SYSTEM OF RICE INTENSIFICATION: AN ANALYSIS OF ADOPTION AND POTENTIAL ENVIRONMENTAL BENEFITS

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By

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PART I: EXTENDED SUMMARY

System of Rice Intensification: An Analysis of Adoption and Potential Environmental Benefits

Abstract

The world's population is increasing and there has been more concerns towards food security but is challenged by increasing food demand with declining water availability. South Asia faced acute shortage of food in 1960s because of declining productivity of rice. Since then, efforts have been made into increasing the rice productivity. System of Rice Intensification (SRI) has emerged as an alternative to traditional way of flooded rice cultivation and is showing great promise to address the problems of water scarcity coupled by doubling the yield. In an effort to evaluate the adoption and potential environmental benefits of SRI, a case study was conducted in Morang district of Eastern Nepal.

Paper I investigates the determinants of SRI adoption. Data were obtained through household survey with structured questionnaire, key informant interviews, focus group discussion, and field observations. With SRI methods, the cost of chemical fertilizers was reduced by 48 percent, seed requirement was reduced by 90 percent, and the cost of pesticide was reduced by 99 percent. In addition, the farmers in the study area were found to achieve 118 percent increase in rice yield with SRI methods compared to non-SRI methods. The results of the binary logistic regression showed that age of the farmer, landholding, irrigated land, livestock, food sufficiency, training facilities and membership into the farmers' association significantly influenced the adoption of SRI. Weed management, water management and lack of institutional support were found to be the major constraints for SRI adoption. Planners and policy makers should consider the farmers' interest, capacity and limitation in order to promote an environmentally and economically sound approach to enhance the prospects of adopting SRI by farmers.

Paper II investigates the effect of SRI on climate gases particularly CH_4 and N_2O. Closed chamber method was used to collect the gas samples in 2-day interval from 19 July to 14 August 2009. Gas chromatography was used to analyze the gas samples. The soil temperature and the gravimetric moisture content were also measured for each sampling site at each day of sampling. Significant effect of SRI on the fluxes of CH_4 and N_2O was observed. The emission of CH_4 from SRI soil exhibited 4 times less than that of non-SRI soil whereas N_2O flux from SRI soil was 5 times less than non-SRI soils. Similarly, the GWP (global warming potential) of CH_4 and N_2O emissions were significantly reduced with SRI treatments. It is well known that agriculture releases significant amount of CH_4 and N_2O into the atmosphere and that the global warming induced by the concentration of such GHGs is a matter for great environmental concern nowadays. SRI practices not only help to minimize CH_4 emissions but also reduce N_2O emissions. SRI practice was found to have double benefits: increase yield and have potential to reduce climate gas emission to the atmosphere.

Keywords: System of Rice Intensification, Nepal, CH_4 flux, N_2O flux, Global Warming Potential, Adoption, Binary Logistic Regression

1. General Introduction:

Rice is one of the prominent cereal crops in Nepal which contributes to almost one-fourth of the GDP (MOF 2009). It generates substantial income and employment for majority of the Nepalese people. More than 75 percent of the working population is engaged in rice cultivation for almost half of a year (ibid). Rice accounts for about 50 percent of the country's total agricultural area and production (ibid). It also provides almost 50 percent of the calorie requirement supplied by the cereals (Pokhrel 1997).

In global scenario, rice is the most common staple food for about 3 billion people and receives an estimated 24-30 percent of the world's developed freshwater resources (Bouman et al. 2007; Satyanarayana et al. 2007). The world's population is increasing and there has been more concerns towards food security but is challenged by increasing food demand with declining water availability (Farooq et al. 2009). The rice production needs to be increased in order to meet the food demand of growing populations (Bouman et al. 2007). According to Zheng et al. (2004) farmers have to grow 50 percent more rice in 2025 in order to assure food security in rice-consuming countries. In addition, the production should be on less land with less water, less labor and less chemical fertilizers. Various water-saving rice production systems have been developed so far eg. aerobic rice culture, ground-cover rice production system, raised beds, alternate wetting and drying etc (Farooq et al. 2009). System of Rice Intensification (SRI) is one of them. SRI has emerged as an alternative to traditional way of flooded rice cultivation and is showing great promise to address the problems of water scarcity, high energy usage and increased use of chemical fertilizers in field.

Henri de Laulanié is credited for the development of SRI, followed by his 20 yrs of observation and experimentation (Uphoff et al. 2008). SRI was promoted initially by a Malagasy NGO - Association Tefy Saina (ATS) which was founded by Laulanié in 1990 (Stoop et al. 2002; Uphoff et al. 2008). From 1994, CIIFAD worked with ATS to help evaluating and spreading SRI internationally (Uphoff et al. 2008). Positive results from SRI practices have been observed in more than 25 countries. China, India and Indonesia are the three largest rice producing countries, where the results of SRI have been validated (Uphoff 2007 a).

SRI is simply the methodology to increase the productivity of rice by changing the management of plants, soil, water and nutrients (Satyanarayana et al. 2007). Uphoff (2007 a) states that SRI is not a technology, rather it is the set of insights and principle changes dealing with how rice can be grown most successfully. He further states that SRI practices are to be adapted by farmers to their own conditions giving them the full grounds for further innovation. SRI does not depend on the two pillars of the crop-improvement paradigm of the green revolution - varietal improvement, and external inputs (Stoop et al. 2002) rather it is simply some changes in the agro-economic practices like using very young seedlings, its careful transplantation, wider spacing, active aeration of soil during weeding, no continuous flooding of fields and more relying on compost fertilizer (Dobermann 2004; Stoop et al. 2002).

Principles of SRI as of Uphoff (2007 a) are described as follows:

Transplanting very young seedling:

It is recommended to use the seedlings of 8-12 days old, but it should not be older than 15 days. This is because the young seedlings have more potential for profuse tillering and prolific root growth than older seedlings.

Single planting:

Planting 3-6 plants in clump inhibits the growth of roots and canopy of rice plants. It should be understand that any trauma to tender roots will impair the rice plant's subsequent performance.

Wider Spacing:

Recommended spacing in SRI practice is 25×25cm i.e. 16 plants/ m^2. Spacing in square pattern, rather than in rows, allows rice plants to achieve optimum exposure to sunlight and air on all sides. Wider spacing helps to achieve 'the edge effect' throughout the field because all the leaves get enough solar radiation for photosynthesis and no leaf need to be subsidized by other leaves' photosynthesis because of shading. In non-SRI practice, the spacing between hills is too narrow for the best plant growth.

Soil to be kept moist with intermittent flooding, but not continuously saturated:

Most farmers believe that rice plant grows better under flooded condition which is not true. Rice is not an aquatic plant, nor does it perform best when grown under submerged, hypoxic soil conditions (Uphoff 2007 a). The farmers might have been flooding their field to control the weeding. Stoop et al. (2002) believes that intermittent flooding helps improving oxygen supply to the roots, thereby decreasing aerenchyma formation due to which the root system will be more stronger and healthier and able to uptake more nutrients.

Aerating the soil:

In SRI practices, the rice fields are not continuously flooded which triggers more weed problems than in non-SRI practices. SRI practices thus needs more weeding. Stoop et al. (2002) have recommended the use of mechanized weeders to get rid out of weeding problems but mechanical weeding is considered by many farmers as more costly and hectic. Conversely, the benefits of mechanized weeding are far beyond the farmers' imagination. Use of mechanical weeders churns up the soil and buries weeds which allow more oxygen and nitrogen into the soil. This process results soil aeration which increases rice yields. Zheng et al. (2004) stated that more time is needed for weeding in SRI but it is compensated by higher yield due to soil aeration.

Use of Organic fertilizers to the extent possible:

The effect of organic fertilizers is slower as compared to the chemical fertilizers but their value lie on what they do to stimulate biotic growth and activity in the soil, things that chemical fertilizers inhibit (Zheng et al. 2004). Organic farmers use to say "don't feed the plant; rather, feed the soil, and the soil will feed the plant". Adequate organic fertilization improves soil structure and biological diversity thereby gives best SRI results. Chemical fertilizers can also be used with SRI, but addition of compost, mulch, manure etc to the extent possible, gives best results (Uphoff 2007 a). Organic soils have relatively higher water retention capacity and allow better root development (Uprety 2004).

1.1 State of Art in Nepal:

Adoption of SRI in Nepal dates back to 1999 but the early trials were unsuccessful (Evans et al. 2002). In 2002 and 2003, the Farmer Field Schools in the Sunsari-Morang irrigation project undertook replicated trials to evaluate SRI and found the production averages to be over 8 t/ha, while the production from improved methods were about 6 t/ha and from farmer practice was around 4 t/ha (CIIFAD 2006). It was since 2002; the positive results from SRI have been reported. SRI evaluation done in 2004 and 2005 by the PARDYP project sponsored by the ICIMOD in Kathmandu reported an increase in grain yield by 40-50 percent and biomass production by 20-25 percent, with a 75 percent reduction in seed requirements and 50-75 percent less water. Also, 50 percent less labor was needed for transplanting, 50-60 percent less labor utilized for irrigation along with less use of pesticides. However, the cost of weeding increased by 50-60 percent. Fertilizer and harvesting cost remained the same. Getting more production with less total costs was considered a clear net benefit with SRI. Conflict among irrigation water users was almost nil due to reduced frequency of irrigation (Dhakal 2005). A year-end report and an economic analysis for 2005 indicated that practicing SRI method helped the farmers of Morang district to harvest rice production by two folds. With the conventional method, they could produce 3.1 metric tons of rice on average (Uprety 2005). SRI evaluation done by District Agricultural Development Office (DADO) in Morang district of Nepal showed 82 percent increase in yield, 43 percent water saving, 2.2 percent reduction in costs (because rotary weeder was not widely available) and 163 percent increase in net income (Uphoff 2007 a).

1.2 Criticism regarding SRI:

Scientists such as Dobermann (2004), McDonald et al. (2006), Sheehy (2004), Moser & Barrett (2003), Sinclair (2004) have raised the questions regarding the yield benefits of SRI.

Dobermann (2004) reports that intermittent irrigation in SRI practice bear short and long term risks. He further reports that SRI favors rice growth on poor soils but it is likely to have little potential for improving rice production in intensive irrigated systems on more favorable soils. McDonald et al. (2006) found no empirical evidence that SRI fundamentally changes the physiological yield potential of rice. Sheehy (2004) has found no major role of SRI in improving rice yields in his experiments carried out in China and reported that the extraordinary high yields may be due to experimental error. But Stoop & Kassam (2005) reacted to Sheehy (2004) as their research being scientifically and methodologically flawed, and therefore the validity of their conclusions to be questioned. Moser & Barrett (2003) raised issue regarding high labor requirement to practice SRI. But Uphoff (2004) clarifies it with saying that SRI can be more labor-intensive initially but once the farmers have mastered the methods, it becomes labor saving.

Sinclair (2004) claims that SRI uses very low plant densities so suffers from poor light interception. Additionally, he claims that SRI replaces flooding of rice field simply by maintaining moist soil conditions but the rice fields are flooded so as to assure no water limitations. He states that ample water maximizes rice yields. Furthermore, he claims that SRI lacks sufficient mineral nutrients in order to achieve high yields. The claimed yield of 15t/ha requires nitrogen from over 50 t/ha of organic matter because rice grains contain about 0.013 gm of N per gram of seed. Despite such criticisms, SRI is gaining popularity all over the rice growing countries. Farmers have been able to grow more with less water, less mineral fertilizer and less seeds. There may be multiple benefits of SRI which may have been poorly studied.

1.3 Benefits of SRI:

Tech (2004) states that SRI practice helps the farmers to improve their livelihood. He says that SRI performances have raised hope among policy makers, development activists and farmers to solve the food deficit problem in remote areas where modern technologies are not feasible in terms of cost and accessibility. SRI helps to increase the yields and production, reduces farmers' costs of production, and decreases the water requirement for irrigation up to 50 percent less (Randriamiharisoa et al. 2006; Stoop et al. 2002; Uphoff 2007 a). Stoop et al. (2002) further says that SRI helps resource-poor farmers to attain higher yields despite having infertile soil, no mineral fertilizer input, reduced irrigation and fewer seeds. Benefits of SRI have been demonstrated in 32 countries of Asia, Africa, and Latin America namely China, Indonesia, Cambodia, Vietnam, Philippines, Laos, Myanmar, Thailand, India, Nepal, Bangladesh, Sri Lanka, Pakistan, Bhutan, Afghanistan, Iran, Iraq, Egypt, Gambia, Guinea, Senegal, Mali, Sierra Leone, Benin, Mozambique, Rwanda, Zambia, Cuba, Peru, and Brazil (Uphoff et al. 2008).

Evidences show that SRI method increases water-saving by 65 percent in China (Satyanarayana et al. 2007). Similarly, the economic return was reported 41 percent higher in Cambodia, also there was 44 percent increase in yield in Srilanka (ibid). The cost of production was reported to be reduced by 25 percent in Indonesia (ibid). Similarly, Dixit (2005) writes that the rice production with SRI was increased by 28 percent with 53 percent less water in Tamil Nadu in India. The income with SRI was increased by 44 percent in Sri Lanka (ibid). Similarly, the harvest increased by 35 to 50 percent in China and 41 percent in Cambodia (ibid).

As compared to the rice grown through traditional way, the SRI has following benefits according to Uphoff (2007 a):

Greater resistance of SRI crop to pest and disease loss:

SRI crops are found to have greater resistance against pest and diseases. Chemical means of controlling diseases and pests are neither economic nor necessary, if SRI practice is followed. Zheng et al. (2004) states that SRI plants have less insect and disease problems.

Greater resistance to abiotic stress:

In coming decades, the farmers have to face various changes in climatic pattern so it is important that the crops can tolerate adverse biotic and abiotic stresses (Uphoff 2007 b). SRI plants have large and strong root systems which enable them to tolerate adverse climatic influences as water stress, drought, storm damage, cold snaps, heat waves etc. Additionally, despite their larger and heavier grain panicles, SRI plants have greater resistance against lodging i.e. falling over.

Higher out-turn of milled rice:

SRI plants not only increase the yield of paddy (kg of un-milled rice harvested per hectare), but also offer 15 percent more of milled rice (kg of consumable rice per bushel of paddy), because SRI grains have less chaff (fewer unfilled grains) and less shattering (fewer broken grains) (Uphoff 2007 b).

More nutritional value and grain quality:

There is 30-65 percent less chalkiness in SRI grains. SRI roots are larger and go deeper into soil so it is believed that SRI plants uptake higher micronutrients from the soil.

Reduction in greenhouse gas emission:

Flooded rice fields are an important source for green house gas emissions. It is believed that methane emission from SRI soils will be less because the rice is grown under aerobic conditions. Also, application of no inorganic nitrogen fertilizer may reduce nitrous oxide formation. However, very few studies have been done so far to evaluate this.

We made an attempt to evaluate both economic and environmental benefit and adoption aspects related to SRI.

1.4 Statement of the problem:

Around 30 percent of the population of Nepal is below the poverty line. Agriculture, being the mainstay of the economy, provides a livelihood for 80 percent of the population and accounts for 36 percent of GDP (MOF 2009). Rice is the most important cereal crop. But there has always been fluctuation in its production due to dependency on monsoon rainfall, added that Nepal has not reached its irrigation potential (ibid). Despite being the main crop of Nepal, rice cultivation is becoming less profitable due to increasing price of inputs and decreasing returns. During monsoon in Nepal, more than 80pc of the cultivated area belong to rice. In absence of rain water, the fields are left barren or grown with the crops which require less water (Uprety 2005).

SRI is feasible in terms of its less water requirement. SRI does not require farmers to shift towards the high yielding variety of genetically modified rice. It's only the change in cultivation method which enables them to harvest more than double thereby increasing their socio-economic wellbeing. It is even claimed that no part of Nepal need to be short of food anymore if SRI is promoted nationally (Dixit 2005).

SRI studies done so far by many researchers and scientists are limited to experimental and demonstration activities. Almost no studies have been carried out on the determinants of adoption of SRI. This study contributes on filling research gap based on Nepalese farmer's experience. Paper I of this study specifically assesses the determinants for adoption of the SRI.

Additionally, Climate change has been a global issue nowadays. Agriculture production being the important source of green house gases emission, it has been recorded that flooded rice field consequently releases large quantities of CH_4 (Bronson et al. 1997; Wassmann et. al. 2004). Applications of N-fertilizers on such fields assist releasing N_2O – a climate gas (Wassmann et. al. 2004). The traditional method of cultivating rice has been practiced by a huge majority of farmers in Nepal ultimately releasing CH_4 and N_2O. Furthermore, reduction in productivity compels them to use chemical fertilizers with N-content thereby releasing more N_2O gas from rice field and decreasing net CH_4 uptake by soil. Role of agriculture as a driving force for climate change can be reduced if certain practices are taken into consideration, SRI is one of them. The rice field needs no flooding which results in less emission of CH_4 gas. Also, there is no need of using pesticides or chemical fertilizers to increase the productivity of land thereby less emission of N_2O gas.

Very few researches have been conducted so far on the green house gas emission on rice field and particularly in SRI system. Johnson-Beebout et al. (2009) concluded that appropriate water and residue management in rice field can reduce greenhouse gas emissions. Water management practices which decrease the length of flooding time can mitigate CH_4 emission but when flood water disappears, N_2O emission occurs and is further exacerbated by application of N fertilizer (Bronson et al. 1997; Cai et al. 1997; Yagi et al. 1996). Maraseni et al. (2009) had studied the relationship between GHG emissions and rice yield and concluded that SRI reduces the length of wetting period and minimize the use of chemical nitrogen input, both practices lead to reduced N_2O and CH_4 emission. Paper II of this study tries to find the effect of SRI on the fluxes of climate gases particularly, CH_4 and N_2O.

1.5 Objectives of the Study:

1. To investigate the determinant factors for adoption of SRI at farm level (Paper I).
2. To find out the effect of SRI on the fluxes of N_2O and CH_4 gases at Jhorahat VDC in Morang district of Eastern Nepal (Paper II).

1.6 Conceptual Framework:

In view of the state of the art on SRI, the conceptual framework of the study was designed so as to address both the socioeconomic and biophysical factors.

The socioeconomic study was carried out to examine the socio-economic and institutional factors responsible for the adoption of SRI at farm level. Personal/social factors such as age, sex, caste, education, household size; resource/economical factors such as off-farm occupation, landholding, landholding, livestock, irrigated land, food sufficiency; and institutional factors such as credit facilities, accessibility to various infrastructure, membership in the farmers' associations, training facilities etc were analyzed to see if they influence the adoption of SRI. Socioeconomic study thus enabled the researcher to determine the constraining factors of adoption at farm level. The results of the study would be vital for the planners and policy makers to promote the SRI.

The biophysical study consists of a field experiment carried out to find out the effect of SRI on the fluxes of CH_4 and N_2O gases. The conceptual framework for the study is outlined in the figure 1.

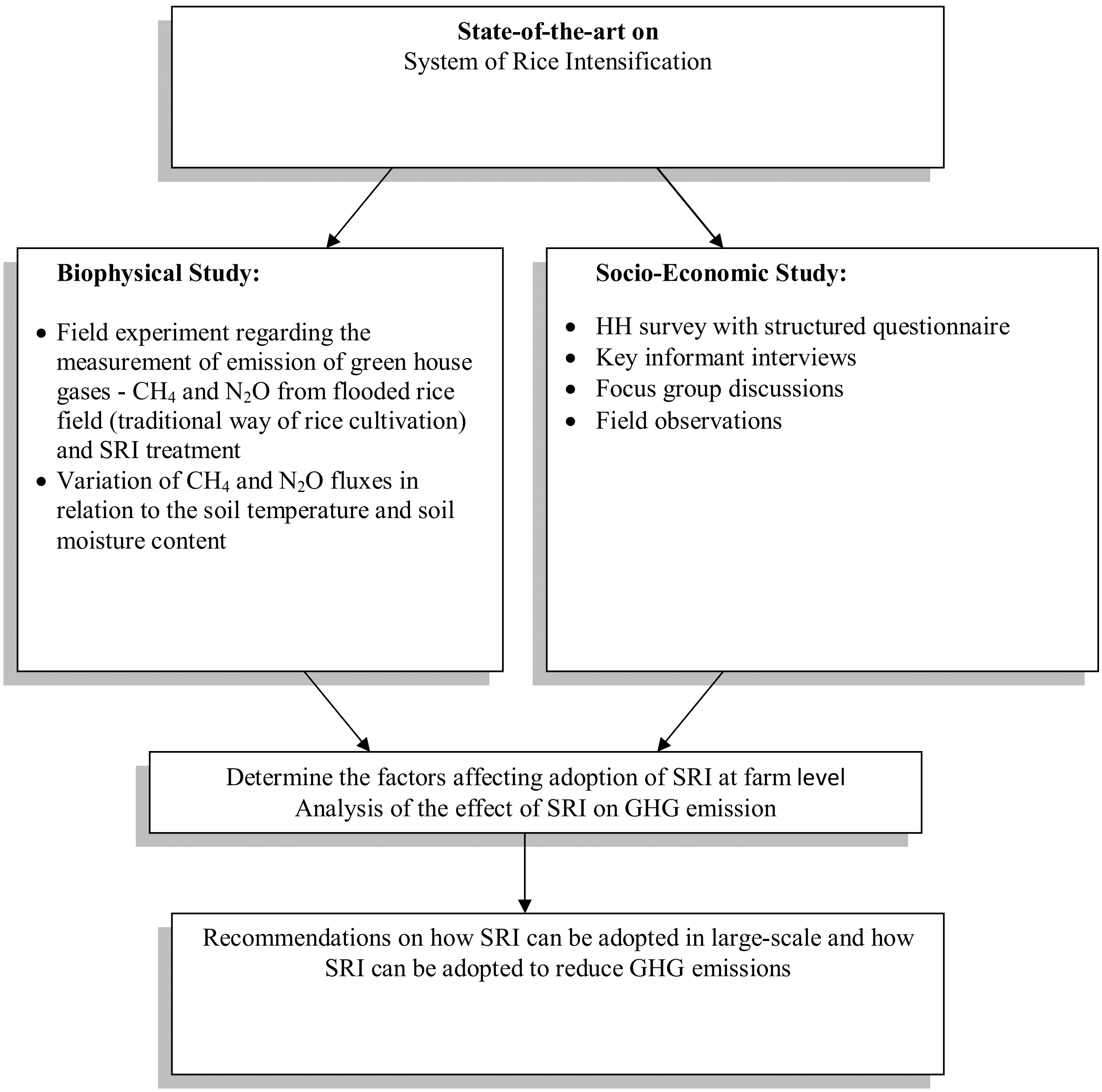

Fig 1: Conceptual framework of the study

2. Materials and Methods:

2.1 Study Area:

The Morang District of Eastern Nepal is situated between latitudes 26°20' to 26°53'N and longitudes 87°16' to 87°41'E. It covers an area of 1,855 km^2 and has a population of 843,220 as of population census 2001. Biratnagar is its headquarter which is also the 2^{nd} largest city after Kathmandu. Altitude varies from 60-2410m. Morang has tropical and monsoonic type of climate with 1312 mm average annual rainfall, and 30.6°C and 14.2°C average annual maximum and minimum temperatures, respectively (DADO 2008). Morang, being one of the important rice-growing districts, has been selected as the study area. Total rice-growing area of this district is more than 94,000 ha. Average rice productivity in the district is 3.173 Mt/ha (Uprety 2005), which is well-above the national average 2.907 Mt/ha for the fiscal year 2008/09 (MOAC 2010).

2.2 Research Methodology:

This study is presented in two research papers, one dealing with the socioeconomic studies (Paper I) while the other dealing with the biophysical studies (Paper II), so both the quantitative and qualitative research methods were applied for this study.

Primary data regarding the adoption of SRI by local farmers (Paper I) were obtained through household survey with structured questionnaire, key informant interviews, focus group discussion, and field observations. Relevant secondary data were obtained from different publications, books, journals, newspaper articles, dissertations, year-end reports and so on. Household survey was conducted at the four VDCs of Morang district namely Jhorahat, Indrapur, Motipur and Kaseni. Quantitative data obtained through household survey was processed using Statistical Package for Social Science (SPSS Statistics 17.0). Frequency tables were generated for general information, t-tests were used to compare the mean difference between SRI and non-SRI farmers, chi-square tests were used to analyze categorical data, correlations were used to identify the interdependence among various factors influencing the adoption of SRI and finally, binary logistic regression model was applied to find out the degree of relationship between dependent and independent variables influencing the adoption of SRI. Similarly, qualitative data obtained through interviews, focus group discussion, and field observations were analyzed to support the quantitative data.

Similarly, from July to August 2009, emission of green house gases particularly CH_4 and N_2O were measured from fields consisting two different treatments – SRI and non-SRI, using closed chamber methods. Details on the differences between two treatments are explained in Table 1 of Paper II. The gas samples were analyzed using gas chromatography (Bakken L. et al. 2010). In each date of gas measurement, the soil temperature and the soil moisture content were also measured to find out their effects on the gas fluxes. The effects of treatment, temperature and moisture on GHG flux were analyzed by General Linear Model (GLM) procedure by using Statistical Analysis System Programme (SAS Institute). Multiple comparison of means for each variable were carried out using Student-Newman-Keuls (SNK) test at $\alpha = 0.05$. Basic calculations and curves were also generated from Microsoft Excel 2007 and Minitab 15.

3. Results and Discussions:

Paper I: Determinants of Farm-Level Adoption of System of Rice Intensification (SRI) in Eastern Nepal

Adopters and nonadopters were significantly different in terms of the personal/social characteristics, resource/economic characteristics and institutional characteristics. Age of the farmer was significantly different at $P<0.001$ whereas the educational level of the farmers was significantly different at $P<0.005$. SRI adopters were younger and well educated compared to non-adopters. Landholding, irrigated land and total livestock standard unit were significantly different among the adopters and nonadopters at $P<0.001$. Eighty one percent of the SRI farmers were found to have more than 1 bigha (0.68 ha) of land. Similarly, sixty two percent of the SRI farmers were found to have sufficient irrigation facilities into their farm. SRI farmers were found to have 1.30 Livestock Standard Unit whereas non-SRI farmers were found to have only 0.75 Livestock Standard Unit. Similarly, membership into farmers association and number of types of trainings taken by the farmers were significantly different among the adopters and nonadopters at P<0.001.

The cost of rice production was significantly different among the SRI and non-SRI farmers at P<0.001. Cost of nursery/land preparation, cost of irrigation, cost of wedding and cost of labor for cutting/threshing with SRI practices were found to be significantly higher compared to non-SRI practices. However, the cost of seed, cost of chemical fertilizer, cost of transplanting and cost of pesticide were found to be significantly reduced in SRI practice. With SRI methods, the seed requirement was reduced by 90 percent, cost of chemical fertilizers was reduced by 48 percent, cost of transplanting was reduced by 17 percent and the cost of pesticide was reduced by 99 percent. The SRI farmers obtained 118 percent increase in rice yield and produced 6 Mt/ha of rice compared to 2.75 Mt/ha of rice production by non-SRI farmers (P<0.001). In addition to these, the use of chemical fertilizer with SRI methods was reduced by 46 – 49 percent (P<0.001).

An increasing trend in the number of SRI adopters from 2003 to 2006 was observed, but after then a downfall in SRI adoption had been found which is mainly attributed to the declining institutional support. Weed management, water management and lack of institutional support were the major constraints for SRI adoption.

The results of the binary logistic regression predicted seven different variables that significantly influenced the SRI adoption. The age of the farmer, landholding, food sufficiency, and membership into farmers' association were significant at 10% whereas irrigated land, total livestock standard unit and number of types of trainings taken were significant at 5% level. These finding could help in policy making process for enhancing SRI in Nepal.

Paper II: Effect of SRI on the fluxes of CH_4 and N_2O gases at Jhorahat VDC in Morang district, Nepal

In the soil with SRI treatment, the net CH_4 emission rate varied from 16 to 117 μg CH_4 m^{-2} h^{-1} whereas it varied from 2 to 318 μg CH_4 m^{-2} h^{-1} in non-SRI soil. Some sink of methane was also observed in SRI soils and the net CH_4 sink varied from 1 to 125 μg CH_4 m^{-2} h^{-1}. In SRI soil, the N_2O flux varied from negligible to 103 μg N_2O m^{-2} h^{-1} whereas in non-SRI soil, it varied from negligible to 642 μg N_2O m^{-2} h^{-1}. Higher emission rates of methane in non-SRI soil as compared to SRI soil was most likely due to the length of anaerobiosis. Aerating of the soil through intermittent flooding enhanced methane oxidation that decreased methane formation in SRI soil. Similarly, high emission of N_2O in non-SRI soil was the result of higher N-fertilizer application.

Multiple comparison of means with SNK test at $\alpha = 0.05$ showed that SRI soil emitted significantly lower emission of CH_4 (30±18 μg CH_4 m^{-2} h^{-1}) than non-SRI soil (125±28 μg CH_4 m^{-2} h^{-1}). Similarly, N_2O flux from SRI soil was observed to be significantly lower (14±5 μg N_2O m^{-2} h^{-1}) at $P<0.01$ compared to non-SRI soil (71±30 μg N_2O m^{-2} h^{-1}). Likewise, the GWP of CH_4 and N_2O emissions were also found to be reduced by 73 and 74 percent respectively with SRI treatments.

The GMC varied from 29% to 46% for SRI soil whereas it varied from 30% to 50% for non-SRI soil. The results of the study found no significant correlation between the fluxes of N_2O and CH_4 with the moisture. This may be because the experiment was carried out when the soil were already saturated with the moisture level that ranged between 29-50 percent. The soil temperature varied from 30 ºC to 35 ºC for SRI soil whereas it varied from 30 ºC to 34 ºC for non-SRI soil. A significant positive linear correlation between methane emission and soil temperature was observed. However, no significant correlation between variation in N_2O fluxes and variation in soil temperature was obtained.

4. Conclusion and Recommendations:

The two research papers compiled in this study represents an effort towards an integrated approach to find out the indicators for SRI adoption and to study the potential environmental and economic benefits of SRI.

The problem of food scarcity can be solved by promoting SRI in the agricultural country like Nepal. With SRI methods, the farmers in the study area were found to harvest more than double the rice yield than non-SRI methods. The cost of seed, cost of chemical fertilizer, cost of transplanting and cost of pesticide were found to be significantly reduced in SRI practice. Age, landholding, irrigated land, livestock, food sufficiency, training facilities and membership into the farmers' association significantly influenced the adoption of SRI. Planners and policy makers should consider the farmers' interest, capacity and limitation in order to promote an environmentally and economically sound approach to enhance the prospects of adopting SRI by farmers.

SRI practice was found to have greater potentiality to reduce climate gas emission. The emission of CH_4 was reduced by 4 times and the N_2O flux was reduced by 5 times with the SRI methods. The GWP of CH_4 and N_2O emissions were also significantly reduced with SRI treatments. Global warming induced by the concentration of GHGs may be minimized if SRI is promoted. However, the results of this study should be taken as early indication than general phenomena due to limited intensity and extent of research.

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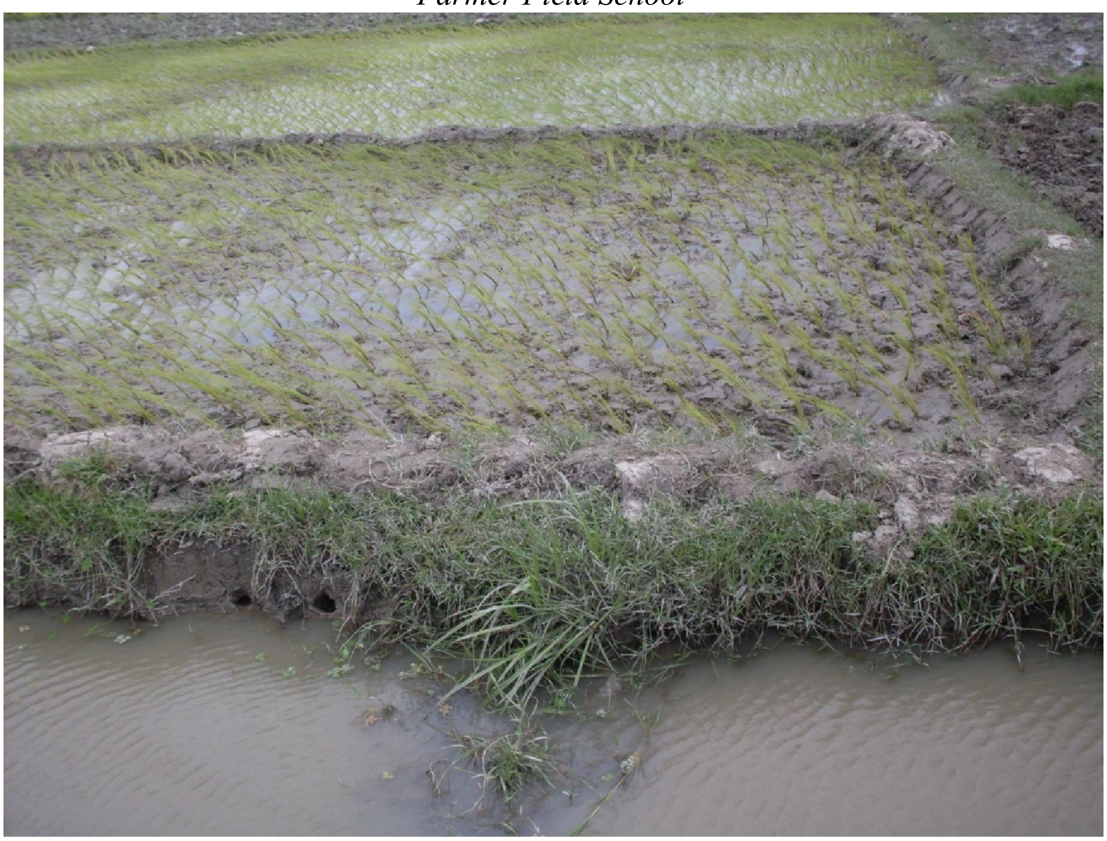
APPENDIX

Key Informants

Household survey

Farmer Field School



Farm land with sufficient irrigation facility

Manual weeding

Farmers with mechanized weeder

Use of animal manure in the farm

Use of oxen for land preparation

Rice plants ready to be transplanted

Flooded method of rice cultivation

PVC chamber installed on the plot with non-SRI treatment

PVC chamber installed on the plot with SRI treatment

Sampling of the gas

Intermittent flooding resulted drying of the field

PART II: RESEARCH PAPERS

Paper I: Determinants of Farm-Level Adoption of System of Rice Intensification (SRI) in Eastern Nepal

Paper II: Effect of SRI on the fluxes of CH_4 and N_2O gases at Jhorahat VDC in Morang district, Nepal

Paper I

Determinants of Farm-Level Adoption of System of Rice Intensification (SRI) in Eastern Nepal

Determinants of Farm-Level Adoption of System of Rice Intensification (SRI) in Eastern Nepal

Abstract:

This study explores different socio-economic and institutional factors influencing the adoption of System of Rice Intensification (SRI) in Eastern Nepal. Household survey with structured questionnaire, key informant interviews, focus group discussion, and field observations were applied to collect the necessary information from farm households. With SRI methods, the cost of chemical fertilizers was reduced by 48 percent, seed requirement was reduced by 90 percent, and the cost of pesticide was reduced by 99 percent. In addition, the farmers in the study area were found to achieve 118 percent increase in rice yield with SRI methods compared to non-SRI methods. The results of the binary logistic regression showed that age of the farmer, landholding, irrigated land, livestock, food sufficiency, training facilities and membership into the farmers' association significantly influenced the adoption of SRI. Weed management, water management and lack of institutional support were found to be the major constraints for SRI adoption. Planners and policy makers should consider the farmers' interest, capacity and limitation in order to promote an environmentally and economically sound approach to enhance the prospects of adopting SRI by farmers.

Keywords: System of Rice Intensification, Nepal, Adoption, Binary logistic regression.

Introduction:

System of Rice Intensification (SRI) is a method that increases the productivity of rice by changing the management of plants, soil, water and nutrients (Satyanarayana et al. 2007). SRI farming practice differs from traditional flooded rice cultivation in terms of i) transplanting younger seedlings preferably 8–12 days old, ii) using low plant densities i.e. planting 1-2 seedling per hill, preferably 50cm apart, iii) intermittent flooding instead of continuous, iv) using rotary weeding to control weeds, v) promoting soil aeration mostly during vegetative growth period and vi) application of organic fertilizers to enhance soil fertility and yield (Menete et al. 2008). SRI helps resource-poor farmers to attain higher yields despite having infertile soil, no mineral fertilizer input, reduced irrigation and fewer seeds (Stoop et al. 2002). SRI has emerged as an alternative to traditional way of flooded rice cultivation and is showing great promise to address the problems of water scarcity, high energy usage and increased use of chemical fertilizers. SRI helps to increase the yields and production, reduces farmers' costs of production, and decreases the water requirement for irrigation up to 50 percent (Randriamiharisoa et al. 2006; Stoop et al. 2002; Uphoff et al. 2008). SRI thus, appears to offer both economic and environmental advantages.

SRI is a recently introduced rice cultivation practice and its adoption history in Nepal dates back to 1999 (Evans et al. 2002). An evaluation of SRI in Nepal reported an increase in rice grain yield by 40-50 percent and biomass production by 20-25 percent, with a 75 percent reduction in seed requirements and 50-75 percent less water (Dhakal 2005). Also, 50 percent less labor was needed for transplanting, 50-60 percent less labor utilized for irrigation along with less use of pesticides (ibid). Fertilizer and harvesting cost remained the same whereas the cost of weeding increased by 50-60 percent (ibid). Getting more production with less total costs was considered a clear net benefit with SRI. A year-end report and an economic analysis for 2005 indicated that practicing SRI method helped the farmers of Morang district to harvest rice production by two folds (Uprety 2005).

Thirty percent of the total population of Nepal is below the poverty line. Agriculture, being the mainstay of the economy, provides a livelihood for almost 80 percent of the population and counts for 36 percent of GDP (MOF 2009). The main agricultural crops of Nepal include rice, wheat, maize, millet, sugarcane, jute, tobacco, oilseeds, barley, and potatoes. Among the cereal crops, rice and wheat are the major crops in the terai, whereas maize and millet are the major crops in the hills (Belbase & Grabowski 1985). Since the implementation of first five year plan 1956, agriculture has remained one of the top priorities in Nepal's developmental plan periods (MOF 2009; Savada 1993). Despite these efforts, the agricultural production has not increased significantly. The national average yield of rice was 1.97 Mt/ha in 1984/85 which has increased only upto 2.91 Mt/ha in 2008/09 (MOAC 2010). Rice is one of the prominent cereal crops in Nepal which contributes to almost one-fourth of the GDP (MOF 2009). It generates substantial income and employment for majority of the people. More than 75 percent of the working population is engaged in rice cultivation for almost half of a year (ibid). Rice accounts for about 50 percent of the country's total agricultural area and production (ibid). It also provides almost 50 percent of the calorie requirement supplied by the cereals (Pokhrel 1997). In developing countries like Nepal, the SRI seems to help the resource poor farmers by providing more income through increasing yields. Despite such anticipated benefits, adoption of SRI by the farmers in Nepal remains low. Very few studies have been carried out to find out the determinants of adoption of SRI practices in Nepal. It is therefore necessary to find out the reasons behind low adoption at farm-level.

Conceptual Framework for Adoption of SRI:

Adoption can be viewed from two perspectives: farm-level and macro-level. At the macro-level, diffusion studies examine how adoption evolves across a population whereas at the farm-level, each household chooses whether or not to adopt the technology including its intensity. Farm level adoption studies are therefore concerned with the factors affecting the adoption decision either statistically or dynamically by incorporating learning and experience (Mercer 2004). No technology, regardless of its ecological and economical soundness, will be significant unless it is adopted by a significant proportion of farmers. Empirical and theoretical studies conducted previously by Feder & O'Mara (1982), Jarvis (1981), Rogers

(1995) indicate that the adoption pattern of new technologies follow logistic function. Adoption is slow in the initial stage but as the early adopters spread the information, knowledge and experience of new technology to other potential adopters, the rate of adoption will increase. The process continues until all the potential adopters adopt the new practice (Neupane et al. 2002).

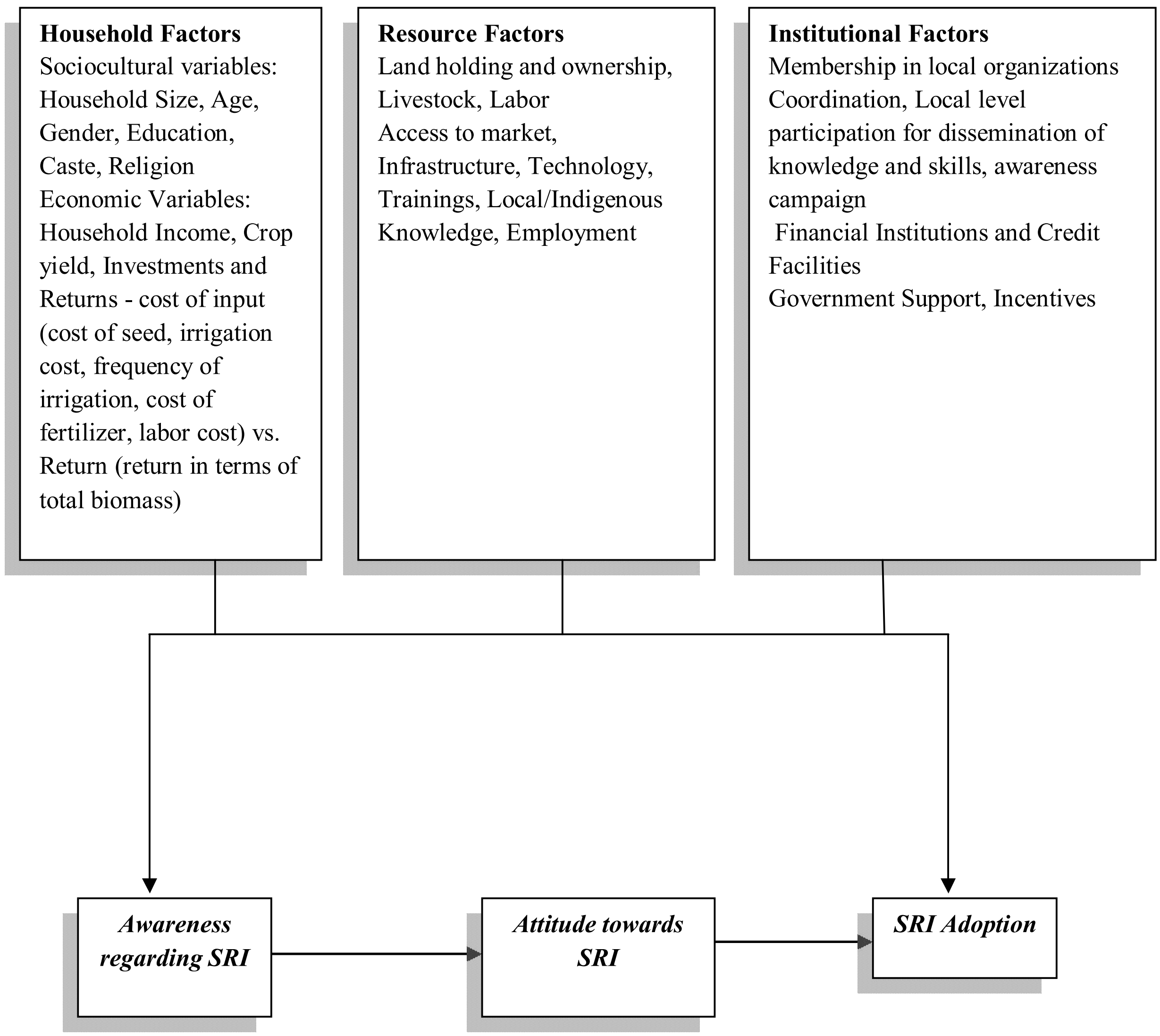


Fig 1: SRI Adoption Framework used in the study

Adoption of SRI can be described as the innovation-decision process as described in Evans (1988) and Rogers (1995), where farmers go through a stage of being aware of the SRI methodology, then forming either positive or negative attitude towards SRI and then finally deciding whether or not to adopt the SRI. The figure 1 illustrates the SRI adoption framework adopted for this study. This framework has been widely adopted in various studies to investigate the adoption pattern of various agricultural technologies (Alavalapati et al. 1995; Neupane et al. 2002).

At each stage during the adoption process of a new agriculture technology, various factors play as constraints and opportunities. These factors include the socio-cultural factors such as caste, religion, gender, education etc.; economical factors such as household income, production etc.; resource factors such as landholding, livestock, access to market and other infrastructures; institutional factors such as membership in local organizations, participation, government supports and incentives. Similar to any other new technologies, SRI is a complicated process which could be influenced by many factors such as socio-economic status of farmers, access to and level of resources, infrastructure, market and other institutional factors. The relationship between those factors and the process of adoption should be understood for large scale adoption of SRI. Farm level studies help to provide insight into those key factors (Neupane et al. 2002). Tiwari (2008) states that solving adoption problem is not possible without understanding the key biophysical and socioeconomic factors. Namara et al. (2003) found labor availability, years of schooling, access to training programs, farm or field location, and the poverty status of the household as the major determinants for adoption of SRI in Sri Lanka. Since socioeconomic and biophysical reality varies from place to place, we have chosen a hotspot of rice growing areas in Nepal for identifying the determinants of adoption of SRI.

Methodology:

Study Area:

The Morang District of Eastern Nepal, situated between latitudes 26°20' to 26°53'N and longitudes 87°16' to 87°41'E, has been selected for this study (Fig 2). It is one of the important rice-growing districts. Total rice-growing area of this district is more than 94,000 ha. Average rice productivity in the district is 3.17 Mt/ha (Uprety 2005). The district covers an area of 1,855 km² and has a population of 843,220 as of population census 2001. Biratnagar is its headquarter which is also the 2nd largest city after Kathmandu. Altitude varies from 60-2410m. Morang has tropical and monsoonic type of climate with 1312 mm average annual rainfall, and 30.6°C and 14.2°C average annual maximum and minimum temperatures, respectively (DADO 2008).

Four Village Development Committees (VDCs) namely Jhorahat, Indrapur, Motipur and Kaseni in Morang district of eastern Nepal were the focus of this study. Details on each VDCs are provided on the Table 1:

Table 1: Details of the studied VDCs:

Name of the VDC*	Area (sq. km.)	Expected Population (2007)	Distance from the district headquarter (km)	No. of Farm Households	Cultivable land (ha)	Rice land under cultivation (ha)
Jhorahat	13.17	5,414	10	788	1250	1180
Indrapur	25.47	19,179	28	2650	2510	2250
Motipur	15.52	5,790	18.2	1046	1530	1330
Kaseni	15.14	8,049	21.5	1553	2633	2633

* VDC is the lowest administrative unit which includes 9 wards within its area *Source: DADO 2008*

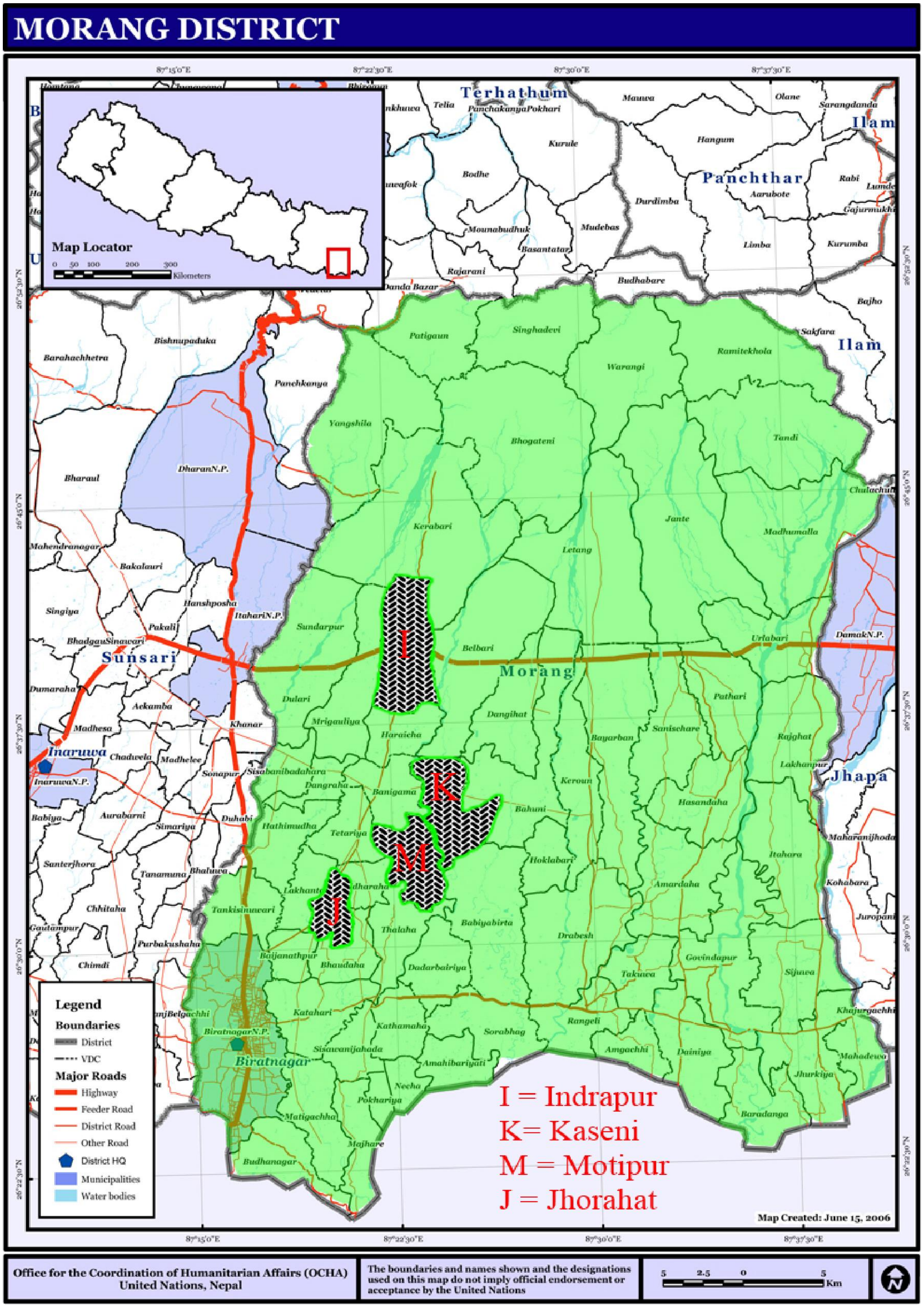


Fig 2: The study area

Survey Methods:

Household surveys with structured questionnaire, key informant interviews, focus group discussion, and field observations were the methods adopted for the primary data collection. Relevant secondary data were obtained from different publications, books, journals, newspaper articles, dissertations, year-end reports and others.

A structured questionnaire (closed as well as open ended) was developed in order to retrieve the quantitative information such as personal characteristics of households, resource endowment, production, infrastructure facilities, role of institutions, fertilizer use, information, trainings etc. Before real field survey, a pilot survey was done in the nearby area with same geographical setup in order to test the applicability of the questionnaire. Pilot survey also called as pre-testing survey is generally conducted when the range of possible answers to each question in the questionnaire is not known (Nichols 2000). The survey was conducted from July, 2009 – August, 2009.

Qualitative information such as constraints faced by farmers while adopting SRI, field experiences of farmers, suggestions for large scale adoption of SRI, activities of governmental and non-governmental organizations to promote SRI in the study area etc were collected by using the key informant interview. Nichols (2000) has listed community leaders, health workers, school teachers and extension officers as the key informants who are particularly knowledgeable and provide valuable information. The information provided by key informants is more reliable as well. For this study, the agricultural extension officers and workers at the District Agriculture Development Office (DADO) in Morang were the key informants because of their continuous service and longer experience for agriculture extension. Besides, some members of farmers groups were also selected as key informants because of their farm-level experience regarding agricultural practices.

Focus group discussion, a widely used social research methodology to obtain qualitative information, is a form of group discussions where individuals in a group share their thoughts and experiences on a set of topics selected by researcher (Morgan & Spanish 1984). This method is very helpful to explore people's knowledge and experiences and used to examine not only what people think but how they think and why they think that way (Kitzinger 1995). In order to obtain the qualitative data regarding this study, four focus group discussions were carried where the groups of farmers were categorized as i) male SRI farmers, ii) female SRI farmers, iii) male non-SRI farmers and iv) female non-SRI farmers. Each group contained around 6 farmers. The groups were believed to be homogenous because they share the same sex and same rice cultivation method. The aim behind such arrangement of the groups was to ease the individuals to feel free to state their views openly without hesitation. A check list was prepared prior to discussion. The issues discussed were noted down.

Selection of Sample:

In order to conduct the household survey, snowball sampling method was applied to determine the sample. The exact number of SRI farmers was unknown and were very few so other sampling methods could not be used. Snowball sampling is useful method to obtain respondents when they are few in number (Lewis-Beck et al. 2004). A list containing 15 farmers at the study area of study was obtained from the DADO Morang. Then the farmers were divided into two categories namely ‘SRI farmers’ and ‘non-SRI farmers’. The farmers who have started to practice the SRI methodology for rice cultivation were categorized into ‘SRI farmers’ and the farmers who have still been practicing the flooded rice cultivation were categorized into ‘non-SRI farmers’. SRI farmers and non-SRI farmers were interviewed. Then, the interviewed farmers were asked to nominate other farmers who were conducting similar practices of rice cultivation. Those new farmers were interviewed and the same process was continued. Altogether, 120 farmers were interviewed of which 60 were SRI farmers and 60 were non-SRI farmers.

Data Analysis Methods:

Quantitative data obtained through household survey was processed using Statistical Package for Social Science (SPSS Statistics 17.0). Frequency tables were generated for general information, t-tests were used to compare the mean difference between SRI and non-SRI farmers, chi-square tests were used to analyze categorical data, correlations were used to identify the interdependence among various factors influencing the adoption of SRI and binary logistic regression was applied to find out the degree of relationship between dependent and independent variables influencing the adoption of SRI. Similarly, qualitative data obtained through interviews, focus group discussion, and field observations were analyzed to support the quantitative data.

Calculating the cost of production:

The total cost of production of rice is calculated by adding the costs of seeds, cost of nursery/ land preparation, cost of chemical fertilizer, cost of transplanting, cost of irrigation, cost of weeding, cost of pesticide and cost of labor for cutting/ threshing. The cost of seed, chemical fertilizer and pesticide were measured by multiplying the local market price and the amount used per area. The local wage rate for men, women and children were obtained from various farmers and the average was used for calculation. In addition to the labor; agricultural activities as land preparation, cutting/ threshing, irrigation required the additional cost for operating the tractors, electrical pumps, threshing machines and commercial fuel used.

Logistic Regression Model:

The logistic regression is very useful statistical tool when the probability of a dichotomous outcome is related to a set to explanatory variables that are hypothesized to influence the outcome (Neupane et al. 2002). Logistic regression describes the relationship between the dependent/response variable and the set of independent/explanatory/predictor variables (Feder et al. 1985). The logistic regression model as specified by Agresti (2007) is:

$$\ln(P_x/(1-P_x)) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots\ldots\ldots\ldots\ldots\ldots \beta_k X_{ki}$$

where, the subscript *i* is the i^{th} observation in the sample, P_x is the probability of the outcome, β_0 is the intercept term and β_1 , β_2 ……..β_k are the coefficients associated with each explanatory variable X_1, X_2…..X_k .

The direction of the relationship between the dependent and independent variable is determined by the positive or negative sign of the coefficient β (Dossa et al. 2008).

For empirical analysis, it is very important to define adoption in terms of an appropriate quantitative measure. For farm level adoption analysis, adoption is usually defined in terms of a dichotomous outcome. For this study, the dependent variable was assigned 1 if the farmer had adopted SRI and 0 otherwise. The choice of the explanatory variables was made on the basis of review of past adoption studies. The list of variables used in binary logistic model is described in Table 2.

Table 2: List of variables used in binary logistic model with their descriptions

Variable	*Description*	*Expected Hypothesis*
Dependent Variable	1 if the household have adopted SRI; 0 otherwise	
Explanatory Variables:		
AGE (X_1)	Age of the respondent in years	-
SEX (X_2)	1 if male, 0 if female	+
EDULEV (X_3)	1 if the respondent has secondary level education or more; 0 otherwise	+
HHSIZE (X_4)	Size of the household	+
OFFFAROCC (X_5)	1 if the respondent has other occupation other than farming; 0 otherwise	+
LANDHOLD (X_6)	1 if the household owns more than 1 bigha (0.68 ha) of land; 0 otherwise	+
IRRILAND (X_7)	1 if the household has all land under irrigation facility; 0 otherwise	+
FOODSUFF (X_8)	1 if the household can produce sufficient food from own production; 0 otherwise	+
LSU (X_9)	Livestock Standard Unit of the household	+
ACCESS (X_{10})	1 if the household scores 3 or more in the accessibility index; 0 otherwise	+
CREDIT (X_{11})	1 if the farmer uses credit for agricultural purposes; 0 otherwise	+
MEMBER (X_{12})	1 if the respondent is the member of farmers association; 0 otherwise	+
TRAINING (X_{13})	Total number of different types of trainings taken	+

A correlation analysis was done to see if these explanatory variables have co-linearity effect. This was done by checking if r values exceed 0.5 (Paudel & Thapa 2004). The correlation matrix presented on Table 3 shows that there is no problem of co-linearity for the variables used in the model.

Table 3: Correlation Matrix for Explanatory Variables used in Binary Logistic Model

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
X_1	1												
X_2	0.21	1											
X_3	-0.36	-0.13	1										
X_4	-0.14	0.03	0.03	1									
X_5	-0.18	0.04	0.44	0.12	1								
X_6	-0.26	-0.07	0.47	0.00	0.24	1							
X_7	-0.23	0.03	0.40	0.11	0.40	0.28	1						
X_8	-0.26	0.09	0.49	0.19	0.27	0.31	0.47	1					
X_9	-0.33	0.06	0.48	-0.04	0.33	0.37	0.34	0.41	1				
X_{10}	-0.10	0.03	0.04	0.07	0.08	0.02	-0.12	-0.07	0.11	1			
X_{11}	-0.04	-0.06	-0.15	-0.10	-0.05	-0.06	-0.24	-0.25	-0.11	0.08	1		
X_{12}	-0.31	-0.07	0.26	0.15	0.14	0.15	0.21	0.17	0.05	0.12	0.01	1	
X_{13}	-0.24	-0.09	0.34	-0.05	0.02	0.20	0.21	0.36	0.29	0.07	-0.04	0.11	1

Definition and measurement of variables:

Dependent Variable:

The dependent variable for this study indicates whether or not a household has adopted SRI practices. The SRI adoption was defined as a binary variable and assigned with '1' for the household which has adopted SRI practices and '0' for the household which has continued the traditional method for cultivating rice with flooded field.

Explanatory Variables and expected impact on adoption:

As described in SRI adoption framework, the adoption of SRI is influenced by a number of socio-cultural, economic, resource and institutional factors. These factors are described as the explanatory variables.

i) AGE:

AGE measures the age of the farmer. Many adoption studies have revealed that the younger farmers are more innovative; have more information regarding new practices and more willing to take risk (Adesina & Zinnah 1993; Polson & Spencer 1991). Similarly, Voh (1982) states that older farmers are less inclined to adopt new farm practices than younger one. It was thus hypothesized that AGE is negatively related to the adoption of SRI.

ii) SEX:

SEX is a dummy variable that indexes the gender of the adopter and takes the value of 1 for men and 0 for women. Zhou et al. (2008) in his research on Chinese farmers' decision to adopt water saving rice technology, have found that male farm managers had higher adoption probability than female farm managers. Similarly, Marenya & Barrett (2007) found that males are more likely to adopt agricultural practices than females. In addition, Nepal has male dominant society, especially in rural households. It was thus hypothesized that males have more probability of adoption of new technology than females.

iii) EDULEV:

EDULEV measures the educational level of the farmers. Farmers with higher education have greater likelihood of adopting the technology because education increases the farmer's ability to understand and apply the methodology (Woldehanna 2003). Namara et al. (2003) also reported that the years of schooling significantly increased the probability of the farmer to adopt SRI. Similarly, Voh (1982) reported that better educated and literate farmers are more prone to adopt new agricultural technologies. It was thus hypothesized that EDULEV is positively related to the SRI adoption.

iv) HHSIZE:

HHSIZE measures the number of family members living in the same household for at least 6 months. Family labor is the main source of labor for farm households. Households with large family size are more likely to adopt new technology because of greater labor availability (Adesina et al. 2000). SRI as argued by several authors Latif et al. (2005), Moser & Barrett (2003) and Namara et al. (2003) is labor intensive. If this is taken into consideration, then SRI is more likely to be adopted by the households with large family size. It was thus hypothesized that HHSIZE is positively related to the SRI adoption.

v) OFFFAROCC:

OFFFAROCC is a dummy variable that measures whether or not the household has any other occupation other than farming. Many studies have shown that off-farm occupation positively influences the adoption of new agricultural technologies (Kebede et al. 1990; Savadogo et al. 1994). Income generated through off-farm occupation helps to meet the capital costs for technology implementation (Adesina et al. 2000; Feder et al. 1985). It also reduces the risks from experimenting with new technologies. It was thus hypothesized that OFFFAROCC is positively related to SRI adoption.

vi) LANDHOLD:

LANDHOLD is a dummy variable that indexes if the household has more than 1 bigha of landholding. In eastern Nepal, the terms dhur (0.0017 ha), katha (0.0339 ha) and bigha (0.6773 ha) are used for measuring area of land. The households with generally 1 bigha or more are believed to be rich in terms of landholding. Kebede et al. (1990) reports that size of farm is the most significant economic factor affecting adoption. Household with large farm land can take more risk and try out new technologies. It was thus hypothesized that LANDHOLD is positively related with SRI adoption.

vii) IRRILAND:

IRRILAND is a dummy variable that measures the irrigation facility of the household and takes the value of 1 if the household has sufficient irrigation provisions in their farm; 0 otherwise. SRI practice requires intermittent flooding of the field which needs proper management of irrigation water. Farmers with sufficient irrigation facility is thus likely to adopt SRI because keeping the field drained would turn risky if the farmers have no control over water supply. Rahman & Shankar (2009) reported that irrigation plays an important role in determining the adoption of high yielding varieties (HYV). Similarly, Shakya & Flinn (1985) found that adoption of modern rice variety is highest where irrigation exists. It was thus hypothesized that IRRILAND is positively related to SRI adoption.

viii) FOODSUFF:

FOODSUFF is a dummy variable that measures whether or not the household can produce sufficient food through own production. Households with food sufficiency have better wellbeing and can bear the risk associated with the adoption of new technology. Floyd et al. (2003) found the FOODSUFF to have positive significant influence on the adoption of agricultural technology. It was thus hypothesized that FOODSUFF is positively related to SRI adoption.

ix) LSU:

Livestock Standard Unit (LSU) indexes the household's total livestock standard unit. Considering total number of animals is an unsatisfactory measure because of variations in age and size (Upton 1993). The total number of livestock was therefore changed to LSU through the livestock unit conversion factors using 0.50 for cattle, 0.50 for buffalo, 0.10 for sheep and goats, 0.20 for pigs and 0.01 for poultry (FAO 2005). Livestock plays a very important role in agriculture. Marenya & Barrett (2007) reports that the household with more livestock are more likely to adopt the agricultural technologies. Similarly, Sidibé (2005) reports that increase in number of livestock increases the likelihood of adoption of agricultural technology. SRI advocates on organic amendments to the farm. Households with large livestock can use the animal waste to produce compost and use it in the farm. It was thus hypothesized that LSU is positively related to SRI adoption.

x) ACCESS:

ACCESS is a dummy variable that measures the accessibility of the household to various infrastructures and gets the value of 1 if the score for accessibility index is 3 or more; 0 otherwise. Five different infrastructures namely school, hospital, road, bank and agricultural extension office were selected to calculate the total score. The household would score 1 for each, if the accessibility to the infrastructure is within 30 minutes of time; and 0 otherwise. The total score is calculated by adding the individual scores. The household with higher score is believed to have better accessibility to various infrastructures and adopt the technology. It was thus hypothesized that ACCESS is positively related to SRI adoption.

xi) CREDIT:

CREDIT is a dummy variable that takes the value 1 if the farmer uses the credit for agricultural purposes and 0 otherwise. Credit is vital for the resource poor farmers when investment is needed for the adoption of new technology (Feder et al. 1985). Availability of the credit facilities helps in improving the farmer's livelihood through better income and employment generation. Many adoption studies have found the positive influence of credit (Feleke & Zegeye 2006; Shakya & Flinn 1985; Tiwari et al. 2008). It was thus hypothesized that CREDIT is positively related to SRI adoption.

xii) MEMBER:

MEMBER is a dummy variable that measures whether or not a farmer is a member of any farmer's organization. Membership into the farmers association increases awareness and exposes the farmers to new technologies and encourages them to adopt the technology. Farmers get opportunity to share their experience regarding new practices. Adesina et al. (2000) states that the farmers who join farmers' association are generally more receptive to new innovations or interventions in the community that affects their attitude to the adoption of new technologies. Sall et al. (2000) and Zhou et al. (2008) also reported that membership was an important driving factor for adoption. It was thus hypothesized that MEMBER is positively related to SRI adoption.

xiii) TRAINING:

TRAINING indexes the number of types of agricultural trainings taken by the respondent. Various NGOs and INGOs together with agricultural extensions were providing different trainings to the farmers in Nepal. Seven different types of trainings were found to be major at the study area which includes trainings on SRI, Nursery Management, off season vegetables, IPM, Compost production, Irrigation and Livestock. Namara et al. (2003) reported that participation in agricultural training programs significantly increase the SRI adoption. It was thus hypothesized that TRAINING is positively related with SRI adoption.

Results and Discussion:

The personal/social characteristics, resource/economic characteristics and institutional characteristics of the respondents are tabulated in Table 4. For continuous variables, *t*-test was conducted whereas for dummy variables, χ-test was used. Age of the farmer was significantly different at $P<0.001$ whereas the educational level of the farmers was significantly different at $P<0.005$. SRI farmers were younger and well educated compared to non-SRI farmers. Other variables such as sex and household size were similar. Landholding, irrigated land and total livestock standard unit were significantly different among the adopters and nonadopters at $P<0.001$. Eighty one percent of the SRI farmers were found to have more than 1 bigha of land. Similarly, sixty two percent of the SRI farmers were found to have sufficient irrigation facilities into their farm. SRI farmers were found to have 1.30 LSU whereas non-SRI farmers were found to have only 0.75 LSU. These values were well below the national average of 4.08, which is because of the differences in livestock holding in different belts of Nepal. Hill regions of Nepal usually have large livestock holding than Terai parts of Nepal. Other variables such as off-farm occupation and food sufficiency were similar among adopters and non-adopters. Membership into farmers association and number of types of trainings taken by the farmers were significantly different among the adopters and nonadopters at $P<0.001$. However, accessibility of the household to various infrastructures and credit facilities were similar. More details on the characteristics of the adopters and nonadopters are given in the Table 4.

Table 4: Descriptive Statistics of the respondents:

Variable	Description	Adopters	Nonadopters	Significance
		n = 60	n = 60	
Personal/Social characteristics				
AGE[a]	Age of the respondent	33	39	0.01***
SEX[b]	Sex of the Respondent (%)			0.16
	Female (%)	60	40	
	Male (%)	46	54	
EDU[b]	Education level of the respondent (%)	64	36	0.02**
HHSIZE[a]	Size of the household	6	5	0.31
Resource/Economic Characteristics				
OFFFAROCC[b]	Occupation other than farming (%)	58	42	0.37
LANDHOL[b]	Landholding (%)	81	19	0.01***
IRRLAN[b]	Land under irrigation (%)	62	38	0.01***
FOODSUF[b]	Food sufficiency of the household (%)	54	46	0.36
LSU[a]	Livestock Standard Unit of the household	1.30	0.75	0.01***
Institutional Characteristics				
ACCESS[b]	Accessibility of the household to various infrastructures (%)	61	39	0.11
CREDIT[b]	Use of credit for agricultural purpose (%)	53	47	0.57
MEMBER[b]	Membership into farmers association (%)	57	43	0.01***
TRAINING[a]	No. of various trainings taken by the respondent	4	3	0.01***

Source: Field survey 2009

n = number of respondents

[a] = continuous variable and use *t*-test

[b] = dummy variable and use χ-test

** = 5% level of significance, *** = 1% level of significance

Analysis of Cost of Production and Yield:

Cost of Production:

The *t*-test showed that the cost of rice production was significantly different among the SRI and non-SRI farmers at $P<0.001$ (Table 5). Cost of nursery/land preparation, cost of irrigation, cost of wedding and cost of labor for cutting/threshing with SRI practices were found to be significantly higher compared to non-SRI practices. However, the cost of seed, cost of chemical fertilizer, cost of transplanting and cost of pesticide were found to be significantly reduced in SRI practice. With SRI methods, the seed requirement was reduced by 90 percent, cost of chemical fertilizers was reduced by 48 percent, cost of transplanting was reduced by 17 percent and the cost of pesticide was reduced by 99 percent. The results of the study corroborate with Zheng et al. (2004), who reported the seed requirement is reduced by 50-90 percent with SRI methods. Similarly, Anthofer (2004) reported that cost of weeding is high in SRI but the cost for uprooting and transplanting was significantly reduced with SRI methods.

Rice Yield:

The *t*-test at $P<0.001$ showed that the SRI farmers produce 6 Mt/ha of rice compared to 2.75 Mt/ha of rice production by non-SRI farmers. The results corroborate with the findings of Uprety (2005), who found the average rice production from different rice varieties using SRI in the same district to be 6.3 Mt/ha. The results of the study indicate that the SRI farmers were able to achieve 118 percent increase in rice yield compared to that of the non-SRI farmers. Uphoff (2002) also reports that the average rice yield with SRI is double than the traditional practices. Similarly, Anthofer (2004) found 41 percent increase in yield with SRI practice.

Table 5: Cost of Production from SRI and Non-SRI Practice:

	SRI	Non-SRI	significance
	n = 60	n = 60	
Cost of Production (NRs/ha)			
Cost of Seed	131 ± 2	1255 ± 21	***
Cost of Nursery/Land Preparation	6547 ± 66	5762 ± 42	***
Cost of Chemical Fertilizer	2348 ± 254	4518 ± 71	***
Cost of Transplanting	2680 ± 26	3245 ± 25	***
Cost of Irrigation	1610 ± 26	522 ± 9	***
Cost of Weeding	4400 ± 97	1915 ± 17	***
Cost of Pesticide	3 ± 2	800 ± 14	***
Cost of Labor for cutting/threshing	5965 ± 56	4700 ± 18	***
Total	23686 ± 280	22718 ± 95	***
Rice Yield (Mt/ha)	6.01 ± 0.11	2.75 ± 0.05	***

Source: Field survey 2009

n = number of respondents

*** = at 1% level of significance

1 US$ = 72 NRs

Amount of Fertilizer Use:

The commonly used chemical fertilizers in the study area include Di-ammonium Phosphate (DAP), Urea and Muriate of Potash (MOP). The *t*-test at $P<0.001$ showed significant difference in chemical fertilizer use among adopters and non-adopters. Non-SRI farmers used double the chemical fertilizers in their farm (74 kg/ha of DAP, 38 kg/ha of Urea and 38 kg/ha of MOP) compared to SRI farmers (38 kg/ha of DAP, 20 kg/ha of Urea and 20 kg/ha of MOP). With SRI methods, the chemical fertilizer is reduced by 46 – 49 percent. Despite doubling the chemical fertilizer use, non-SRI farmers were able to produce only half of the rice yield than SRI farmers.

Table 6: Differences in the amount of chemical fertilizer used by adopters and nonadopters:

Amount of Chemical Fertilizer Used (Kg/ha)	Adopters	Nonadopters	Significance
	n = 60	n = 60	
Di-ammonium Phosphate (DAP)	37.8 ± 4.1	74.4 ± 1.12	***
Urea	20.22 ± 2.23	37.63 ± 0.65	***
Muriate of Potash (MOP)	20.27 ± 2.24	37.9 ± 0.63	***

Source: Field survey 2009

n = number of respondents

*** = at 1% level of significance

Determinants of SRI adoption:

The binary logistic regression was run to identify the determinants of SRI adoption. The logit model predicted seven different variables which significantly influenced the SRI adoption (Table 7). The age of the farmer, landholding, food sufficiency, and membership into farmers' association were significant at 10% whereas irrigated land, total livestock standard unit and number of types of trainings taken were significant at 5% level. These variables were perfectly predicted in the model where Hosmer and Lemeshow chi-square was 4.83 at 8 d.f. and 0.78 level of significance. The -2 log likelihood was 120.43, Cox and Snell r^2 was 0.32, Nagelkerke r^2 was 0.42 and overall percentage of right prediction was 78.3 percent.

Table 7: Analysis of determinant factors for SRI adoption using Binary Logistic Model

Variables	β	S.E.	Sig.	Odds ratio (e^{β})
AGE	-0.06	0.03	0.07*	0.94
SEX	-0.36	0.52	0.48	0.69
EDULEV	-0.70	0.68	0.31	0.50
HHSIZE	0.14	0.16	0.37	1.15
OFFFAROCC	-0.63	0.65	0.33	0.53
LANDHOLD	1.32	0.75	0.08*	3.73
IRRILAND	1.21	0.58	0.04**	3.35
FOODSUFF	-1.22	0.64	0.06*	0.29
LSU	0.70	0.34	0.04**	2.02
ACCESS	0.54	0.52	0.30	1.71
CREDIT	0.33	0.49	0.51	1.39
MEMBER	1.41	0.75	0.06*	4.11
TRAINING	0.60	0.27	0.03**	1.83
Constant	-2.54	2.02	0.21	0.08

Hosmer and Lemeshow Test: Chi-square = 4.83, d.f. = 8, Sig. = 0.78, -2 Log Likelihood = 120.43. Cox & Snell r^2 = 0.32, Nagelkerke r^2 = 0.42, Overall percentage of right prediction = 78.3%, sample size = 120 households.

χ-test: ** =Significant at 5%, * =Significant at 10%

Personal/Social factors for SRI adoption:

Age of the farmer, as hypothesized, was found to have significant influence on the adoption of SRI. The negative sign of the coefficient β implies that younger farmers are more likely to adopt SRI. The results are in consistent with Marenya & Barrett (2007) who state that with the increase in age; the physical effort, health and incentive to invest in farm diminishes. Thangata & Alavalapati (2003) also report that younger farmers have longer planning horizons and willing to take more risks than older farmers.

Other variables as sex, education level of the farmer and the household size did not significantly influence the SRI adoption. The sex has negative sign indicating that females have more likelihood to adopt SRI; however it is not statistically significant. In Morang district, there are 175 female farmers association, 212 male farmers association and 228 mixed farmers associations. Of the total members, 8963 are female farmers and 6133 are male farmers (DADO 2008). These data shows that females are more actively participating into the farmers association and have more likelihood to adopt new innovations. Negative sign on educational level indicates that less educated farmers have more likelihood of adopting SRI, however no significance has been found. The possible explanation could be that the well educated people are more focused on off-farm employment than farming activities. The reason behind non-significance of educational level might be because SRI practices are simple and can be practiced without any need of formal education. Besides, with the help of extension workers and trainings, even uneducated farmer is able to grow the rice with SRI practices. The positive sign on household size implies that SRI is likely to be adopted by the households with large family size which supports the labor intensive nature of SRI; however no significance has been found.

Resource/Economic factors for SRI adoption:

As hypothesized, landholding was found to have positive and significant influence on SRI adoption. Farmers with large landholding can initially try out new innovations in small plots as trials. With the success, they can expand it to larger plots. Sarwar & Goheer (2007) reports that with the increase in landholding, farmers have better choices to experiment with new technologies. Farmers with large landholding can take the risk associated with the crop failure. Farmers with less landholding are not willing to take such risk because if they failed to grow as expected, they should strive.

As hypothesized, land under irrigation facility was found to have positive significant influence on SRI adoption. Without sufficient irrigation facilities, SRI practice is not possible. Being dependent on monsoon rainfall is not feasible because SRI needs frequent drying and wetting of the field. Many adoption studies have reported positive significant influence of irrigation on adoption and stated that with the increase in irrigated land, adoption of agricultural technology increases (Arellanes & Lee 2003; Fernandez-Cornejo et al. 1994; Shakya & Flinn 1985).

LSU, as hypothesized, was found to have positive significant influence on SRI adoption. Anthofer (2004) reported that there was huge reduction in the use of mineral fertilizer with the SRI practice, and was compensated by increase in the use of compost derived from animal manure. Farmers with large livestock holding can apply the animal manure directly into their farm or apply after changing it to higher quality compost. Agricultural extensions and some NGOs were found to provide the training on livestock and compost production to the farmers of the study area. So, increase in livestock increases the probability of SRI adoption.

Unexpectedly, food sufficiency was found to have negative significant influence on SRI adoption. It implies that the household which cannot grow sufficient food from their own production are more likely to adopt SRI. The possible explanation for this result could be that the farm households who cannot meet the food demands may be more interested on SRI to increase the rice production than the farmers who have already better wellbeing. The main attraction of SRI is its increase in yields. Many studies revealed that with SRI, production are increased by 50-100 percent or more (Dhakal 2005; Uphoff et al. 2002; Uprety 2005). The farmers in the study area might have adopted SRI in order to increase the yield so that they could have enough food year round.

However, off-farm occupation was not found to have significantly influence the SRI adoption. Negative sign on off-farm occupation indicates that farmers having no off-farm occupation are more likely to adopt SRI. Zhou et al. (2008) also reported that off-farm occupation negatively influence the adoption. With the absence of off-farm income, on-farm income should be prioritized in order to sustain the livelihood.

Institutional factors for SRI adoption:

Membership into the farmers association, as hypothesized, was found to positively influence the SRI adoption. It implies that the membership into farmers' association significantly affects the probability of SRI adoption. Similar results have been found by many adoption studies (Adesina et al. 2000; Ntege-Nanyeenya et al. 1997; Sall et al. 2000; Tiwari et al. 2008; Zhou et al. 2008). Farmers' associations have better access to technical information and receive support from extension workers (Ntege-Nanyeenya et al. 1997). Membership into farmers' association allows the farmers to share their experiences about farming to the other farmers in the group, discuss the problems and explore new opportunities on farming which increases their confidence (Tiwari et al. 2008). It is therefore, membership significantly influences the adoption decision.

As hypothesized, number of types of trainings taken by the farmers was found to positively influence the SRI adoption. It implies that the farmers who have taken more training have increased probability of adoption of SRI. Similar results have been found by Namara et al. (2003) who reported that participation in agricultural training programs significantly increase the SRI adoption. Various national and international organizations were found to be working in the district and providing different trainings to the farmers. The major trainings provided to the farmers in the study area included the trainings on SRI, Nursery Management, off season vegetables, IPM, Compost production, Irrigation and Livestock. Training increases the knowledge and skills of the farmer and they become more responsive to the agricultural innovations.

Despite the results of the various adoption studies, the results of the study found the use of credit on agricultural sector not to be significantly influencing the SRI adoption. This could be because of the fact that there are 376 cooperatives and 19 banks currently operating in the district (DADO 2008) and the credit is readily available to the farmers. The positive sign on credit however, implies that the use of credit on agricultural sector somehow increases the adoption of SRI. Accessibility to the various infrastructures, on the other hand, was also not found to significantly influence the SRI adoption.

SRI Adoption history of the respondents:

Fig. 3 shows the history of adoption of SRI among the respondents. It indicates that from 2003 to 2006, there had been increasing trend in the number of SRI adopters. But in later years, the number of SRI adopters has been decreased.

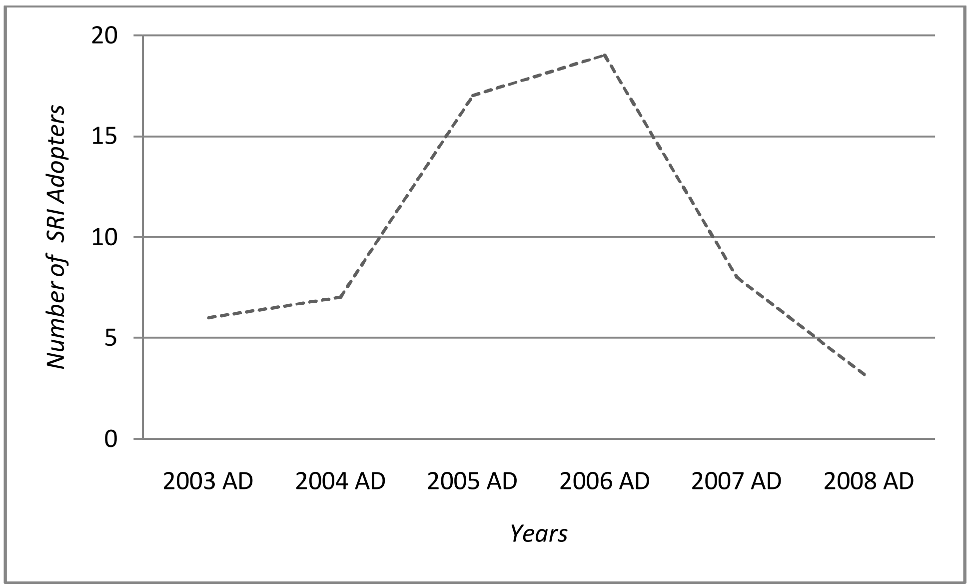


Fig 3: History of SRI adoption

In 2005, SRI promotion project was rewarded with US$ 20,000 at the World Bank's Nepal Development Marketplace (CIIFAD 2005). Huge adoption of SRI between 2005 and 2006 indicates that the farmers have received lot of institutional support at that time. Paudel & Thapa (2004) states that adoption would be higher among farmers if they get enough material support from the agricultural extension services. The downfall of SRI adoption in the recent years may be due to the number of constraints as described below.

Constraints for adoption of SRI:

Focus group discussion was used to find out the constraints for adoption of SRI. The farmers listed weed management followed by water management and lack of institutional support as the first, second and third topmost constraints for SRI adoption. Similar to the findings of the study, Zheng et al. (2004) also listed short supply of organic fertilizers, weeding and water management as the limiting factors for SRI adoption. He also reported that many farmers find it difficult to transplant younger seedlings. Nepalese SRI Farmers have been practicing hand-weeding due to lack of sufficient mechanized weeders. This has created SRI to be more time and labor consuming. Tech (2004) also reported the lack of water management facilities has been one of the major constraints for adoption of SRI in Cambodia. SRI practice requires intermittent flooding in the land. If the land has not sufficient irrigation facility, then it becomes difficult to practice SRI. Only 56.7 percent of the total land in the district is suitable for agriculture (105,270 ha), out of which only 64,745 ha of land is under cultivation through various irrigation systems (DADO 2008). Uphoff (2004) also reports that more investment is needed in water management for large scale adoption of SRI. Lack of institutional support is also the limiting factor for large scale SRI adoption in the study area. Institutional support includes the material support from related organizations, subsidies from governments, relevant trainings, field inspection from agricultural extension workers etc. The field observation revealed that the farmers do not seem to get enough institutional support from the relevant organizations.

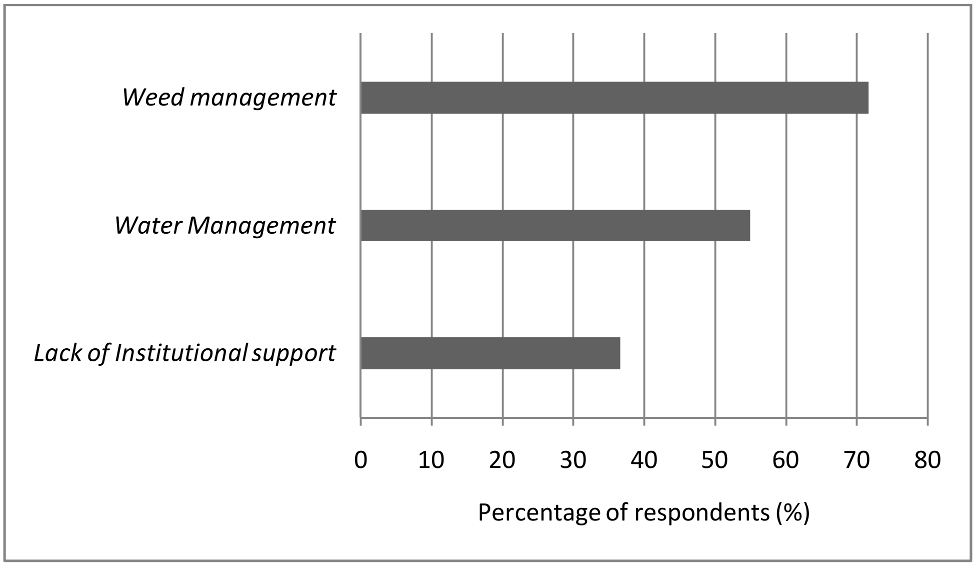


Fig 4: Constraints for SRI adoption

Accordingly, the key informants suggested that if the farmers are provided with mechanized weeders and provided with enough training, the condition for SRI adoption would become feasible. Similarly, irrigation facilities have to be well managed for large scale adoption of SRI.

Conclusion:

With SRI methods, the farmers in the study area were found to achieve 118 percent increase in rice yield compared to non-SRI methods. The total cost of production with SRI was found to be slightly higher (NRs. 23, 686) compared to non-SRI (NRs. 22, 718) but it was well compensated by the increase in yield (6.01 Mt/ha for SRI vs 2.75 Mt/ha for non-SRI). With SRI methods, the cost of chemical fertilizers was reduced by 48 percent, seed requirement was reduced by 90 percent, and the cost of pesticide was reduced by 99 percent. The results of the binary logistic regression showed that age of the farmer, landholding, irrigated land, livestock, food sufficiency, training facilities and membership into the farmers' association significantly influenced the adoption of SRI. The downfall of SRI adoption in the recent years was observed which may be due to the constraints related to weed management, water management and lack of institutional support.

The findings of this study have important policy implications for the SRI adoption. The problem of food scarcity can be solved by promoting SRI in the agricultural country like Nepal. Planners and policy makers should consider the farmers' interest, capacity and limitation in order to promote an environmentally and economically sound methodology like SRI.

Recommendations:

Based on the results of the study, following recommendations are made in order to promote the SRI in large scale. Training was the most influencing for SRI adoption, therefore it is recommended to provide the farmers with trainings on SRI. Increase in livestock also enhanced the SRI adoption process so it is also recommended to encourage the farmers to keep livestock. Keeping livestock not only increases the farmers' income through milk and meat products but also provides the animal manure which can be used in farm directly or after converted into high quality compost. The results of the study indicate that membership into farmers' association increases the adoption process, so it is recommended to encourage the farmers to be a member of farmers' association. Many farmers reported the lack of institutional support, so it is suggested to provide them with essential institutional support from all relevant agencies. Poor farmers lack the mechanized weeder thereby consuming more labor, cost and time during weeding. It is therefore recommended to provide subsidy in mechanized weeders to ease the weeding process. Irrigation is vital for any agricultural activities, so well provision and effective management of irrigation facilities to the farm through various irrigation projects is a necessity.

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Paper II

Effect of SRI on the fluxes of CH_4 and N_2O gases at Jhorahat VDC in Morang district, Nepal

Effect of SRI on the fluxes of CH_4 and N_2O gases at Jhorahat VDC in Morang district, Nepal

Abstract:

Agriculture releases significant amount of GHGs (greenhouse gases) into the atmosphere that contributes to global warming and climate change. There is need for searching better agricultural practices that minimize the fluxes of GHGs to the atmosphere. System of Rice Intensification (SRI) is a practice with frequent intermittent flooding and less input of N-fertilizer, which may have potential mitigating effects on the fluxes of climate gases (CH_4 and N_2O). The fluxes of CH_4 and N_2O in relation to the SRI treatment were studied at the Jhorahat VDC in Eastern Nepal. Closed chamber method was used to collect the gas samples in 2-day interval from 19 July to 14 August 2009. Gas chromatography was used to analyze the gas samples. The soil temperature and the gravimetric moisture content were also measured for each sampling site at each day of sampling. Significant effect of SRI on the fluxes of CH_4 and N_2O was observed. The emission of CH_4 from SRI soil was found to be 4 times less compared to non-SRI treatments whereas N_2O flux from SRI treatment was 5 times less compared to fluxes from non-SRI treatments. A significant positive correlation between CH_4 emission and soil temperature was observed. SRI practices appear to potentially minimize CH_4 emissions and N_2O emissions. The net GWP (global warming potential) due to combined CH_4 and N_2O emissions were significantly less in SRI treatments. Since our work was carried out for a short period, there is need for more extended research covering high spatial and temporal variability to obtain results with generalization values.

Keywords: System of Rice Intensification, Nepal, CH_4 flux, N_2O flux, Global Warming Potential

Introduction:

IPCC defines greenhouse gases as "those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds" (IPCC 2007). The important greenhouse gases include carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). CH_4 is 25 times while N_2O is 298 times more powerful on a molecular basis than CO_2 in terms of global warming potential, in a 100-year perspective (Carlsson-Kanyama & González 2007; IPCC 2007; Jantalia et al. 2008; Van der Gon et al. 2002). Agriculture releases significant amount of CH_4, N_2O and CO_2 into the atmosphere. In 2005, agriculture accounted for 10-12% of total global anthropogenic GHG emissions (5.1 to 6.1 $GtCO_2$-eq/yr) where CH_4 and N_2O contributed 3.3 $GtCO_2$-eq/yr and 2.8 $GtCO_2$-eq/yr respectively (IPCC 2007). From 1990 to 2005, agricultural emissions of CH_4 and N_2O have been increased by 17% (IPCC 2007). CH_4 is produced when organic materials decompose under anaerobic conditions such as cultivation practices under flooded conditions (Smith et al. 2008). Aerobic soils however, act as an important sink for CH_4 (Awasthi et al. 2005). N_2O is produced as the intermediate product during nitrification and denitrification process. Nitrification is the process of aerobic microbial oxidation of ammonia into nitrate whereas denitrification is the process of reduction of nitrate into gaseous nitrogen (Carlsson-Kanyama & González 2007; Vibol & Towprayoon 2010; Zhou et al. 2010). Production of N_2O is enhanced when available N exceeds plant requirements, especially under wet conditions (Smith et al. 2008).

More than 90 percent of the world's rice is produced in Asia followed by Latin America 3.2 percent, Africa 2.1 percent and 2.5 percent rest of the world (Neue 1993). Rice provides 35-59 percent of the calories consumed by 2.7 billion people in Asia (ibid). In South and East Asia, rice is the major food and is grown primarily under flooded condition. Due to increasing food demand for increasing population, cultivated areas as well as input of chemical fertilizers would become severe, which would ultimately lead to the higher emissions of CH_4 and N_2O (IPCC 2007; Zheng et al. 2000). GHG emission needs to be mitigated in order to combat climate change. According to IPCC, improved water and rice management is a significant mitigation option for GHGs (IPCC 2007). One of the best methods of suppressing CH_4 emission is intermittent drainage of rice field, creating alternately anaerobic and aerobic conditions (Wassmann et al. 1993). Intermittent flooding improves soil permeability and increases soil redox potential thereby lessen CH_4 emission (Tyagi et al. 2010). Similarly, during off-rice season, the soil should be kept as dry as possible and avoid water logging (Smith et al. 2008; Tyagi et al. 2010). Drainage of agricultural lands not only promotes productivity but also inhibits N_2O emissions by improving soil aeration (Smith et al. 2008). Proper nutrient management is also very essential in reducing N_2O emissions. Adjusting application of N-fertilizer according to crop needs e.g. Precision farming; improved timing of N application, avoiding excess N application etc are the core practices to improve N use efficiently (Smith et al. 2008).

In SRI, the rice is not grown in flooded field, but rather in moist soil with intermittent flooding (Dobermann 2004; Stoop et al. 2002). Only few studies have revealed the fact that intermittent flooding of rice paddies help reducing CH_4 emissions. Proper nutrient management is also one of the principles of SRI (Menete et al. 2008). Practices such as the application of organic fertilizers and avoiding the use of chemical fertilizers to the extent possible, help in contributing towards reducing N_2O emissions as well.

SRI studies done so far by most of the researchers are focused on demonstration activities. Much of these studies are concerned more on yield increase (Krishna et al. 2008; Latif et al. 2009; Satyanarayana et al. 2007; Uphoff 2007 a; Zheng et al. 2004). Very few studies have been carried out on the measurement of climate gas emission from SRI field. The study aims to demonstrate the possible environmental benefit of SRI in terms of reduced GHG emission. The main objective of the study is to measure the fluxes of important GHGs (CH_4 and N_2O) in response to SRI and non-SRI treatments. The objective is also to demonstrate variation in N_2O and CH_4 fluxes in relation to SRI treatments and climatic variables such as temperature and moisture.

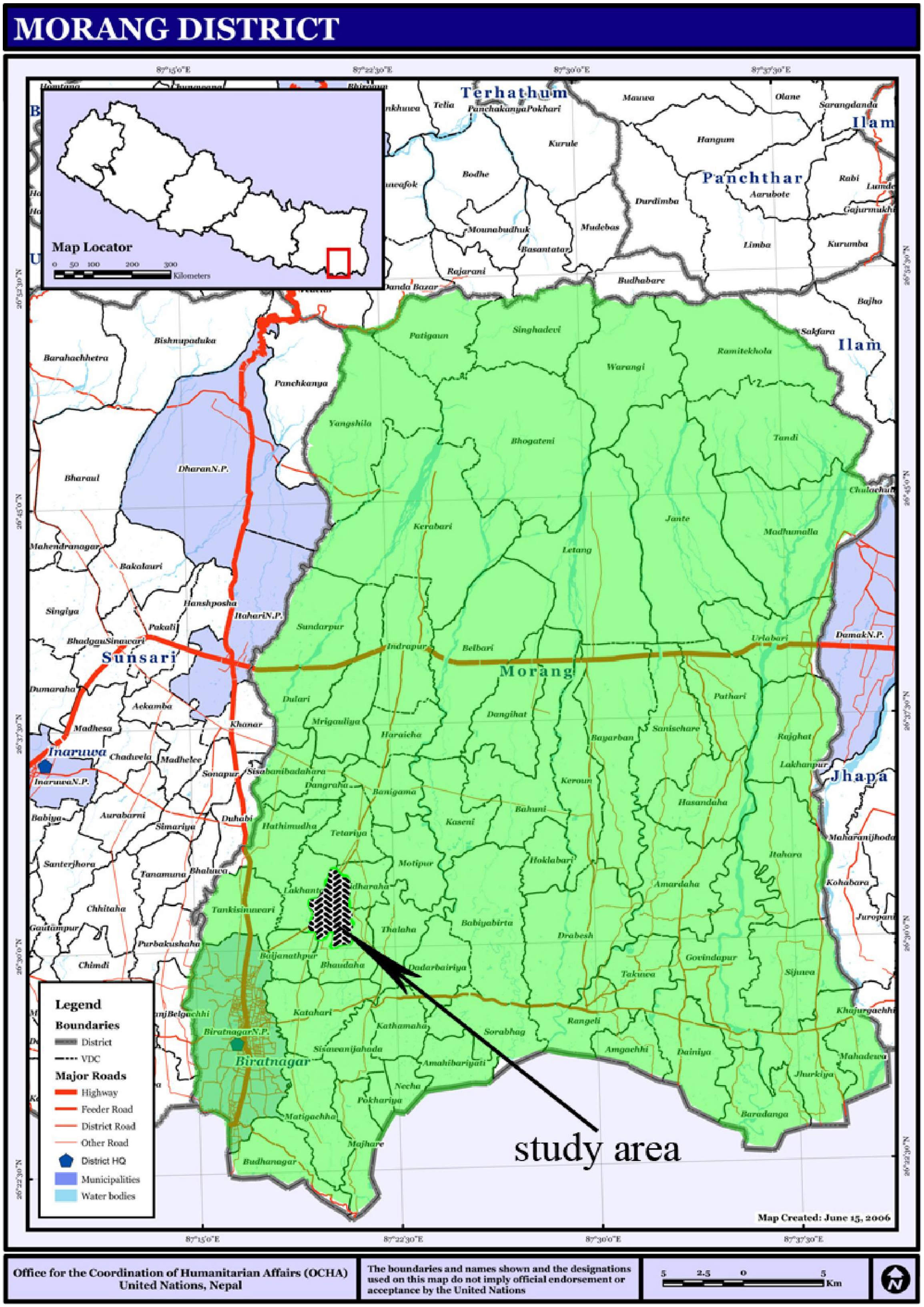

Fig 1: The study area

Materials and Methods:

Study Area:

The study was carried out at the hotspot of rice growing area in Nepal (Jhorahat VDC – 2 in Morang district of Eastern Nepal) (Fig 1). Morang, a part of Koshi Zone, is one of the 75 districts of Nepal which covers an area of 1,855 km² and has a population of 843,220 as of population census 2001. It is situated between latitudes 26°20' to 26°53'N and longitudes 87°16' to 87°41'E. Biratnagar is its headquarter which is also the 2nd largest city after Kathmandu. Altitude varies from 60-2410m. Morang has tropical and monsoonic type of climate with 1312 mm average annual rainfall, and 30.6°C and 14.2°C average annual maximum and minimum temperatures, respectively (DADO 2008). Morang is one of the important rice-growing districts in Eastern Nepal. Total rice-growing area of this district is more than 94,000 hectares. Average rice productivity in the district is 3.173 Mt ha^{-1} (Uprety 2005).

Site description:

Two sites representing two different treatments, SRI and non-SRI, were selected for collecting the gas samples. The rice plants from SRI and non-SRI were 26 and 24 days old respectively when the gas sampling was started. The selected sites were adjacent to each other, in order to minimize the differences in terms of soil properties. The descriptions of the each treatment are described in Table 1:

Table 1: Description of the treatments:

Treatments	Description
SRI	• The field representing SRI used ‘Ranjit’ as the rice variety. • The seedlings transplanted were 12 days old. • Transplant per clump was 1 • Spacing of clumps was 30×30cm • Intermittent flooding • Weeding was carried out 3 times • NPK content was 18:22:12 kg ha^{-1} • Vermi-compost was also used

Non-SRI	• The field representing non-SRI used ‘Kanchi Mansuli’ as the rice variety. • The seedlings transplanted were 18 days old. • Transplant per clump was 3-4 • Spacing of clumps was random • Continuous flooding • Weeding was carried out only 1 time • NPK content was 37:41:27 kg ha^{-1} • No organic amendments

* Ranjit and Kanchi Mansuli are both high yielding rice varieties.

Field Gas Sampling:

Gas fluxes at the soil surface were collected using closed circular PVC chambers (260 mm internal diameter, 650 mm high, 20mm rim for inserting into the soil; Asihant Thermoware, Daman Industrial Estate, Kadaiya, India). One 12-mm-diameter hole was made at the top of the chambers and was capped by a butyl rubber stopper (type 20-B3P, Chromacol Ltd, London) for transferring gas into the gas vials (10-CV Chromacol Ltd, London). Gas vials had been evacuated up to 10^{-1}kPa at the laboratory before sampling. Gas samples were then, taken by piercing a two-way needle through the rubber stoppers of the soil chambers and then through 10-ml evacuated glass vials (Awasthi et al. 2005; Jantalia et al. 2008; Sitaula et al. 1995).

4 replicate chambers were installed randomly in each site (NS1, NS2, NS3 and NS4 for non-SRI plot and S1, S2, S3 and S4 for SRI plot). The gas samples were taken in 0 hours and after 2 hours of soil cover. The gas samples were collected from July 2009 to August 2009 at a 2-day interval. 14 measurements were taken during this period [19, 21, 23, 25, 27, 29, 31 July; 2, 4, 6, 8, 10, 12, 14 August]. The gas vials thus collected were brought to Norway and analyzed for gas fluxes. The soil temperature and the gravimetric moisture content were also measured for each sampling site at each day of sampling.

Gas Analysis and calculation:

The gas samples were analyzed in gas chromatography Agilent 7890A, which was equipped with two columns 10 m pora PLOT U (special) and 20 m 5Å Molsieve (part cp 740149). The column pressure (He) was 200 kPa and the column temperature was 36 ºC for the PLOT U whereas the column pressure was 250 kPa and the column temperature was 50 ºC for the molsieve column (Bakken L. et al. 2010). CH_4 was measured on a FID (flame ionizing detector) whereas N_2O was measured on ECD (electron capture detector). Details on the gas chromatography is described in (Bakken L. et al. 2010).

Closed chamber method is based on the principle of measuring the increase in concentration of gas within the chamber as a function of time. The flux of gas at the soil surface is then calculated as:

$$f = \frac{\Delta C}{\Delta t} x \frac{V}{A}$$

where, f is the flux density of the gas; $\frac{\Delta C}{\Delta t}$ is the time rate of change of gas concentration in the chamber during the incubation time Δt; V and A are the volume of air within the chamber and the area of the soil covered by the chamber respectively (Jantalia et al. 2008; Rolston 1986; Yang et al. 2009). CH_4 flux and N_2O flux were expressed in µg m^{-2} h^{-1}. The CH_4 and N_2O emission rates present in this paper are the mean of four replicates.

Other measurements:

From each site, the bulk density was measured by using core method (Nelson et al. 1982) and the soil moisture content was measured using the methods for gravimetric water content (Klute 1986).

Similarly, the effect of fluxes of CH_4 and N_2O on global warming was calculated on the basis of global warming potential (GWP). Global warming potential is a measure of how much a given mass of a specific greenhouse gas contributes to global warming. GWP is measured in a relative scale to CO_2, which has a GWP of 1 (Elrod 1999). The impact of the fluxes of N_2O and CH_4 on climate can be compared by converting them into a common basis of CO_2-equivalent using the GWP methodology (Li et al. 2005). The accumulated CH_4 flux and N_2O flux was calculated and expressed to find out the GWP. Details on the calculation are described on (Li et al. 2005; Pathak et al. 2005). GWP values for CH_4 and N_2O depend on the time horizon chosen. According to IPCC (2007), the global warming potential of CH_4 and N_2O are 72 and 289 times higher than that of CO_2 in 20-years horizon. Then, the GWP value for CH_4 was calculated as (accumulated CH_4 flux) × 72 × (16/12) whereas the GWP value for N_2O was calculated as (accumulated N_2O flux) × 289 × (44/28) (Li et al. 2004). GWP calculations are done with molecular masses, not C or N masses (Li et al. 2005).

Statistical Analysis:

The Statistical Analysis System Programme (SAS Institute Inc. 9.2) was used to analyze the experimental data. The effects of treatments on GHG flux were analyzed by General Linear Model (GLM) procedure. The comparison of means for each variable were carried out using Student-Newman-Keuls (SNK) test at $\alpha = 0.05$. The observed gas fluxes were correlated with measured temperature and moisture in the soil. Microsoft Excel 2007 and Minitab 15 were also used for basic calculations and to generate the graphs and curves.

Results and Discussion:

CH_4 Fluxes:

SRI treatments showed significantly less CH_4 emission compared to non-SRI. In SRI soil, the CH_4 emission rate varied from 16 to 117 µg CH_4 m^{-2} h^{-1} whereas it ranged from 2 to 318 µg CH_4 m^{-2} h^{-1} in non-SRI soil. Some sink of methane was also observed in SRI soils and the oxidation rate varied from 1 to 125 µg CH_4 m^{-2} h^{-1}. The figure 2 presents the variation of methane emission in two treatments over the sampling period.

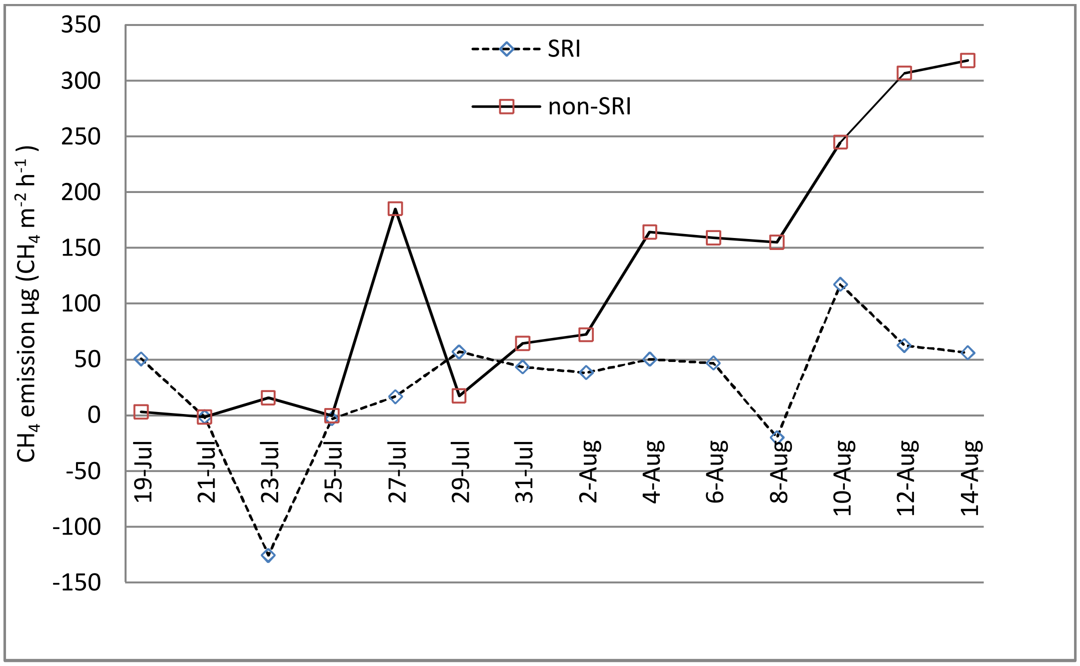

Fig 2: Temporal variation in the emission of CH_4 during sampling period

In non-SRI treatment, the field is flooded all the time which creates anaerobic condition in the soils. Yang & Chang (1998) state that anaerobic conditions favor methane production because of methanogenesis and reported that methane production under anaerobic conditions was 10 times higher than under aerobic conditions. Similarly, Neue (1993) reveals that in strict absence of free oxygen and at redox potentials of less than -150 mV, methanogenic bacteria metabolize to produce methane. In flooded paddy soil, methane is produced largely by transmethylation of acetic acid and by reduction of CO_2 (Takai 1970). Higher emission rates of methane in non-SRI soil as compared to SRI soil might be attributed to the anaerobiosis during the measurement period.

Oxidation of methane is done by methane-oxidizing bacteria which is called methanotrophs. Methanotrophs, found in oxidized floodwater soil, oxidize methane to CO_2 via methanol, formaldehyde and formate (Neue 1993). Adhya et al. (2000) reports that 80 percent of the methane produced in aerobic soil is oxidized to CO_2. Aerating the soil through intermittent flooding enhances methane oxidation and therefore decreases methane formation (Neue 1993; Towprayoon et al. 2005). The observed oxidation of methane in SRI soil is thus may be the result of intermittent flooding practices.

Low emission of methane from SRI soil may also be attributed to its low fertilizer use and more use of compost. Adhya et al. (2000) reports that organic amendments and nitrification inhibitors increase methane oxidation potential whereas fertilizer N inhibits the CH_4 oxidation process. Among different organic sources applied on paddy field, use of compost is regarded as one of the best measures to mitigate CH_4 emission (Kumaraswamy et al. 2000).

Table 2: Mean ± SE fluxes of N_2O and CH_4 as influenced by treatments

Variables	Treatments	
	non-SRI (Mean ± SE)	SRI (Mean ± SE)
CH_4 emission (µg CH_4 m^{-2} $h^{-1)}$	125±28A	30±18B
N_2O emission (µg N_2O m^{-2} h^{-1})	71±30A	14±5B

Treatments are compared with the letters AB; values followed by different letters in the same row are significantly different (SNK test $\alpha = 0.05$)

Significant effect of treatment on the emission of CH_4 was observed (Table 2). Multiple comparison of means with SNK test at $\alpha = 0.05$ reveals that SRI soil emitted 4 times lower CH_4 emission (30±18 µg CH_4 m^{-2} h^{-1} vs. 125±28 µg CH_4 m^{-2} h^{-1}) compared to non-SRI soil.

Water drainage is one of the important practices to reduce the methane emission from rice field (Kongchum et al. 2006; Yue et al. 2005). Tyagi et al. (2010) in his experiment in India found the emission of methane from flooded field to be 346.6 mg m^{-2} d^{-1} whereas it was reduced it to 204 mg m^{-2} d^{-1} with multiple drainage practices. He further indicates that intermittent flooding improves soil permeability and increases soil redox potential which helps in reducing methane emissions. When the field is drained, oxic condition is created in the sediments which suppresses methanogenesis and leads to low methane emission. Similarly, Adhya et al. (2000) reports that CH_4 emission was reduced by 15 percent with intermittent flooding; CH_4 emission was 13.80 mg m^{-2} d^{-1} for alternatively flooded plots while it was 16.32 mg m^{-2} d^{-1} for continuously flooded plots. Yan et al. (2003) also reported CH_4 flux from the rice field with intermittent flooding to be 53 percent of that from continuously flooded field. Likewise, Mishra et al. (1997) reported that methane emission from intermittent flooding was distinctly less than that from continuous flooding.

N_2O Fluxes:

SRI treatment emitted significantly less N_2O compared to non-SRI treatment. In SRI soil, the N_2O flux ranged from 0.17 to 103 µg N_2O m^{-2} h^{-1} whereas in non-SRI soil, it ranged from 0.2 to 642 µg N_2O m^{-2} h^{-1}. The marked differences were observed during the initial few dates of sampling (21 July to 25 July) and smaller differences in the later dates. The figure 3 presents the variation in N_2O fluxes in two treatments over the sampling period.

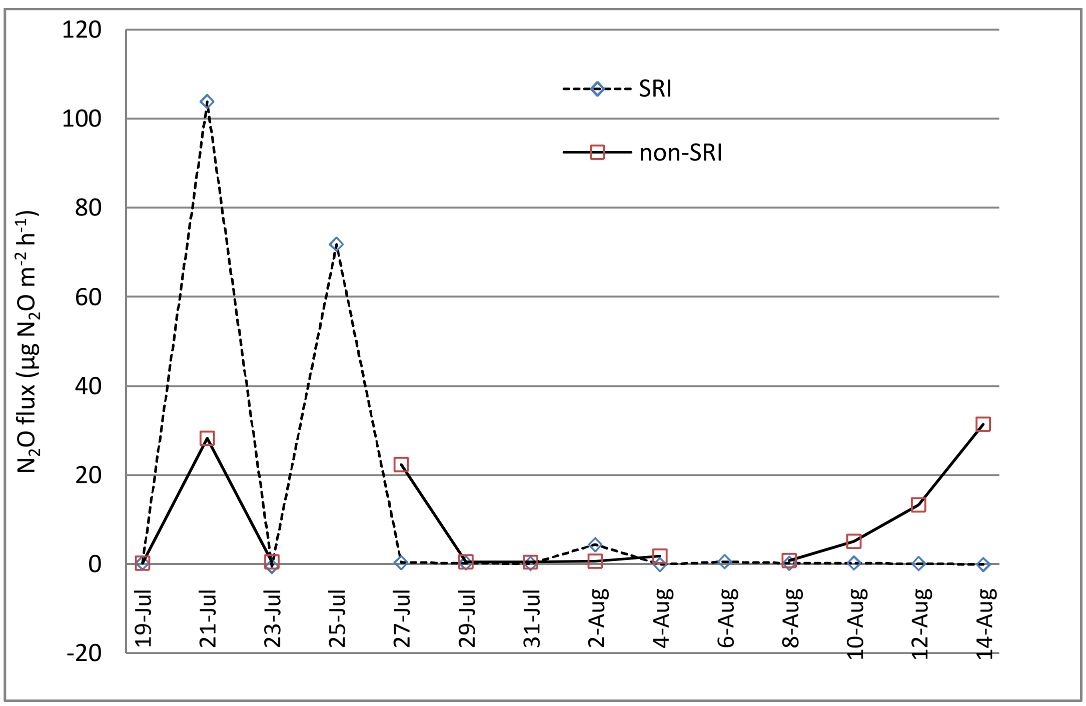

Fig 3: Temporal variation in the emission of N_2O during sampling period

N_2O flux is affected by the addition of N-fertilizer, soil moisture and soil temperature. High emission of nitrous oxide is the result of N-fertilizer application (Mosier et al. 1991) that supply substrate for both nitrification and denitrification processes in the soil. Minami (1997) reports that efficient use of N-fertilizer reduces N_2O emission. Higher N_2O emission from non-SRI soil is likely due to higher N-input (37 vs 18 kg N ha^{-1}).

N_2O flux from SRI soil was observed to be 5 times lower (14±5 µg N_2O m^{-2} h^{-1} vs. 71±30 µg N_2O m^{-2} h^{-1} at P<0.01) compared to non-SRI soil (Table 2). The reason behind such difference in the fluxes may be attributed to the differences in N-fertilizer input between two treatments. SRI treatment has comparatively lower N-application rate (18 kg N ha^{-1}) than non-SRI treatment (37 kg N ha^{-1}). Cai et al. (1997) reported that N_2O emission increased significantly with the increase in N-application rate. Similarly, Hua et al. (1997) reported that potentiality of the rice field to emit N_2O increases with the amount of N fertilizer.

We could look at the soil properties and climatic variables to further explain the variation in the results.

Relation with soil moisture:

The bulk density (BD) for SRI soil was found to be 1.18 g cm^{-3} whereas for non-SRI, it was found to be 1.27 g cm^{-3}. This indicates that non-SRI soil was somewhat more compact. Gravimetric Moisture content (GMC) for SRI was found to be 34.23% while for non-SRI, it was 45.14%. Similarly, the Volumetric Moisture Content (VMC) for SRI soil was found to be 40.39% whereas for non-SRI soil, it was 57.33%. This implies that the non-SRI field is moister than SRI.

The GMC varied from 29% to 46% for SRI soil whereas it varied from 30% to 50% for non-SRI soil. The figure 4 shows the variability in the GMC during the sampling period.

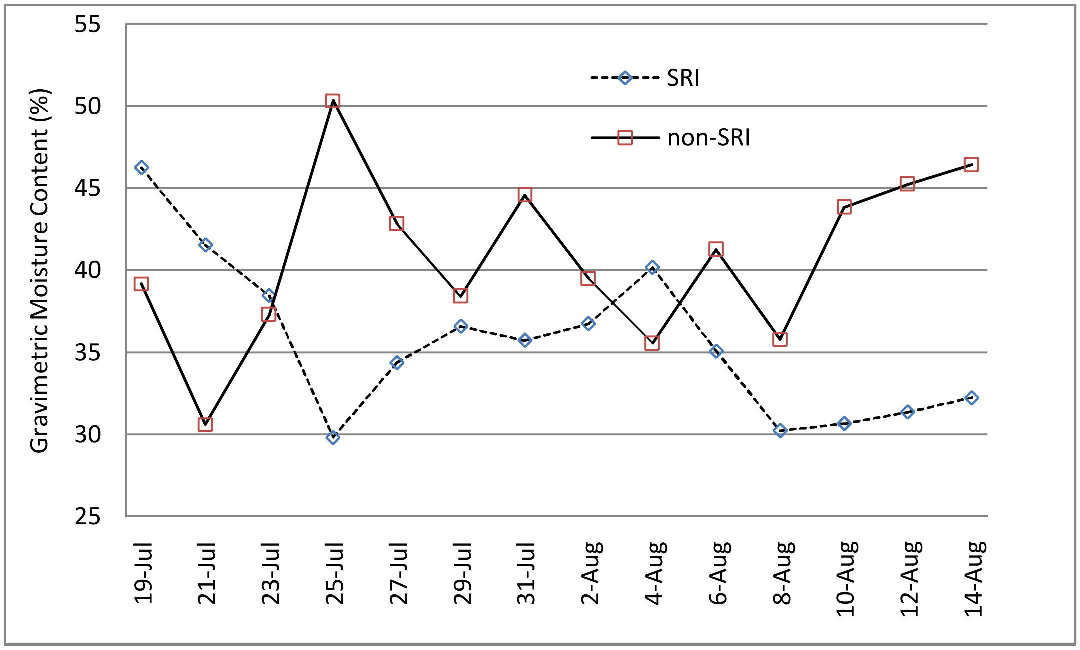

Fig 4: Variation of GMC during sampling period

Methane is produced by methanogenic bacteria and oxidized by methanotrophic bacteria. Soil moisture affects the populations and activity of methanogenic and methanotrophic bacteria thereby affecting methane production and oxidation potentials during rice-growing period (Xu et al. 2003). Yang & Chang (1998) reported that methane production increases with increasing water content due to increasing anaerobiosis. It is generally recognized that the anaerobic-aerobic cycling enhances N_2O emission (Cai et al. 1997; Xiong et al. 2007). N_2O emission decreases when the rice field is flooded but it begins to increase with the disappearance of flood water (Cai et al. 1997). Bronson et al. (1997) also reports that N_2O emission from rice fields occurs when the soil is drained. But, Yagi et al. (1996) reported that the short term drainage practice (short anaerobic-aerobic cycling) reduces the emission of N_2O in addition to the reduction of CH_4. However, the results of the study found no significant correlation between the fluxes of N_2O and CH_4 with the moisture.

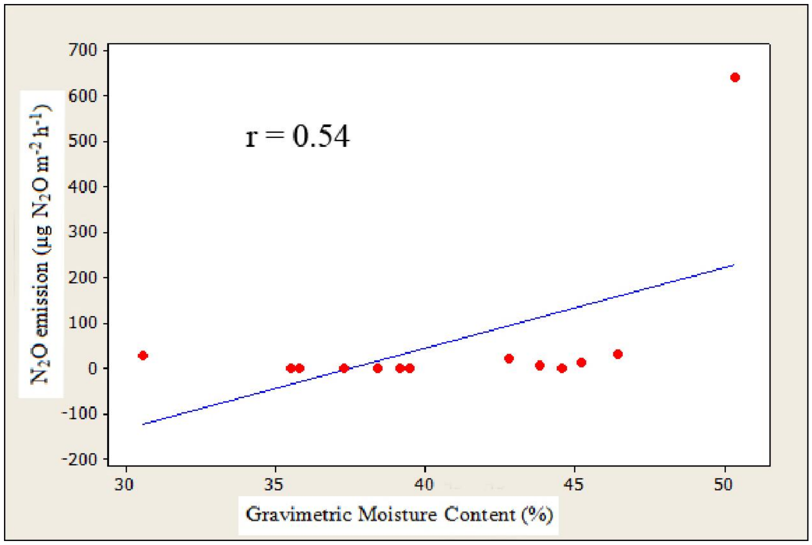

Fig 5: Scatter plot of N_2O Flux vs. Gravimetric Moisture Content

Relation with soil temperature:

The soil temperature varied from 30 ºC to 35 ºC for SRI soil whereas it varied from 30 ºC to 34 ºC for non-SRI soil. The figure 5 shows the variability in the temperature during the sampling period.

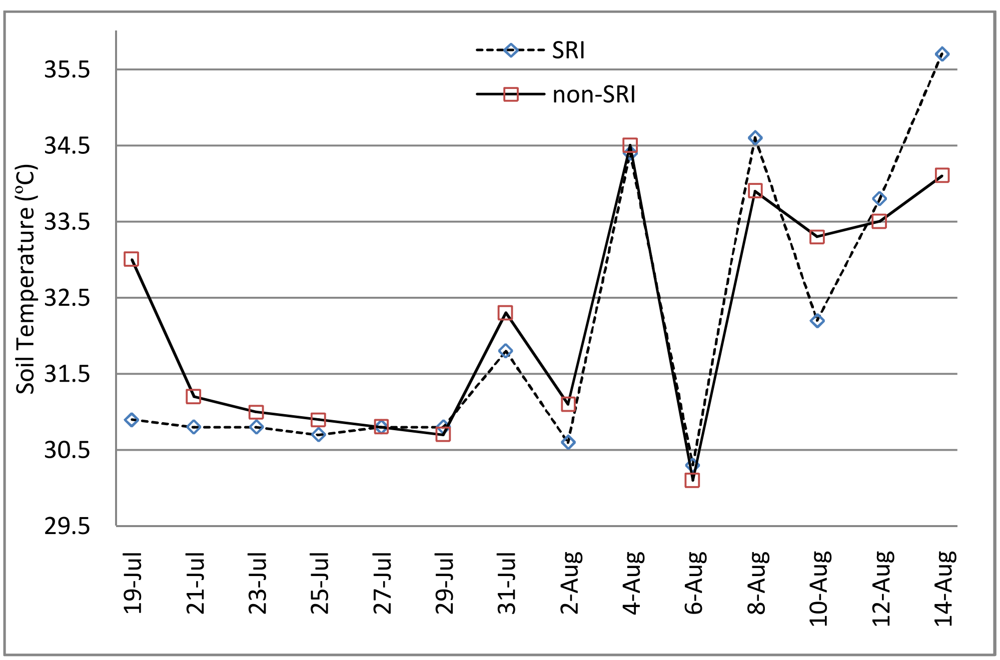

Fig 6: Variation of soil temperature during sampling period

Soil temperature is an important factor for methane production (Minami 1997). High temperature increases organic matter degradation and enhance the activities of methanogens (Liou et al. 2003). A significant positive linear correlation between methane emission and soil temperature was observed (Fig 7). The findings corroborate with the findings from Yang & Chang (1998), who found methane emission to be higher with the increase in the soil temperature between 15 and 37 ºC. Neue (1993) also reported that methane production is positively correlated with soil temperature. Similarly, Parashar et al. (1993) reported that the methane emission increased with soil temperature up to 35.5±0.5 ºC.

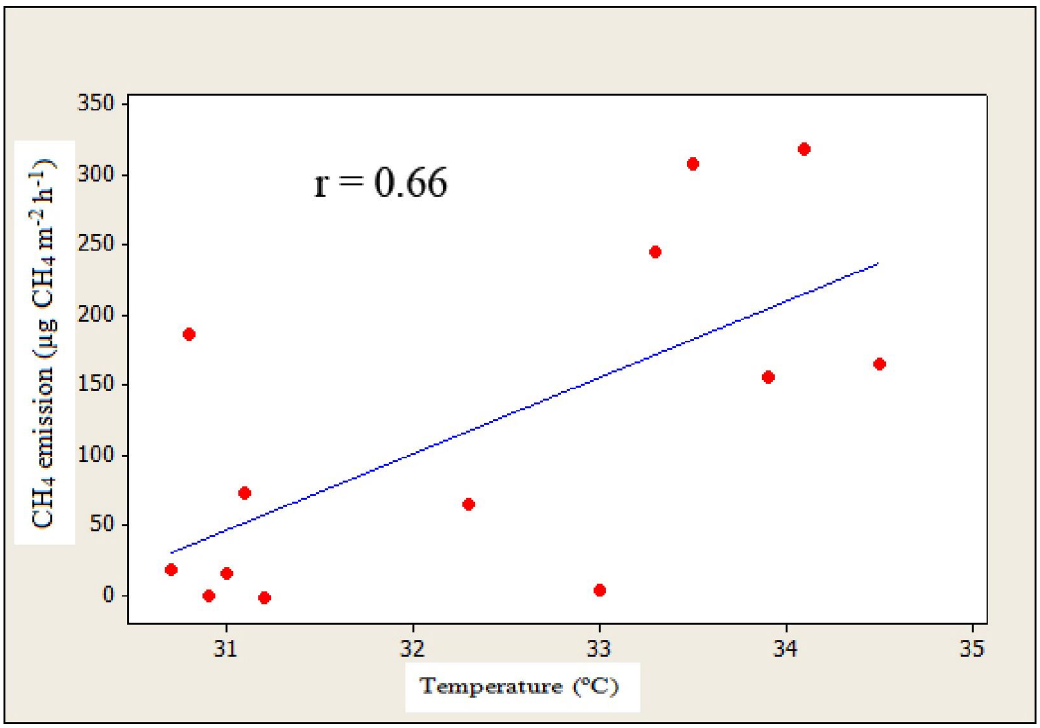

Fig 7: Scatter plot of CH_4 Flux vs. Soil Temperature

However, no significant correlation between variation in N_2O fluxes and variation in soil temperature was obtained. The soil temperature fluctuated between 30-35 ºC and in such range; temperature was not a limiting factor for nitrification and denitrification. The results of the study corroborate with Hua et al. (1997) who found no significant correlation between N_2O flux and soil temperature between 21-35 ºC.

Global Warming Potential (GWP) of combined (CH_4 and N_2O) emissions:

The GWP was calculated on the basis of mass factors of 72 for CH_4 and 289 for N_2O for 20-year horizon. The GWP was expressed in g CO_2 m^{-2} $season^{-1}$. The rice growing season for this study was taken as 6 months.

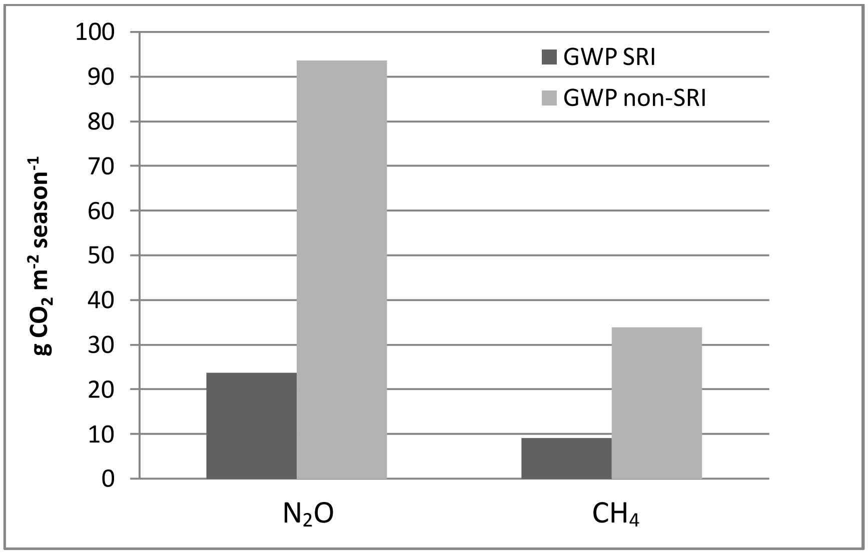

Fig 8: GWP of N_2O and CH_4 emissions from SRI and non-SRI fields

The GWP in 20-years horizon of N_2O emission for non-SRI was 94 g CO_2 m^{-2} $season^{-1}$ whereas it was reduced by 74 percent to 24 g CO_2 m^{-2} $season^{-1}$ for SRI. Similarly, the GWP in 20-year horizon of CH_4 emission for non-SRI was 34 g CO_2 m^{-2} $season^{-1}$ whereas it was reduced by 73 percent to 9 g CO_2 m^{-2} $season^{-1}$ for SRI. The combined GWP was calculated by adding the GWP of N_2O and CH_4 and it was found to be 128 g CO_2 m^{-2} $season^{-1}$ for non-SRI and 34 g CO_2 m^{-2} $season^{-1}$ for SRI. The results of the study corroborate with the findings from Yu et al. (2004), who reported that non-flooding treatment in rice field with organic matter addition reduced the cumulative GWP by 72 percent in China (163 mg CO_2 m^{-2} d^{-1} for non-flooded field vs. 591 mg CO_2 m^{-2} d^{-1} for flooded field). The results of the study indicate that the SRI practices have higher potentiality to reduce the global warming potential. Similar findings were obtained by Jiang et al. (2006) and Zou et al. (2009), who reports that intermittent flooding of rice field reduces the total GWP of CH_4 and N_2O emissions.

Limitation of the study:

The study is constrained by limited measurement of gas fluxes both in terms of time (for only 1 month) and space (only 4 replicates), so the findings of the study should be interpreted with caution. High spatial and temporal variability of gas fluxes could limit the generalization value of the results. In order to generalize the results, there is need for extended measurements in terms of time (at least one year) and in terms of spaces (more replicates than it was used in this study). Therefore, the results of the study should be taken as early indication rather than general phenomena.

Conclusion:

Significant effect of SRI on the fluxes of CH_4 and N_2O was found. The emission of CH_4 from SRI soil was found to be 4 times lower than that of non-SRI soil whereas N_2O flux from SRI soil was 5 times lower than non-SRI soils. No significant correlation of N_2O flux with soil moisture and soil temperature was obtained. However, a significant positive correlation of CH_4 flux and soil temperature was obtained. SRI practices appears to minimize CH_4 emissions most likely because of frequent intermittent flooding practices and also appears to reduce N_2O emissions because of reduced N-fertilizer input. The GWP of CH_4 and N_2O emissions were also found to be reduced by 73 and 74 percent respectively with SRI treatments. Hence, the SRI practice has greater potentiality in reducing emission of CH_4 and N_2O from rice fields of Nepal.

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