the silage were reduced by 14.4% compared to the dry stalk (Fan et al., 2006). Na Renhua et al. (2010) showed that corn straw after treatment of silage technology can help improve feed digestibility and reduce methane production through in vitro digestion test; with identical ratio of fine feed to coarse feed, the methane emission was decreased by 30% by feeding silage than by feeding dry corn. In China, the proportion of silage and ammoniated straw feeding is only 44% at present. Feed saving, improvement of feed conversion efficiency, and reduction in methane emission can all be achieved by constantly increasing the proportion of silage to ammoniated straw. The potential for methane emission reductions is also tremendous.

The investment in straw ammonisation and silage technology is concentrated on expenses in construction of storage facilities, machinery, and covers. More economic benefits are reaped mainly by increasing daily weight gain and milk yield of animals fed with treated forage. Wang et al. (2008) showed through the experiment of beef cattle with corn stalks conducted with different treatment methods that the cost of coarse feed per head of cow increased by 45.5% and 51.6% with the use of ammoniated straw and silage, respectively. However, the corresponding revenues increased by 153% and 68.8% . The research result by Li wenbin et al. (2010) showed that the profit of breeding beef cattle with silage increased by 51.5% more than that with dry corn stalks. It can be concluded that considerable economic benefits are achieved by feeding animals with ammoniated straw and straw silage.

v. Examples/locations where presently practiced

Since 1985, China has promoted straw ammonisation technology, and it has already been applied in various regions throughout the country. According to the 2009 national survey and evaluation report of crop straw resources, the theoretical amount of crop straw resources in China was 820 million tonnes. By demonstrating and promoting feeding ruminant animal with forage, the use of feed straw in China rose from 110 million tonnes in 1992 to 211 million tonnes in 2009. Of this, the amount of straw processed through ammonisation and silage was about 92 million tonnes, accounting for 44% of the total amount of forage (MOA, 2010). Promoting and applying this method, 60 million tonnes of grain feed can be saved annually. Milk production and quality has also been increased effectively, with the costs of feed and labour reduced and the breeding efficiency improved. At the same time, straw contains high levels of energy and nutrients. This technology has great development and utilisation potential with bright prospects for further development (China Husbandry Yearbook, 2006).

vi. Barriers to dissemination

In China, the promotion and application of straw ammonisation and straw silage is mainly on large-scale cattle farms. Households and small farms are the main ruminant producers in China. Since these farms operate on a small scale, with no supporting ammonisation and silage facilities, the farmers cannot fully grasp the key technical points of scientific processing methods for straw ammonisation and silage, so further support on application of this technology is currently restricted.

4.1.2 Reducing enteric CH_4 emission by feed optimisation

i. Technology definition

The methane emissions of ruminant animals are a result of their unique digestive systems. Their stomach can be divided into rumen, reticulum, omasum and abomasum. Lyford (1988) reported that the rumen volume of an adult bovine is about 56.9L, generally occupying the left half of the entire abdominal cavity, and taking up 78% to 85% of the stomach's total volume (Li, 2007). After the feed enters the rumen, carbohydrates (mainly composed of crude fibers) in the feed are converted into carbon dioxide and hydrogen after a series of fermentation and decomposition steps by anaerobic microbes, which are then used by methanogens to generate methane as substrate. The amount of methane emissions is mainly affected by feed type, feed intake, ambient temperature, rate of consumption of feed, the balance of nutrients in the feed for microbial growth and the balance of micro-organisms that develop (bacteria, protozoa and fungi) which largely depend on the chemical composition of diet (Ding, 2007).

The principle of nutrition regulation technology to reduce methane emissions is: to optimise the concentrate to forage ratio in diet by controlling the crude fiber content of the diet or the fermentation process to reduce methane emission while ensuring normal production performance of ruminant animals without increasing production cost. This way, the rumen fermentation pattern or rumen microbial populations (such as methanogens, ciliates) and pH characteristics are altered to reduce methane emissions. At present, nutritional regulation is one of the most feasible approaches to reduce methane emissions and much research is being carried out to reduce methane emissions by changing the concentrate to forage ratio in diet.

ii. Technology description

The diet of ruminant animals (mainly cattle, sheep, buffalo, camels, etc.) is primarily made up of forage and concentrate. Forage mainly refers to grass or hay with crude fiber content over 18%, most commonly including corn straw, alfalfa, and silage. Forage provides the animals with crude fiber, which plays an essential role in maintaining normal rumen fermentation, providing body energy and sustaining normal microbial flora, as well as promoting the synthesis of milk fat by the milk cow. At the same time, concentrates mainly supply the animals with protein, fat, minerals, and vitamins. Therefore both forage and concentrate are necessary for ruminant animals. Moreover, the ratio of concentrate to forage in diet will substantially affect the ruminant animal's growth performance, rumen's fermentation function, methane emission, and health condition.

Generally, when the proportion of forage feed is larger, the cellulolytic bacteria proliferate, and acetic acid fermentation is the dominant fermentation type in rumen with a large amount of hydrogen produced. As a consequence, partial pressure of hydrogen increases, which stimulates the massive proliferation of methanogens, with an increase in methane emissions. When soluble carbohydrates or starch are fed, i.e., the proportion of dietary concentrate increases, then rumen pH values decline, thereby inhibiting the propagation of methanogens and ciliates, while increasing propionic acid production (Demeyer and Henderickx, 1967). Since propionic acid fermentation consumes hydrogen, which reduces the raw materials needed for methane formation, methane emissions are lowered. An appropriate increase of the proportion of concentrate in the ruminant animals' diet can increase the proportion of propionic acid in rumen, while reducing the content of acetic acid, and improving feed utilisation efficiency and production performance of animals. Propionic acid is mainly converted into body composition by the liver, and then it provides energy for breeding, growth, milk production, and meat production. Methane emissions and propionic acid production are negatively correlated (Church, 1979). Hence, controlling the concentrate and forage ration can not only reduce the amount of methane emitted, but also improves the production performance of ruminant animals.

iii. Advantages and disadvantages

The production of methane during rumen fermentation is a necessary byproduct, which can not be completely eliminated. The control of concentrate to forage ratio in ruminant animals' daily diet to reduce methane emissions has certain advantages and disadvantages.

Advantages of straw ammonisation

1. There is no additional cost of methane reduction.
2. Methane reduction and improvement of productivity could be consistently realised.
3. The technology could be applied in any animal production system by using feed optimisation.

Disadvantages of straw ammonisation

1. Improper ratio of concentrate to forage feed may result in abnormal rumen fermentation and increase of CH_4 production.
2. The technician is required to produce the best possible results of feed optimisation.
3. Monitoring the characteristics of the forage and concentrate is required.

iv. Economics and mitigation potential

There are considerable potentials to improve animal production performance such as yield per unit, and to reduce methane emissions by using feed optimisation techniques. Many experimental tests have shown that with the improvement of feeding technology, methane emissions per unit of livestock is reduced (You, 2007; Na, 2010).

It is reported that when daily milk production increases from 25kg to 30kg, then the methane emissions per unit milk product decreases by 10% (Yang, 2000). When the average daily gain increases from 0.65kg to 0.8kg, the methane emitted per unit of weight gain can be reduced by 14%. According to the Na (2010) studies, when milk yield of milk cow increases from 11kg to 13kg, the methane emission per unit of milk product decreases by around 39%.

According to the Shiyo report (Shiyo, 2000), the regression relationship between 4% fat corrected milk (FCM), yield (Y) and grain supply (X) has the equation $Y=1.962X + 3.492$. This indicates that with every additional 1kg of grain feed intake, the milk production could increase by 2kg. Moreover, the regression relationship between methane production per unit of FCM and grain supply was expressed as $Y=-2.546X + 46.442$. This also indicates that with every additional 1kg of cereal feed intake, the methane emission per kg of FCM can be reduced by about 2.5 litres.

For analysis of economic benefits brought by reducing methane emissions of ruminant animals through changing the concentrate to forage ratio, the case study of Na (2010) in a small (30 cows) dairy farm is considered. In this study, 12 healthy Chinese Holstein dairy cows with average weight of 525 ± 40kg were selected as test animals. The average age of test animals was 3.5 years old. Animal groups were randomly allocated to three different rations (Rations A, B and C) featuring different forage types and concentrate to forage ratios (CTFR). On dry matter (DM) basis, Rations A and B had 40:60 CTFR whereas Ration C had 60:40 CTFR. The forage ingredient for Ration A was corn stalk. The forage component for rations B and C was corn silage. The animals in each dietary regimen were fed fixed amounts daily, consisting of 5.33±0.05kg, 4.83±0.26kg, and 7.63±0.29kg head^{-1} d^{-1} of concentrate and 8.10±0.07kg, 27.75±0.07kg, and 18.58±0.28kg head^{-1} d^{-1} of forage for rations A, B and C respectively. The concentrate was delivered twice daily and the forage was delivered three times daily. The cows had free access to drinking water at will, and they were milked twice a day. The results show that the methane outputs of Ration A, B and C were 353, 283, 263 kg head^{-1}d^{-1}, respectively. Ration A differed significantly from Ration B and C (p ▪ 0.05), while rations B and C show no significant difference (p ▪ 0.05). The milk yield of the three feed regimes are 10.73,12.56,12.97 kg head^{-1}d^{-1}, respectively. The milk production of rations B and C increased by 17.05% and 20.88%, respectively, compared to Ration A. Ration C increased by 3.26% compared to Ration B, without anomalies detected in rumen fermentation. Analysis of specific economic benefits is presented in Table 4.1.

Table 4.1 Cost analysis of methane emission reduction of cows fed with the three diets

Items	Treatment			
	Ration A	Ration B	Ration C	Notes
Amount of concentrate (kg d^{-1} head^{-1})	5.33	4.83	7.63	
Price of concentrate (RMB/kg)	2	2	2	
Cost of concentrate (RMB d^{-1} head^{-1})	10.66	9.66	15.26	
Amount of forage (kg d^{-1} head^{-1})	8.10	27.75	18.58	
Price of forage (RMB/kg)	0.6	0.9	0.9	
Cost of forage (RMB d^{-1} head^{-1})	4.86	24.98	16.72	
Other cost (RMB d^{-1} head^{-1})	20	10	10	Labor wage and water and electricity cost
Cost per head (RMB/head)	35.52	44.64	41.98	
Milk production (kg/d^{-1} head^{-1})	10.73	12.56	12.97	
Price of milk (RMB/kg)	4	4	4	
Benefit from milk (RMB/d)	42.92	50.24	51.88	
Profit per head (RMB/d)	7.4	5.6	9.9	
CH_4 emissions (L d^{-1} head^{-1})	353	283	263	
CH_4 emissions per milk production (L/kg)	32.90	22.53	20.28	

Source: Na, 2010

From Table 4.1, since there is a need for corn stalk chopping in Ration A, the labour cost of this diet is higher than the other two rations. The daily profit per cow per day of Ration C increases by 4.3 yuan compared to Ration B, with a reduction of methane emissions by 7%. The methane production for each kg of milk decreases with the increase of the proportion of dietary concentrate.

v. Examples/locations where presently practiced

There are several studies showing that changing concentrate to forage ratio to reduce methane emissions of ruminant animals is feasible technically. Fan (2006) has shown that the rank of methane output of beef cattle fed different concentrate to forage ratios on methane output of intestines of beef cattle is 0:100>25:75>50:50. Han et al. (1997) tested the methane emissions of bullocks fed diets with concentrate to forage ratio of 0:100, 25:75, 50:50, 75:25. The methane emissions of bullock was 208L/d, 201 L/d, 194 L/d, and 171 L/d, respectively. Similarly Sun et al. (2008) found similar results of methane output of Holstein cows with diets with different concentrate to forage ratios varied significantly. The methane emissions from cattle fed diets with different concentrate to forage ratios were 70: 30>60: 40>20: 80>30: 70>40: 60>50: 50. These results from Sun et al. (2008) suggest that the optimum concentrate percentage in diets is 40% to 50%, and that if the concentrate percentage becomes greater than 60%, the concentration of propionic acid in the rumen rises but such diets likely cause dyspepsia syndrome However, if the concentrate percentage becomes lower than 30%, the concentration of acetic acid in the rumen increases, which leads to higher methane emissions.

vi. Barriers to dissemination

There are constraints in promoting methane emission reductions by changing the proportion of fine feed to forage feed in daily diet. First, the concentrate to forage ratio in daily diet refers to the proportion of the dry matter contained, and the actual feed intake of animals may not be consistent with the calculated proportion. Secondly, corn stalks are not palatable to animals, so the ammonia treatment or silage process is necessary, and there should be a process of adoption. Thirdly, methane emissions may increase if the proportion of dietary concentrate is out of suitable range (40% to 50%) (Sun et al., 2008). Furthermore, farm management sees no direct benefits in methane reduction. There is therefore a need to explore new financial mechanisms under climate conventions to encourage the application of feed optimisation for reducing the methane emissions.

4.2 Long term structural and management changes and animal breeding

4.2.1 Development of genetically modified rumen bacteria that produce less methane

i. Technology definition

To optimise the synthetic or metabolic pathway of micro-organisms related to methane synthesis by employing modern molecular biotechnology to obtain genetically modified microorganisms. Then he genetically modified micro-organisms are introduced back into the rumen ecosystem to establish a relatively stable microbiota that can replace or compete with the original pathway of methanogenesis, to reduce methane synthesis in the rumen.

ii. Technology description

Most methane emissions from ruminants are synthesised by methanogenic archaea in rumen. The methanogens mainly use carbon dioxide and hydrogen to synthesise methane. Protozoa and other microbes involved in cellulose-degrading or glucose-metabolic pathways provide carbon dioxide and hydrogen, and other mono carbon compounds necessary for methanogens. Therefore, the process of methane synthesis is implicated with complex symbiotic relationships of ruminal microbes and improper manipulation may break metabolic homeostasis in rumen. However, the development of modern molecular biotechnology and gene engineering technology provides a great opportunity for the improvement of rumen microbiota to bring about optimal reduction in methane emissions.

With respect to the process of feed degradation and methane synthesis, there are some possible links in realising the methane-mitigating goal with the application of developing genetically modified micro-organisms. First, digestibility is one of the important factors influencing methane synthesis in the rumen. Cellulose, semi-cellulose and lignin contents are high in forage and they are difficult to degrade completely, and therefore they are positively associated with methane emissions. Based on mutagenic breeding methods and transgenic technology, high-efficiency exogenous genes could be introduced into microbial genomes, and then express high-efficiency degrading enzymes in rumen. As a consequence, the cellulose decomposition bacteria are strengthened to better degrade refractory carbon structure in forage, thus resulting in high efficient feed digestibility and energy use. Since more energy is obtained from an equal quantity of feed and animal production is improved, methane emission per unit of product could be reduced.

The reaction of carbon dioxide and hydrogen to form methane is a key step to decrease the hydrogen partial pressure in the rumen, so finding new hydrogen competitor or methane oxidative pathway could reduce methane production. For example, acetogens can also utilise hydrogen as substrate and have been found to be dominant in kangaroos' rumen. If acetogens that can out compete methanogens in hydrogen intake are selected by genetically modified technology and then form stable microflora in rumen, less methane would be produced from ruminants. Methane oxidation may be another possible solution to solve this problem. Methanotrophic bacteria can oxidize methane to carbon dioxide, and they inhabit widely diverse environments. Through genetic modification, bacteria with high methane-oxidative efficiency can be obtained. Once these bacteria are introduced into rumen and form stable microflora, methane will be used to form carbon dioxide without affecting ruminal fermentation.

iii. Advantages and disadvantages

Advantages

1. Improving digestibility, fermentation, energy utilisation efficiency of feed, and animal performance.
2. Methanogens and other micro-organisms form symbiotic relationships and benefit mutually (Thiele et al, 1988; Joblin et al, 1989), so introducing genetically modified microbes favours the homeostasis of microbial diversity and complexity of symbiotic relationship in rumen, avoiding side effects on rumen ecosystems.
3. Many approaches for reducing methane emissions have been tried, including research on feed preparation, vaccines, and additives (Han et al, 1997; Beauchemin et al, 2005; Yvette et al, 2009; Wright et al, 2004; Machmüller et al, 2001; Animut et al, 2007). However, these approaches lack sustainability and heritability. In comparison, once the genetically modified microbes survive in rumen, they will be carried by ruminants as long as they live and can be inherited by their offspring, without any extra costs to maintain methane mitigation.
4. Although chemical inhibitors or antibiotics can reduce methane synthesis, the long-term adoption may cause residues of organic matter or antibiotics in meat and milk and bad health conditions of animals. However, genetic modification of micro-organisms in rumen can eliminate all the adverse effects mentioned above and achieve methane emission reduction on the premise that food security is guaranteed.

Disadvantages

In spite of the advantages of genetic modification of rumen micro-organisms in reducing methane emissions in rumen, several problems and technical barriers remain.

1. Most of the microorganisms in rumen are hard to isolate or culture. Mutagenic screening and genetic modification require more information on the mechanism and ecological functions of microbial metabolism and are still at a trial stage.
2. Relevant reports indicate that technical barriers exist for introducing genetically modified strains into the rumen ecosystem, as well as for establishing a stable microflora and a stable symbiotic relationship (Wallace et al., 1994; Cotta et al., 1997; McSweeney et al., 1994).

iv. Economics and mitigation potential

Genetic modification of rumen organisms is a systems engineering problem involving nutrition, molecular biology, physiology, genetics, microbiology, biological chemistry, and so on. Though this field has just started, the perspective of methane mitigation in ruminants has been highlighted by this technology. Since the research on genetic modification of rumen micro-organisms is based on the principles of genetics, this modification is, in theory, supposed to be inheritable, which is the greatest advantage of this technology. Once this technology can be put into actual application, ruminants will not only reduce methane emissions but also be capable of passing their ability in methane reduction to their offspring, permanently. Compared to others, this technology could change the rumen methane problem once and for all, in theory. If this is so, it would remarkably reduce production costs and achieve considerable economic benefits because no more extra expense would be required to maintain long-term methane mitigation.

v. Examples/locations where presently practiced

Methane emissions of ruminants has been a focus of wide concern nowadays. It has been reported that the total methane emissions of cattle and sheep in the world is equivalent to 140.8 × 106 tonnes of CO_2e, with a large impact on the atmospheric environment (Environmental Protection Agency, 2010). The research on methane reduction of ruminants has now become a frontier science. Compared with other approaches, the genetic modification of rumen organisms started later, and it still has problems to be solved. Over the past ten years, researchers have been focused on searching for appropriate modification carriers and metabolic regulation of micro-organisms. So far, several research findings have shown good application prospects. Several studies have been conducted on the classification and metabolism of acetogens and several types of specific acetogens have been found (Shink et al., 1994; Breznak et al., 1994 and 1995; Drake et al., 2002). These acetogens can compete with methanogens for hydrogen (Joblin et al., 1996 and 1999). Experimental results indicate that by introducing acetogens into aseptic sheep rumen, comparatively satisfactory experimental results can be achieved. On the premise that food intake and volatile fatty acids (VFAs) synthesis of sheep is unaffected, it has been proven that acetogens can replace methanogens as metabolic receptors of hydrogen in the rumen, with potential for reducing methane emissions (Fonty et al, 2007). When other rumen micro-organisms, such as *Veillonella parvula* and *Megasphaera elsdenii,* are selected for genetic modification, their fermentation products are more likely to be propionic acid. The ratio of acetic acid to propionic acid in VFAs is thus significantly lowered (Yang et al., 2007; Sun et al., 2010), which indicates fewer methane emissions. E. coli has also been selected in some other studies of genetic modification in an attempt to mitigate methane emissions by promoting nitrous reduction (Sar et al., 2005a and 2005b and 2005c). On the whole, the genetic engineering of rumen micro-organisms to achieve methane reduction in ruminants is still at the initial stage. Currently, the emphasis is still being placed on basic research, and there is a long way to go to realise actual application.

vi. Barriers to dissemination

At present, the researchers worldwide engaging in methane emission mitigation of ruminants mainly focus on nutrition regulation, optimisation of feed formula and application of additives. In comparison, the methane mitigation in ruminants using genetic modification is only just now being investigated. This technology, marked by complexity of operation, excessively high up-front investment and long period of study, requires multi-disciplinary cooperation. All these factors together restrict the development of genetic modification of micro-organisms to reduce methane emissions.

5. Manure and Bio-solid Management

5.1 Improved storage and handling

5.1.1 Covering manure storage facilities to reduce GHG emissions

i. Technology definition

Manure coverage is the practice of covering the surface of manure with materials of certain thickness instead of the traditional method of piling up manure to be exposed to air. Manure coverage changes the amount of manure surface in contact with air. Due to some reactions, i.e., a series of physical, biological and chemical reactions, it can reduce GHG emissions.

ii. Technology description

By covering manure with materials of a certain thickness (such as plastic sheeting, organic matter and expanded clay), the manure's surface in contact with air is altered. This method can reduce the emission of GHGs and store nutrients in the manure.

Generally, covers are classified as impermeable or permeable. Impermeable covers do not allow gases coming from the manure to be emitted to the atmosphere. Permeable covers permit the transmission of some gases. Permeable covers usually include straw, geotextile, expanded clay, corn stalk, etc. The impermeable covers include floating plastic, suspended plastic, concrete, etc. Impermeable covers offer the opportunity to collect and use methane gas for fuel and power generation. A covered lagoon is a good example of a manure storage basin with an impermeable cover. It's a large anaerobic lagoon, which can stably digest manure, reduce odour, and supply nutrient-rich effluent for application on fields and crops. Pathogens and weed seeds are reduced and biogas can be produced for use on the farm.

The effects on GHG emissions reduction vary for different covering materials and techniques. The principles of emission reduction are also different. For instance, impermeable materials such as plastic sheets can isolate manure from the external environment, thereby preventing loss of volatilised gases into the air. An anaerobic environment is also created within the manure. Since the first stage of N_2O generation is the aerobic nitrification reaction of ammonia nitrogen, the adoption of manure covering technology prevents exposure to oxygen. By stopping this first reaction, N_2O emissions are lowered.

Factors, such as temperature, moisture content, and pH of the manure also have a significant impact on the mitigation effect of storage covering technologies. The moisture content of manure greatly affects the generation of CH_4. When the moisture content is high, anaerobic fermentation dominates, with greater production of CH_4 and less production of CO_2. When the moisture content is low, aerobic fermentation dominates, with CO_2 generated as the major fermentative products and basically no CH_4 is generated. The moisture content also affects nitrification and denitrification of manure. Neither extremely good nor poor permeability is conducive to the generation of N_2O in nitrification or de-nitrification processes. Therefore, in both cases of very low moisture content of animal manure and long-time submergence under water, N_2O emissions are very low. However, the dry-wet alternation of manure promotes the generation and emission of N_2O. Suitable pH environments vary for different microorganisms. In this sense, adjusting the pH value of liquid manure to affect the process of biochemical reaction and then lower the GHG emissions is another approach for emission mitigation.

iii. Advantages and disadvantages

Advantages of covering manure

1. The advantages are low cost, simplicity of operation, and ease of implementation.

2. Commonly used materials such as straws, expanded clay, thin films, etc. are low-cost and readily available. This makes it possible for animal farms to change the storing method of manure easily and conveniently.

Disadvantages of covering manure

1. Covering and compacting manure creates an anaerobic environment within manure, which increases methane emissions although the generation of nitrous oxide is inhibited, i.e., a case of swapping one form of pollutant for another (Monteny, 2006).

2. The potential for emission reductions is greatly affected by manure properties, temperature, and other factors for which there is currently limited understanding. Different covering materials should be selected for solid and liquid manure. Many experimental results indicate that covering liquid manure with organic matter, including straw, will greatly increase the amount of methane emissions, generating more methane in anaerobic fermentation of straws instead of reducing emissions. To adapt to the differences in climatic types (temperature, precipitation), manure properties and covering materials, experiments should be conducted to analyse and test the potentials of various combinations of these parameters to reduce greenhouse gas emissions.

iv. Economics and mitigation potential

Chadwick (2005) conducted an experiment to test the impact of compaction and covering methods of cattle manure on GHG emissions. Experimental results showed that compaction and covering with plastic film can reduce emissions of ammonia and N_2O from manure by 90% and 30%, respectively. However, compaction and coverage created an anaerobic environment inside the manure, increasing the amount of methane emissions (Chadwick, 2005).

Additionally, by decreasing the surface area of the manure heap and by timely transport of manure to an enclosed storage chamber, the amount of NH_3 and CH_4 emissions can be reduced effectively (Weiske et al., 2006).

Generally, reducing ammonia volatilisation and preventing odour can be achieved by covering liquid manure with straw, which may also increase methane emissions. Berg (2006) achieved GHG emission reductions by combining straw coverage with an acidising technique. Experimental results showed that methane emissions were reduced by 40% by adjusting the pH value of liquid manure to less than 6 with lactic acid and integrated covering with straws.

A hard crust is naturally formed during the storage of manure, which prevents ammonia produced by manure from escaping. An experiment by Smith et al. (2007) showed that ammonia emissions from manure with naturally formed crust can be reduced by over 60% compared to the emissions from manure without the crust. Besides slowing ammonia loss, the hard crust on manure slurry also reduces methane emissions. Sφren (2006) proved that methane-oxidising bacteria exist in the hard crust of manure slurry, which oxidise methane into CO_2, thus achieving an emission reduction because methane is a more potent greenhouse gas than CO_2. When the concentration of methane is 500-50,000 ppmv, the amount of emission reduction by methane-oxidising bacteria is -1~-4.5 $gCH_4\ m^{-2}d^{-1}$) (Sφren, 2006).

Permeable covers are less expensive than impermeable covers, but they do not last as long and are not as effective at reducing the emissions of odours and gases. However they can provide reductions in odour, ammonia and hydrogen sulfide emissions from manure storage facilities. A wide variety of organic and manmade materials have been utilised to construct permeable covers with variable results. Costs range from \$1.10 to \$18.80 per m^2 installed. Straw shown in Figure 5.1 is the least expensive permeable cover material with an approximate cost of \$1.10 per m^2 installed. The installed costs of longer lasting materials such as lightweight expanded clay aggregate (LECA) presented in Figure 5.2 can exceed US \$10.80 per m^2 installed (Burns, 2008). Impermeable covers may cost US \$21.50 per m^2 installed (Powers, 2006).

If impermeable covering materials are adopted, then the mass transfer between manure with the outside is cut off. Meanwhile, an anaerobic environment is created within the manure, promoting the generation of methane. Then gas collection devices can be installed to capture methane for cooking and heating purposes. In addition, the use of covering materials can effectively prevent the emission of nitrogen-containing gases such as ammonia, thereby retaining nutrients in the manure. After a period of storage, it can be applied onto farmland as organic fertiliser.

v. Locations where presently practiced

So far, research has been carried out in covering manure storage technology yielding results relating to covering materials, external temperature, and composition of manure (Berg et al., 2006). In China, several experiments have been performed, which utilised straw and expanded clay to cover beef manure (Lu, 2007) and swine waste water (Li, 2008). In practice, however, due to a limited area of farms, and a lack of storage facilities for manure, the manure is discharged directly, digested by biogas plants, or applied to farmland.

In developed countries, the regulations concerning the management of animal manure and odour emissions are very rigid. With complete storing facilities, manure storage, and a large number of storage pools in animal farms, the loss of manure nutrients is prevented and odour emissions are controlled by extensive application of covering measures.

vi. Barriers to dissemination

Although, impermeable materials such as concretes and thin films are relatively stable and long-lasting, high initial investment expenses are a barrier to their widespread adoption. On the other hand, although permeable covering materials such as straw are inexpensive, they are not stable and have short service lives which makes their use seem futile and therefore also a barrier to adoption. Moreover, some covering materials, including straw, decompose when they come in contact with manure slurry, and then they themselves become an emission source.

Figure 5.1 A permeable straw cover

Source: Burn R. 2008

Figure 5.2 Lightweight expanded clay aggregate (LECA) cover on a concrete manure storage tank

Source: Burn R. 2008

5.1.2 Biocovers of landfills

i. Technology definition

An inexpensive way to reduce greenhouse-active methane emissions from existing Municipal Solid Waste (MSW) landfills is to exploit the natural process of microbial methane oxidation through improved landfill cover design. Landfill top covers, which optimise environmental conditions for methanotrophic bacteria and enhance biotic methane consumption, are often called 'biocovers' and function as vast bio-filters. Biocovers are typically spread over an entire landfill area. They are often waste materials, such as diverse composts, mechanically-biologically treated waste, dewatered sewage sludge or yard waste.

Methane oxidation in compost materials shows high oxidation capacity. Manipulation of landfill covers to maximise their oxidation capacity provides a promising complementary strategy for controlling methane emissions.

ii. Technology description

Simple but well-engineered biocovers can mitigate methane emissions from landfills. Mature composts show higher microbial methane consumption relative to conventional landfill soil, which can most probably be related to nutritional factors provided by the compost or to changes in the microbial ecology. Physical factors such as the increased porosity, water-holding capacity, or thermal insulation properties of compost seem to be responsible for much of the observed positive effects.

The minimum recommended thickness of a final compost cover to mitigate methane emissions on bioreactor landfills is 1.2m in the construction phase for climatic conditions in middle Europe (Huber-Humer et al., 2008). Bogner et al. (2005) tried to determine a minimum biocover design made of recycled materials capable of mitigating methane emissions in subtropical environments.

The function of biocovers and their long-term durability and bio-active lifetime will reduce the rate of methane emission from MSW landfills. However, the temperature, moisture, gas fluxes and gas ratio may influence the role of compost cover for the mitigation of methane emissions.

iii. Advantages and disadvantages

Advantages

1. Optimised and well-adapted biocovers are relatively less expensive in terms of operation and installation compared to a conventional gas collection system, whose cost can be high compared to the value of the captured fuel.
2. These biocovers have low maintenance requirements and they can be maintained by a relatively untrained person. Thus, they are suitable for both high and low income countries.

Disadvantages

1. Biocovers need to be designed and modified for local, landfill site-specific conditions.
2. Landfill chambers require homogeneity of gas fluxes and special cover material properties which still require significant research and development efforts.
3. Due to the shifting of methane oxidation layer downwards, the mats get clogged due to microbially-produced biomass and therefore much labour is required to sweep the chamber's basal gravel layer. However, the sweeping of the chamber basal gravel layer can be done by relatively untrained persons.

iv. Economics and mitigation potential

Future CH_4 emission scenarios indicate rising shares of MSW and coal bed methane (CBM), where mitigation technologies have good penetration potential.

v. Examples/locations where presently practiced

Landfills exist all over the world. While soil is probably the most used landfill cover, a Google search reveals numerous reports of tests underway to determine the best approaches to utilise biocovers at specific sites in order to reduce GHG emissions.

vi. Barriers to dissemination

A lot of site-specific research needs to be done worldwide to determine availability of suitable materials, the thickness of material to apply, longevity and so on.

5.2 Anaerobic decay of agriculture waste

5.2.1 Household biogas digesters with CH_4 recovery and utilisation

i. Technology definition

Biogas is a flammable gas produced by organic materials after it has been decomposed and fermented by anaerobic bacteria in tightly sealed environmental digesters under certain temperature, humidity, acidity and alkalinity conditions. The process in which biogas bacteria decompose organic materials to produce biogas is known as biogas fermentation. Manure-based biogas digesters refer to fermentation tanks which are used to treat animal manure including human waste via anaerobic fermentation. The methane concentration of biogas is around 60%, so the recovery and utilisation of biogas from digested slurry in a biogas digester will reduce CH_4 emissions from just escaping from the manure. In addition, the biogas can be used to provide electricity or thermal energy and reduce CO_2 emissions from fossil fuel (coal) displaced by biogas.

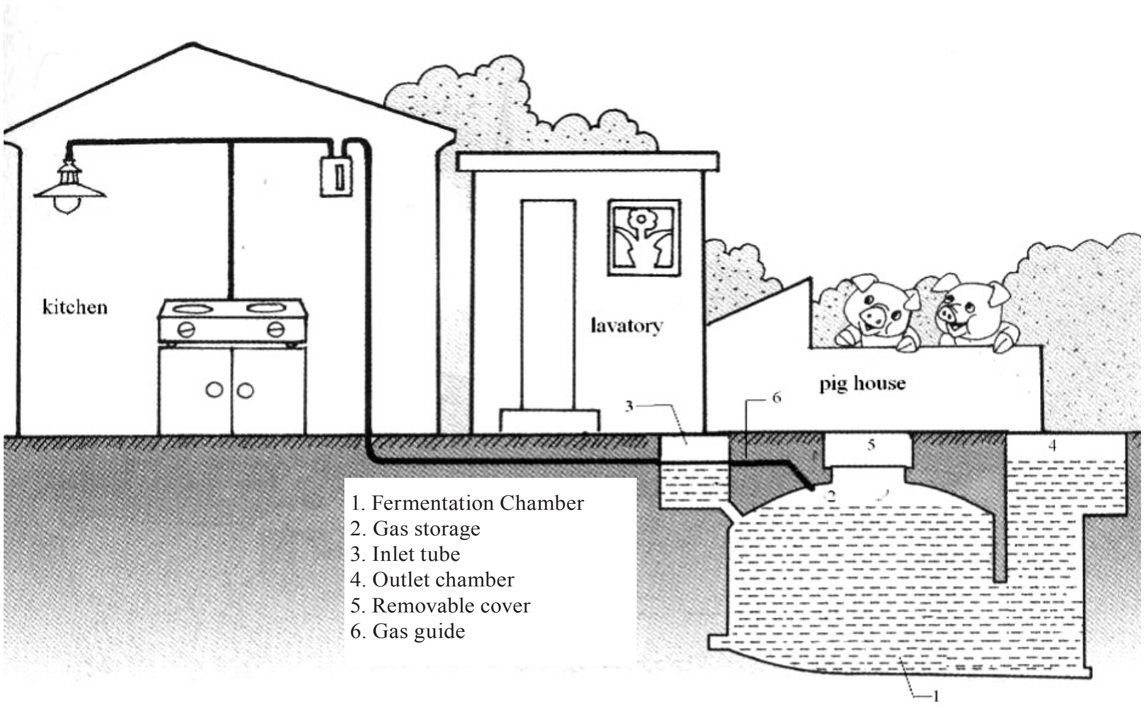
ii. Technology description

A biogas digester is composed of six parts: fermentation chamber, gas storage, inlet tube, outlet chamber, removable or sealed cover, and a gas pipe line (see in Figure 5.3).

The mechanics of biogas generation can be described as follows:

- The captured gas is stored in the upper part of the digester tank (gas storage area), which is constructed in an arc shape. The generation of biogas will gradually increase the pressure in the stored area. When the volume of the captured gas is larger than the amount consumed, the pressure in the gas storage will increase and slurry will be pushed into the outlet chamber. If the amount of gas consumed exceeds gas availability, the slurry level drops and the fermented slurry flows back into fermentation chamber.
- The placement of the digester tank (underground fermentation) keeps the temperature in the tank relatively stable ensuring that the slurry can be fermented at adequate temperatures throughout the year without requiring additional heating.
- The bottom of the digester inclines from the material-feeding inlet to the material-outlet, allowing free flow of the slurry.

Figure 5.3 Schematic of ‘Three in One’ combination of household biogas digesters



Source: Department of Science , Education, Ministry of Agriculture, China. 2003

- The digester has been designed to allow the effluent to be removed without breaking the gas seal, taking the effluent liquid out through the outlet chamber.

As stated in the Technology definition section above, biogas fermentation is a process in which certain bacteria decompose organic matter to produce methane. In order to obtain normal biogas fermentation and a fairly high gas yield, it is necessary to ensure the basic conditions required by the methane bacteria are met for them to carry out normal vital activity (including growth, development, multiplication, catabolism etc.).

Strict anaerobic environment

Microbes that play a major role in biogas fermentation are all strict anaerobes. In an aerobic environment, the decomposition of organic matter produces CO_2; however, in an anaerobic environment, it results in CH_4. A strict anaerobic environment is a vital factor in biogas fermentation. Therefore, it is essential to build a well-sealed, air-tight biogas digester (anaerobic digester) to ensure a strictly anaerobic environment for artificial biogas production and effective storage of the gas to prevent leakage or escape.

Sufficient and suitable raw materials for fermentation

Sufficient raw materials for biogas fermentation constitute the material basis for biogas production. The nutrients that methane bacteria draw from the raw materials are carbon (in the form of carbohydrates), nitrogen (such as found in protein, nitrite, and ammonium), inorganic salts, etc. Carbon provides energy, and nitrogen is used in the formation of cells. Biogas bacteria require a suitable carbon-nitrogen ratio (C:N).

The suitable carbon-nitrogen ratio for rural biogas digesters should be 25~30:1. The carbon-nitrogen ratio changes with different raw materials, and one must bear that fact in mind when choosing a mix of raw materials for the digester.

Appropriate dry matter concentration
The appropriate dry matter concentration in the raw materials for biogas fermentation in rural areas should be 7%-9%. Within this range, a low concentration of raw materials may be selected in summer, while in winter a higher value is preferred.

Appropriate fermentation temperature
Biogas fermentation rates depend greatly on the temperature of the fermenting liquid in the digester. Temperature directly affects the digestion rate of the raw materials and gas yield. Biogas fermentation takes place within a wide temperature range (Xu Zengfu, 1981). The higher the temperature, the quicker the digestion of the raw materials will be, and the gas production rate will also become higher. Based on real fermentation conditions, we have identified the following three temperature ranges for fermentation:

- High temperature fermentation: 47°C~55°C.
- Medium temperature fermentation: 35°C ~38°C.
- Normal temperature fermentation: ambient air temperature of the four seasons.

Selecting the temperature range for bio-gas fermentation depends on the type, sources, and quantities of raw materials; the purposes and requirements of processing organic wastes; and their economic value. Most household biogas digesters are normal temperature fermentation.

Appropriate pH Value
The pH value of the fermenting liquid has an important impact on the biological activity of biogas bacteria. Normal biogas fermentation requires the pH value to be between 7 and 8. During the normal process of biogas fermentation in a rural digester, the pH value undergoes a naturally balanced process, in which it first drops from a high value to a low value, then rises again until it almost becomes a constant. This process is closely related to the dynamic balance of three periods of biogas fermentation. After feeding the biogas digester, the time that the pH value takes to reach its normal level depends on the temperature and the kinds and amounts of raw materials that are fed in.

iii. Advantages and disadvantages

Advantages

1. Reducing GHG emissions by reducing CH_4 emissions from manure management and CO_2 emissions from coal burning or other carbon based fuel source.
2. Saving on energy costs for cooking and lighting by providing biogas which is clean energy.
3. Fertiliser saving by applying the effluent from biogas digesters by replacing commercial fertiliser.
4. Improving local environmental conditions in rural areas.

Disadvantages

1. Medium to high capital costs and the initial investment cost are the main constraints for installing a digester.
2. Skilled and trained labour is required for the construction of a biogas digester.
3. Requires availability of animal excrements for optimal biogas production.
4. There are sometimes cultural prejudices against using gas from human waste.

iv. Economics and mitigation potential

Biogas technology can reduce emissions from farmyard manure, and its price ranges from US$12-40 per t CO_2e saved. Biogas technology becomes suitable for mitigating GHG emissions if there are high amounts of organic inputs at a price of approximately US$12 per t CO_2e saved (Wassmann and Pathak, 2007).

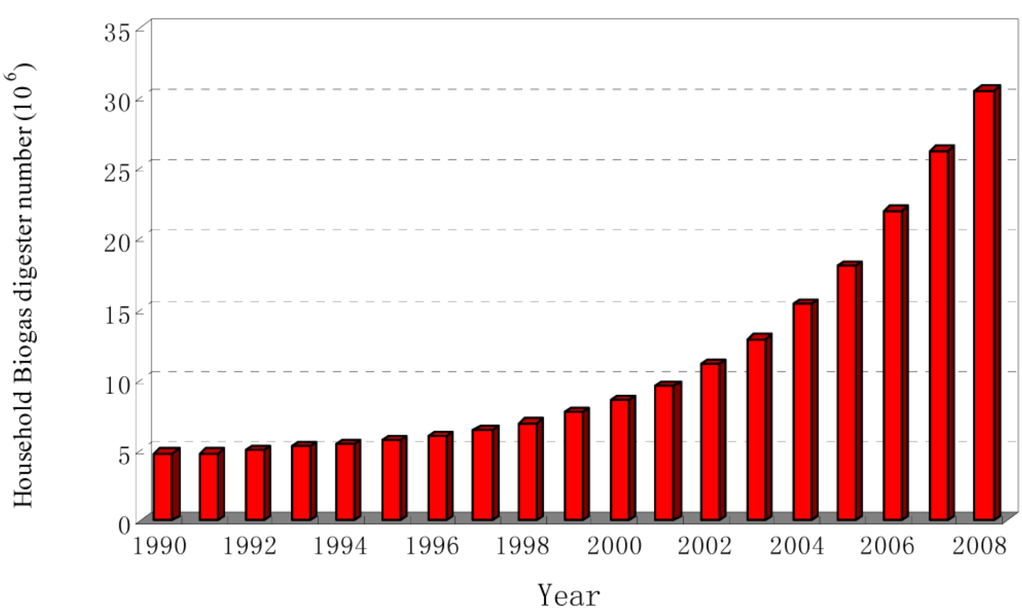
Each household biogas digester (8~15 m^3) costs between US$500-1,000 depending on the digester size.

It is estimated that an 8 m^3 household biogas tank can treat the manure from 4 to 6 pigs, yielding around 385 m^3 biogas annually. It can save 847-1,200 kg of coal based on the calculation of effective heat equivalent. According to the methodology recommended by IPCC in 2006, if a household biogas digester treats the manure of 4 pigs, it can reduce GHG of 1.5~5.0 tonnes CO_2e.

v. Examples/locations where presently practiced

Figure 5.4 shows the development trends of household biogas projects in China. By the end of 2008, the number of the overall household biogas digesters had reached 30.49 million. One can see that during the period of 1990-2008, the implementation of household biogas digesters increased 6.4 fold. Unfortunately, due to limited finances, most farmers have not been able to afford a biogas digester.

Figure 5.4 Household biogas numbers during the period 1990-2008 in China



Source: Author estimate

vi. Barriers to dissemination

The dissemination of biogas digesters face investment and technical barriers.

Investment barrier
The cost of each household biogas digester (8-16 m^3) ranges from US$500 to US$1,000 depending on the digester size. Most rural households within developing countries have low disposable income and weak financial capacity for making such a large investment. In addition, the household will continue to pay a biogas digester maintenance cost. By contrast, the current practice of deep-pit treatment method is by far considered the most attractive option for manure treatment given that it requires very limited additional investment and labour input.

Technical barrier
The biogas digesters have to be located in many cases in the remote rural areas, where farmers lack ready access to improved technologies and management methods. According to current experiences in China, the performance of some digesters are unstable, with varying levels of gas production. This is due to the lack of experience among the individual households, limited resources for biogas service support, and insufficient farmer training. Expertise is required to ensure that the digesters function properly, so maintenance and management of biogas digesters require adequate support services and trained staff, which is not available in rural areas.

5.2.2 Off field crop residue management

i. Technology definition

Crop-residue management is an important mitigation technology using biomass, vermi-compost etc. processed under aerobic conditions which is being utilised as a commercial option to reduce greenhouse gas emissions. Vermi-composting is a modified method of composting using earthworms to eat and digest farm waste and turn it into a high quality vermi-compost in two months or less. It is different from other composts due to the presence of worms such as earthworms, red wigglers, white worms etc. (Satavik, 2011).

ii. Technology description

Most byproducts of cereals, pulses, and oilseeds are useful as feed and fodder for livestock. Byproducts of other crops like cotton, maize, pigeon pea, castor, sunflower, and sugarcane are used as low calorie fuel or burnt to ashes or left in the open to decompose over time. Modest investments in decentralised facilities for aerobic digestion of agricultural residue through vermi-composting and biogas generation can meet the needs of energy-deficit rural areas.

Crop residue management is an important component of organic farming that helps the conservation of carbon in the rhizosphere thereby mitigating the emissions of GHG to the atmosphere. It includes leguminous cover crops grown as green manure to provide a cost-effective source of N to subsequent crops. Organic farming relies heavily on inputs of organic residues in the forms of green manure (i.e., cover crops), plant compost, and composted animal manures added to the soil along with integrated biological pest and weed management, crop rotation, and mechanical cultivation to sustain and enhance soil productivity and fertility without the use of synthetic N fertiliser and pesticides (Table 5.1). The handling of crop residues also has an impact on net carbon gains. Removal of straw or stover can result in significant loss of soil organic carbon (SOC). If they are used as bedding for livestock, then much of the carbon may be returned to the soil as manure (Lal et al., 1998b).

Table 5.1 Estimated crop residues (million tonnes) in India (2006-2007)

Crop residue	Dry weight
Cotton stalks	16.36
Maize cobs	2.72
Pigeonpea	6.93
Sunflower	2.46
Castor	1.41

Source: Dixit et al., 2010

iii. Advantages and disadvantages

Advantages

1. When crop-residue is incorporated into soil, the soil's physical properties and its water-holding capacity are enhanced.

2. Organic residues and N fertilisers increase soil organic carbon and subsequently improve soil structure and aggregate stability. By stabilising soil aggregates, soil organic matter is more protected from microbial decay (Six et al., 1999). The use of organic residue management cover crops and manures can lead to soil organic carbon accumulation by improving aggregation as well as reducing the need for synthetic fertiliser application while providing crops with equally adequate amounts of nutrients.

3. Addition of organic residue to the soil reduces environmental pollution potential while maximising the N-use efficiency and providing crops with sufficient N.

Co-benefits of organic amendments applied to soil are a reduced need for herbicides by reducing weed emergence and enhancing soil quality, which provides better habitat for beneficial soil fauna. For example, decomposers such as earthworms can help in organic amendments. The castings and the channels that earthworms create improve root growth, water infiltration, and the physical structure of the soil. Earthworms also stabilise soil organic matter and contribute to the formation of stable soil aggregates.

Disadvantages

1. The carbon and nitrogen mineralization rate of these manures and organic residues are relatively low for the recovery of N, which ranges between 5-18% of total N for manures and 8% for compost. Thus, these organic amendments would need to be applied in huge amounts in order to considerably increase the short term N supply, which would lead to higher costs.

iv. Economics and mitigation potential

Tschakert (2004) estimated the cost-effectiveness of crop residue (millet) based compost application for soil carbon sequestration in small-scale dry land farming systems for three resource-endowment groups at Old Peanut Basin, Senegal, for a 25-year project period (Table 5.2).

Table 5.2 Cost benefit analysis of crop residue (millet) based compost application at Old Peanut Basin, Senegal, for a 25-year project period

Poor households	First year costs ($/ha)	Input	1076
		Labor	123
	Per year costs Y 2–25 ($/ha)		129
	First year benefit ($/ha)		54
	Per year benefit Y 2–25 ($/ha)		262
	Undiscounted net benefits (in $/tC/ha)		3983
	Net present values (in $; 20% discount rate)		-643
Medium-rich households	First year costs ($/ha)	Input	139
		Labor	93
	Per year costs Y 2–25 ($/ha)		26
	First year benefit ($/ha)		54
	Per year benefit Y 2–25 ($/ha)		96
	Undiscounted net benefits (in $/tC/ha)		2926
	Net present values (in $; 20% discount rate)		22

Source: Tschakert, 2004

Crop residue management through vermi-composting brings about 463 mg CO_2e m^{-2} hr^{-1} compared to their anaerobic digestion value of 694 mg CO_2e m^{-2} hr^{-1}. The experiments done by Chan et al., (2011) in Australian cities clearly confirm the reduction in GHG emissions through crop residue and vermi-compost management. There will be ample opportunity for farmers to reduce GHG emissions in vermi-compost production by reducing the use of chemical fertilisers which generally initiate the emission of N_2O and CH_4.

v. Examples/locations where presently practiced

Off-field management of crop residues by composting or digesting is not widely practiced.

vi. Barriers to dissemination

Lack of availability of proper chipping and soil incorporation equipment to ensure that proper height of crop residue is cut, is one of the major reasons for the colossal wastage of agricultural biomass.

Increased cost of labour and transport is another reason for lack of interest in utilising the crop-residue management technologies.

6. Organic Agriculture

i. Technology definition

Organic agriculture is a production system which avoids or largely excludes the use of synthetic fertilisers, pesticides and growth regulators. It can sequester carbon using crop rotations, crop residues, animal manure, legumes, green manure, and off-farm organic waste (Lampkin et al., 1999). It can also reduce carbon emissions by avoiding the use of fossil fuels used in the manufacture of the chemicals used to make synthetic materials.

ii. Technology description

Organic farming restricts the use of artificial fertilisers and pesticides, and it promotes the use of crop rotations, green manures, compost, biological pest control and mechanical cultivation for weed control. These measures use the natural environment to enhance agricultural productivity. Legumes are planted to fix nitrogen into soil, and natural insect predators are encouraged. Crops are rotated to renew soil, and natural materials such as potassium bicarbonate, and mulches are used to control diseases and weeds. Crop diversity is a distinct feature of organic farming. However, organic farming originated as a small-scale enterprise with operations from under 1 acre (4,000m^2) to under 100 acres (0.40km^2). Crop rotation, cover cropping, reduced tillage, and application of compost are varieties of methods used in organic agriculture. Organic agriculture is one of the important options of carbon sequestration which can reduce greenhouse gases.

Organic farmers use several different techniques. The most effective ones are fertilisation by animal manure, by composted harvest residues, and by leguminous plants such as (soil) cover and (nitrogen) catch crops. Introducing grass and clover into rotations for building up soil fertility, diversifying the crop sequences, and reducing ploughing depth and frequency also augment soil fertility. All these techniques increase carbon sequestration rates in organic fields, whereas in conventional fields, soil organic matter is exposed to more tillage and consequent greater losses by mineralisation. The annual sequestration rate increases up to 3.2 tonnes of CO_2/ha^{-1} yr^{-1} by organic farming (Smith et al., 2007).

Although not limited to organic farming, the use of N from manure and compost or fixed from the air by leguminous plants has a mitigation potential that amounts to 4.5-6.5Gt CO_2e yr^{-1} (out of 50Gt CO_2e yr^{-1} global GHG emissions) or about 9-13% of the total GHG emissions. The mitigation is accomplished by sequestering C in soils due to intensive humus production (Smith et al., 2007). Regular applications of livestock manure can induce substantial increases in soil organic carbon over the course of a few years (Lal et al., 1998b). Organic agriculture has lower N_2O emissions i.e., 1.2-1.6 Gt CO_2e yr^{-1}. In organic agriculture, biomass is not burned. It reduces the N_2O emissions by 0.6-0.7Gt CO_2 e yr^{-1} in comparison to conventional agriculture (Smith et al., 2007). Organic systems are highly adaptive to climate change due to: (a) the application of traditional skills and farmers' knowledge, (b) soil fertility-building techniques, and (c) a high degree of diversity.

Organic farming could considerably reduce the GHG emissions of the agriculture sector and make agriculture almost GHG neutral (Niggli et al., 2009). Greenhouse gas emissions due to the applications of synthetic fertilisers are estimated to be 1,000 million tonnes annually. These emissions would not occur using an organic approach. GHG emissions of agriculture would be reduced by roughly 20 per cent. Another 40 per cent of the GHG emissions of agriculture could be mitigated by sequestering carbon into soils at rates of 100kg of C ha^{-1} yr^{-1} for pasture land and 200kg of C ha^{-1} yr^{-1} for arable crops. By combining organic farming with reduced tillage, the sequestration rate can be increased to 500kg of C ha^{-1} yr^{-1} in arable crops as compared to ploughed conventional cropping systems, but as the soil C dynamics reach a new equilibrium, these rates will decline in the future. This would reduce GHG emissions by another 20 per cent. Organic farming is an important option in a multifunctional approach to climate change.

Historically, agriculture was organic, relying on the recycling of farm wastes and manures. Very little or negligible amounts of external inputs were applied. Sustainable farming practices and cycles evolved over centuries, integrated with livestock rearing. For instance, farmers of ancient India are known to have evolved nature-friendly farming techniques and practices such as mixed cropping and crop rotation.

iii. Advantages and disadvantages

Advantages

1. Organic agriculture aims to improve soil fertility and N supply by using leguminous crops, crop residues and cover crops, to eliminate fossil fuel used to manufacture N fertiliser. The addition of the crop residues and cover crops leads to the stabilisation of soil organic matter at higher levels and increases the sequestration of CO_2 into soils.

2. Organic agriculture increases soil's water retention capacity, which would enable a crop to go longer into a drought cycle assuming an initial full profile. This should provide an adaptation to unpredictable climatic conditions. Soil C retention is more likely to withstand climatic challenges and soil erosion, an important source of CO_2 losses.

3. Organic agriculture can contribute to agro-forestry production systems, which offer additional means to sequester carbon.

4. Organic systems are highly adaptive to climate change due to the application of traditional skills and farmers' knowledge, soil fertility-building techniques and a high degree of diversity.

5. Organic agriculture as a water protector reduces water pollution due to the absence of pesticides and chemical fertilisers.

6. Organic agriculture is compatible with conservation tillage, thereby enabling even greater C sequestration potential by incorporating this mitigation technology.

Disadvantages

1. Organic agriculture is less productive compared to intensive conventional agriculture. Consequently, the yield of highly demanding crops such as potatoes, grape fruits and horticultural crops is too low and energy input becomes relatively more on per unit of crop production bases (Smith et al., 2007).

2. Quality of organic-grown produce is often lower due to insect damage, which is less in conventional agriculture with its use of pesticides.

3. Highly dependent on nutrients derived from livestock.

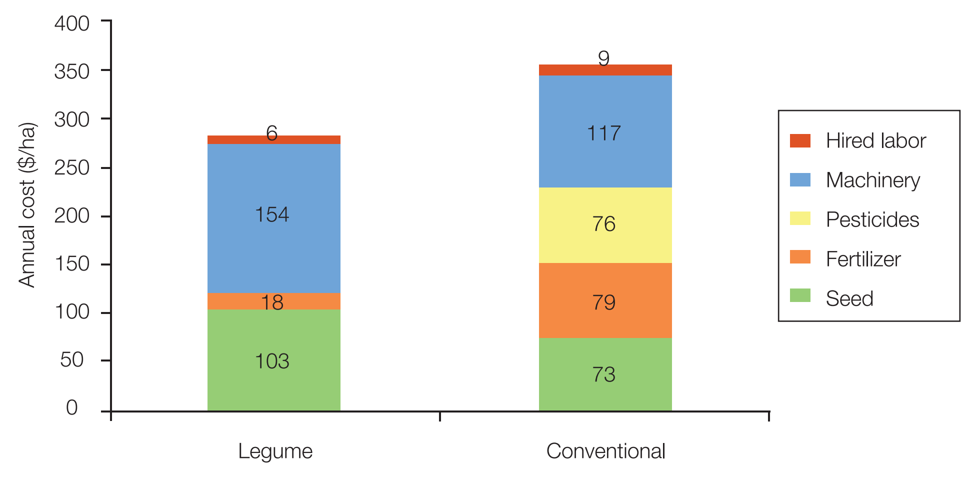
Figure 6.1 Leguminous crops as green manure in organic farming

Source: International trade Center UNCTAD/WTO, Monograph, Organic farming and climate change, 2007.

iv. Economics and mitigation potential

Organic agriculture requires 28% to 32% less energy compared to conventional systems. Input costs for seed, fertiliser, pesticides, machinery, and hired labour are approximately 20% lower in a rotation that includes a legume compared with a conventional rotation system (Figure 6.2), (Kimble et al., 2007).

Figure 6.2 Annual input costs for the legume and conventional grain rotations



Source: Kimble et al., 2007

In the East African Highlands, animal manure application leads to 2,820 kg ha^{-1} yr^{-1} carbon inputs with $156 per ha cost and 5.5% carbon sequestration efficiency (Woomer et al., 1998). The sequestration of one tonne of soil carbon using cattle manure requires $260, but return will increase by $1,066 (4.1 return ratio) as a result of the addition. Some experts estimate the cost of manure to be around $1,000, in which case the additional returns would almost vanish. Maize stover leads to 1,830 kg $ha^{-1} yr^{-1}$ carbon inputs with $37 per ha cost and 5.4% carbon sequestration efficiency. The sequestration of one tonne of soil carbon using maize stover requires $374, but this application also suppresses crop yields resulting in a loss of $112 (-1.3 return ratio).

Annual global sequestration potential of organic agriculture amounts to 2.4-4Gt CO_2e yr^{-1}, and it can be improved to 6.5-11.7Gt CO_2e yr^{-1} by using new technologies in organic agriculture (Smith et al., 2008).

Organic agriculture has lower methane and nitrous oxide emissions of 0.6-0.7Gt CO_2e yr^{-1} in comparison to conventional agriculture, which includes the burning of crop residue (Smith et al., 2007).

Organic agriculture has a significant potential to provide on-farm energy by biogas production from slurry and compost, although this would detract from the quantities of organic material to return to the soil.

If all agriculture were organic, the elimination of nitrogen fertilisers would save substantial emissions. For example, in case of UK 1.5% of national energy consumption and 1% of national greenhouse gas emissions would be saved (Mae-Wan and Ching, 2008). Earlier studies showed that GHG emissions would be 48-66% lower per hectare in organic farming systems in Europe. The lower emissions were attributed to zero input of chemical N fertilisers, less use of high energy consuming feed stock, low input of P (phosphorus) and K (potassium) mineral fertilisers, and elimination of pesticides. However, productivity likely would be lower.

v. Examples/locations where presently practiced

There are around 76,000ha of organic farmland in India. Uttrakhand and Sikkim have declared their states as organic states out of 28 states in India. In Nagaland 3,000ha are under organic farming with kholar, maize, ginger, soybean, large cardamom, passion fruit, and chillies. Tribal regions where organic farming has been practiced are high priority areas to promote continuation of the practices. The regions include the tribal areas in Orissa, M.P. and North East, delicate ecosystems in Himalaya and Western Ghat, rainfed dry areas, and green revolution areas (Masood, 2009).

According to Willer et al., (2008; http://orgprints.org/8535/), organic agriculture is developing rapidly and is now practiced in more than 130 countries. At the end of 2006, 30.4 million hectares of agricultural land were managed organically, constituting a growth of 1.8 million hectares compared to 2005. Oceania is the region which has the largest proportion of its land devoted to organic agriculture, followed by Europe and Latin America. Currently, the country with the largest organic area is Australia (more than 12 million hectares) followed by China (2.3 million ha), Argentina (2.2 million ha), USA (1.6 million ha) and Italy (1.1 million ha). Other countries are below 1 million ha.

Global demand for organic products remains robust, with sales increasing by over US$5 billion a year. *Organic Monitor* estimates international sales reached US$38.6 billion in 2006, double that of 2000, when sales were at US$18 billion. An analysis of the global organic data for the countries on the list of recipients of Official Development Assistance (DAC List) shows that more than one quarter of the world's organic agricultural land (8.8 million ha) is in countries on this list. Most of this land is in Latin America followed by Asia and Africa.

vi. Barriers to dissemination

Besides overcoming a tradition of recently adopted synthetic fertilisers and pesticides, the primary barriers to adoption of organic farming are the lower productivity and consequently higher prices, as well as lower produce quality in the marketplace. Greater education of farmers and the public needs to be done to show that the environmental and long-term sustainability advantages of organic agriculture are worth to the added current costs.

7. Bioenergy

7.1 Agriculture for biofuel production

i. Technology definition

Biomass from the agriculture sector can be used to produce biofuels – solid, liquid and gaseous. Biofuels substitute fossil fuels for energy delivery. If biomass is grown in a sustainable cycle to produce biofuels, such agriculture practices mitigate GHG emissions due to fossil fuel not being combusted. Biofuels can be derived from biomass sources such as corn, sugar cane, sorghum, soybean, crop residues, oil palm *(Elaeis guineensis),* switch grass, *Miscanthus,* bioengineered algae, and *Jatropha curcas* seeds, trees, and grasses. First generation biofuel crops (such as sugarcane and maize) from which sap or grain ethanol are obtained are already being used. In addition, second generation cellulosic ethanol crops (e.g., *Miscanthus*) appear promising. Third generation biofuels, where micro-algae is grown on CO_2 and water to directly produce biodiesel, are covered in Section 7.1.2 in this guidebook.

ii. Technology description

Agricultural crops and residues are the major sources of feed stocks for energy to displace fossil fuels. A wide range of materials such as grain, crop residue, cellulosic crops (e.g., switch grass, sugar canes and various tree species) are used for the production of biofuel (Paustian et al., 2004; Eidman 2005). These products are processed further to generate liquid fuels such as ethanol or diesel fuel (Richter, 2004). These fuels release CO_2 when burned, but this CO_2 is of recent atmospheric origin (via photosynthesis) and displaces CO_2 which otherwise would have come from fossil carbon. The net benefit to atmospheric CO_2, however, depends on energy used in growing and processing the bioenergy feed stock (Spatari et al., 2005).

iii. Advantages and disadvantages

Advantages

1. Some of the biofuel production such as Jatropha and oil-palms can be grown in dry land and fallow area, through commercial experiences.
2. About 70-88 million biogas plants can be run with fresh/dry biomass residues.
3. The substrate such as cattle waste and biomass used for this technology are easily available. Their availability to biogas plants can meet the requirement of 12-30 million families.

Disadvantages

1. A larger area of land will be required to satisfy global biofuel demand. Projected growth of biofuel crops until 2030 may require over 30 million hectares of land (IEA, 2009). However, Field et al. (2008) suggested a need for 1,500 million hectares of land under cultivation of biofuel crops. Melillo et al.

(2009)'s calculations show biofuel crops would require 1,600-2,000 million hectares by the year 2100 assuming most fuel demand would be met by biofuels by this time. It is practically impossible to spare such a large area of cropland to grow biofuel plants.

2. The land requirement for biofuel crops would compete with that for food and feed crops, causing food prices to increase.
3. In many cases for current ethanol production from grain, the fossil fuel associated with use of chemical fertilisers, tractor power and so on, results in an unacceptably small net reduction in fossil fuel use (e.g., Scharlemann and Laurance, 2008).
4. Production systems with suitable enzymes for utilising cellulosic feedstocks have not yet become commercially viable.
5. The resources for biogas generation are not properly managed to generate its maximum biogas potential.
6. The lack of availability and the structural operation of biogas digesters are not able to generate and develop family-size biogas plants.

iv. Economics and mitigation potential

The use of husks as a fuel appears to be a promising mitigation option. Husk could be used for direct burning, in biomass gasifier, as briquettes or as solid char. Its relative cost is around US$4 per t CO_2e saved and the reduction potential ranges from 0.9-1.2t CO_2e ha^{-1} (depending on the level of biomass production). Rice husk can easily be collected at milling facilities, so that this source of renewable energy seems even more promising than utilisation of straw (Junginger, 2000;Wassmann and Pathak, 2007).

The potential for mitigation is huge, particularly if cellulosic biomass sources can be commercialised. However, the economics are such that biofuels have required help from legislation and subsidies to penetrate the market, at least in parts of the US where currently a proportion of gasoline must be ethanol at certain times of the year more to mitigate air pollution from ozone than to mitigate GHG emissions (e.g., Regalbuto, 2009) and there is a legislative mandate for 16 billion gallons of cellulosic ethanol by 2022 (Robertson et al., 2008). Similarly, Europe has a mandate that 10% of all transport fuels be from renewable sources by 2020 (Robertson et al., 2008).

v. Examples/locations where presently practiced

Brazil probably leads the world in the use of biofuels with about 25% of its ground transportation fuel coming from sugar cane ethanol (Somerville, 2006). As mentioned above, in the US ethanol (mostly from corn) is blended in gasoline to reduce air pollution in parts of the country at certain times of the year.

vi. Barriers to dissemination

As already mentioned, a significant barrier to production of biofuels from grain is the competitive need of the grain for food and feed. Systems to utilise cellulosic biomass are not yet commercially viable, although much research and subsidies are being implemented to stimulate its use. Even if research at the laboratory scale is promising, challenges exist in scaling up the infrastructure to provide a feasible supply chain for cellulosic bioenergy (Richard, 2010).

7.2 CO_2 mitigation by micro-algae

i. Technology definition

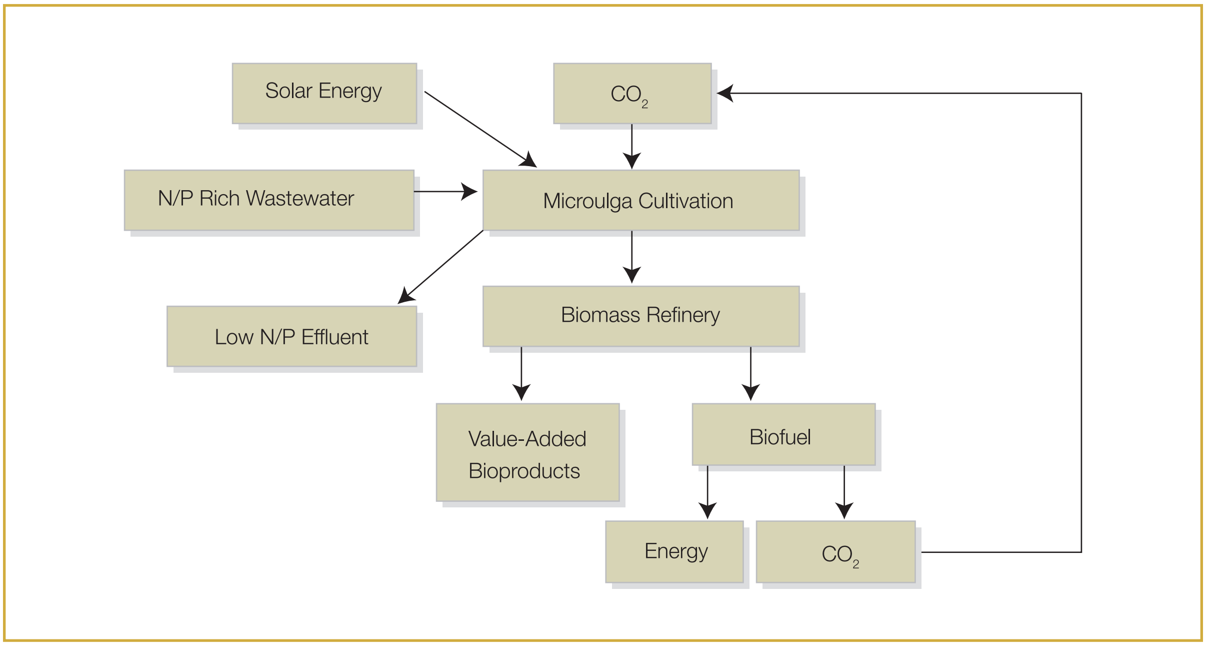
Micro-algae are a group of unicellular or simple multicellular fast growing photosynthetic microorganisms that can conserve CO_2 efficiently from different sources, including the atmosphere, industrial exhaust gases, and soluble carbonate salts. Micro-algae act as a major system for converting atmospheric CO_2 into lipids under sunlight and increase the output of algal oil. The enzyme acetyl Co-A carboxylase (ACCase) from micro-algae catalyses the key metabolic step in the synthesis of oil in algae.

Micro-algal technology for mitigating carbon dioxide

About 3,000 species out of 200,000 species were found to be useful for sequestration of CO_2 and the production of biodiesel (Keffar, 2003). Micro-algae are a promising alternative to CO_2 mitigation by CO_2 fixation, biofuel production, and wastewater treatments. CO_2 fixation by photoautotrophic algal cultures has the potential to diminish the release of CO_2 into the atmosphere, thereby helping to alleviate the trend toward global warming (Figure 7.1). Biofuel is derived from microbes that can live on land unfit for crops and generate nearly engine-ready chemicals which are considered to be third generation biofuels (New Scientist, 2011).

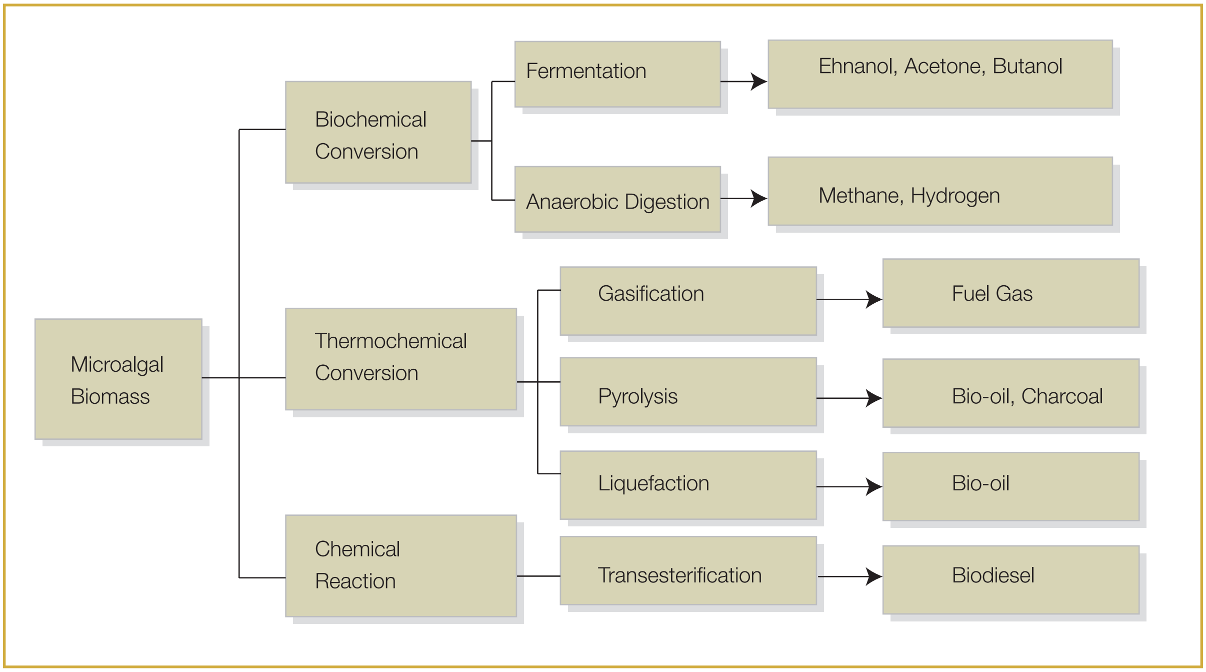
Micro-algae, when fed with CO_2 and sunlight, produced large amounts of lipids and hence increase the output of algal oil. The enzyme Acetyl CoA Carboxylase (ACCase) from micro-algae helps to catalyse and transform CO_2 in the synthesis of oils in algae.

Figure 7.1 A conceptual micro-algal system for combined biofuels production, CO_2 bio-mitigation, and N/P removal from wastewater. Inputs: carbon source, CO_2; nitrogen and phosphorus sources, N/P rich wastewater; energy source, solar energy. Outputs: low



Source: Wang et al., (2008).

Figure 7.2 Microalgal biomass conversion to secondary products



Modified from: Tsukahara and Sawayama, 2005.

Technological developments, including advances in photo bioreactor design, micro-algal biomass harvesting, drying, and other downstream processing technologies are important areas that may lead to enhanced cost-effectiveness and therefore, effective commercial implementation of the biofuel using a micro-algae strategy.

ii. Technology description

Micro-algae can fix carbon dioxide from different sources, which can be categorised as:

1. CO_2 from the atmosphere.
2. CO_2 from industrial exhaust gases (e.g., flue gas and flaring gas).
3. Fixed CO_2 in the form of soluble carbonates (e.g., $NaHCO_3$ and Na_2CO_3).
4. Can be grown in closed systems, which could result in savings of precious freshwater resources.

The systems for using micro-algae for CO_2 sequestration involve the following sub systems:

1) The open pond system

The size of open pond micro-algae production systems typically ranges from 0.22-0.4ha (Pedroni et al., 2001). An even larger (900ha) single algae production system has been reported from Mexico City (Becker, 1994). Similarly, the Arizona Department of Environmental Quality reported an algal growing pond of 1,406ha in Florida (Arizona Department of Environmental Quality, 1995). Advantages for utilising the open pond system are low initial and operational costs. Disadvantages of open pond system are the enormous size of the area required, which is not affordable in many regions, and a high water requirement.

Figure 7.3 Azolla algae production in open pond

Source: NAIP (ICAR), Annual report 2009, CRIDA, Hyderabad, India

2) The closed photo-bioreactor system

Photo-bioreactors provide advantages such as large surface/volume ratios, a barrier to minimise contamination, a capacity to achieve a high density of biomass, a high biomass productivity, and therefore, high CO_2 fixation rate (Rosello et al., 2007). The tubular photo-bioreactor is one of the most popular configurations of photo –bioreactors used in algal carbon sequestration process (Travieso et al., 2001).

Advantages

1. The photo-bioreactor system has a higher potential productivity due to better environmental control and harvesting efficiency.
2. Even though the open pond systems seem to be favored for commercial cultivation of micro-algae at present due to their low capital costs, closed systems offer better control over contamination, mass transfer, and other cultivation conditions.
3. Closed photo-bioreactors require less fresh water than open ponds. However, cooling systems that utilize water may be needed to cool the reactors under excessively warm conditions, although poorer quality water may be utilised for the cooling.

Disadvantages

1. Photo-bioreactors are highly uneconomic due to their prohibitive cost.
2. Photo-bioreactors can be used only for micro algal strains that are easily harvested.

3) Environmentally controlled system

Another strategy explored for CO_2 sequestration use by algae is to build moderate environmentally controlled systems, such as greenhouses. Growers can control the environment inside greenhouses while construction costs are not as high as a photo-bioreactor with a solar collector system.

iii. Advantages and disadvantages

Advantages

1. Micro-algal CO_2 bio-mitigation can be made more economic, cost-effective, and environmentally sustainable, especially when it is combined with other processes such as wastewater treatment. The utilisation of wastewater for micro-algae cultivation will bring about remarkable advantages including the following:

   a) Micro-algae have been shown to be efficient in nitrogen and phosphorus removal (Mallick, 2002), as well as in metal ion depletion, and combination of micro-algae cultivation with wastewater treatment will significantly enhance the environmental benefit of this strategy.

   b) It will lead to savings by minimising the use of chemicals such as sodium nitrate, potassium and phosphorus as exogenous nutrients.

   c) Micro-algae have much higher growth rates and CO_2 fixation abilities compared to conventional forestry, agricultural, and aquatic plants (Li et al., 2008).

2. Some micro-algae species, such as *Chlorella, Spirulina and Dunaliella* have commercial values. It is expected that commercial profit from biomass production will offset overall operational costs for CO_2 sequestration.

3. Species such as *Chlorella* can grow under 20% CO_2 conditions, and therefore, they can use industrial exhaust gases for a CO_2 source, and they can be used as a health food (Becker, 1994).

4. Some micro-algae (eg. *Dunaliella*) use CO_2 to produce secondary metabolites such as β-carotene, fertilisers, and biofuels as byproducts of economic importance. These products are used as food, medicine and cosmetic products. They also produce cost-effective biofuel (Graham and Wilcox, 2000).

5. Micro-algae are also considered as multifunctional systems which are used as waste treatment, especially for the removal of nitrogen and phosphorus from effluents (Mallick, 2002) and in aqua culture farms, as well as being an environmental friendly technology.

6. The high growth rate of micro-algae makes it possible to satisfy the massive demand for biofuels, using limited land resources without causing potential biomass deficit.

7. Micro-algal cultivation in closed systems consumes less water than land crops.

8. The tolerance of micro-algae to high CO_2 content in gas streams allows high-efficiency CO_2 mitigation. (Table 7.1).

9. Nitrous oxide release could be minimised when micro-algae are used for biofuel production.

10. Micro-algal farming could be potentially more cost-effective than conventional farming.

11. Micro-algal farming can be coupled with flue gas CO_2 mitigation and wastewater treatment.

Table 7.1 CO_2 tolerance of various micro-algae species

Species	Known maximum CO_2 concentration	References
Cyanidium caldarium	100%	Seckbach et al., 1971
Scenedesmus sp.	80%	Hanagata et al., 1992
Chlorococcum littorale	60%	Kodama et al., 1993
Synechococcus elongatus	60%	Miyairi, 1995
Euglena gracilis	45%	Nakano et al., 1996
Chlorella sp.	40%	Hanagata et al., 1992
Eudorina spp.	20%	Hanagata et al., 1992
Dunaliella tertiolecta	15%	Nagase et al., 1998
Nannochloris sp.	15%	Yoshihara et al., 1996
Chlamydomonas sp.	15%	Miura et al., 1993
Tetraselmis sp.	14%	Matsumoto et al., 1995

Disadvantages

1. A low biomass concentration in the micro-algal culture must be maintained in order not to limit light penetration which in combination with the small size of algal cells makes the harvest of algal biomasses relatively costly.
2. The cost of production is very high.

iv. Economics and mitigation potential

As per Schenk et al. (2008) and Benemann and Oswald (1996) the cost of algal oil production comes in the range of US$52–$91 per barrel. This estimate was based on 400 hectares of open ponds, using either pure CO_2 or flue gas from a coal-fired power station and productivity assumptions of 30-60 g m^{-2} day^{-1} with 50% algal lipid yield. Such high yields are theoretically possible but to date have not been demonstrated. Another analysis (Huntley and Redalje, 2006) estimated algae oil production costs to be US$84 bbl. This scenario was based on the infrastructure cost assumptions utilising a hybrid system with an aerial productivity of 70.4 g m^{-2} $day^{-1}$and 35% algal lipid yield.

v. Examples/locations where presently practiced

Obtaining biofuels from micro-algae is a research topic at several locations around the world. However, commercial production does not yet exist. According to Wijffels and Barbosa (2010), current worldwide micro-algal manufacturing infrastructure can produce only about 5,000 tonnes of dry algal biomass per year, and that is devoted to extraction of high value products, such as carotenoids and omega-3 fatty acids for food and feed ingredients.

A biotechnology company Joule Unlimited of Cambridge, Massachusetts has set up a plant with photosynthetic cynobacteria with modified DNA. Unlike normal cynobacteria which accumulates greater oil content within their cells, these secrete alkanes – the primary components of diesel – which simplifies collection efforts. Previous scientific studies provide evidence that some microbes, including a number of cynobacteria, can synthesise alkanes. The genetic pathways involved have been unclear, but it has been found that enhanced expression of genes and in species such as *Thermosynechococcus elongates* (which inhabit hot springs) encouraged the microbes to secrete their alkanes (New Scientist, 2011).

vi. Barriers to dissemination

The main barrier is the enormous cost of production, as well as practical aspects, such as harvesting and drying. Wijffels and Barbosa (2010) estimate an area the size of Portugal would be needed to supply the transport fuel needs of Europe from micro-algae, so the scale of production would have to increase by three orders of magnitude. They also state that a concomitant decrease in the cost of production by a factor of 10 is needed.

8. Conclusions

i. Overcoming barriers

There are significant opportunities for greenhouse gas mitigation in agriculture, but numerous barriers need to be overcome. Many recent studies have shown that actual levels of greenhouse gas mitigation are far below the technical potential for these measures (Smith et al., 2005a). The gap between technical potential and realised greenhouse gas mitigation is due to barriers to implementation, including climate and non-climate policies, as well as institutional, social, educational, and economic constraints. The mix of agricultural mitigation options that are adopted in the future will also depend upon the price of carbon dioxide equivalents. The total biophysical potential of approximately 5,500-6,000Mt CO_2e yr^{-1} will never be realised due to these constraints, but with appropriate policies, education, and incentives, it may be possible for agriculture to make a significant contribution to climate mitigation by 2030.

ii. Co-benefits

Mitigation of greenhouse gases through agricultural actions that increase soil C reduces vulnerability to drought and other stresses. It also improves the water holding capacity due to increase in soil C content to help in sustainable agriculture. Efficient use of N fertilisers would improve falling yields and control of N_2O emissions.

Policies that are the most effective at reducing emissions may be those that also achieve other social goals such as rural development, poverty elimination, improved water management, and agro-forestry. These other goals are synergistic with mitigation. Mitigation policies that encourage efficient use of fertilisers, maintain soil C, and sustain agricultural production are likely to have the greatest synergy with sustainable development. Reductions in emissions per unit of production can be achieved by increases in crop yields and animal productivity. This is possible by better management of crops, cultivation, nutrients, and irrigation, genetically modified crops, improved cultivars, precision agriculture, improved animal breeds, improved animal nutrition, dietary additives and growth promoters, improved animal fertility, bio-energy feed stocks, and anaerobic slurry digestion and methane capture systems. Here precision agriculture is not only nutrient management but also involves many other activities such as irrigation, cultivar types, soil management, integrated pest management and other activities involving agricultural systems. These technological improvements could potentially counteract the negative impacts of climate change on cropland and grassland soil carbon stocks. Therefore, technological improvements are a key factor in future mitigation of greenhouse gas emissions.

iii. Carbon crediting

Carbon sequestration and emissions reductions achieved through many of these technologies can also avail carbon credit benefits through the carbon market. A few projects have been successfully registered for Clean Development Mechanism (CDM) benefits so far. Intermittent irrigation, alternate wetting and drying and direct seeded rice technologies already have an approved CDM methodology titled

‘Methane emission reduction by adjusted water management practice in rice cultivation’ (AMS-III.AU) methodology (UNFCCC, 2012b). One project in Java, Indonesia based on this methodology is listed in the CDM project pipeline. The project includes an area of 5,250ha and 8,900ha during the first two years and 12,500ha for subsequent years. The project is still at validation stage and proposes to generate 49,209 carbon credits per year for a crediting period of 7 years (UNFCCC, 2006a; CD4CDM, 2012). ‘Consolidated baseline methodology for GHG emission reductions from manure management systems’ (AMC0010) and ‘Methane recovery in animal manure management systems’ (AMS-III.D) methodologies are applicable to manure and bio-solid management (UNFCCC, 2012a; UNFCCC, 2012c). Many CDM projects have been registered using these methodologies. One such project is ‘Ramirana Emission Reduction Project of Agrícola Super Limitada’ in Chile. This involves use of advanced treatments for swine waste and proposes to generate 58,684 carbon credits per year for a crediting period of 7 years (UNFCCC, 2006b; CD4CDM, 2012).

However uncertainties regarding the future of the Kyoto Protocol and unavailability of approved methodologies for other technologies (like agriculture biotechnology, cover crop, nutrient management, tillage/residue management, potassium fertiliser application, nitrogen inhibitor application, application of electron acceptor, agro-forestry, improved feeding practices and organic agriculture) that lead to either carbon sequestration or GHG emissions reduction suggest that a very large role for CDM is unlikely. In the future, however, the dissemination of many of the technologies listed in this guidebook depends greatly on the progress in global climate negotiations with respect to financing of climate friendly technologies.

iv. Adapting technologies

Adapting the technologies to local conditions is necessary. Involving local farmers, extension agents and research institutions in technology design and dissemination is critical. The effectiveness of mitigation strategies also changes with time. Some practices, like those which elicit soil C gain, have diminishing effectiveness after several decades. Others, such as methods that reduce energy use, can reduce emissions indefinitely.

v. Research

The technologies available for mitigation are at different stages of development. Much research and development are required to make these technologies commercially viable and usable. International agencies can play an important facilitator role for appropriate technology development, demonstration, and subsequently increased penetration. Various research and implementation agencies representing different stakeholders in the country would have to work in close coordination to develop and utilise existing and innovative technologies for mitigation. For example, in identifying low methane-emitting rice systems the following need consideration:

1. Characterising site specific settings for mitigation.
2. Developing packages of mitigation technologies on a regional basis.
3. Ascertaining synergies with improving productivity mitigation technologies to account for the balance between methane mitigation and N_2O emissions.
4. Utilisation of the GIS database for identifying low methane-emitting rice cultivars and for their site characterisation.

The agriculture sector is a significant contributor to GHG emissions and requires major consideration in global mitigation efforts. Despite this, not much progress has been made towards mitigation in this sector. A lack of awareness and guidance as well as a lack of economic strength of farmers have led to continuation of older and higher GHG-emitting agricultural practices. Suitable government policies and programmes are key requirements for better implementation of new GHG mitigation technologies, especially in developing countries. There are several policies already promoting GHG emissions reduction from this sector including land management practices, bio-energy plantation and utilisation, reduced tillage farming and other soil organic carbon management policies in some developed regions of the world. New policies should be adopted in developing regions which promote the execution of such mitigation technologies through imposition, incentives or subsidies. Policies encouraging research in this domain are also needed to understand adaptability of new technologies in various climatic and ecological conditions.

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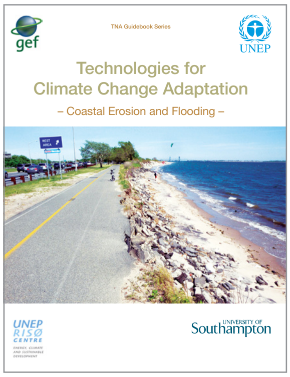

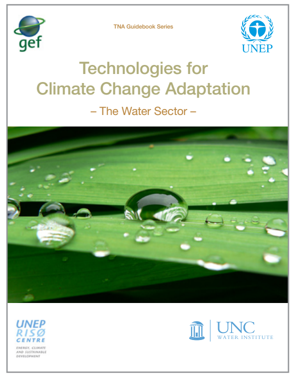

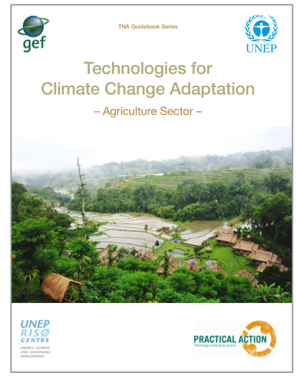

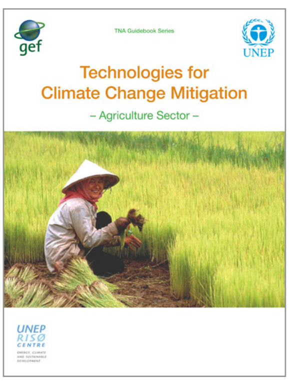

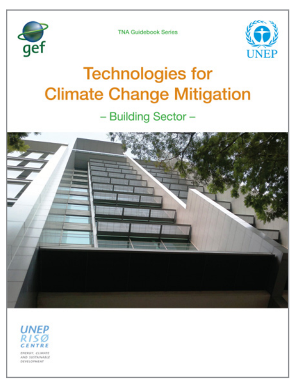

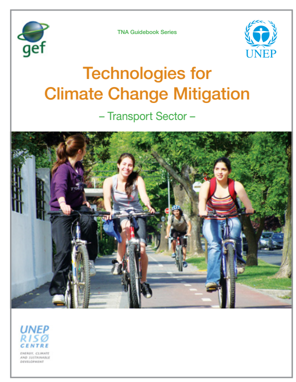

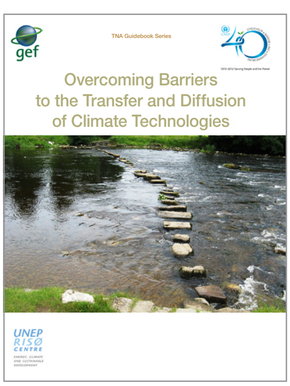

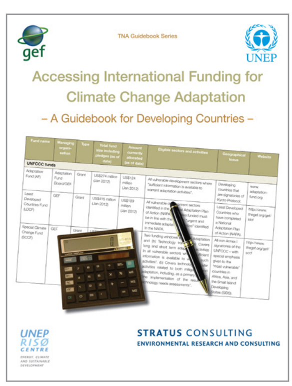

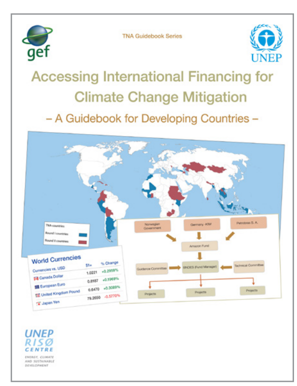

This guidebook covers a range of technologies and practices in the agricultural sector related to crops and livestock that can control emissions of greenhouse gases, and help improve productivity at the same time. All the options are dealt with in simple language, and approaches for implementing these technologies are also provided. The guidebook will be used by the national TNA teams comprising stakeholders from government, non-governmental organisations and the private sector.

The publication is authored by Dr. D.C. Uprety, Dr. Subash Dhar, Professor Dong Hongmin, Dr. Bruce A. Kimball, Professor Amit Garg and Ms. Jigeesha Upadhyay. The authors combine their individual expertise in the agricultural sector and climate change to provide a balanced description of technologies from a development and climate perspective.

This publication is one of the adaptation and mitigation technology guidebooks, produced as part of the GEF-funded Technology Needs Assessment (TNA) project. This project is undertaken by UNEP and URC in 36 developing countries.

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