【Review】



# Soil Conservation Practices for Sustainability of Rice-wheat System in Nepal: A Review

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## Abstract

Declining crop productivity and environmental pollution are two key issues associated with sustainability of rice-wheat system in Nepal. The former one is related to declining soil organic matter and shortage of water as well as laborer; whereas, the latter is due to emission of greenhouse gases (GHGs) from this system. This article reviews the potential of soil conservation practices, especially organic matter and zero-tillage, against these two issues in rice-wheat system of Nepal. Farm Yard Manure (FYM), compost and green manure are the major sources of organic matters in rice-wheat system in Nepal. The organic matter improves the physical, chemical and biological properties of soil; and contributes in minimizing GHG emission. Adoption of biogas technology, improved FYM/compost and spring season green manure crops hold enormous potential to minimize GHGs emission from rice-wheat system. Similarly, zero-tillage reduces the cost of cultivation, allows early planting of wheat, reduces water requirement and increases the crop yield by 16-50 % as compared to conventional tillage. This practice also reduces the consumption of fossil fuel (up to 64 %) by reducing the tillage requirement, and minimizes the oxidation of soil organic matter, thereby contributing in the GHGs mitigation. The other options contributing to the above two issues are water, land, and fertilizer management, and upland rice varieties. This review shows that the integration of the above options would contribute in sustainability of the production system and environmental but more understanding is needed regarding the applicability of the zero-tillage using seed drill in wheat under different geographical and socio-economic contexts of Nepal given the limited studies available.

## 1. Introduction

Rice-wheat system, the practice of growing wheat after rice, is the dominant cropping system in the Indo-Gangetic Plains and is important for the food security of the region. It is practiced in about 13.5 million ha in Bangladesh, India, Nepal, and Pakistan (Ladha et al., 2003). In Nepal, this system covers 0.5 million hectares of land both in tarai (350,000 ha) and hills (140,000 ha). Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) crops in total share 65.8% and 72.1% to the total area and total production of cereal crops in the country, respectively. In spite of the great potential of these crops on food security of people, yield of rice and wheat is low (rice: 2.7 $tha^{-1}$ and wheat 2.1 $tha^{-1}$), and is in declining trend for a decade under constant input management condition (Regmi et al., 2009; MoAC, 2010). Also, there are huge gaps (rice - 5.4 $tha^{-1}$ and wheat - 1.3 $tha^{-1}$) in the yields of these crops between the on-station and on-farm conditions (Pandey, Shah and Becker, 2008). Due to these reasons and increasing population pressure, Nepal has been importing food grains including these crops from foreign countries to address the increased domestic food demand. In the year 2009/10, this country imported 350,000 tons of food grains and this figure is 150% higher than that of 2008/09 (WFP, 2010). So, to address the food insecurity situation in the country, there is a need to improve the yield and cropping intensity of this system. But, rice-wheat system is considered the potential source of greenhouse gases (GHGs) in Nepal and further intensification of this system increases addition GHGs. So, promotion of appropriate options that harmonize these two problems is important. This paper discusses the potentials of soil conservation practices, especially organic matter management and zero-tillage for the sustainability of rice-wheat system in Nepal.

## 2. Characteristics of Nepalese rice-wheat system

Growing rice and wheat is the ancient phenomena in Nepal; the country is rich in landraces of these crops which are grown from tarai to hills. Most of the landraces are photosensitive, long duration and adapted to specific niches. The development of short duration and photo insensitive varieties of rice and wheat crops in 1960s led to the expansion of rice-wheat system in the country (Joshi, Mudwari and Bhatta., 2006).

Basically, rice is a summer crop grown from March to April and harvested from September to October in hills, whereas it is planted from June to July and harvested from September to October in the tarai. However, there is quite a variation in planting and harvesting times even within hills and tarai. These times are determined by types of crop varieties (short duration varieties mature earlier), geographical locations (e.g. rice planting in western region occurs 20-30 days earlier than that of eastern tarai) and cropping patterns (Khanal et al., 2006; Tripathi et al., 2006). Wheat is grown as a winter crop in tarai (planting in November and harvesting in March) and hills (planting in November and harvesting in April). In addition to rice and wheat, spring season crops are also grown in the land that remains fallow after the harvesting of wheat and before the planting of next season rice where irrigation facilities or residual moisture exist (FORWARD, 2010). These crops include spring season rice (planting in March/April and harvesting in June/July), mungbean (*Vigna radiata* L.), maize (*Zea mays* L.), linseed (*Linum usitatissimum* L.), pea (*Pisum sativum* L.) and so on. With the increased irrigation facilities and accessibility of short duration varieties of the above crops, the area under spring season crops is increasing, especially in the tarai region (NGLRP, 2010).

Generally rice-wheat system is considered the input intensive system as compared to other cropping systems such as rice-fallow. This system is prevalent both in non-irrigated and irrigated land, and the level of input use is quite higher in the former one. On an average, farmers in Nepal use chemical fertilizer @ 30 kg $ha^{-1}$ and 35 kg $ha^{-1}$ in rice and wheat, respectively in a year in the irrigated system. But information is not available about how much chemical fertilizers farmers apply in non-irrigated condition. (MoAC, 2010).

Rice is normally grown in the water retaining soil and to increase the water holding capacity of soil farmers adopt some practices such as puddling in the process of land preparation. This practice develops a pan below the soil surface which reduces the percolation of water from rice field. Farmers also prepare bunds around the plot/field to harvest water coming from rain or flood, especially in the rainfed or partially irrigated fields. In contrast to this, wheat needs well-drained soil and this crop cannot withstand water logging condition at any time of its growth and development. So, based on the soil moisture regimes farmers adopt appropriate agronomic techniques for maintaining drainage in wheat field. Raised bed preparation, land leveling, preparation and maintenance of drainage canals and use of appropriate irrigation scheduling are some of the techniques adopted by the farmers (Regmi et al., 2009)

## 3. Sustainability issues in rice-wheat system

Being the dominant cropping system of the country, increasing cropping intensity of the system is one of the important strategies to increase food production. But this system has already faced sustainability challenge which is depicted in the form of declining crop yield. The exact reasons behind this issue are yet to be fully understood; however, the existing literature suggests that declining soil fertility and shortage of water are the major ones. The fertility status of the Nepalese rice-wheat system has been declined due to poor organic matter content in the soil (>60% field with low organic matter content) and improper use of chemical fertilizers. Imbalance use of chemical fertilizers in the soil hampers the physiochemical and micro-biological properties of soil. The second sustainability issue associated with rice-wheat system is the shortage of water. Due to increased pressure on water resources with increased population and associated development efforts, declining water table and drying up surface water sources have been the common phenomena in recent years. The third sustainability issue in rice-wheat system is its potential to emit green house gases (GHGs) such as nitrous oxide ($N_2O$), Carbondioxide ($CO_2$) and Methane ($CH_4$). Existing literature suggests that though Nepal's share to global GHG emission is negligible (0.025%) the emission rate is very high (IPCC, 2007). From 1990/91 to 1994/95 the annual emission growth rate of GHGs in Nepal was 13.1% in which agriculture and forestry sectors were the major contributors (Maharjan, Joshi and Piya, 2011). The emission of $N_2O$ is mainly concerned with the application of nitrogenous chemical fertilizer whereas $CO_2$ with fossils fuel consumption and $CH_4$ with water logging condition in rice, and burning of crop residues. Since GHG emission is related to the climate change and in the context of Nepal's facing the negative consequences of climate change in agriculture sector, the rice-wheat system cannot be the exception. So, minimizing GHGs from the system is important for rice-wheat system itself and to the global community.

## 4. Soil conservation practices in rice-wheat wystem

Soil conservation practices are the techniques that are built on integrating local resources and indigenous knowledge farmers have gained from long period of time (Dumanski et al., 2006). Due to these reasons, they are considered sustainable. These practices are primarily concerned with judicious application of agriculture inputs without deteriorating the soil quality (Tripathi et al., 2006; Regmi et al., 2009). In this article we focus our discussion on organic matter management and zero-tillage.

## 5. Organic matter and its sources in rice-wheat system

Organic matter is defined as carbon compounds which originate from living beings such as plants and animals (Toomsan et al., 2000). Naturally, the carbon compounds are built-up on earth surface through in-situ deposition and decomposition of organic matter. But in the rice-wheat system, the level of organic matter has been depleted over the years. Forest, livestock and farm are the major sources of organic matter in Nepal. The forest-based sources of organic matter are green biomass, which are either directly incorporated into the soil (green manure) or used as mulch or fed to animal and later converted to farm yard manure (FYM) or compost. The farm-based organic sources are crop residues and green manures. Many developed countries have been using the crop residues from rice and wheat as major source of organic matter, but most of the residues of these crops are used as animal feed in Nepalese context (IFPRI, 2009). So, FYM/compost and green manures offer great potential to supply organic matter in this system

### 5.1 Farm Yard Manure (FYM) and compost

Farm Yard Manure (FYM) and compost are prepared from the same materials: animal dung and residues from field crops and forest. However, the concentration of dung is higher in FYM. Large ruminants such as cows and buffaloes are the major sources of animal dung in Nepal. The dung and urine dropped in the shed is mixed with plant residues and deposited in a pit. The decomposed product is called FYM/compost and is applied at different rates on crop fields before the final land preparation (Subedi, 1997). There is no exact data how much amount of FYM/compost is applied by households per unit land in rice-wheat system; however, two studies show that farmers apply FYM/compost @ 0 to 23 $tha^{-1}$ (Tripathi et al., 2006; Regmi et al., 2009). Generally, farmers use FYM/compost in the field during the wheat growing season (i.e. November) because of heavy weight of the FYM/compost during rice growing season (rainy months i.e. June to July). This is because normally farmers prepare FYM /compost pits in open area without any shed (Subedi, 1992).

### 5.2 Green manures

Green manures are collected from a variety of plants grown on-farms, forests and marginal lands. Farmers incorporate them into soils as manure in rice-fields or as mulch in nurseries, and these practices have been adopted by farmers both in tarai and the hills under rice-wheat system. Due to geographical diversity, there is quite a variation in plants used as green manures in tarai and the hills. In the hills, *asuro* (*Justicia adhatoda* L.), *siplikan* (*Crataeva magna* Lour.), *titepati* (*Artemisia capillaris* Thunb.), *bakaino*

(*Melia azedarach* L.) and rice bean (*Vigna umbellate* Thunb.) are the popular green manures (Subedi, 1997). All these plants except the last one can also be used as a fence crop against stray/wild animals. In tarai and foothills, mungbean is grown as a sole crop or mixed crop with maize and its biomass is incorporated in the soil before rice planting. People used to grow local landraces of mungbean as green manure in some Tarai districts of Nepal for the long time. But the introduction of short duration and high yielding mungbean varieties such as Kalyan and Prateeksha made it possible to harvest the grain yield (up to 2 $tha^{-1}$) in addition to green manures. *Dhaincha* (*Sesbania* spp.) is another green manure grown in rice-wheat system. Its two to two and half months old biomass is incorporated in soil before rice planting. People in tarai also grow macuna (*Macuna acuminata* L.) as a green manure crop during spring season. Being leguminous species, mungbean (10 $kgha^{-1}$), *dhaincha* (90 $kgha^{-1}$) and macuna (30 $kgha^{-1}$) fix atmospheric nitrogen in symbiotic association with soil bacteria (Rhizobia) (Toomsan et al., 2000; Pandey, Shah and Becker, 2008; Shah et al., 2011).

## 6. Roles of organic matter for enhancing crop yield

Organic matter increases the carbon and other plant nutrients in the soil and it results to improve the soil quality and crop yield (Stanhill, 1990). For example, incorporating mungbean biomass after two pickings of pods in rice fields increases the grain yield of rice by 20% (Khanal et al., 2006). Similarly, another study shows that incorporating *asuro* leaf increases the rice yield by 45% (Subedi, 1992). Similarly, in-situ incorporation of *dhaincha* increases the rice yield by 25%. The green biomass of these species is rich in plant nutrients especially in nitrogen (2.5%) which results into increased crop yield. Similarly, mungbean biomass incorporated fields have shown to have increased the biodiversity of soil micro-organisms, which are important for maintaining soil health (Devkota et al., 2006).

Various physiochemical and biological basis have been postulated to describe the mechanism behind the roles of organic matter in the sustainability of rice-wheat system. The first mechanism is associated with tolerance to drought. Organic matter holds moisture and makes it available to plant roots, so under drought condition, crop yield in organically managed systems is higher than that of crops managed integrating chemical fertilizer and organic manure (Dormaar, Lindwall and Kozub, 1988; Denison, 1996). The second mechanism is to facilitate plant roots to uptake nutrients from soil. The population of mycorrhizae (a symbiotic association of fungi with plant roots) has been shown to be more abundant in the roots of crops grown in soils with higher organic matter (Eason, Scullion and Scott, 1999). This makes the plants able to extract nutrients that are bound with soil particles and not easily available to plant roots. Thirdly, the organic matters lead to improve soil stability and resistance to water erosion due to higher carbon content and improved soil aggregation. Better soil aggregates improve permeability, lower bulk density and enhance resistance to wind and water erosion (Stanhill, 1990).

## 7. Relationship of organic matter management with GHGs emission

Methane ($CH_4$) and Nitrous oxide ($N_2O$) are the major GHGs associated with fertility management in rice-wheat system. Methane gas mainly produced from rice field grown under water logging condition whereas the nitrous oxide is emitted not only from rice and wheat but also from fallow land remaining after harvesting of wheat and before the planting of next season rice.

Methane emission from rice field is an important source of GHGs in Nepal. In 1994/95, rice fields emitted 306 giga tons of $CH_4$ which is equivalent to 35% of the total $CH_4$ emitted in the country. Anaerobic decomposition of organic matter in the flooded field produces methane and is escape to the atmosphere by diffusion through the rice plant during its growing season. The major pathways of $CH_4$ production in flooded soils are the reduction of $CO_2$ with $H_2$, with fatty acids or alcohols as hydrogen donor, and the transmethylation of acetic acid or methanol by methane-producing bacteria (Dormar, Lindwall and Kozub, 1988). Incorporation of undecomposed organic matter in soil increases the emission of $CH_4$. The FYM/compost, which is the most dominant source of organic matter in Nepalese rice-wheat system, is prepared through anaerobic fermentation and even the fermented product is not well-decomposed in most of the cases (Subedi et al., 1997). The application of not well-decomposed manure increases $CH_4$ and severity of crop pests. This can be solved by the use of effective microorganisms such as *Trichoderma* spp., *Gliocladium virens* to speed up the decomposition process. Also, arrangement of aeration in FYM/compost pit has been found effective to minimize the emission of $CH_4$. Another option to minimize emission from FYM/compost is the promotion of bio-gas plants. While doing so, the $CH_4$ produced from decomposed organic matter can be used as a source of household energy and the slurry (by product from biogas plant) can be used as organic manure in the field. A study has shown that biogas could reduce emissions by approximately 60% as compared to FYM prepared from conventional method (Eason, Scullion and Scott, 1999). So, biogas saves fossils fuel by providing alternative energy source for household energy consumption and it contributes in the GHGs mitigation at the same time. There is a growing trend of establishing biogas plants in the country and clean development mechanism (CDM) of the Kyoto

Protocol seems to be a good opportunity to promote more biogas plants in the country (Maharjan, Joshi and Piya, 2011).

The emission of $N_2O$ from rice-wheat system is linked with the nitrogen cycle associated with the system (Figure 1). Farmers use both chemical fertilizers (e.g. urea) and organic sources (FYM/compost, green manure) in the field. Also, nitrogen is added in the soil by symbiotic (if green legumes grown in the field) and non-symbiotic (e.g. blue green algae) nitrogen fixation processes. When nitrogenous fertilizers dissolved/decomposed in soil, ammonium ($NH_4^+$) ion is released and it further converts into nitrate ($NO_3^-$) ion through the process called nitrification. This nitrate ion is taken by plant roots. But the plant roots do not uptake all the nitrate ion at the same time, the remaining part is lost either through leaching or through denitrification (the process through which the nitrate form of nitrogen converts into nitrous oxide or nitrogen gas). Studies have shown that 30-70% of nitrogen applied through chemical fertilizer in rice field in Nepal is lost through denitrification and leaching (Toomsan et al., 2000; Pandey, Shah and Becker, 2008)

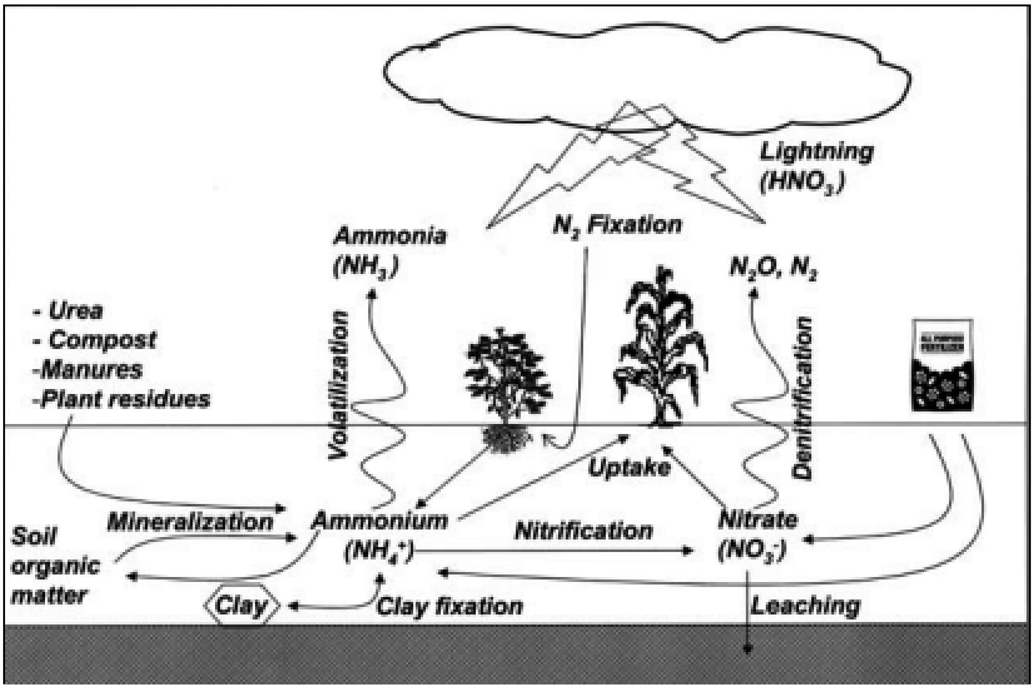


**Figure 1.** Nitrogen cycle in rice-wheat system of Nepal

**Source:** Toomsan et al., 2000.

During the wheat growing season, most of the nitrogen applied in the soil is taken by wheat crop and therefore the loss of $N_2O$ and $NO_3$ is generally low. Once the wheat crop is harvested in April or May, the air and soil temperature increases due to intense sun light. Then, the process of mineralization and nitrification is accelerated by which the nitrogen bound in the plant roots and organic matter (in ammonium form) is released (in nitrate form). Pande, Shah and Becker (2008) found that $NH_4$-N content in the bare soil decreased from 21.2 to 5.9 kgha$^{-1}$ and from 12.3 to 9.3 kgha$^{-1}$ after 6 weeks of wheat harvesting in the year 2001 and 2003, respectively. But he found the peak of $N_2O$ 11micro mol per m$^2$ at that time and this concentration drastically reduced (2 micro mol $N_2O$ per m$^2$) after the rain. This is due to the fact that when $N_2O$ reacts with water it converts into $NO_3^-$ form and leaches out from the soil surface. Similar studies carried out in China and India have found that $N_2O$ is lost from the bare soil in the range of 0.034-0.06 kg $N_2O$-N ha$^{-1}$ during the spring season (Chen et al., 1997). There is no exact information available how much amount of $N_2O$ is emitted from rice-wheat system as a whole from per unit land in Nepal.

There is about 0.4 million hectare land fallow in the spring season due to limited irrigation facility, agronomic options as well as free grazing (Khanal et al., 2006). At this circumstance, planting spring season crops at the fallow land holds enormous potential to mitigate $N_2O$ emission from soil. Field experiments carried out in Chitawan and Rupandehi districts during 2001 to 2003 show that growing maize, mungbean or macuna reduces the $NO_3^-$ nitrogen peak by 50 to 75%. However, macuna shows the highest response (75% reduction) and is followed by mungbean (65%) and maize (20%) with reference to loss of nitrate nitrogen from bare soil 20 kgha$^{-1}$) after 7 weeks of wheat harvesting. The plant analysis show that total N accumulation by mucuna, mungbean and maize were 108, 80 and 54 kgha$^{-1}$. These results demonstrate the high potential of spring season crops in trapping the nitrate nitrogen from. However, the legumes are considered much more important than maize considering their roles in fixing atmospheric nitrogen.

## 8. Zero-tillage and its application in rice-wheat system

Zero-tillage is a method of tilling the field with minimum soil disturbance. It is synonymously used with conservation tillage because minimizing the soil disturbance improves soil quality and production efficiency. Based on crop species in which it is applied zero-tillage is named with some modification. For example, if small band or trench is made while applying the zero-tillage practice in legumes to ensure the crop establishment covering the seed with the layer of soil or organic matter, it is called strip-tillage or minimum tillage or reduced tillage (Dumanski et al., 2006; Derpsch, 2007). And if seed is sown directly in the field manually or using seed drill, it is called no-till or surface seeding, and this practice is common in wheat in India and Pakistan, and is spreading to Nepal (Tripathi et al., 2006). In this article zero tillage is synonymously used with surface seeding or no-till.

Surface seeding is a traditional practice in Nepal being adopted by farmers in lentil, wheat, garlic and linseed since the long time period, especially in the residual moisture that exists after rice harvest. However, in all the above cases seed sowing is done manually. National wheat research organization started on-station research on surface seeding in wheat in the 1980s, and from the 1990s, the organization started validating the practice in farmers' fields. From mid 1990s research activities were started for the validation of seed drills for surface seeding in wheat both in on-station and on-farm conditions (Tripathi et al., 2006; Regmi et al., 2009).

## 9. Relationship of zero-tillage with crop yield

Zero-tillage practice in wheat offers various socio-economic benefits to the growers. The first one is associated to increasing cropping intensity and yield. Studies have shown that it is possible to sow wheat about 15-20 days earlier than that of the conventional practice through zero-tillage (Ladha et al., 2003; Regmi et al., 2009). As a result, wheat can be harvested earlier and it is possible to grow spring season crops such as maize, mungbean and so on. Timely planting of wheat (Oct 15 to Nov 15 as per recommended by Nepal Agriculture Research Council) is also important to escape the problem of terminal drought that causes sterility problem in wheat. Studies have confirmed that planting of wheat after first week of December reduces the wheat yield @ 1-1.5% per day (Gupta and Sayre, 2007; Ladha et al., 2003). Regmi et al. (2009) found 30-40% higher yield in zero-tillage practice as compared to conventional practice in tarai areas of Nepal. Similarly, Shah et al (2011) found 16% higher wheat grain yield in zero-tillage (1.8 $tha^{-1}$) than that of conventional tillage (1.58 $tha^{-1}$) in case of Rampur district. The long-term experiments carried out India and Pakistan from 1985 to 2003 show 30-50 % higher grain yield of wheat in zero-tillage as compared to the conventional one (IFPRI, 2009). It is estimated that about one-third of wheat in Nepal is planted late due to late-maturing rice varieties such as *Basmati and Radha 12*. At this circumstance, zero-tillage would positively contribute to solve this problem.

**Table 1.** Comparison of potential benefits between zero-tillage and without zero-tillage in wheat

| Variables | Without zero-tillage | With zero-tillage |
|---|---|---|
| Cropping pattern | Rice-wheat-fallow | Rice-wheat-mungbean |
| Cropping intensity (%) | 200 | 300 |
| Sterility in wheat | High | Low |
| Water use efficiency | Low | High |
| Weed management | Difficult | Easy |
| Nutrient use efficiency | Low | High |
| Labor use efficiency | Low | High |

Second benefit from zero-tillage is related to increasing resource use efficiency. In Nepal, about 30-40% of the total cost is involved in land preparation during wheat sowing (Yadav et al., 2010). Erenstein and Farooq (2009) showed that zero-tillage saves cost (US$ 52 per hectare) due primarily to the reduction in tractor time and fuel for land preparation, which leads to into higher benefits of US$ 97 per hectare than conventional practice. Similarly, Regmi et al (2009) claimed that zero-tillage saves 64% of the cost involved in land preparation.

Zero-tillage has been found promising not only in land preparation but it makes the others intercultural operations easier. For example, it is easier to control obnoxious weeds like *Phalaris minor* Retz. in zero tillage if wheat sown using seed drill. Since this machine sows the seed in rows and it makes the weeding easier (Erenstein and Laxmi, 2008). Zero-tillage also increases the water use efficiency allowing the field to irrigate faster as compared to conventional tillage. It is due to the fact that more water is needed to irrigate tilled soil than non-tilled soil. Studies (Ladha et al., 2003; Gupta and Sayre, 2007) have shown that zero-tillage saves 30-50% water in wheat considering two irrigations (first during crown root initiation stage after 25-30 days of seed sowing and second during flowering). In addition to wheat, zero-tillage technique was also tested in rice through direct sowing of rice seed, but the crop yield was found lower (5.5 $tha^{-1}$) than that of conventional tillage (6.3 $tha^{-1}$). Heavy infestation of weed has been found one of the factors reducing rice grain yield (Regmi et al., 2009).

In addition to economic benefits, zero-tillage contributes to social benefits. One such benefit is associated with the time saving. There are evidences that households can use the saving time in social, and leisure purposes (Erenstein and Farooq 2009). Women generally appreciate zero tillage due to less anxiety at the time of wheat field preparation, and this results into more peace at home (Erenstein and Laxmi 2008; Gupta and Sayre, 2007). Similarly, Joshi, Mudwari and Bhatta (2006) claims that zero-tillage leads to nutritional security of women allowing them additional time to grow other food sources such as vegetables.

All the above comparisons were made in the farming communities where tractor is the main source of traction and seed sowing was done using seed drill. But there is lack of information about how much extra benefit farmers would realize adopting bullock-drawn seed drill for seed sowing in wheat as bullock is still the major source of traction in Nepalese farmers (MoAC, 2010).

## 10. Relationship of zero-tillage with GHG emission

The environmental benefits of zero-tillage are associated with its potential to minimize the consumption of fossil fuels needed for tillage operations and irrigation (Ladha et al., 2003). A case of South Asia shows that zero-tillage saves 36 liters of diesel for the cultivation of wheat in a hectare, which is 8 percent less as compared to the conventional tillage (Erenstein and Laxmi, 2008). Similarly, zero-tillage saves water where wheat is grown in the irrigated condition. Reducing the consumption of water is also associated with decreasing fossil fuel consumption. Moreover, zero-tillage minimizes the decomposition of soil organic matter in the soil which ultimately contributes in reducing the emission of $N_2O$ (Tripathi et al., 2006; Gupta and Sayre, 2007).

## 11. Other soil conservation options

Though zero-tillage and organic matter management contribute both in the crop yield and mitigation of GHGs, these techniques need to be integrated with other agronomic practices such as fertilizer management, water management and use of crop varieties to increase crop yield and to mitigate GHG s.

### 11.1 Fertilizer management

Improper application of chemical fertilizers reduces crop yield, deteriorates the soil quality, and increases GHG emission. To increase the fertilizer use efficiency and to reduce GHGs, identification of appropriate fertilizers and their application method is important. For example, the application of urea granules coated with dicyandiamide (DCD) or calcium carbide (CC) (Denison, 1996) matching with crop growth stage not only increases nitrogen use efficiency but also decreases the nitrogen leaching from soil. It is because using these granules, nitrogen releases to the soil slowly and most of the released nitrogen is absorbed by plants. In addition, botanicals, such as neem (*Azadirachta indica* A. Juss.) seed was found promising as nitrogen inhibitor in India. Another way of minimizing the nitrogen loss from rice field is to apply the nitrogenous fertilizers in split dozes as per the crop requirement which can be identified through leaf color chart or photometer. The other option in minimizing N loss is selection of appropriate fertilizers. The release of nitrogen from amonium sulphate is slower than that of urea. Also, due to the availability of sulphur, ammonium sulphate minimizes the emission of $CH_4$ from rice field. Similarly, the application of gypsum ($CaSO_4$) in the rice field reduces the $CH_4$ emissions by 29-46 % (Domaar, Lindwall and Kozub, 1988).

### 11.2 Water and land management

Rice is grown in water retaining soil whereas the wheat in drained soil. Combining land management techniques with irrigation would increase the water use efficiency, crop yield and mitigate the $CH_4$ emission from rice-wheat system. Some land management techniques such as laser land leveling, bed planting, have been promising to increase the water use efficiency in wheat. One study shows that laser leveling in wheat field in Pakistan saves 25% water (Yadav et al., 2010). Similarly, management of proper drainage and adoption of SRI (System of rice intensification techniques) are other practices contributing on water management. The SRI technique combines the concept of drainage along with adoption of young (10-14 days old) single seedling, space planting and organic manure application. This technique is being promoted across the rice growing environments. Though farmers have internalized the resource (water, fertilizer and seed) and yield advantage of this technique over conventional one; however, its adoption is limited due to weed infestation and higher cost involved in the planting of seedling (Upreti, 2008).

### 11.3 Upland rice varieties

Methane gas emission is associated mainly with lowland rice varieties where water logging exists. The emission of $CH_4$ can be reduced with the promotion of upland varieties (Yadav et al., 2010). These varieties are of short duration and do not need water logging condition for long period of time. But, upland varieties have lower yield potential. For example, Radha 4 (the variety released for upland in Nepal) yields 4-5 $tha^{-1}$ which is 50 % less than that of lowland variety such as Radha 12 (6-7.5 $tha^{-1}$). So, how to increase the yield potential of upland varieties could be an important breeding issue to address the mitigation of $CH_4$ from rice.

## 12. Factors affecting the adoption of soil conservation practices

Existing literature shows that the adoption of soil conservation practices is affected by various technological, socio-economic and policy factors (Subedi, A, 1997; Tripathi et al., 2006; IFPRI, 2009; Regmi et al., 2009). For example, the household characteristics, accessibility of farmers' friendly seed drills, and pest management have been found to have significant effect on the adoption of zero-tillage/seed drill in wheat in Indogangetic plain (Ladha et al., 2003). Larger and medium households (in terms of landholding) have better access to extension agencies and higher risk bearing capacity than small farmers. So, the adoption of zero-tillage using seed drill in wheat has been found higher in this category of households and vice versa. Similarly, increased infestation of stem borer (*Scirpophaga incertulas*) in aromatic rice variety (basmati) has been a concern in the adoption of zero-tillage practice in some parts of India and Nepal. Moreover, government policy plays significant roles in promoting the soil conservation practices. For example, subsidy scheme on seeds of green manures, field demonstrations for creating effective demand of new technology in the rural farm communities, public private partnerships in designing and marketing of small farmers' friendly seed drill are some of the strategies that contribute positively on the adoption of surface seeding on wheat (IFPRI, 2009).

## 13. Conclusion

Soil conservation practices: organic matter management and zero-tillage hold enormous potential for the sustainability of rice-wheat system. Organic matter improves the physical, chemical and biological properties of soil and also contributes in mitigating GHGs from this system. In this connection, improved composting technologies, biogas plants and spring season legumes seem to be important. Similarly, zero-tillage practice in wheat offers economic, social and environmental benefits. But its applicability is yet to be fully understood in Nepalese context given the availability of limited studies. Together with these soil conservation practices, some agronomic practices such as s water and land management, judicious use of chemical fertilizers and development of high yielding upland rice varieties would contribute in the sustainability of the system.

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