EFFECT OF THE SYSTEM OF RICE INTENSIFICATION (SRI) ON LIVELIHOOD STRATEGIES FOR CAMBODIAN FARMERS AND POSSIBLE CARBON STORAGE AND MITIGATION POSSIBILITIES FOR GREENHOUSE GAS EMISSIONS

Master Thesis by

Marc Kristof Dumas-Johansen
HSK06004

Supervisors:

Andreas de Neergaard, Associate professor at Faculty of Life Sciences, University of Copenhagen
Dr. Steffen Johnson (NORDECO)

Frontpage picture: Rice fields in Prey Veng. All pictures taken by Marc Kristof Dumas-Johansen.

Abstract
The System of Rice Intensification (SRI) has been adopted by many resource poor farmers throughout the world. In Cambodia approximately 80.000 farmers practice some sort of SRI and farmers are able to increase their rice yields with lower input costs. SRI is based on transplanting one seedling per hill as opposed to several for traditional rice and managing a drying and flooding regime of the soil leading to alternately anaerobic and aerobic conditions.

This study targeted farmers in the ILFARM project (Improved Livelihood of Small Farmers) initiated by the Cambodian NGO CEDAC (Centre d'Étude et de Développement Agricole Cambodgien) and the Danish organization NORDECO (Nordic Agency for Development and Ecology) in Cambodia's Prey Veng province. The objectives were to evaluate the effect of SRI on the farmers' livelihood situation, potentials of increasing the soil Carbon pool and mitigation of greenhouse gases (CH_4, N_2O and CO_2). The applied methods were interviewing households in the target group and soil sampling in the SRI fields for total Carbon and Nitrogen respectively.

The target farmers were able to increase their rice yields significantly using SRI as compared to their traditional rice fields. Traditional rice fields yielded 2.19 t ha^{-1} and SRI fields yielded 3.53 t ha^{-1} respectively. The main reason seems to be the use of only one seedling per hill thus reducing the competition for nutrients. The use of water management was not practiced due to no or little irrigation facilities. Main constraints for further development of SRI would be the lack of high amounts of biomass. In order to cope with this, the ILFARM project will however supply the farmers with 500.000 trees in order to increase the amount of available on site biomass. It was estimated that such measures could increase the soil C pool with roughly 116 kg C ha^{-1} $year^{-1}$. The SRI conducted by the target farmers did not have large influences on mitigation as farmers were not able to manage a fluctuating water table due to no irrigation facilities. However if all concepts of SRI is followed this could decrease emissions of especially CH_4.

SRI appears to be a suitable and sustainable way of growing rice for resource poor farmers and in addition it carries the potentials of being able to increase soil fertility through an increased C pool and mitigation possibilities of greenhouse gases.

Resumé

Systemet for Ris Intensivering (SRI) er blevet anvendt af mange landmænd overalt i verden. I Cambodia dyrker cirka 80.000 landmænd en eller anden form for SRI, og de er i stand til at forhøje deres risudbytte med lavere udgifter. SRI går ud på at udplante en enkel udplantningsplante pr. ”hill”(”udplantningshøj”) frem for adskillige, som ved traditionelle ris systemer, samt at styre en vandingsmodel med overrisling og tørlægning af jord, hvilket resulterer i skiftevis anaerobiske og aerobiske tilstande for jorden.

Dette studie omhandler landmænd fra ILFARM projektet (Improved Livelihood of Small Farmers) igangsat af den Cambodianske NGO CEDAC (Centre d’Étude et de Développement Agricole Cambodgien) og den danske organisation NORDECO (Nordic Agency for Development and Ecology) i Prey Veng provins, Cambodia. Formålet har været at evaluere effekterne af SRI på landmændenes livsvilkår, potentialet for at forhøje kulstof mængden i jorden og reducere udledningen af drivhusgasser (CH_4, N_2O and CO_2). De anvendte metoder indebar interviews med hushold inden for målgruppen og jordprøver fra SRI marker for henholdsvis total kulstof og kvælstof.

Målgruppen har været i stand til at forhøje deres risudbytte markant, når de anvendte SRI sammenlignet med deres traditionelle marker. Traditionelle rismarker gav 2.19 t ha^{-1} og SRI markerne 3.53 t ha^{-1}.

Hovedgrunden til dette synes at være, at landmændene kun anvendte én udplantningsplante per ”høj”, og derved har kunnet reducere konkurrencen om næringsstofferne. Brug af overrisling og tørlægning af jord har ikke været taget i brug af landmændene pga. ingen eller få vandingsfaciliteter. Den største udfordring for at udbrede SRI synes at være mangel på store mængder organisk materiale. For at løse dette vil ILFARM projektet donere 500.000 træer til landmændene for at forhøje tilgangen til biomasse på stedet. Der antages, at med sådanne inputs ville landmændene kunne forhøje kulstofpuljen med 116 kg C ha^{-1} $år^{-1}$. SRI praktiseret af landmændene i målgruppen har ikke vist nogen større effekt på reduktion af udledningen af drivhusgasser, eftersom landmændene ikke var i stand til at hæve og sænke vandstanden pga. ingen adgang til vandingsfaciliteter. Men hvis alle SRI koncepter bliver fulgt, vil dette kunne have stor indflydelse på reduktion af specielt CH_4.

SRI synes at være en egnet og bæredygtig måde at dyrke ris på for ressourcefattige landmænd, og desuden har metoden potentialer for at kunne højne jordens næringsværdi igennem en forøgelse af kulstofpuljen og reduktion af drivhusgasser.

Preface

This report is part of my MS.c degree in Horticultural Sciences at the Faculty of Life Sciences, University of Copenhagen, Denmark. The idea of working with rice in Cambodia came to me early 2008 when I did an internship with the Danish NGO (Non Governmental Organization) ADDA (Agricultural Development Denmark Asia) in Siem Reap and Banteay Mean Chey Province - northwest Cambodia. I became very fascinated with Cambodian culture and rice production has always been near to my heart. I therefore decided to combine Cambodia and rice systems.

Working with this report (data collection, field work, data analysis and writing) took place from the 1st of July 2008 till the 14th of July 2009. The first months were spent on studying and reviewing the literature for existing data and information on my topic. I spent two months in Cambodia from the 15th of September 2008 till the 15th of November 2008 collecting data. In Cambodia I was assisted and guided by CEDAC (Centre d'Étude et de Développement Agricole Cambodgien) a Cambodian NGO collaborating with NORDECO (Nordic Agency for Development and Ecology) on SRI farming in Prey Veng province. All data for my interviews and soil samples were collected in Prey Veng. Throughout my time in Cambodia I was assisted and facilitated by RUPP (Royal University of Phnom Penn) and CEDAC in data collecting and forming the project. I also spent time with the ENLAB (Environmental Analysis Laboratory) of PNSA (Preak Leap National School of Agriculture) who analyzed my soil analysis. I finalized all data analysis and writings at the Plant and Soil section, Department of Agriculture and Ecology at the Faculty of Life Sciences, University of Copenhagen.

Acknowledgements

I would like to express my gratitude to my two supervisors Associate professor Andreas de Neergaard (Faculty of Life Sciences) and Dr. Steffen Johnson (NORDECO) for guiding, assisting and encouraging me throughout the process. I would also like to thank my first supervisor (who left his position at Faculty of Life Sciences for a new job in late 2008) Associate professor Henning Høgh Jensen (National Environmental Research Institute, Aarhus University) for inspiring me to work with this project and starting up the whole process.

Furthermore I would like to pay my gratitude to:

Mr. San Vibol (RUPP) for his invaluable help throughout my stay in Cambodia.

Mr. Ma Veasna (CEDAC) for his help and guidance in collecting my data in Prey Veng province and for helping me throughout the period with valuable information on the ILFARM project and CEDAC.
Ms. Leakana (RUPP) for her excellent translation and help as my field assistant in Prey Veng during the data collection.
Local CEDAC staff at the Prey Veng head office for their assistance, driving, field work, kindness and enthusiasm.
Ms. Men Sokuntheary (ENLAB, PNSA) for her help and assistance for my soil data analysis.
To Eva-Maria Didden, Alonzo Alfaro and Bhim Bahadur Ghaley for our constructive and interesting discussion on statistics and rice production respectively.

Lastly but not least I would like to thank my family and friends, for their moral support, comments and encouragements.

Copenhagen the 14th of July 2009 **Marc Kristof Dumas-Johansen**

Table of contents

1. Introduction

Rice (*Oryza sativa* L.) is the basic diet of approximately 40% of the world's human population (Kundu & Ladha, 1999) but with a still increasing population the need for more rice is alarming (Surridge, 2004). Facing this threat already some decades ago, the "Green Revolution" was initiated in order to intensify rice production through Higher Yielding Varieties (HYV), chemical fertilizers and pesticides (Greenland, 1997). As a result the world's production of rice doubled in the periods of the 1960's to the 1980's (Tsujimoto *et al*., 2009). However the rice yields in irrigated rice areas in Asia have stopped increasing during the last decade and with a still increasing human population the need for a continuous increase is highly necessary (Tsujimoto *et al*., 2009). The Green Revolution focussed mainly on irrigated areas (Dobermann & White, 1999). However, in order to reach sustainable levels of rice production, the rainfed lowland areas must be developed as they possess the potentials of increasing future rice production (Dobermann & White, 1999). It is expected that in order to feed a growing human population, yield increases of up to 70% are required from both irrigated and rainfed lowland areas (Dobermann & White, 1999). Most of the rainfed lowland areas are dominated by small scale farmers conducting various types of rice farming but all depending on rainfall and natural flooding (Stoop *et al*., 2002).

The System of Rice Intensification (SRI) is one of them. It was developed during the early 1980's in Madagascar as a low input system for resource poor farmers (Stoop *et al*., 2002). It differs from rainfed traditional/conventional rice systems in several ways. The two main differences are i) transplanting only one younger seedling per hill and ii) a proper water management lowering and increasing the water table in a specific pattern (Laulanie, 1993). This water management involves a moist soil during the vegetative stage, flooded during the panicle stage and some two weeks before harvest total drainage of the field (Sheehy *et al*., 2004). It is believed that SRI systems can increase rice yields remarkably (Uphoff, 1999; Stoop *et al*., 2002; Kabir, 2006) through fewer inputs and improve soil quality over time (Satyanarayana *et al*., 2007) from amendments of organic materials. SRI is based on different management techniques but also relies heavily on farmers' skills and investments of labour (Uphoff, 1999). Many critical voices though claim that the SRI is a labour intensive system (Moser & Barrett, 2003) and requires irrigation facilities in order to work properly (Sinha & Talati 2007). The access and availability of organic materials may also pose problems (Dobermann, 2004) for full scale adoption by small scale farmers.

The majority of Cambodia's 1.8 million farmers (Koma, 2007) grow their rice under rainfed lowland conditions (Tong *et al*., 2007) with a national rice yield of 2.49 t ha^{-1} (IRRI, 2006). The yields for resource poor farmers (RPF) located in areas with poor soils are though often much lower. The Prateah Lang soil group is Cambodia's largest rice growing soil group (28%) which is low in nutrients and Carbon and where yields often range from 800 to 1400 kg ha^{-1} (White *et al*., 1997a). Pheav *et al*. (2005) refer to the Soil Survey Staff (1994) who characterizes the Preateah Lang soil group as a Plinthustalf. The soil type is a sandy loam. Prey Veng province is one of many areas in Cambodia containing this soil group where farmers are short of resources with little access to chemical fertilizers and rice yields stay low.

SRI was introduced to Cambodia in 2000 through various NGO projects (Anthofer, 2004) and it is now practiced by approximately 80.000 farmers out of Cambodia's total 1.8 million farmers (Koma, 2007). Farmers do however practice it in many different ways with modified structures thus making it slightly different from the concepts developed by Laulanie (1993). Household income and access to labour input and biomass will have a large influence on the type of SRI practiced by the farmers.

The local Cambodian NGO CEDAC has implemented a new SRI project in Prey Veng province in cooperation with the Danish organization NORDECO and the organic Danish dairy Oellingegaard. Together they investigate the possibilities of storing C in the soils and reducing emissions of greenhouse gases (GHGs) through the SRI concept (NORDECO, 2008). CEDAC has a lot of experience with SRI and are considered as one of the pioneers in introducing SRI in Cambodia.

Flooded rice fields are in focus because they are major contributors to emissions of GHGs. It Flooded rice production, animal production (ruminants), animal production waste and burning of biomass account for app. 33% of the world's total methane emissions (Mosier *et al*., 1998). Methane is produced from decomposition of organic matter during anaerobically conditions (Wassmann *et al*., 2000) and is a GHG as it traps 23 (Yue *et al*., 2005) to 30 times more heat than CO_2 (Neue, 1993). Many studies on GHG emissions from flooded rice fields conclude that several drainage periods during the rice crop cycle will lower the total emission of methane from a flooded rice field (e.g. Wassmann *et al*., 2000; Yue *et al*., 2005) which however might increase other GHGs such as nitrous oxide (Zou *et al*., 2005; Li *et al*., 2009) hence result in a trade-off situation. The use of different organic inputs might as well influence the emission rates. Compost applied to flooded fields will normally result in lower emissions of methane than applications of green manure and rice straw (Yagi & Minami, 1990; Neue, 1993) which are all typical farming inputs in resource poor areas.

Carbon (C) storing in soils is as well in focus because it is one of many indicators of soil quality – as it is a large component of organic matter (OM) (Brady & Weil, 1999a) which when decomposing mineralizes nutrients and thereby increase soil fertility (Larson & Clapp, 1984).

This report takes part in the project initiated by CEDAC and NORDECO in Prey Veng province assessing the impact of SRI on the livelihoods of RPF.

1.1 Research objectives and hypotheses

- SRI fields will result in higher yields than traditionally grown rice fields.

- Farmers with higher incomes will potentially be the most suitable to adapt the new SRI techniques. This will result in a higher soil quality (assessed by soil Carbon and Nitrogen content) and SRI rice yields as compared to farmers with lower incomes.

- Can SRI be regarded as part of a sustainable livelihood strategy/farming system and at the same time environmentally sustainable? i.e. is SRI able to mitigate GHG emissions (CH_4, N_2O, CO_2) and increase soil quality in terms of C storage?
    - The SRI practiced by the target farmers and the “true” theoretical concepts of SRI are compared with regards to efficiency and sustainability.

- The success of SRI will very much depend on the way it is introduced to farmers and the organization(s) behind. Can SRI survive in a farming community without a strong organization to monitor, inspire and involve farmers?

1.2 Delimitations

SRI

The implementation and sustainability of SRI is tested and evaluated. The target farmers' perception of SRI is compared with the theoretically described SRI concepts. The farmers' SRI perception is documented from the field data from Cambodia and compared with the theoretical writings of SRI as no such fields were present in the area. SRI in Cambodia is often found in areas where rainfed lowland rice is grown. Other rice cropping systems will not be dealt with in details.

Soil quality

This report is measuring the soil quality based on the total soil C content and to a minor extent soil N. An estimated nutrient budget is evaluated on the basis of literature findings as a total soil analysis was too expensive to include in this report. Soil pH is measured and evaluated but is not included in any further discussion and but included in order to key and identify the soil type and general characteristics. The fertility value of the compost/biomass production in the project was evaluated theoretically as compost analysis was too expensive to include in this report. The main idea is to evaluate the effects of SRI on the livelihood strategies and include its effects on the soil parameters C and N and other macro and micronutrients are therefore not dealt with in details.

GHG emissions

The emissions of CO_2, N_2O and CH_4 are discussed but most focus will be put on methane as it is the most dominant gas emitted from flooded rice fields. The general causes why these three GHGs are produced will be introduced, but the focus lies on the potential of SRI to mitigate CO_2, N_2O and CH_4. Other GHGs are not included. The effect of SRI on the mitigation rates was evaluated theoretically. GHGs emission data was too expensive to address and no materials to assess such rates are available in Cambodia.

1.3 Structure of the report

For a better understanding on the potential effects of SRI on the soil C level and GHG emissions, chapter 2 introduces general characteristics of flooded rice soils and the effects of organic material applications. Chapter 3 discusses the emissions of CO_2, N_2O and CH_4 from flooded rice fields and evaluates mitigation effects from applying SRI alike water management and application of organic materials. These two chapters lead to chapter 4, 5 and 6 introducing SRI, Cambodian rice culture and development strategies in developing countries respectively. Chapter 7 and 8 introduce the target area in Cambodia and materials and methods applied in the field and laboratory for data collection respectively. Results are discussed and evaluated in chapter 9 and finally general conclusions are drawn in chapter 10.

2. The role of Soil Organic Matter (SOM) in flooded rice soils

2.1 Definition of SOM

SOM can be defined as the sum of all organic matter (OM) in a soil, resulting from undecayed OM from plant tissues, soil microorganisms and animals, grasses, weeds, leaves and roots (Borggaard & Elberling, (2003). These different soil ingredients are part of different pools all responsible for the definition of SOM. The most important pools are i) the litter pool comprising e.g. crop residues, ii) light fraction - with root residues and iii) microbial biomass – the degradation of plant material (Stevenson & Cole, 1999). As all OM contains large percentages of C (Brady & Weil, 1999a) and in average SOM contains 58% C (Borggaard & Elberling, 2003). Roughly speaking can C in soils divided between two pools: Soil Organic Carbon (SOC) and Soil Inorganic Carbon (SIC) (Lal, 2002). The SOC pool is composed of two very different fractions. The inert pool which does not comprise mineralization and is determined by climate, soil type and landscape position (Lal, 2006). The other pool is the labile pool which relies on management practices (Lal, 2006). The SOC pool comprising the labile factors can be influenced by management and there are direct effects on soil quality and the SOC content is linked to the labile pool (Lal, 2006). The labile pool is also interesting to focus on as it is near to the soil surface and possible GHG emissions will emit from this pool (Schlesinger & Andrews, 2000) and it has faster turnover rates of OM than the inert pool (Mandal *et al.*, 2008). Mineralization is taking place in this pool and thereby the key to increase productivity is through SOC. This report measured the percentage of OM in the soils of Prey Veng, Cambodia. The terms, SOM, SOC, OM and C will all be used throughout this report to express the soil quality.

2.2 Decomposition and effects of OM in flooded soils

As flooded rice soils provide anaerobic conditions for the soil environment, the decomposition reactions are very different than under aerobic soil conditions. Decomposition rate is very slow under anaerobic conditions resulting in a larger build up of OM under flooded conditions as compared to non flooded fields (Mitsuchi, 1974; Greenland, 1997; Brady & Weil, 1999a), and thus both already existing and added OM will be decomposed with a slower rate (Mitsuchi, 1974). Anaerobic conditions will lead to several changes in the soil. Some important ones are a lowered redox potential and a change in the population of microorganism (Watanabe, 1984).

The decomposition of OM depends on several factors such as the quality of the applied material, the general soil texture, the climate and soil disturbances (Morari *et al.*, 2006). C:N ratio of the applied organic compounds is as well very important as it indicates how fast a given material is decaying (Brady & Weil, 1999a). The lower the C:N ratio of an organic input the faster the decay.

When a soil is submerged the soil Oxygen is depleted and pore spaces are filled with water leaving only a few cm of soil near the surface and below the plough layer with Oxygen (De Datta, 1987). This layer is typical less than 10 cm in depth and is oxidized due to the floodwater above which is oxygenated and then oxygen is diffused to this thin soil layer (Dobermann & Fairhurst, 2000). Under this oxidized layer is the reduced bulk soil (Dobermann & Fairhurst, 2000) which is depending on the redox potential. The redox potential is seriously affected under submerged conditions and most substances found in the soil are reducing agents as compared to aerated soils where substances are oxidizing agents (Brady & Weil, 1999a). General advantages are increased supplies of Nitrogen, Phosphorus, Potassium, Iron, Manganese, Molybdenum and Silicon (De Datta, 1987). General disadvantages are losses of N from denitrification, decreased availability of Sulfur, Copper and Zinc and increased production of toxic compounds damaging plants.
Greenland (1997) states that due to the reduction in submerged soils some elements like Iron and Manganese might reach very high and toxic levels – and plants might be damaged from such high concentrations.

SOM can increase soil quality in terms of possessing high percentages of C and nutrients, increasing good soil structure, enhancing Cation Exchange Capacity (CEC), pH buffering and aggregate stability (Borggaard & Elberling, 2003). Aggregate stability is though destroyed through the process of puddling – which is also the purpose (Greenland, 1997). Puddling is a process, initiated before transplanting/seeding rice, where fields are flooded and then harrowed or ploughed resulting in a decrease of the aggregate stability due to both a wetting and mechanical intervention of the aggregates (De Datta & Hundal, 1984). Puddling is used in order to prevent loss of water from e.g. percolation on especially alluvial and mountain soils, to level the fields and make it easier to transplant rice seedlings (Greenland, 1997).

When OM is decomposed nutrients are mineralized and thereby increasing soil fertility (Larson & Clapp, 1984). But in submerged conditions decomposition is very slow and mineralization is therefore slowed down as well and nutrient availability might therefore be decreased. The most important effect of adding composts to rice fields is to increase available N and to balance the immobilization and mineralization of N found in the soil (Kumazama, 1984).

Nutrients will though not be available to plants before a decomposition of the OM sets in and the OM is mineralized and releases inorganic nutrient ions in available forms to plants (Brady & Weil, 1999a). Fresh OM inputs should be avoided such as fresh rice straw as larger amounts applied to fields will result in N-immobilization and a high reduction of the soil and should like all other fresh OM be composted in order to reach a higher level of efficiency (Inoko, 1984). If large amounts of fresh OM inputs are applied , it is possible that the soil will be further reduced and produce GHGs (Greenland, 1997). These risks will be introduced in chapter 3. Submerged soils normally mineralize higher amounts of N as less is immobilized compared to aerobic soils even if decomposition of OM is slower (De Datta, 1987).

2.3 Storing of C in soils

The content of SOM depends on the equilibrium between losses of C and gains of C from mainly respiration, erosion, removal of plant residues, plant growth in situ and applications of organic inputs respectively (Brady & Weil, 1999a). The key issue is to apply enough inputs of high quality materials in order to maintain the C content at equilibrium or slowly increase its content.

2.4.1 Ways of increasing C in soils through management

Many studies have identified possible management methods which can alter the C content in a soil hence affecting the OM content. However, most studies relate to aerobic field conditions.

Lal (2006) estimates that by using the Recommended Management Practices (RMPs) it is possible to increase the SOC content of the soil and then directly increasing the yield 15-25 kg ha^{-1} $year^{-1}$ if the RMPs will enhance the SOC pool with at least 0.5 Mg C ha^{-1} $year^{-1}$.
RMPs are a set of tools which will apply to all kinds of plant production sectors and are as described and discussed by Follett (2001) including various concepts such as conservation tillage, crop residue management, fallow management etc. Some of the concepts might not be possible to perform when growing flooded rice though or they will not be as effective as under aerobic conditions.

Jarecki & Lal (2003) evaluated the potentials for SOC sequestration for rice and concluded that 401 kg C ha^{-1} can be stored annually with an average rice yield of 3.96 t ha^{-1} and a C input in terms of crop residues of 2.67 t ha^{-1} $year^{-1}$. Mandal *et al*. (2008) investigated the role of time and fertilizer application and their role on the SOC content from a long term study involving 36 cropping seasons of double rice cropping in India. They concluded that applying NPK fertilizers and NPK + compost increased the total C content in the soil with 33.5% and 54.9% compared to the control of 28.5 Mg C ha^{-1} (Mandal *et al*., 2008).

Green manures are often an important part of rice cropping systems as e.g. legumes and bushes/trees (Greenland, 1997). Ramesh & Chandrasekaran (2004) investigated the role of the green manure (GM) crop *Sesbania rostrata* Berm in a double rice cropping system per year and concluded that the trials with GM resulted in the highest SOC contents of 10.63% increase compared to the control for a period of two years[1].

Other management ways adding C to the soil is by conservation tillage (Lal, 2007) or zero/no tillage. Reduced tillage was initiated in the 1950ies with the use of pesticides such as dalapon (2,2-dichloropropionic acid) and later paraquat and glyphosate were used to destroy soil surface cover (De Datta, 1987). Under especially tropical conditions where heavy rainfalls can destroy soil structure and lead to erosion and little or no disturbance of soil can be a method to cope with such problems (De Datta, 1987). The benefits of zero tillage or conservation tillage are amongst others: saving of water with up to 20-30% of what the rice crop needs (De Datta, 1987) and a reduction in loss of SOC and plant nutrients (Jarecki & Lal, 2003) respectively.

[1] The GM *Sesbania rostrata* Berm was sown a rate of 50kg of seed ha^{-1} (Ramesh & Chandrasekaran, 2004).

Crop residues

The use of rice straw rice is a free source of nutrients for farmers (Olk *et al*., 2000) although it is low in nutrients. In resource poor areas rice straw is though often removed from the fields in order to use as e.g. animal fodder (Dobermann & Witt, 2000) even though rice straw contains high amounts of lignins and silicas making it difficult for animals to digest (Greenland, 1997).

If straw is present, the time of incorporation and the incorporation depth are very important factors in order to gain the full potential from the straw (Dobermann & Witt, 2000). Rice stubble and roots will as well have some importance supplying organic materials to the soil.

3. Greenhouse gas emissions and possible ways of mitigation

Applying plant residues in several forms will not only benefit soils but also influence the possible dangers of GHG emissions. In especially the tropics, farming and global warming might go hand in hand concerning rice production as there is a potential future threat of contributing to global warming.

3.1 GHG emissions through time

Since the beginning of the industrialization and till present (1998) Land Use Changes (LUC) and fossil fuel burning + cement production have caused emissions of 136 + (-) 55 Gt[2] C and 270 + (-) 30 Gt C in form of carbon dioxide respectively (IPCC, 2000). LUC through the 1980ies and 1990ies caused emissions of approximately 1.7 +(-) 0.8 Gt C and 1.6 + (-) 0.8 respectively (IPCC, 2000). Agriculture is one of the main contributors to LUC. Agricultural related activities account for approximately 33% of the world's total methane emissions comprising: animal production (ruminants), waste from animal production, burning of biomass and flooded rice production (Mosier *et al*., 1998). According to Lal (2002) the outlets of carbon (C) from LUC, agricultural activities and deforestation were higher than outlets from fossil fuel combustion until the 1970's. Since 1750 the amount of atmospheric CO_2 has increased with 31% due to burning of fossil fuels LUC (Lal, 2004). Global emissions of CO_2 from LUC + cultivation and fossil fuel burning amount to app. 136 and 270 Pg respectively (Lal, 2004). Agriculture (through human related activities) is presently

[2] 1GT = 1Pg = 10^{12} kg.

responsible for 50% of the world's total emissions of CH_4, 25% of CO_2 and 70% of N_2O respectively (Hutchinson *et al*., 2007).

LUC in Cambodia has during the last decades resulted in a decrease of forest areas of 2.5 million ha in the period from 1973 to 1997 (Sasaki, 2006). As a result of these actions it is estimated that an annual C emission from Cambodian soils due to LUC and logging was app. 13.7 Tg C in the period 1993-2003, (Sasaki, 2006) which is probably much higher now as logging and LUC are to be found everywhere in Cambodia.

Irrigated rice fields emit CO_2 and CH_4 (Kimura *et al*., 2004) and especially CH_4 emissions from irrigated rice fields are very significant (Neue, 1993). Vergé *et al*. (2007) estimate that the emissions of methane from rice paddies in Asia in 1990 and 2000 were 705 Tg CO_2 equivalent and 732 Tg CO_2 equivalent respectively compared to global emissions of 845 and 898 Tg CO_2 equivalent for the same period respectively. Neue (1997) evaluates that the annually seasonal emission rates of methane for Asian irrigated rice paddies is 312 kg m^{-2}. Kimura *et al*., (2004) estimate that the average CO_2 and CH_4 production from Japanese and Thai rice fields are; Japan: 1.4-1.5 t C ha^{-1} and 37-38 t C ha^{-1} Thailand; 1.8-2.1 t C ha^{-1} and 52-66 t ha^{-1} respectively. Figure 1 illustrates global annual methane emissions from rice fields. Asia and especially South East Asia is a main contributor to methane emissions compared to the other rice growing areas.

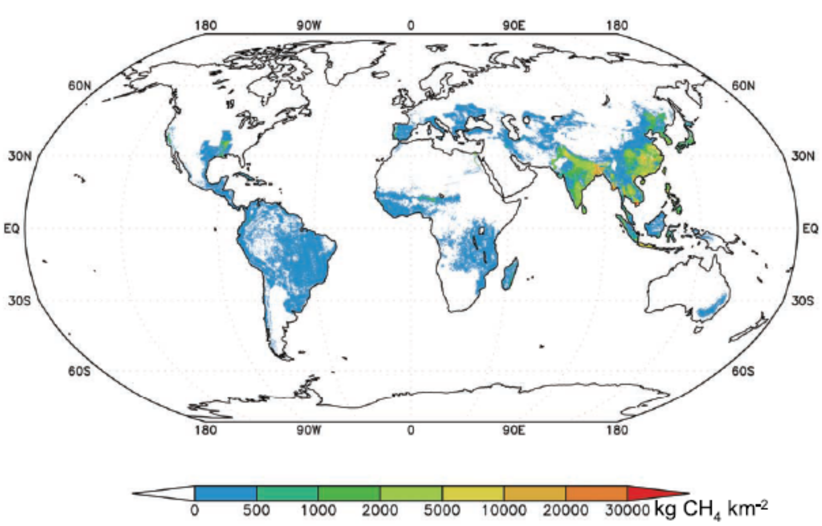


Figure 1. Global annual CH_4 emissions from the rice growing areas of the world. Yan *et al*. (2009).

The degree of GHGs emissions will to a large extend depend on what type of rice cropping systems is used. Irrigated/continuously flooded systems will pose the largest risks. Flooded rice fields with anaerobic conditions will produce methane from decomposition of organic matter anaerobically (Wassmann *et al*., 2000) and emit CH_4 through rice plants (roots and stems) as either diffusion or ebullition (Neue, 1993). Methane is found in smaller amounts in the atmosphere than CO_2 but one molecule of methane will trap as much heat as 30 molecules of CO_2 (Neue, 1993), although Yue *et al*. (2005) state that the Global Warming Potential (GWP[3]) of CH_4 is 23.

Nitrous oxide (N_2O) is emitted when N is added to agricultural soils, in forms of e.g. fertilizers, through volatilization of e.g. NH_3, leaching, run-off and redeposition (Zou *et al*., 2009) and though it is found in smaller concentrations than CO_2 in the atmosphere the GWP of N_2O is 296 times those of CO_2 (Li *et al*., 2009). N_2O in soils is derived from production of nitrification and denitrification processes (Zou *et al*., 2005) and is favored by aerobic conditions. CO_2 derived from soil is produced from respiration from microbes, roots and from bulk soil respectively (Xu *et al*., 2008).

3.2 The effect of organic amendments and chemical fertilizers on GHG emissions

Organic amendments or chemical fertilizers will pose various and different affects on GHGs emissions from soils. Lou *et al*., (2007) conducted studies on CO_2 and N_2O emissions from irrigated rice fields and concluded that when rice straw was applied and incorporated in the soils the emissions of CO_2 and N_2O were much higher than fields where straw had been removed and only rice roots were left. This is because straw contains more cellulose than roots and roots contain more lignin than straw and will therefore decompose slower than straw (Lou *et al*., 2007). Irrigated rice soils amended with rice straw emit more than twice as much CH_4 compared to soils amended with mineral fertilizers (Yagi & Minami, 1990) and soils without any amendments (Watanabe *et al*., 2005). However disposal of rice straw long time before a rice crop is initiated will decrease methane emissions (Yan *et al*., 2009). Yan *et al*. (2009) estimated that if all single and double cropping rice growing areas would apply their straw off the season, methane emissions could be decreased with 4.1 Tg a^{-1} per year. Yan *et al*. (2009) develop a theoretical map of south East Asia (figure 2) illustrating potential mitigation possibilities (drainage and application of straw off the growing season) and their effects per year on the emission of methane.

[3] GWP is a set of tools comparing a given GHG and how much heat it will capture compared to CO_2 (Li *et al*., 2009)

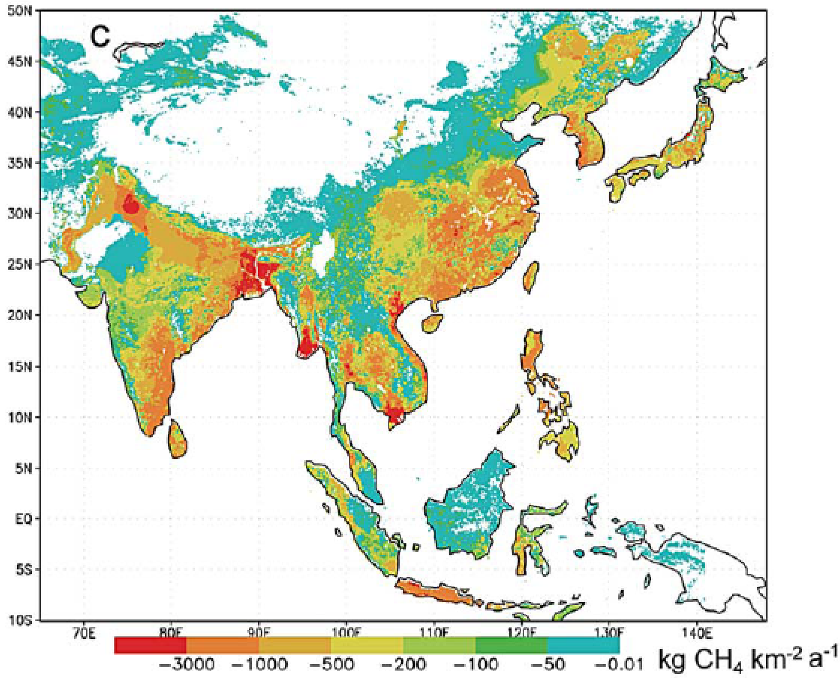


Figure 2. Effects of applying rice straw outside the season and draining continuous flooded rice fields. Units are in emissions of kg CH_4 km^{-2} a^{-1} year^{-1}.Yan *et al.* (2009).

Yagi & Minami (1990) also studied effects of soil types on methane emissions and concluded that soils with high OM content have a higher influence on CH_4 than soils with low OM content. Thus emitting more methane than soils low in OM is most likely due to a lower anaerobic decomposition.

Resource poor farmers (RPF) who cannot afford to invest in mineral fertilizers rely on natural amendments such as compost and green manure. The most sustainable amendments would seem to be composts as compost only slightly increase methane emissions compared to green manure and rice straw (Neue, 1993; Yagi & Minami, 1990). Compost combined with mineral fertilizers decreased CH_4 emissions from rice fields in India twice as much as mineral fertilizers alone (Nayak *et al*., 2007) indicating that possible combinations of these two amendments would be ideal.

3.3 Management practices and their effect on GHG emissions

Management practices such as puddling will have some effect on GHG emissions. Harada *et al*., (2007) studied the effect of no puddling in irrigated rice farming and found that the emissions of CH_4 was 43% lower than in conventional puddling practices in Japan. CO_2 emissions from no puddled fields were 1740 kg CO_2 ha^{-1} lower than in puddled fields (Harada *et al*., 2007). It is though questionable if RPF conduct puddling. De Datta (1987) states that large quantities of water are required (app. 150-200 mm) and farmers producing lowland rainfed rice are forced to wait app. one to three months before there is enough water to puddle.

3.4 Drainage periods and GHG emissions

The effects of a changing water level in a rice field leading to anaerobic and aerobic conditions will influence GHGs emissions and especially methane emissions. Wassmann *et al*., (2000) conducted studies on CH_4 emissions from five locations in Asia and discovered that soils amended with organic manure had higher emissions of GHGs compared to soils fertilized with mineral fertilizers. Intermittent flooding and mid season drainage resulted in lower emissions than with conditions of continuous flooding (Wassmann *et al*., 2000). Emission rates ranged from less than 100 kg CH_4 ha^{-1} to more than 400 kg CH_4 ha^{-1} for intermittent irrigation and continuous flooding respectively (Wassmann *et al*., 2000). Emissions were different within the different periods of the rice crop with highest emissions during the reproductive stage and the highest temperatures (Wassmann *et al*., 2000) which is also true for the other GHGs.

Drainage periods will lower CH_4 but will however affect the emission rates of N_2O. Yue *et al*. (2005) compared continuous flooding with intermittent flooding and their role on CH_4 and N_2O emissions in Southern China and found that intermittent flooding showed a 17% lower GWP compared to continuous flooding while there was no significant differences between yields. Methane emissions decreased but N_2O increased with intermittent flooding but the trade-off was the most optimum as compared to continuous flooding (Yue *et al*., 2005). Zou *et al*. (2005) found that in Chinese rice fields with continuous flooding N_2O emission rates was 0.03 mg m^{-2} d^{-1} as compared to rice cropping with a mid season drainage of 14.1 mg m^{-2} d^{-1}. Both treatments received 2.25 t ha^{-1} of wheat straw. Mid season drainage periods are often used in China and Japan but not to a large extent in warmer rice growing climates (Greenland, 1997). The effect of drainage in the Cambodian climate, which is very different from the Chinese and Japanese climatic situation, might result in different emission rates due to temperature and a faster decomposition of OM.

Water management involving mitigation interests or because of water shortages will have large influences on emission rates of CH_4, N_2O and CO_2 with many trade-offs involved (Frolking *et al*., 2004). A farming system trying to involve mitigation of all three GHGs and involve and deal with the trade-offs would be an optimal one. But which system can cope with such challenges and still sustain the farmer and his family?

4. The System of Rice Intensification (SRI)

RPF might identify an optional and possible ideal rice based farming system within the newly developed concept; System of Rice Intensification (SRI) which is ground to heavy discussion throughout the world due to its opposing views on rice farming.

4.1. The history of SRI

SRI was developed by a French Jesuit priest, Father Henri de Laulanie, in Madagascar in 1983, who during a persistent drought noticed a good growth of the rice plants (Stoop *et al.*, 2002). De Launanie continued with the idea, and developed a farming system with few external inputs to benefit poor farmers and at the same time an environmentally friendly system (Satyanarayana *et al.*, 2007). Laulanie formed the NGO, Association Tefy Saina (ATS), to supervise and support SRI in Madagascar and from country to country (Moser & Barrett, 2003).

SRI seems to be a very potential method and as described by Mcdonald *et al*. (2006): "SRI satisfies the often conflicting objectives of agricultural development: tremendous grain yields with few external inputs". The introduction of the green revolution led to modern technologies which required too high input costs for some RPF to cope with (Sinha & Talati, 2007) and here SRI might represent an alternative low input cost method accessible for poor farmers.

Cultivating plants often follow the equation G x E (Genotype x Environment) i.e. plants are results of the genotype and the environment they are grown in (Satyanarayana *et al.*, 2007) and highly influenced by the management practices as well. SRI focuses more or less on changing the environment such as soil, water and nutrient management for any given genotype (Satyanarayana *et al.*, 2007).

4.2 The concepts of SRI

Laulanie (1993) developed the SRI concepts during the 1980's and concentrated on two major issues:

- As little irrigation as possible and non flooded fields to obtain a higher air flow to the soil and roots.

- The use of young seedlings transplanted one by one with wider spacing than normally (25cm x 25cm minimum).

Laulanie (1993) further states that these two concepts define SRI but other techniques have been and are used by SRI practising farmers to ensure and increase the potential benefits of SRI. More concepts and techniques have through the years been identified and correlated with SRI. According to Sheehy *et al*. (2004) a new and modernised SRI technology could be characterized as:

1. Use of young seedlings being app. 8-12 days old per hill with a minimum distance of 25 cm x 25 cm.
2. Regular hand weeding.
3. Irrigation is managed on a daily basis in order to maintain a wet but not flooded soil in the vegetative stage. During the panicle stage the fields are flooded with 1-2 cm of water and 10-15 days before harvest time the fields are drained.
4. Application of compost or organic residues in big quantities. If this is not possible or non present then no application should be chosen or an application of mineral fertilizers.

Figure 3 illustrates how a SRI field could look like.

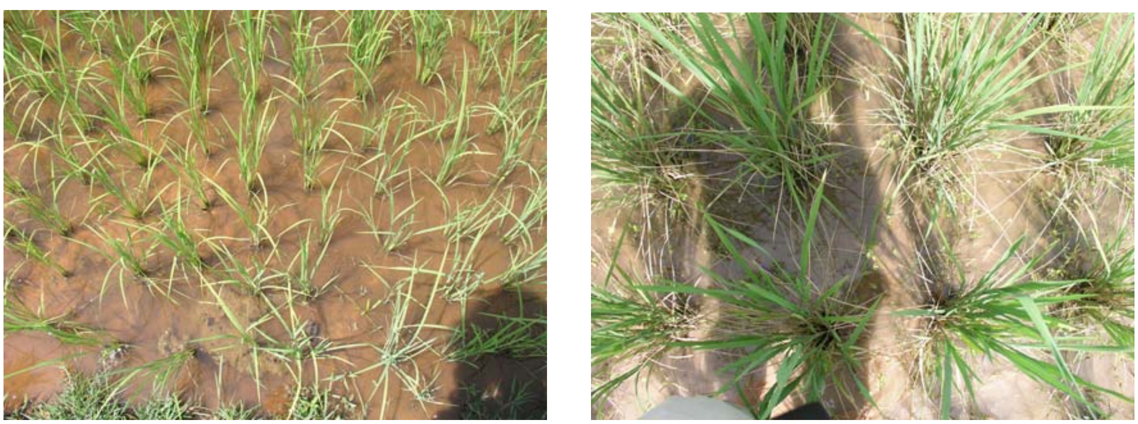


Figure 3. Newly transplanted SRI fields.

The use of composts is not due to organic concepts. SRI uses composts and natural fertilizers produced locally because chemical fertilizers would be too costly for RPFs (Stoop *et al*., 2002). Initially the first steps of SRI in Madagascar were based on chemical fertilizer applications, but then the Madagascan government stopped the subsidies for chemical fertilizers and farmers had to seek new alternatives and the use of compost hence became more important (Satyanarayana *et al*., 2007). It should be notified that SRI should not be regarded as a fixed system, but one that will differ between countries and regions because it depends on the agro-ecological characteristics in a given area (Stoop & Kassam, 2005).

The reason why less water is stressed to be so important is due to several reasons. Normally rice is categorised as being an aquatic plant due to its formation of aerenchyma cells in the roots under flooded conditions – but is not necessarily because rice will grow better under such conditions (Kabir, 2006) as there is no evidence that flooded conditions will result in better plant growth (Stoop *et al*., 2002). Dobermann (2004) however states that the reason why the rice plant developed the aerenchyma cells is due to its evolution from being native to wetlands because conditions were more favourable there with more nutrients and less competition. Continuous flooding is though believed to decrease root growth due to lack of oxygen (Satyanarayana *et al*., 2007). The idea of keeping soils just moist and not flooded will enhance a larger root growth making the rice plants more adapted to situations with water stress (Kabit & Uphoff, 2007) which are typical for rainfed lowland systems (Greenland, 1997; Javier, 1997) creating shortage of water for the plants (Seng *et al*., 1999). Lowland rainfed systems are discussed more in section 5.2 and 7.1. The use of younger seedlings is believed to result in an improved and larger root growth (Satyanarayana, 2004) which will take up more nutrients (Kabir, 2006) and hence improve growth and yield potential of the rice plant.

4.3 The differences between SRI and a traditional/conventional rice system

There are large differences between SRI and traditional/conventional rice production methods. Table 1 below illustrates these variations where especially the amount of seeds needed per ha and age of seedlings are some of the major differences.

Table 1. The major differences between SRI and conventional rice production methods. Taken from Stoop *et al.* (2002).

	Seed requirement (kg/ha)	Age of seedlings (days)	Transplants per clump	Spacing of clumps (cm)	Transplants per m^2	Water management	Fertility management	Weed management
SRI methods	5–10	8–15	1	25×25 to 50×50	4 to 25	Moist soil; intermittent drying	Compost	3 to 4 rounds, with rotary hoe
Conventional production methods	80–120	20–30	3 to 4	10×10 to 20×20; usually in rows	75 to 150	Continous flooding	Basal mineral fert. + N top dressing	2 rounds; may use herbicides

There are however large disputes concerning SRI and its successes with farmers as there are many pros and cons. Supporters claim that SRI often yield the double of conventional rice farming, but opponents state that there is no scientific evidence for such potentials (Surridge, 2004). There are however many experiments which illustrate the benefits of SRI and those that illustrates that there is no difference between SRI and conventional rice growing. Very high yields have been reported with SRI as compared to traditional farming or farmers practice. Table 2 below illustrates some of the reported high yielding situations from rice growing countries.

Table 2. SRI vs. farmer practice yields.

SRI (t/ha)	Conventional - Farmer Practice (t/ha)	Specifications	Country	Reference
7,4	2,5	N = 10	Gambia	Caesay (2002)
5,3	2,5	N = 8 groups of 20 farmers.	Sierre Leone	Yamah (2002)
7-15			Madagascar	Stoop *et al*., (2002)
6,5	2,08		Myanmar	Kabir & Uphoff (2007)
2.3	1,6	N = 500	Cambodia	Anthofer (2004)

Such yields as described above are though according Dobermann (2004) not scientifically reliable and non comparable to conventional rice growing. Dobermann (2004) further states that in many experiments where SRI is compared to conventional farming a scientific methodology has not been followed and it is therefore very difficult to compare the two systems. McDonald *et al*., (2006) compared and compiled data from yields between SRI and conventional rice growing in China, Laos, Nepal, Thailand, India, Sri Lanka, Indonesia, Bangladesh, and the Philippines and found that in a majority of these countries SRI provided lower yields than conventional growing. Sheehy *et al*. (2004) compared SRI with conventional grown rice at three sites in China regarding grain yield, number of panicles, spikelets per panicle, grain filling and grain weight and found no difference between the two methods. Sheehy *et al*. (2004) further states that the very high reported yields from Madagascar are not possible and are due to measurement errors.

4.4 Difficulties associated with SRI

Farmers often only follow a few of the steps of the SRI concepts and leave out the other concepts which make SRI difficult to compare within a given area to another area (Sinha & Talati, 2007). Moser & Barrett (2003) reports that the very high yields observed around the world are due to farmers managing all the concepts of SRI and using them together. But SRI is not always easy for farmers to adopt which as stated by Sinha & Talati (2007) could be prescribed three main factors:

1. “Lack of irrigation facilities” (Sinha & Talati, 2007)
2. “Absence of sound on-farm water management due to poor infrastructure and technology” (Sinha & Talati, 2007)
3. “Lack of expertise and risk-taking ability among farmers. In rainfed areas it is difficult to adopt SRI if there is no facility available for protective irrigation, in the event of monsoon failure. On the contrary, too much rain also makes it difficult to drain the fields“. (Sinha & Talati, 2007)

Management and minimization of water are often the most difficult steps for farmers to reach and understand (Moser & Barrett, 2003). Furthermore the success of SRI depends on land levelling which can be costly and applying SRI on large fields seems therefore more ideal than on small fields (Moser & Barrett, 2003) which then might leave out small scale farmers.

SRI can be characterised as a LEISA (Low External Input Sustainable Agriculture) system where high labour inputs are often necessary (Moser & Barrett, 2003) which is one of the many weaknesses appointed by many authors (e.g. Moser & Barrett, 2003; Dobermann, 2004). Other identified constraints are the access and availability of organic materials and the labour involved in transporting and applying it (Dobermann, 2004).

Koma (2007) though reports that it is not all SRI farmers in Cambodia who manage all the steps of the SRI concepts but even when only managing some of the factors involved in SRI they are still able to increase their yield per hectare and a reduction in the amount of seeds used.

5. Rice in Cambodia

5.1 The history of rice in Cambodia

Rice is grown throughout the world in various ways depending on climate and soil and is the major food source for millions of people. In Cambodia rice has been cultivated since before the 8th century (Mak, 2001) and is still a very important crop in Cambodia. Table 3 summarizes the fate of rice in

Cambodia during modern times. In 1940 Cambodia was the third largest exporting country of rice in the world (Tong *et al.*, 2007) and still during the 1960ies Cambodia was a leading partner in rice production in the world and continued to be so for many years (Koma, 2008) but civil wars later blocked any further development (Tong *et al*., 2007).

Table 3. Average rice production, harvested area and rice yield in Cambodia from 1961 to 2006. Derived from IRRI (2006).

Year	Area (ha)	Production (t)	Yield (t/ha)
1963	2.182.000	2.383.000	1.09
2006	2.516.000[1]	6.264.000	2.49

[1] According to Koma (2008) the total grown area in Cambodia with rice is app. 3.1 million ha with a potential of total agricultural production of app. 6.7 million ha.

5.2 Rice cropping systems

In Cambodia rice based farming systems often include lowland rice, dry season rice and early wet season rice (Mak, 2001), depending on location and access to water. The main rice cropping systems vary a lot especially regarding the water table. Figure 4 highlights the difference in water depth. The different rice cropping systems can be characterized as the following:

- *Upland rice or dryland rice*: grown without water, normally related to areas with shifting cultivation (Greenland, 1997). Upland rice can often be intercropped with e.g. cassava, but often severe weed problems occur (De Datta, 1987).
- *Irrigated rice*: The water table in the field can be controlled through the use of river/stream water and several rice crops are possible per year although sometimes drought is existing (Greenland, 1997).
- *Rainfed lowland rice*: Dikes are build to catch both flood or rain water and the rice is often transplanted to the fields although also direct seeding sometimes dry or wet is existing (De Datta, 1987). Periods with drought can exist (Greenland, 1997).
- *Deepwater rice*: 51 -100 cm water table normally grown in e.g. swampy areas in deltas (De Datta, 1987). Water regimes cannot be controlled and there are large risks of either drought damage or sudden flooding as seeds are sown on dry soil (De Datta, 1987).

- *Floating rice:* 1-6 m of water, modern rice varieties are not well adapted, seeds are sown before flooding (De Datta, 1987). The problems are similar to those found in deepwater rice.

The yields are very different and according to Greenland (1997) a rough estimate of the rice yields from the different rice systems is in the following order:
irrigated > flood/deepwater > rainfed > upland. This is though very variable depending on soil, climate and management.

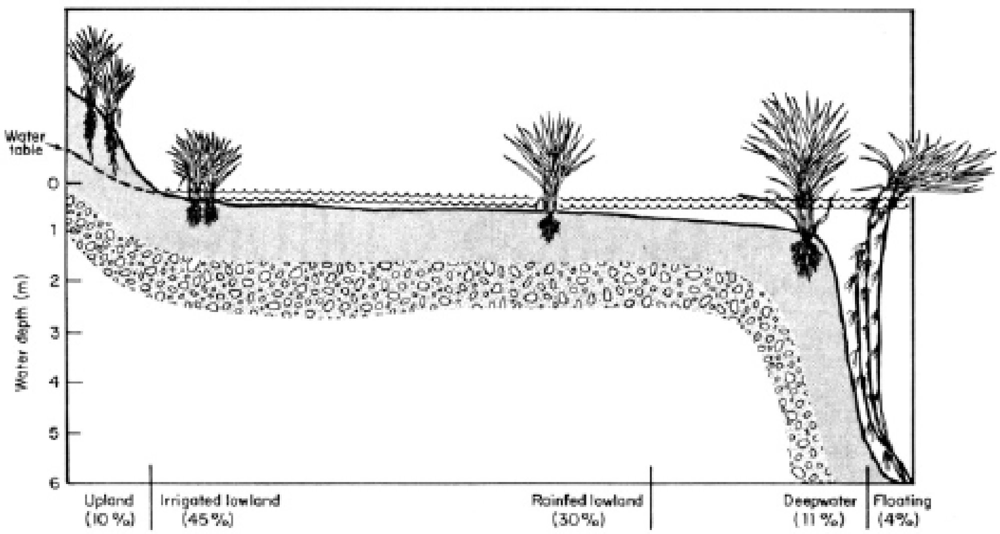


Figure 4. The different rice cropping system as a function of water depths and the importance (%) in the world's total production of rice. De Datta (1987).

These rice based farming systems in Cambodia often include various other supporting factors such as livestock raising, aquaculture, vegetable and fruit production (Mak, 2001). Most households in Cambodia possess around two to five ha of land and the majority of the total grown rice area in Cambodia is lowland rainfed rice (Tong *et al*., 2007). Most of this rice is managed with manually labour and it takes in average 60-70 people per ha to transplant rice seedlings (Tong *et al*., 2007).
The majority of the rice in Cambodia (85%) is produced during the wet season with rainfed rice being the main cropping system and the remaining 15% is produced during the dry season under irrigated conditions (Koma, 2008). Wet season is the period between May and November (Javier, 1997).

Rainfed rice in Cambodia is often grown with water levels ranging from 0 to 25 cm and in some situations after e.g. floods even more (Javier, 1997). During some periods of the cropping season for rainfed rice the soil might not be covered with water and aerobic conditions will be present due to little or no rainfall (Javier, 1997).

Characteristic for rainfed lowland rice systems is typically that the possibility of drainage is often non-existing or only present to a small extent (Greenland, 1997) and the dependence on precipitation is enormous (Wade *et al*., 1999). Some of the main problems concerning rice yields from lowland rainfed rice systems are the time of rainfall, the amount of rainwater and low soil fertility (Pheav *et al*., 2005). As a consequence of the dependence on rainfall, water shortage is common (Seng *et al*., 1999). If the rainfall during the growing season is less than needed, this can lead to poor growth even if a given area receives enough precipitation throughout the year (Tsubo *et al*., 2007). As it is impossible to control the water level in the field for lowland rainfed rice systems, the rice crop will experience periods with total flooding and anaerobic conditions and other periods with drought which will have major influences on the availability of nutrients (Wade *et al*., 1998). Rice plants grown in this rice system are often tall (as submergence comes and goes very unpredictable) and have limited root growth and might not be able to take up enough water during drought periods (Wade *et al*., 1999). Due to the very changing water table weeds, insects and diseases are as well a major problem (Wade *et al*., 1999).

5.3 SRI in Cambodia

SRI was introduced to Cambodia in 2000 through various NGO based projects (Anthofer, 2004) and by 2003 approximately 10.000 farmers practised SRI and in 2004 50.000 farmers practised SRI (Surridge, 2004). This number increased to 60.000 farmers in 2006 and in 2007 the number was approximately 80.000 farmers out of approximately 1.8 million rice farmers in Cambodia (Koma, 2007). As a result of this development the Cambodian government has now adopted the SRI methodology in their National Development Plan for 2006 to 2010 (Koma, 2007). CEDAC has been one of the leading agencies spreading and providing extension for SRI throughout Cambodia.

6. Development Paradigms[4]

What is the most sustainable way of implementing a development project? And in what ways should the extension services of a given project be operated in order to secure long term sustainability of a given implementation strategy? This chapter evaluates some brief history on development strategies and focuses on the use of local knowledge and resources in order to implement a project. This chapter is intended in order to assess how SRI is introduced to farmers and if it is sustainable in the long run.

6.1 Development strategies

When "developing" or influencing a target area there will always exist local knowledge which can be included in a project on various levels. Local knowledge representing farmers (Blaikie *et al*. 1997) or also defined as Rural Peoples Knowledge (RPK) have often been denied and not involved in any decision making in development designs (Scoones & Thompson, 1994). The concept of Transfer of Technology (TOT) has often been used in the past as a way of combining scientific research with extension to end up with farmers (Röling, 1994). Technology has been passed on to farmers who have not been involved throughout the process (Röling, 1994) thus making TOT a very top-down system. Often involving a large hierarchy and the extension system of Training and Visit (T&V). One reaction to TOT has been to introduce Farmer Field Schools (FFS). FFS concentrates on improving social learning though small group units and experimentation and does not rely so much on top-down extension support (Tripp *et al*., 2005). The FFS concept was introduced after the initiation of the Green Revolution and a heavy use of insecticides in paddy rice production in Asia as a more environmental friendly farming system (Tripp *et al*., 2005) and was first used in Indonesia in 1989 trying to introduce Integrated Pest Management (IPM) for rice production which would make farmers use less insecticides (Berg & Jiggins, 2007) as a corporation between the Food and Agriculture Organisation (FAO) within United Nations and the Indonesian Government (Röling & van de Fliert, 1994). The general idea behind the principles of FFS is that a small group of farmers will manage a field throughout a crop cycle (Tripp *et al*., 2005) and then learn from participatory learning and discovery. FFS concentrates on improving social learning though small group units and experimentation and does not rely so much on top-down extension support (Tripp *et al*., 2005).

[4] A paradigm is a set of thoughts and tools relating to decision-making in a development process in order to reach some given development assumptions and goals (Blaikie *et al*., 1997).

In general there are three types of development strategies, the so called paradigms, which involve or do not involve RPK (Scoones & Thompson, 1994). Three paradigms used in the recent history of agricultural development can be identified according to Blaikie *et al*. (1997) as:

- **Classic paradigm** – A top-down system where TOT is based on state research institutions and technological solutions related to development issues and passed to local populations through a long line of extension workers and researchers and does not involve local knowledge at any level in the procedure.

- **Neo-liberal paradigm –** The tools for development already exist in the target area, and are based on local market forces. Local knowledge is accepted but is not involve to any large extent.

- **Neo-populist paradigm –** Based on participatory learning and empowerment reached through mainly Farmer Participatory Research (FPR). This paradigm involves locals in decision making and problem solving. It is the opposite of the classic paradigm as it is based on a bottom-up structure and the farmer-first concepts where farmers are involved in the entire development process (Scoones & Thompson, 1994).

Pretty *et al* (2003) identifies three ways of conducting agricultural development through increasing one of the following situations: 1) total agricultural area in a country, 2) yield per hectare (industrializing) and 3) total farm productivity. SRI seems to belong to the Neo-Populist paradigm which fits very well with Pretty *et al*. (2003) scenario 3 focusing on using the local resources to increase productivity.

6.3 Sustainability in rural livelihood strategies

When introducing a method into a given community it will affect the livelihoods of the involved persons in many different ways and it can influence the already existing sustainability. This section briefly introduces livelihood strategies often used by RPF.

Sustainability can be defined in multiple ways depending on location, participants, conditions and many other factors. Regarding sustainable agricultural systems Pretty (2000) defines it as being systems who "..tend to have a positive effect on natural, social and human capital whilst also producing food, fibre, oil etc." Relating to subsistence farming Greenland (1997) comes up with a more broad definition of a farming system's sustainability as one being able to sustain the involved people and produce enough food and if a given farming system cannot sustain the involved people they will shift to another "more" sustainable one.

Farming practices are one way of distinguishing different farming systems and comparing them and their sustainability. Pretty (2000) states that a farming system which "..sequesters carbon in soils through organic matter accumulation both contributes to the global good by mediating climate change and the private good by enhancing soil health" could be termed sustainable.

Such sustainability for a given livelihood can however be difficult to measure and assess. Livelihood resources can in general be split into four categories named capitals which all connect to the sustainability of a system according to Scoones (1998):

- Natural: natural resources such as e.g. soil, water and environment.
- Economic: e.g. amount of financial means, infrastructure and production technologies
- Human: e.g. knowledge and skills
- Social: e.g. social networks, groups and relations amongst people

These different components of the four capitals are often combined into three different livelihood strategies which can be defined as (Scoones, 1998):

- Agricultural intensification/extension – based on capital resources, labour intensification, initiatives and as well initiation by policy makers
- Livelihood diversification – adapting other livelihood strategies and increasing the sources of income
- Migration – voluntary/involuntary migration in order to cope with a given situation

These different strategies are often combined in different ways for rural people and are termed Livelihood Portfolio which can either be very focussed on few activities or a broader range which often have evolved over some time as a response to various choices made over time (also termed livelihood pathways) (Scoones, 1998).

7. Study and experimental implementation site

This study is targeting RFP in Cambodia's south eastern province, Prey Veng bordering Vietnam to the north and south, Svay Rieng province to the east and Kandal province to the west with special focus on Kanhchriech district in the north eastern part of Prey Veng province. See figure 5 below for more details.

The present study is part of a larger project by the Danish organisation NORDECO, the Danish organic dairy Oellingegaard and the local Cambodian NGO CEDAC who together are implementing the ILFARM project (Improved Livelihood of Small Farmers) in three communes in Kanhchriech district in Prey Veng province.

The focus is on improving livelihoods through sustainable agriculture with special attention to rice cropping systems and changing agricultural techniques to SRI based systems with low dependency to CO_2 input criteria and possibilities of storing C in the soils and reducing GHGs through the SRI concept (NORDECO, 2008). The ILFARM project involves 800 agricultural occupying households in the three communes in Kanhchriech district, for agricultural activities for three years. 500.000 trees are planted on homestead lands and near rice fields in order to increase the production of green manure (CEDAC, 2008c).

7.1 Prey Veng province

The rice farming system in Prey Veng can be described as shallow water wet season rice (SCW, 2006) or it can also be termed a more general term, rainfed lowland rice (Nesbitt & Phaloeun, 1997).

Figure 5. Map of South East Asia and Cambodia with the red arrow directing to Prey Veng province. Derived form: http://upload.wikimedia.org/wikipedia/commons/7/70/Cambodian-provinces-bgn.png

The target area of the present study in Prey Veng is located on old alluvial – colluvial plains which mostly are flooded by rainwater in the growing season (White & Öberthür, 1997). There are only in very few occasions second rice crops during the dry season in Prey Veng. The level of water management is rather low as irrigation and channels are almost not present. Farmers are able to lower the water table but not to increase it. 50-75 % of the population in the target area in Kanhchriech district are considered poor (SCW, 2006) and depend on agriculture as their main source of income.

7.2 Climatic conditions

The main rice growing areas in Cambodia are located in the regions with rainfall ranging from 1250 mm to 1750 mm which are mainly found in the south and south eastern parts of Cambodia (Nesbitt & Phaloeun, 1997). Such precipitation patterns would normally provide a successful system for growing rice but the Cambodian rains are unpredictable and do not follow any regular pattern, and may be very delayed causing drought in the middle of the wet season and sometimes flooding (Nesbitt & Phaloeun, 1997).

The Cambodian climate stretches over two seasons, a wet and a dry season with the wet season running from May till November and the dry season from mid November till the end of April-beginning of May (Nesbitt, 1997). The dry season often stretches for less than four months in Prey Veng province (SCW, 2006). Table 4 illustrates the climate in Phnom Penn which is somewhat very similar to the climate in Prey Veng.

Prey Veng province has an annual average temperature of 27.23 ^{o}C and annual average precipitation of 1599 mm (SCW, 2006). As a result Prey Veng is one of the driest and warmest provinces of Cambodia with a growth potential being characterized as a medium concerning rice production (SCW, 2006).

Table 4. Climatic data from 1995, Phnom Penn. Modified after Nesbitt (1997).

Climate factors	1995 data, Phnom Penn
Relative humidity %	60 – 80
Temperature (^{0}C)	22 – 40
Day length (hours)	11.5 – 13.2
Evaporation (mm)	120 – 260

8. Materials and methods

30 farmers conducting SRI within the ILFARM project in two communes Chorng Om Pil and Kdeuon Reay Kanhchriech district, Prey Veng province were identified by computing a stratified random sampling. The project villages located closets to Prey Veng city (where the ILFARM project is managed from) were chosen and in total were 8 villages chosen. See figure 6 for location of the eight villages. The number of farmers involved within the project was different from village to village hence it was not possible to identify the same number in each village. The farmers were chosen randomly from a list comprising all farmers in the project available at the local CEDAC office. 30 farmers were chosen due to limitations of funding and time. 30 farmers do as well represent a fair sample of the total involved number of farmers in the project.

15 farmers were chosen randomly from four villages in Chorng Om Pil commune and likewise 15 farmers from four villages in Kdeuon Reay commune. Most farmers had one field where they conducted SRI but a few ones possessed several SRI fields. The smallest SRI field was always chosen in case of farmers having more than one field. If farmers were absent or non available in some way the farmer conducting SRI nearest to them in the village was chosen. See Appendix A for details on participating farmers.

8.1 Soil sampling

The farmers grow very different areas of SRI and their fields have very different shapes from one another and are very heterogeneous. The field sizes ranged from 10 m^2 to 2000 m^2 amongst the 30 farmers. Often the water level is changing from spot to spot in the field and the growth of the rice plants is very different within a single field. The soil samples were all collected in the period 12^{th} to 17^{th} of October 2008.

19 subsamples forming a star shaped pattern were systematically identified for every field, see Appendix B for full description of the procedure. The 19 subsamples were mixed into one composite sample for every field. The top 20 cm of soil was collected with a stainless steel auger tube with each subsample consisting of 240 cm^3 soil incl. present stones and plant residues. As the fields were very heterogeneous the 19 star systems covered all areas of the field. It would also have been accessible to sample less than 19 subsamples for each field however the level of accuracy is increased with more subsamples.

The collected soil samples were analyzed at the Environmental Analysis Laboratory (ENLAB) at the Preak Leap National School of Agriculture (PNSA) in Phnom Penn, Cambodia and at the department of Agriculture and Ecology, Faculty of Life Sciences, University of Copenhagen, Denmark with three parameters being determined: pH, C and N content.

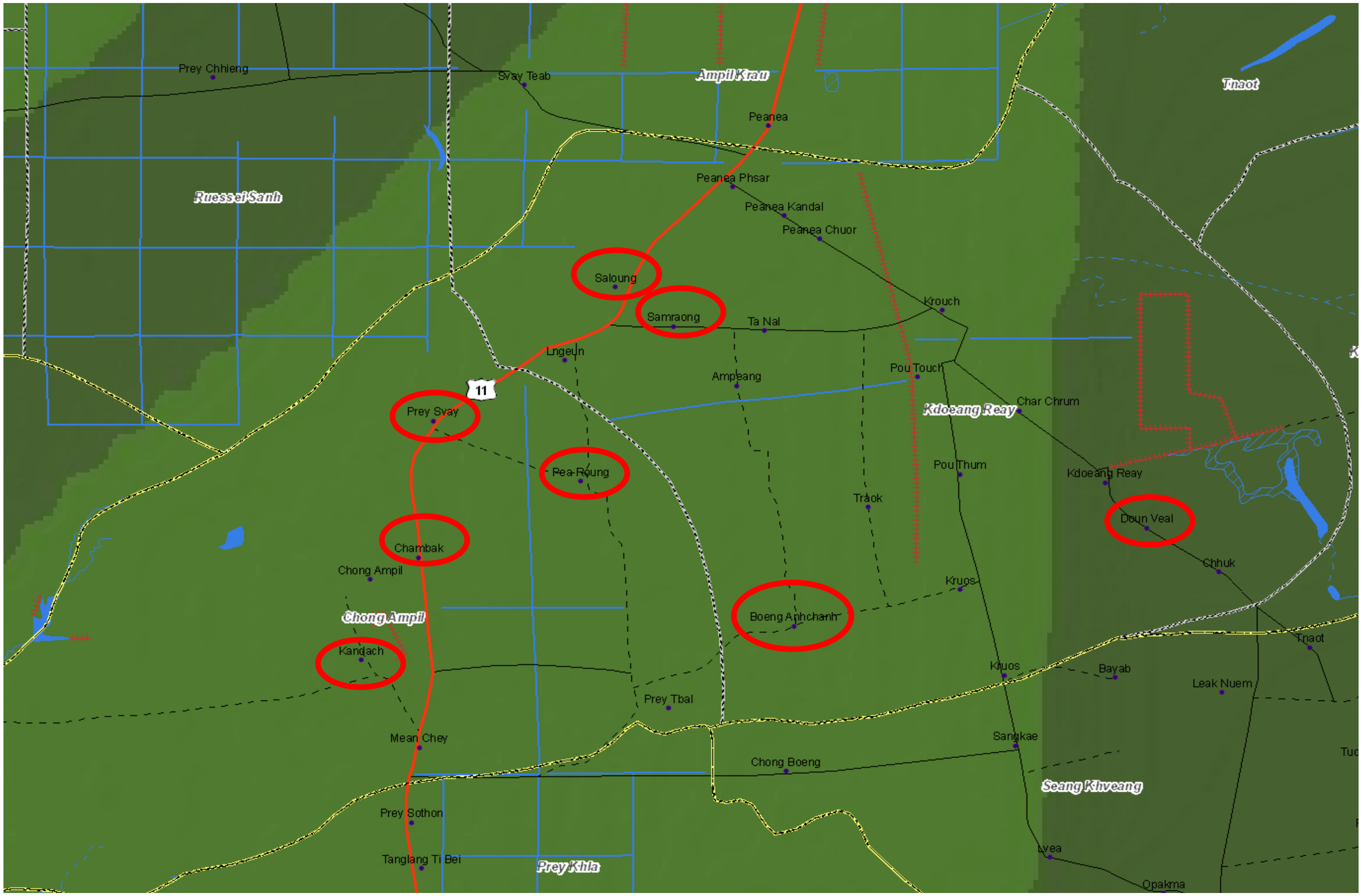


Figure 6. Map of the two target communes Choung Om Pil and Kdoun Reay with the four target villages in each circled with red. Grey stippled lines are commune borders. Modified from SCW (2005).

8.1.2 pH

pH was measured with an electrode pH meter (multi-meter) in a KCL solution with a 1:2:5 ratio. Measurements were made by the ENLAB, Cambodia.

8.1.3 C and N

Total C and N were first measured in Cambodia at the ENLAB by the following methods.

C

OM contents were identified with the Walkley-Black method comprising:

- Reduction of potassium dichromate ($K_2Cr_2O_7$) by organic carbon compounds
- Determination of the reduced dichromate by oxidation-reduction titrates with ferrous ammonium sulphate. OM was converted to C% by multiplying with 58%.

N

Total Nitrogen was determined by the use of the Kjeldahl method comprising;

- Digestion in concentrated H_2SO_4
- Conversion from organic – N to NH_4-N by steam distillation
- Distillation was collected with boric acid
- Titrated with H_2SO_4

Soil samples were also brought to Denmark and were analysed at the Faculty of Life Sciences, University of Copenhagen in order to verify the results from Cambodia. C and N content was analyzed with Automated Nitrogen Carbon Analysis for Gas Solids and Liquids (ANCA-SL/GSL) which uses the theory of Dumas involving a stable isotope spectrometer. For further details please refer to SerCon Ltd (2001). The results from the analysis made in Denmark were used due to higher validity.

8.2 Interviews

30 farmers were questioned regarding their livelihood and agricultural practices. Please refer to ANNEX C for the questionnaire. The interviews were performed in Khmer by two field staff connected to the ILFARM project and then translated into English.

The following main topics were examined within each household: household size, income sources, use of organic amendments, compost production, agricultural practices (traditional vs. SRI). This was done in order to identify their livelihood strategies.

8.3 Statistical analyses

All data analyses were carried out in Excel 2002 and in the statistical package “R” 2.8.1. Significant differences and correlations were tested between soil, household and rice yield data.

9. Results and discussion

9.1 Soil pH, Carbon and Nitrogen – the biophysical environment

9.1.2 pH

The average pH value for the soil was 4.53 and no significant difference was found from farmer to farmer or village to village. Such a low pH really illustrates how acidic the soils are of the target area and the surrounding area of Prey Veng. See appendix D for details on pH for every farmer. Normally the soil type of Prey Veng has a higher pH according to the CASC (Cambodian Agronomic Soil Classification System[5]) of pH 5.4 (White *et al*., 2000). The given soil type in the target area and one of Cambodia’s most important rice soils is termed the Prateah Lang group (White *et al*., 1997) a Plinthustalf (Pheav *et al*., 2005) sandy loam. This low pH value indicates that the availability of nutrients and microbial activity are rather limited compared to an optimum pH of 5.5-7.0 (Brady & Weil, 1999b). With a low pH there can be risks of Aluminium toxicity (Brady & Weil, 1999b) but this scope has not been a part of this project and has therefore not been examined. The potential of liming the acid soils with e.g. calcite ($CaCO_3$) to increase pH (Brady & Weil, 1999b) does not seem to be an option for the target farmers and farmers in general in Cambodia as such an investment would most likely be too expensive for them.

In general though as the flooding of rice field takes place the pH will turn towards neutrality and can change the pH of the soil with 0.5 to 2 pH units all depending on the acidity prior to flooding

[5] CASC was developed by CIAP (Cambodia-IRRI-Australia-Project) in the 1990ies within a very large agricultural project for several years by Cambodian and international experts in order to develop an easy to use and applicable system to use for farmers and technicians in order to key soils and set up management methods (White *et al*., 2000). instead of an older but more complex system developed by Crocker in the early sixties (Oberthür *et al*., 2000).

(Street & Bollich, 2003). De Datta (1987) mentions that this is due to the change of ”..ferric to ferrous iron, accumulation of ammonium, change of sulfate to sulphide, and change of carbon dioxide to methane under reducing conditions” De Datta (1987). When an acid soil is submerged, the changes of pH will depend on temperature and soil properties such as e.g. OM content and iron concentration (De Datta, 1987). The problem is that soils with low OM content will not reach pH 6 even after several months of flooding (De Datta, 1987). Brady & Weil (1999b) though states that organic amendments such as farm manures and especially poultry manure and leaf residues can increase pH values. However in order to really have an increase, large amounts are probably needed which RPF will not have access to. As discussed later do most farmers have chickens on their homestead land from which they will use the chicken manures they can gather for composting – but the possible amounts are limited. Oberthür *et al*. (1997) state however that the pH for the given soil type in Prey Veng province is not problematic as flooding will increases the pH value. All soil samples were taken during the wet season, hence the fields were flooded (except a few spots in a few fields where there was no water as the fields were very uneven) and pH should then have been higher.

9.1.3 C and N

The total average % C and % N was 0.33% C + (-) 0.09 and 0.04 % N + (-) 0.008 respectively. No significant difference was found for C and N from village to village or from farmer to farmer. See Appendix D for detailed information for every involved farmer. The average C:N ratio is 7.1 + (-) 0.72 with no significant difference between villages or farmers. White *et al*., (1997a) report that the Prateah Lang soil group has an average C:N ratio of 9,7. The difference of two units might be because the measured sampled size only consisted of 30 farmers and the C:N reported by White *et al*. (1997) covers a large area of 28% of Cambodia’s rice land. However both values are quite low.
Assuming the plough layer is 15 cm deep and the bulk density is 1.0 g cm^{-3} (estimates are derived from Kundu & Ladha, 1999) a rough assumption of C and N content per ha is: 49,5t C ha^{-1} and 600 kg N ha^{-1} respectively. It is very likely that the Soil C content of the given soil in Cambodia has been rather constant over the years. Assuming that the soils in the target area, like in most areas of Cambodia, have been cultivated for centuries and rice has been grown once a year the soil C has reached some sort of steady state. The inputs match the outputs thus creating a balance. In order to change this large amounts of organic materials are needed. These issues will be discussed later under section 9.5.

White & Seng (1997) state that not only the Prateah Lang soil but also most other rice soils in Cambodia have a low CEC and organic C content hence making it difficult to preserve supplies of N, K and water in the soil.

For RPF growing rice on the given sandy loam Prateah Lang Soil groups or similar lowland rainfed soils, applications of OM could change the C:N ratio. For instance will amendments with OM with C:N ratios of 25:1 or higher decrease the soil N content as micro organisms cannot locate enough N in the soil and they therefore will be forced to take up all the available N in the soil solution (Brady & Weil, 1999a). As the N content is so low in the Prateah Lang soil - the decomposition of OM might be slowed down as micro organisms cannot find enough quantities of N (Brady & Weil, 1999a).

It is well recognized that applications of organic inputs to lowland rice soils such as rice straw, animal manures, rice stubble and green manure can increase N content in soils (Kundu & Ladha, 1999). It is estimated that 1t of dried rice grains will provide app. 1.5 t of rice straw which contains 9 kg N and thereby a free nutrient source (Kundu & Ladha, 1999). Straw is however often removed in resource poor areas to use for animal fodder or burned in situ (Dobermann & Witt, 2000) which is also the case for the target farmers in this study. The stubble and the roots will however still be present in situ and is hence another source of N and other nutrients. Only few farmers use chemical fertilizers. Most of the chemical fertilizers used in Cambodia are used in irrigated rice systems (Nesbitt & Phaloeun, 1997).

The rainfed lowland rice which is the most common rice cropping system in Cambodia - and in many other south Eastern Asian countries (Wade *et al*., 1999). The shift between anaerobic and aerobic conditions due to a fluctuating water table will lead to oxidation and reduction of the soil which can result in losses of gaseous N, other nutrients are immobilized and changes in pH (Wade *et al*., 1999). The very changing water table may give rise to losses of N – as drying of flooded rice fields result in large losses of N through nitrification and denitrification (Seng *et al*., 1999). The RPF not only in this study but in Cambodia and many other locations are kept in a difficult situation with the low soil fertility and few means of changing this.

9.1.4 Soil description

The Prateah Lang soil group found in the target area in Prey Veng and other places in Cambodia has a very limited O and A epipedon and most of the plough layer is composed of the E horizon and some 15 cm down there is a very hard structure like a hard pan making it very difficult to penetrate. According to a soil key developed by the CIAP project the soils of identified in Prey Veng is a Prateah Lang soil group (White *et al*.1997b) as mentioned earlier. The soil factors identified such as pH, C and N contents fits very well as well with the description of the Prateah Lang soil (White *et al*., 1997a; White *et al*., 2000). SCW (2006) mentions the soils of Prey Veng are cultural hydromorphics. Oberthür *et al*. (1997) mentions that by using the keys to soil taxonomy by Soil Survey Staff from 1994, that the Prateah Lang soil group could be translated into belonging to the Alfisol soil order. Pheav *et al*. (2005) report that by using the soil Survey Staff (1994) the soil belongs to the soil subgroup Plinthustalf. Given the percentages of clay, silt and sand respectively the soil can by using the Soil Survey Staff's (2006) soil key be characterized as a sandy loam.

The texture as described in the table 5 is also in accordance with the CASC classification through personal observations in the target area.

Table 5. The characteristics of the Prateah Lang soil type as described and developed by CASC. After Oberthür *et al*., (2000).

CASC soil definition	Clay %	Silt %	Sand %	pH	Organic C
Prateah Lang	13,2	37	49,8	5,4	0,4

The topsoil in the target area has a light texture with a little structure and low water holding capacity followed by more heavy subsoil according to White *et al*., (1997a). Hence drought is often a problem as mentioned before. When ploughing and harrowing it is necessary to transplant very short time after the procedure as soil particles will settle very fast (White *et al*., 1997a) thus making it difficult to transplant. Gravel is also common to find, CEC is very low, low OM content is found and rice yields are very low, ranging in average from 800 kg to 1400 kg per ha (White *et al*., 1997a). Figure 7 pictures the typical soil texture.

Dobermann and White (1999) participated in the CIAP project and developed materials and strategies for nutrient management in rainfed and irrigated rice cropping systems. Modern varieties grown on Prateah Lang soils should receive NPK in the following rates 60:29:30 or 42:23:0 if the farmers do not apply any K (Dobermann & White, 1999). These values are for favourable conditions signifying little or no water shortage during the cropping season (Dobermann & White, 1999).

For unfavourable conditions implying water shortage for longer periods the recommended doses of NPK are 40:23:20 and 30:15:0 if farmers do not apply any K (Dobermann & White, 1999). The latter condition is probably the most common for the target area as droughts are quite common and water management is limited as irrigation systems are limited. RPF do however often not have the means to apply chemical fertilizers and the recommended rates would then have to be applied through organic inputs, which would require very large amounts. The means of applying organic amendments will be discussed in chapter 9.5 and 9.5

Figure 7. Typical soil texture in the target area.

9.2. Identified Livelihood strategies

The identified livelihood strategies of the study could be classified as agricultural intensification and livelihood diversification as described by Scoones (1998). Their differences and importance is discussed within this chapter and the rest of the discussion.

The interviewed farmers consisted of 50% males and 50% females with an average age of 42 years and with 4 household members in average. These findings correspond well with CEDAC's results from their baseline study[6] in the summer of 2008 (CEDAC, 2008a). See Appendix E for further details. The total income is very different from household to household ranging from 98$ to 2927$ per year.

The income is what is left to sell after a household has consumed rice and agricultural products. The households with higher income mostly have several members working outside the farm selling labour or working as community/village chiefs. One farmer and his family makes 98$ per year which is the lowest amongst the 30 interviewed farmers and even compared to a national scale but the income comprise all the goods and farm products sold after what has been consumed at farm level. The variation is large as illustrated in figure 8 below. Raising cattle/pigs results in the highest income followed by working outside the farm and then selling rice. It is however only 57% of the interviewed farmers who have cattle and 37 % who have pigs. Animals can be regarded as a wealth indicator as they provide security in times of hardship and they provide manure. Nesbitt & Phaloeun (1997) mention that most of the farming households in Cambodia mostly have a few domestic animals. Chickens and ducks (eggs and meat) are used for self consumption and pigs and cattle as an important cash income possibility (Nesbitt & Phaloeun, 1997).

[6] CEDAC conducted a baseline survey in the summer of 2008 in the three target communes of the ILFARM project and interviewed 451 randomly chosen farmers where 376 farmers where participating in the project (CEDAC, 2008a). This baseline survey is the background and assistant paper on many of the agricultural findings within this paper.

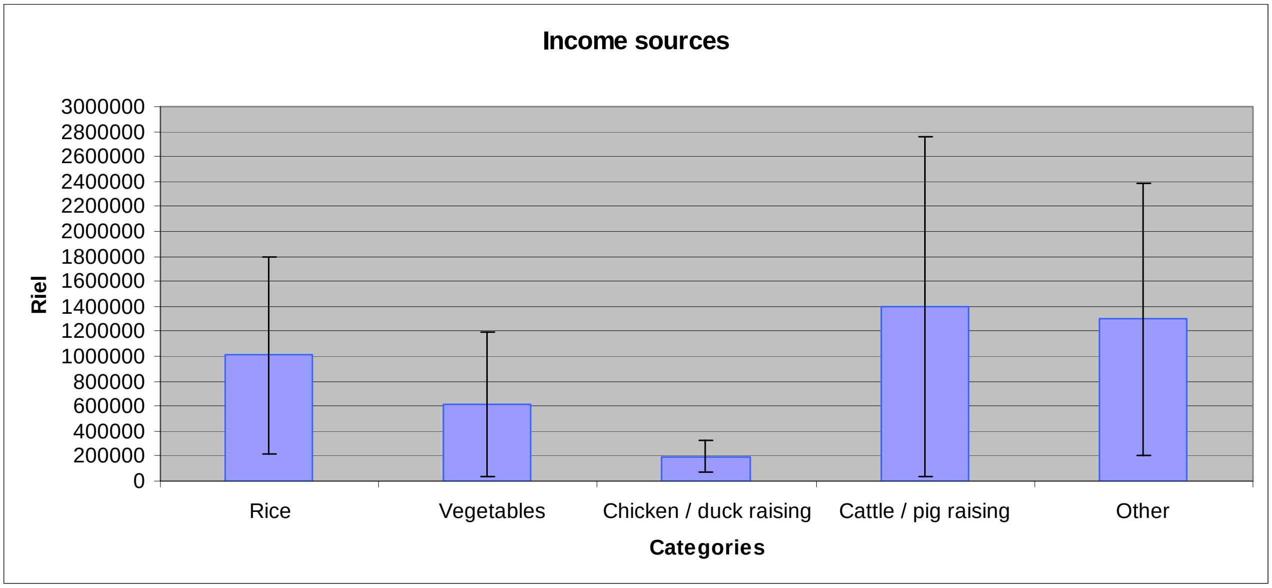


Figure 8 illustrating different sources of income. The category "other" is work outside the farm such as construction worker, village leader, seller, fishing and in general selling labour. 4000 riel = 1$.

The income from rice is rather low which is due to the fact that farmers often consume their rice and if something is left it is sold. Hence in order to be able to afford investments of any kind for their household they rely mostly on their income from animal husbandry and off-farm work. Some families will however prefer to sell rice even if they are not subsistent and hence lack rice for several months a year. According to CEDAC (2008a) 26% of the households in the target area do not have enough rice to consume for several months every year. Within this percentage a majority of households lack rice for two to five months every year, often before the beginning of the rice season (CEDAC, 2008a).

No correlation was found between sex, income, age and SRI yield. The sole correlation identified was a '*' R^2 = 0.158 correlation between number of household members and income which is not surprising as many family members provide essential labour in the family farm, and contribute to the family economy with off-farm work. Figure 9 illustrates the correlation between household size and income.

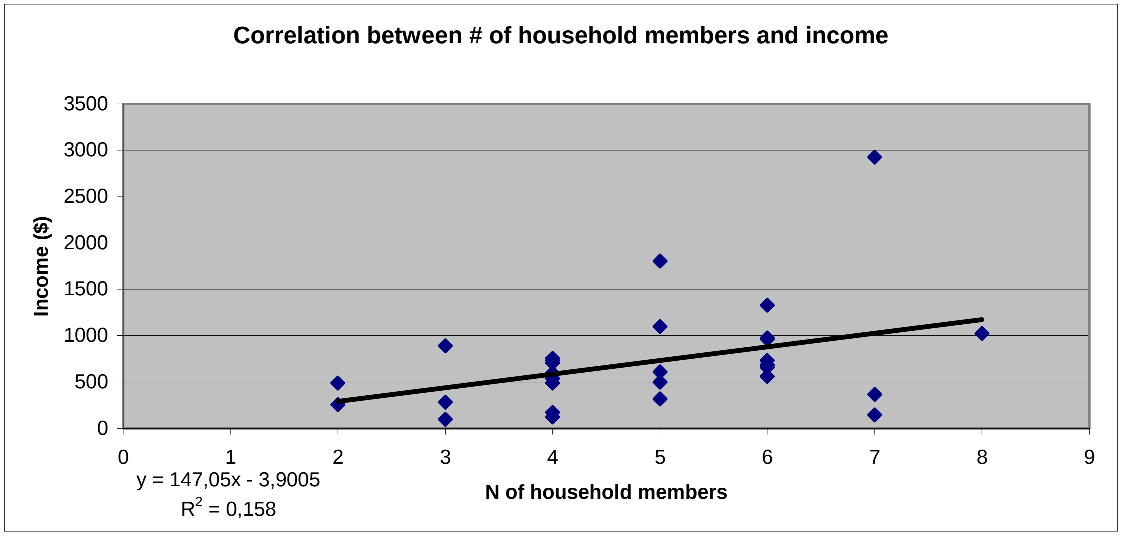


Figure 9. The correlation between the number of household members and income.

Typical off-farm work is as construction worker and motor bike taxi driver which are very typical jobs found in many areas of Cambodia. To work off-farm is part of the livelihood strategy "livelihood diversification" which seeks to reduce the risks of stresses or shocks by spreading the income sources of the household (Scoones, 1998). Risks/stress could in this study e.g. relate to severe droughts causing a very low rice yield and outbreaks of pests and diseases.

Provided these informations on household income the question arises on which livelihood strategy is the most important for these RPF and many others in a similar situation. Figure 10 illustrates the various income sources for each of the 30 interviewed households. For a majority of the households the income from other sources (off-farm work – mostly selling labour, construction worker, motorbike driver) is a rather important source of income for the households. This livelihood strategy is as mentioned before livelihood diversification.

The other livelihood strategy agriculture intensification/extensification provides the rest of the income but most of the production from this strategy is consumed at home. This livelihood strategy can be used in two ways roughly as mentioned by Scoones (1998):

- Intensification – the outcome per unit of land is increased through extra input of labour or financial means.
- Extensification – produce more output from more land

The involved farmers seem to belong to the strategy category of intensification as a majority of them have sustained themselves from the same pieces of land through ages. In order to succeed within this strategy they are therefore very dependant on additional financial income from the diversification strategy in order to be sustainable. It is likely for the involved farmers and many other RPF that if land prices will increase in the future the extensification strategy is left out as land prices will be too expensive and intensification is the only mean of survival. If such a scenario would take place the migration livelihood strategy described by Scoones (1998) might become more important than it is today.

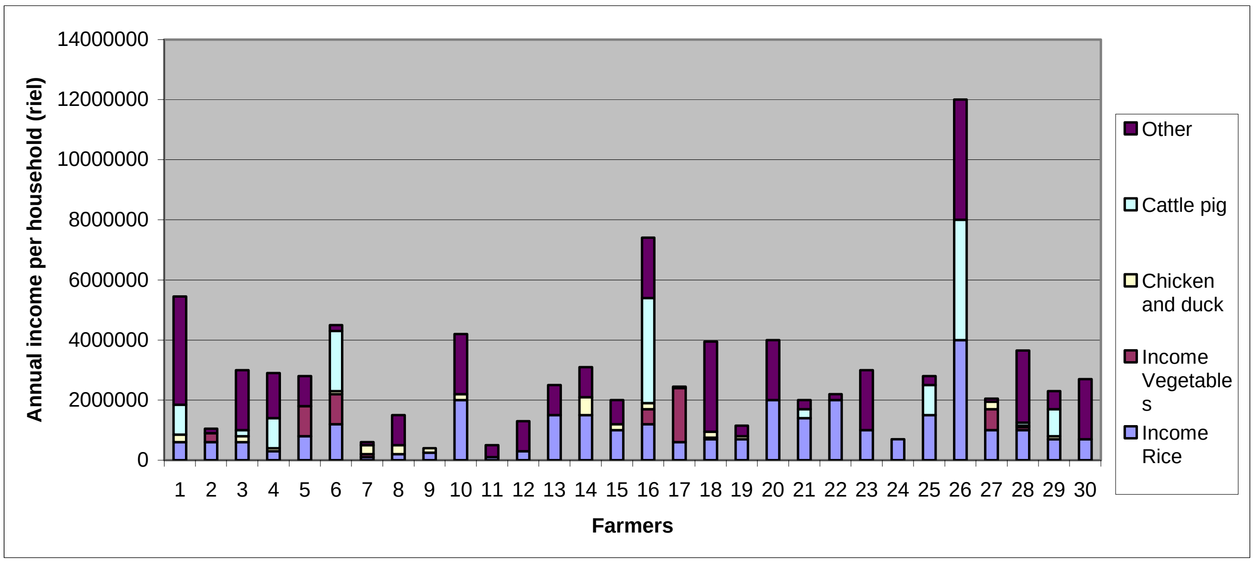


Figure 10. Annual income per household. The category "Other" covers off-farm work

9.3. Household assets

The average size of conventional grown rice land including the land surrounding the homestead and present vegetable gardens was 16766 m^2 + (-) 8926 and average SRI land was 534 m^2 + (-) 558. See Appendix E for all livelihood assets discussed in this and the following chapters. The vegetable production often takes place on the homestead land but production is not large enough to provide households with enough vegetables (CEDAC, 2008a). The possessions of land can be regarded as a wealth indicator. Which is also the case for the domestic animals (Nesbitt & Phaloeun, 1997; SCW, 2006) in times of difficulties especially buffaloes and cattle provide the household with security in terms of illness or sudden expenses (SCW, 2006). Most families have either a few cows or buffaloes, which are very important as draft power (SCW, 2006). Other domestic animals include, chickens, ducks, pigs and fish. Chickens and ducks are normally for home consumption (CEDAC, 2008a) while pigs and fish are sold for additional income.

9.4. Compost production

24 farmers make their own compost but only 16 of them use the compost for the rice fields. This would imply that the rest of the farmers use the compost for vegetable production or to produce rice seedlings in a nursery which is quite common practice for Cambodian farmers (CEDAC, 2008a). Composts are located on the homestead land and the distances to the different fields vary a lot, but are often quite large. Figure 11 illustrates the different types of composts produced by farmers. Figure 12 pictures typical compost huts and compost piles found in the target area. The most common compost mix was: animal manure from mostly cows/buffaloes + chickens, crop residues (small amounts of rice straw), leaves, ash and general waste[7]. Rice straw is often used as livestock fodder during the dry season and is stored in large piles on the homestead land. The remainings of the rice plants on the fields is often burned or incorporated in the soil. Human waste is used for fish raising and toilets are often constructed near or over fish ponds and is therefore not an option farmers can use for rice fertilizers.

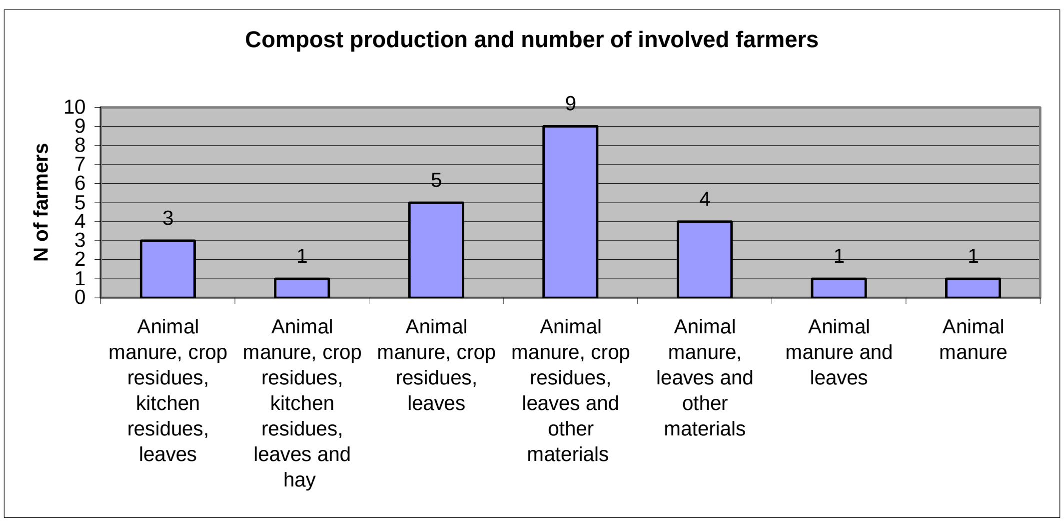


Figure 11. Number of farmers producing compost with different components. Other materials include hay, ash and waste but differs from farmer to farmer. Leaves are in a majority of cases often from Sesbania, Leucaena and Neem trees.

[7] Waste does not include human waste but is a general definition for household waste of any kind.

The farmers' composts were often found in sizes ranging from 6-9 m^3 and located very close to the house on the homestead land. In a few cases a small hut or roof was constructed in order to protect the compost from rains and high temperatures. A majority of farmers were certain that they could produce more compost than they needed for one growing season. The farmers stated that to produce around 6-9m^3 of compost would in general take them two to three months. The question is however if they will have enough biomass and of a high enough quality? CEDAC (2008b) suggests that in areas with scarce resources for compost production a shift to biomass production could be used to increase soil fertility, such as e.g. green manure crops in the beginning of the wet season.

Figure 12 illustrating a typical compost hut and a compost pile.

9.5. Application of amendments

73% and 53% the farmers applied green manure[8] (GM) and compost to their SRI fields respectively while 40% of farmers applied both green manure and composts. No correlation was found between the different kinds of fertilizers and the C and N content in the soil which is not surprising as only long term experiments can identify such correlations. See Appendix E for details on application rates. Average application rates for green manure and compost were 200 kg +(-) 188 and 303 kg +(-) 195 respectively per field size of 534 m^2. Average application rates per m^2 were 0.33 kg and 1.90 kg for compost and green manure respectively. Table 6 illustrates compost applications from other SRI growing areas.

[8] Green manure is often related to trees and shrubs where leaves are used as fertilizers or cover crops and nitrogen fixing species are also used. In this case green manure refers to leaf manures from Leucaena, Sesban and Neem.

Table 6 illustrating five trials from four countries where different amounts of composts are applied. * The reported application of compost was for one single very successful farmer with a yield of 21 t/ha.

Compost t/ha	Compost kg/m2	Details	Location	Reference
7 t/ha	0,70	60 % cow + goat manure, 35% leguminous vegetation and 5% ash	West Java, Indonesia	Haden *et al*., (2007)
10 t/ha	1,00		Madagascar	Uphoff & Tefy Saina.
2 – 3 t/ha	0,2 – 0,3	Organic manure mixed with cow dung and straw. Chemical fertilizers were also applied.	Bangladesh	Latif *et al*., (2005)
12 t/ha	1,20	Cow manure and straw. Contains 4.6 g kg-1 total N. Chemical fertilizers were also applied.	Mozambique	Menete *et al*., (2008)
5 t/13 acres*	4		Madagascar	Uphoff, 1999.

An application rate of 0.33 kg m^{-2} corresponds to 3.3 t ha^{-1} which is similar to the applications from Bangladesh listed in Table 6 above. However the composts above do to a large extent consists of large quantities of animal manure which the composts in Cambodia only comprise to a small extent. Thus there is a difference in quality and nutrient content. Latif *et al*. (2005) report that composts in Bangladesh had the following percentages of N, P and K: N (1,67%), P (0,83%) and K (1,66%) (Latif *et al*. 2005). No nutrient measurements were taken from the composts in Cambodia but it is likely that the contents are lower as composts mostly consist of plant material.

CEDAC (2008a) states that during their baseline study, 98% of interviewed farmers used chemical fertilizers during the last year (2007) with an average amount of 180 kg. However during this report's investigation in the area, only 13% used chemical fertilizers but in very small amounts. Chemical fertilizers are not "officially" a part of SRI (Stoop *et al*., 2002) but can very well be used if no organic matter or too little is available (Satyanarayana *et al*., 2007; Sheehy *et al*., 2004). The farmers might have told the author and CEDAC what they thought they had to say, i.e. that they only use composts and thus in reality more of the farmers probably still use small quantities of

chemical fertilizers. It is part of the ILFARM project to inspire farmers to use more composts for those who use chemical fertilizers and thus reducing the chemical fertiliser consumption (CEDAC, 2008c) and farmers do perhaps therefore not dare to say that they still use some chemical fertilizers as they have an interest in receiving extension services from CEDAC.
Given that the sample size for this report was 30 households and the baseline study involved 451 households (CEDAC, 2008a) the large reduction in chemical fertilizer use identified in the present study might have resulted from a skewed picture due to the sample size.

The access and amount of biomass might pose problems upon extending SRI to larger areas. Dobermann (2004) states that a major constraint with SRI is the labour input needed to transport and apply organic materials to the fields. Bunch (2002) reports that upon a visit in Madagascar SRI farmers spent up to l00 labour days collecting organic materials and applying them to their fields. In the area of Prey Veng access to organic material is scarce as all straw is removed in order to use as animal fodder. Anthofer (2004) found from SRI trials in Cambodia that farmers would conduct SRI on the nearest field to the homestead land. This would imply that the load and transport of compost and organic amendments is reduced. Considering the workload involved in transporting and producing composts it would indicate that farmers are forced to use many labour hours, and only larger households can afford to use labour on such a large scale.

The use of GMs might therefore be a solution in order to increase the amount and the access to organic materials. GMs are however normally not considered to be used traditionally by Cambodian farmers but is in many cases introduced by organizations (Anthofer, 2004). However most of the interviewed households had several trees such as e.g. *Neem* and *Sesbania* which are common around homesteads in Cambodia (Author’s own observation, 2008). The ILFARM project plans to plant 500.000 trees in order to increase the access to GM (NORDECO, 2008). Appendix E provides information on five main trees already found and which will be planted any time soon.

9.5. SRI

The sustainability of a farming system can be measured in many ways. The following parameters were examined: use of seeds, rice varieties grown, SRI techniques, yields, present SRI field sizes and future SRI field sizes.

9.5.1. Seeds and varieties

The amount of seeds used for SRI versus traditional growing was very significant: farmers only used 0.02 kg seeds m^{-2} compared to their traditional fields where they used 0.63 kg seeds m^{-2} respectively. The seeds are not directly sown in the fields but in small nurseries where after the rice seedlings are transplanted. These results are in accordance with SRI practices in other countries. Menete *et al*. (2008) used 0.1 kg of seed per m^2 for trials in Mozambique and Satyanarayana *et al*. (2007) report that SRI farmers in India are able to reduce the seeding rates (20% of conventional use) with app. 0.0005 kg to 0.001 kg m^{-2}. Anthofer (2004) reports that Cambodian SRI farmers were able to reduce seeding rates from 90 kg ha^{-1} 30 kg ha^{-2} by converting to SRI corresponding to 0.009 kg ha^{-1} to 0.003 kg ha^{-1} respectively.

Most of the identified rice varieties used by farmers were traditional – 36 different (see Appendix E) with only few being modern introduced varieties such as IR varieties. The farmers use in average four different varieties, often mixed within the same field. Farmers use the same varieties for both SRI and their traditional fields. Koma (2002) states that local varieties perform very well with SRI practices and even though modern cultivars give higher yields, consumers still prefer local varieties hence market prices are higher. Local varieties have probably adapted to the lowland rainfed conditions which according to Wade *et al*. (1999) are very alike in all lowland rainfed rice systems and often are tall as submergence comes and goes very unpredictable. Prasad (2006) evaluates that SRI can be seen as a variety independent system which does not seek higher yields from growing different varieties. Kabir & Uphoff (2007) did however find from SRI FFS in Myanmar that most popular non SRI methods included selecting better genetic material and higher quality seeds which resulted in 18% and 28% increase in yield respectively (performed with SRI).

The green revolution only introduced new varieties for dry season production in Cambodia and only few varieties for the wet season (Koma, 2008) meaning few varieties for the rainfed systems. The green revolution had a great impact on irrigated areas with good soil with fertilizer responsive varieties but in indigenous systems trials have often tried to replace and not complement the farming systems which were not successful (Greenland, 1997). However with future breeding on rainfed rice the possibility of varieties performing well with rainfed conditions might prove very efficient with SRI practice.

9.5.2 SRI techniques

The different SRI techniques were identified within the group of target farmers. The three main techniques were: i) use of natural fertilizers, ii) one seedling per hill and iii) to plant in lines. Farmers used the term "natural fertilizers" which in this case means composts and green/leafy manures. The farmers also considered to plant seedlings in lines to be part of the SRI techniques which is most likely due to the fact that CEDAC encouraged farmers, when transplanting, to use a rope and plant in straight lines in order to achieve the same distance from plant to plant. Figure 13 illustrates the SRI techniques practiced by percentage of farmers.

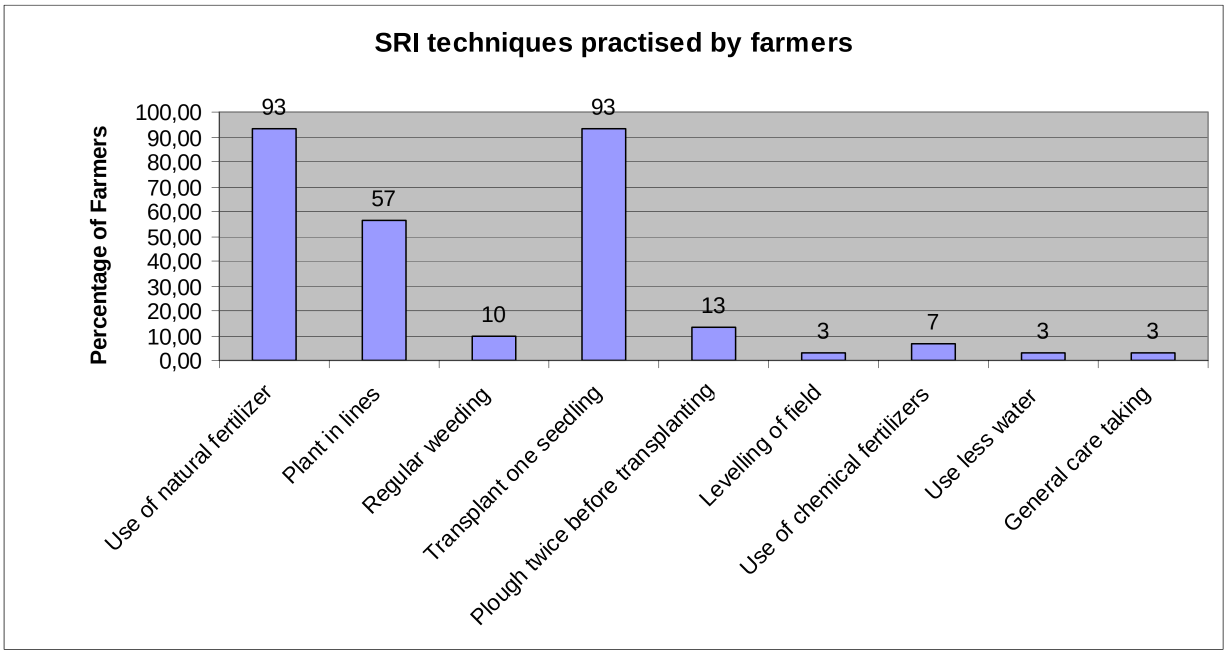


Figure 13. SRI techniques practiced by interviewed farmers.

The use of natural fertilizers is not new to the farmers as they have used animal manure for growing rice for decades. Some respondents identified chemical fertilizers as being part of SRI. Chemical fertilizers can very well be used with SRI (Laulaníe, 1993) but the use of composts have been in focus as many RPF do not have access to chemical fertilizers (Stoop *et al*., 2002; Sheehy *et al*. ,2004). The target farmers mainly combined use of natural fertilizers and one seedling per hill. See Appendix E for details for combinations on SRI techniques.

A majority of the farmers do however not identify the age of the seedlings as being important – which is a rather important part of SRI. It is common to use young seedlings around 10 days (Prasad, 2006) or 8-12 days (Haden *et al*., 2007) which will ensure a better root growth and space for tiller development (Satyanarayana, 2004). The latter being a fair indicator of the yield potential (Moldenhauer & Gibbons, 2003).

Another key force within SRI is the water management. Only very few farmers do however mention water management as a SRI technique. Probably due to no or very limited irrigation systems and channels in the area in order to control and manage water. Anthofer (2004) discovered similar results from a survey on SRI in Cambodia in 2004 and concluded that water management including flooding in some periods and dry conditions in other periods and regular weeding was difficult for farmers to manage. Husain *et al*. (2004) and Mcdonald *et al*. (2006) both concluded that main constraints to increase number of farmers practicing SRI are due to lack of irrigation facilities, which for the farmers in Prey Veng is very true.

9.5.3 Rice yields

Farmers have improved their yields significantly with SRI compared to their traditional grown rice fields, considering that this is their first season with SRI. Figure 14 illustrates the average yield for farmers' traditional grown rice and their SRI grown rice. The average SRI yields of 3.53 t/ha is 1 t above the Cambodian national average rice yield of 2.49 (IRRI, 2006). The SRI yield was significantly different from the traditional yield with a *** p-value = 0.0001097. The traditional rice yield is however quite high compared to CEDAC's findings from 2005 with an average yield of 1.59 t/ha (CEDAC, 2008a) which is more in accordance of the expected yields of 800-1400 kg ha^{-1} from the given soil conditions (White *et al*, 1997a). It is however possible that farmers have been influenced to adopt some SRI techniques for their traditional run fields thus improving their traditional rice production. Another possibility is that when questioned on their yields from SRI and traditional rice by CEDAC staff, the farmers exaggerated the yields from both systems or at least the SRI yields in order not to disappoint CEDAC and to attract free extension services from CEDAC.

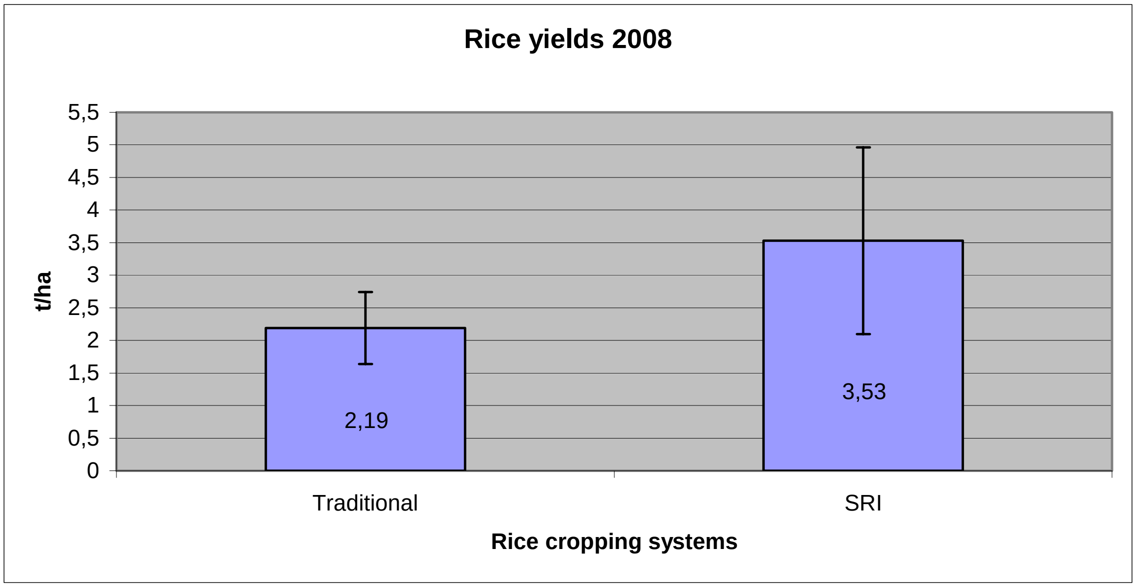


Figure 14. Average rice yields for traditional and SRI farming systems from the crop season of 2008.

In reality the yields are not per ha as none of the farmers grow SRI fields that large but they have been recalculated to t/ha as a more flexible way of comparing local yields with other yields from Cambodia and other countries. Assuming the reported yields by farmers are correct the difference is significant and similar to other comparisons examined by e.g. Caesay (2002); Yamah (2002); Stoop *et al*. (2002); Anthofer (2004) and Kabir & Uphoff (2007). Table 2 illustrates the yield differences as well between SRI and traditional grown rice.

There was however no correlation between amount and type of amendments (incl. chemical fertilizers) and SRI yield nor between income and SRI. However it would have been expected that larger farmers (higher household incomes) would be able to invest in more chemical fertilizers and labour input and thereby increase yields.

The only real difference between the farmers' traditional field and SRI is then the use of only one seedling per hill with a wider spacing as water level and management was the same for the two systems. One seedling per hill with wider spacing is known by SRI supporters to increase the root growth, tiller and canopy development of young transplanted seedlings because the plant has more time and space to develop itself (Satyanarayana, 2004; Kabir & Uphoff, 2007;). Fewer roots per hill reduce the risk of root growth inhibition sometimes found when seedlings are transplanted several together (Satyanarayana *et al*., 2007). Larger root systems will then increase nutrient uptake (Kabir, 2006). Hence both nutrient uptake is higher and competition due to nutrients is lower than in a traditional field with 5-6 seedlings per hill. Normally the narrow spacing of transplants in conventional fields will produce fewer tillers app. 8-13 per plant (Stoop *et al.*, 2002), although this will depend on soil and management practices and the used varieties. However for the conditions in Cambodia it was observed that traditional fields often had a little more than 10 tillers per plant whereas SRI plants often had a few more tillers. It is however notable here that most farmers did not transplant younger seedlings to their SRI fields (1 farmer mentioned he used younger seedlings). It is then remarkable that the difference in yields is more than 1 t. If farmers used younger seedlings the difference in yield could have related to uprooting damage from the seedbed as younger seedlings will be less damaged by uprooting upon transplanting (Yoshida, 1981). Young seedlings used in SRI are also believed to be more easily adapting to the new environments found in the field and the "stress" involved in transplanting (Kabir, 2006).

The competition between the plants might have an effect on the yield potential – also called intraspecific competition which is competition between plants of the same species and is very much depending on density (Antonovics & Levin, 1980). Kawano *et al.* (1974) state that in soils low in N content, rice plants will first compete for the soil Nitrogen and later light which is vice versa in soils high in N content. Kawano *et al.* (1974) further conclude from trials in Peru on spacing and intraspecific competition involving 25 different varieties that in soils low in N content, wider spacing is beneficial which especially is suitable for vigorous tall growing varieties with long growth duration. With the given low N containing soils in Prey Veng, the wider spacing might thus have caused a yield increase in the SRI field as compared to the traditional fields.
The competition from weeds could not have caused the differences in yield as weed problems are low in the traditional systems due to dense spacing and in the SRI fields hand weeding was done regularly by most farmers. Koma (2007) states that farmers can obtain higher yields with SRI, even if they only manage some of the concepts.

Given these yield increases is also one of the reasons why farmers would like to continue with SRI for the next season. Figure 15 pictures main reasons why farmers would like to continue with SRI next year. However, when farmers were interviewed, only one household had harvested and the farmers could therefore not have experienced the increase in yield. This illustrates how confident the farmers are with SRI. Or farmers respond in this way because they are interviewed by CEDAC and the author and would like to satisfy CEDAC and the author on responding positively about SRI.

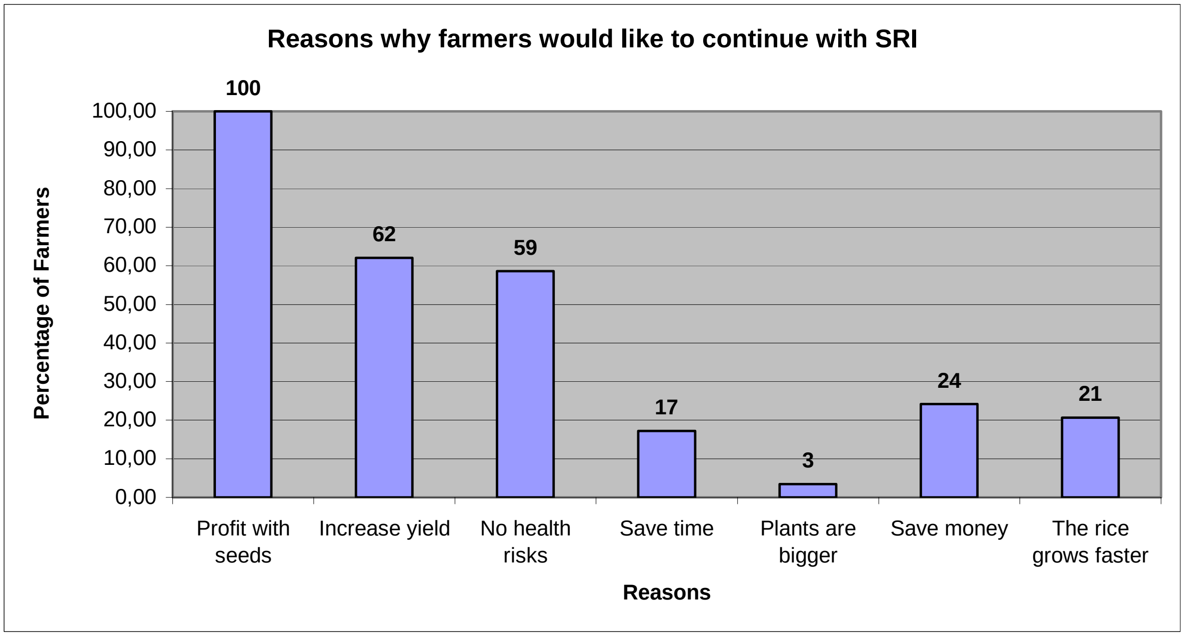


Figure 15 illustrates 7 major reasons why the interviewed farmers would like to continue with SRI next year.

The profit with seeds (farmers relate this to reduced costs for seeds and the fact that they use less of their stored seeds from last season) is the main reason why farmers would like to continue with SRI next year which also relates to the column of saving money. The reduction in seeding rates is one of the milestones of SRI trying to reduce external input costs (Stoop *et al*., 2002) and not surprisingly farmers find this approach appealing.

A majority of farmers state that health risks by use of chemical pesticides are reduced with SRI although most farmers conducting SRI world wide cannot afford chemicals (Uphoff, 1999). All the identified farmers except two however responded that they do not use chemical pesticides, which then questions if they though still use small amounts but sense that when interviewed by CEDAC or the author they feel afraid or insecure of telling that they use agrochemicals.

Saving time was also appointed by the farmers as being one important issue why to continue SRI next season. SRI is however viewed by many critics and advocates as a labour intensive farming system (Moser & Barrett, 2003 & Dobermann, 2004) or as stated by the advocates as labour investing (e.g. Uphoff, 1999 & Stoop *et al*., 2002). It is especially hand weeding which is time consuming due to larger spacing and a longer timeframe until closure of the canopy which will enhance weed growth (Dobermann, 2004). Anthofer (2004) states that for SRI trials in Cambodia farmers saved labour time during transplanting as seedlings were easier to uproot and transplanting fewer plants per field saved time as well, although first time, SRI practising farmers needed more time for this. Tong *et al*. (2007) reports that in average it takes 60-70 people to transplant a conventional/traditional rice field of 1 ha. By only transplanting 1 seedling instead of several, it is probably possible to decrease the number of people needed for transplanting dramatically.

Anthofer (2004) states that for weeding the amount of labour increased within SRI trials from Cambodia. It is however expected that when farmers are more experienced with SRI techniques the amount of labour will decrease (Prasad, 2006) and SRI can become a labour saving technique (Satyanarayana *et al*., 2007). The work load relating to compost production and transporting it to the fields might however be a constraint for converting all fields to SRI, especially those located far from the homestead land which is typical in Cambodia.

As a response to the factors illustrated in figure 12 on why farmers would like to continue they were also questioned on how big an area they would plan to conduct SRI on for next year's crop season. At present farmers grow in average 534 m^2 with SRI and next year the average area is 3676 m^2. Table 7 illustrates this year's and next year's percentage of SRI of the farmers' total land.

Table 7. Present and 2009 percentage of SRI of total agricultural area.

	2008	2009
% SRI of total land	5 (+ - 9)	24 (+ - 27)

The increase in land area with SRI corresponds to an increase of almost 20% which is quite an increase. It is however questionable if the farmers will be able to produce enough compost for next year's SRI crop. This is discussed further in subsection 9.5.4

All the participating farmers in the study would as mentioned want to continue with SRI, but in most cases the farmers will not be able to increase SRI production unlimited to all their land due to lack of enough compost or money for chemical fertilizers. Moser and Barrett (2003) found that the disadoption rate of SRI was higher amongst farmers with lower incomes in Madagascar. Barrett *et al*. (2004) suggest that poor farmers in Madagascar have difficulties to afford the interseasonal credit needed to conduct SRI as they cannot afford to use family available labour on SRI as they are forced to sell labour in order to survive at this time of year. Husain *et al*. (2004) concluded from trials with SRI in Bangladesh that only large farmers could increase their production of SRI without any risks as they are not as vulnerable to changes and difficulties as small scale farmers. Larger farmers would in this case be identified as farmers with higher incomes.

Richer farmers will in general have more time as they do not only rely on income from rice as illustrated in figure 9. Farmers with lower incomes will have to use large percentages of their available time on selling labour far away from their homestead thus having less time available to take care of their rice fields. In terms of compost production larger farmers would most likely also be able to produce larger amounts due more domestic animals.

All in all the target farmers seem to have adopted SRI now, at least for the moment. Before the initiation of the project 50% of the households experienced some degrees of conflicts but after some time the SRI fields showed strong growth and the conflicting counterparts in the households are now satisfied and believes in SRI. Such scepticism is most likely found in many implementing projects in the beginning. Presumably it relates to the type of paradigm used out of the three described by Blaikie *et al*. (1997): Classic, Neo-Liberal and Neo populist.

Another sign of the success of SRI so far in the area is that farmers have spread the knowledge of SRI to their neighbours, approximately 10 persons (+ -9) who did not attend any training with CEDAC. Again it is a very high number and the fact that the author and CEDAC staff interviewed the farmers might have affected them to respond in a more positive way than reality. The effect is however very interesting. It is a so called “roll on” effect where practising SRI farmers will share their techniques with other interested farmers (Kabir, 2006) and again these farmers will inspire others to adopt SRI. The success of such a roll on effect will depend on the way a given system (in this case SRI) has been introduced to the community – which is a different way of sharing knowledge often practised by organizations introducing and bringing an idea to farmers (Kabir, 2006). CEDAC has introduced SRI to the farmers through SRI experiments, campaigns and leaflets amongst others. Thus the interpretation is rather open and hence farmers will perform SRI as they think it should be which by involving them in such a way must be considered more sustainable.

However even with this roll-on effect and free interpretation it is questionable how SRI will develop and in what form in the future. There is a tendency that farmers practising SRI after some time will mix SRI with some of their traditional methods and thus move away from SRI (Ma Veasna – personal communication, 2008). Such tendencies are in accordance with the findings from Moser & Barrett (2003) on disadoption rates amongst SRI farmers in Madagascar. CEDAC is providing various extension services: SRI, production of organic fertilizers, pesticide reduction, developing farmer associations, saving groups etc. (CEDAC, 2008c). The ILFARM project is ending in October 2009 (CEDAC, 2008c) which raises the question, how will SRI survive without a strong organization like CEDAC providing extension and training? First of all SRI is not a set of rules to be strictly followed (Stoop & Kassam, 2005) and should not be regarded as a part of a TOT and T&V strategy but a tool farmers can use and adapt like they wish. Farmers have participated in SRI training sessions and have been involved throughout the process. Therefore the sustainability must be larger – as the more participatory a project is, the more sustainable it is. Matteson (2000) states that the conversion of development projects changing strategy from T&V to FFS experienced much higher success rates, as farmers were involved more throughout the process of the project. CEDAC did not use FFS but similar training strategies thus SRI would probably still be practiced by the target farmers in the future but perhaps in a different set up.

However considering the major impact CEDAC has had with the farmers during the project the lack of extension services after the end of the project might result in some farmers moving away from SRI. The target farmers are now used to have some sort of access to extension through CEDAC after the end of the project they will suddenly face another truth. Probably the most labour intensive techniques will be left out such as. e.g. compost production and farmers who can afford chemical fertilizers will increase in using it which is most likely the richer farmers. Poorer farmers might still use compost production as means of supplying nutrients to their farming system.

9.5.4 Can farmers produce enough compost/GM for the future expansion of their SRI fields?

This section will evaluate if farmers will be able to produce enough compost and apply enough biomass for the increase in area of SRI production for the season of 2009. According to the findings from the household survey as mentioned earlier, the farmers will in average expand their SRI from the present 534 m^2 to 3676 m^2. According to CEDAC (2008a), 14% of interviewed household in the ILFARM project area are in average able to produce 2.550 kg of compost per year and 81% of households were in average able to collect 1.817 kg of natural fertilizers per year[9]. Table 8 illustrates how farmers split their compost and natural fertilizers between seedbed preparation, rice fields and vegetable productions.

Table 8. Farmers' use of compost and natural fertilizers for seedbeds, rice fields and vegetable production. Numbers are given in percentages of total compost and natural fertilizer production respectively. Derived from CEDAC (2008a).

	Seedbed	Rice fields	Vegetable production (dry season)
Compost	38%	57%	3%
Natural fertilizers	51%	44%	4%

If in average one household is able to produce/save/collect 1.817 kg of natural fertilizers and use 44% for rice fields then 805 kg will in average be available to use for the rice fields. With the given application rate of green manure of 1.90 kg per m^2, a household will then be able to grow an area of 423,65 m^2 with such applications of GM.

The situation will be similar if the natural fertilizers are changed with the production and application of compost. One family can approximately produce 2550 kg year $^{-1}$ of compost and if they use 58% of this amount for the rice field they will have 1475 kg available for their rice fields. With an average application rate of compost of 0.33 kg per m^2 their amount of compost will cover an area of 4472 m^2.

A gap in year 2009's production

It is assumed that the farmers are able to produce the app. same amount of compost every year. Average fields next year are, as mentioned before above, in average 3676 m^2. Farmers relying on compost will need to produce 1213 kg of compost to meet the needs of next year's area of 3676 m^2 if they still rely on the same application rate of 0.33 kg compost m^{-2}. This is however not a problem as the farmers with compost are able to produce 4472 kg of compost only for rice fields disregarding the two other sectors: seedbed and vegetable production but on the other side is the application rate very low compared to other studies (see table 6) and could thus be increased.

Farmers who rely on natural fertilizers will have to find 6985 kg to be able to grow SRI for the 2009 season with an application rate of 1.9 kg m^{-2} which is an additional amount of 6180 kg and it will therefore be difficult for farmers to reach. The application rate of 1.9 kg m^{-2} is however also very

[9] Natural fertilizers comprise plant residues, green manure and leafy manures such as Neem, Sesbania, Leucaena etc.

high compared to other doses (see table 6). 1.9 kg m^{-2} corresponds to 19 t/ha which is a very large amount for small scale farmers to produce/collect and very labour intensive. Almost 50% of the farmers do however apply both compost and green manure and such a method will lead to many possibilities on finding the necessary means and amounts of amendments needed in order to reach a sustainable level of inputs.

The amount of compost collected per year will cover the increase next year, but the amount of natural fertilizers collected will not be enough. Farmers only relying on natural fertilizers will need to find additional amounts of organic amendments. In theory the more compost the farmers apply the higher the yield and improved soil quality they will reach. Uphoff (1999) reports from SRI practising farmers in Madagascar that amount and quality of added composts was very different from farmer to farmer and those with highest yields did also apply high amounts of compost or had a higher soil quality than other farmers. Husain *et al*. (2004), Mcdonald *et al*. (2006) and Satyanarayana *et al*. (2007) state that a major limitation for farmers practising SRI is the lack or low quantity of organic amendments applied to fields, which will decrease benefits of SRI. SRI can however very well be practiced with chemical fertilizers (Laulanie, 1993) but only few farmers can afford to buy these or have been encouraged by CEDAC not to use them and instead focus more on natural amendments. The farmers will through the ILFARM project receive app. 500.000 multipurpose trees to plant on their homestead land and around rice fields in order to increase production of especially green manures (leaf manures). See Appendix E. Depending on which rate and amount of added compost/fertilizers farmers will somehow be forced to grow a certain area of SRI. They can choose to apply less amounts per m^2 thus reaching a larger area but with the given soil conditions (low C and N) the need for large applications is necessary in order to reach sustainable yields.

9.5.5 Nutrient balance

Assuming the farmers convert all their rice land to SRI and obtain average rice yields of 3.5 t/ha, and the increase in leafy manures together with increased compost production will reach an average amount of 3t/ha per year. A rough estimate of a nutrient budget could then look like the illustration in Table 8. The net balance indicate that N and P inputs are in excess but the K pool is being depleted most likely due to the removal of straw, which is typical for rice systems with removal of residues (Greenland, 1997; Dobermann & Fairhurst, 2000). However given the inputs of N, P and

K, only a minor fraction is available to the plants upon application. Kundu & Ladha (1999) refer to Shi *et al*. (1980), Koyama, (1981) and Zhu *et al*. (1983) who suggest that only 20-30 % is assimilated by the rice crop, 20-30% is lost and the rest is immobilized. Within the anaerobic conditions in flooded rice systems added OM will accumulate (Hesse, 1984) and the release of plant available nutrients is slowed down (Greenland, 1997) due to a slower mineralization rate.

The low K contents are common in lowland rainfed soils in Asia and can limit future production in terms of yield increase and may as well result in poorer N use efficiency (Dobermann & Fairhurst, 2000). By just returning some parts of the straw, K content can be increased (Greenland, 1997). If the target farmers in the future can sustain the high yields identified in this survey, the need to remove all straw might not be necessary and thus some of the straw could be returned to the system increasing K input.

The drying and flooding of the soil will have large impacts on the loss of N. Upon flooding NH_4 amount is increasing in the soil and by the end of the flooded period organic N and NH_4 – N is governing (George *et al*., 1992). When the water table decrease and aerobic conditions are prevailing, aerobic N transformations are enhanced, resulting in mineralization of organic N to NH_4 which is nitrified to NO_3 accumulating in the soil (George *et al*., 1992). However when the soil is flooded again in the beginning of the wet season the accumulated NO_3 is lost within a short time (George et al., 1992). Rainfed lowland rice systems do in general experience a high nitrate leaching especially on soils rich in coarse textured materials (Dobermann & Fairhurst, 2000) which is typical for the soil in Prey Veng. Catch crops such as legumes can be grown during the dry season and accumulate NO_3 and at the same time fix N from the air, and thus before the transplanting of the rice in the wet season, be incorporated in the soil and a significant amount of N is then returned to the soil (George *et al*., 1992).

Another way of increase inputs of N could be to enhance the Biological Nitrogen Fixation (BNF) through various sources such as the intended planting of trees within the ILFARM project (See appendix E). Some important world wide used BNFs are e.g. *Sesbania* and *Leucaena* (De Datta, 1987) and *Azolla* (Li, 1984) – the latter being native to many rice fields. *Azolla* is listed in Table 8 to be able to account for inputs of 30 kg N ha^{-1}, which might be too high, as the examined fields experienced periods with drought where the production of *Azolla* would decrease most likely.

The effect of the leafy manures is though very much depending on the time of incorporation and growth period (De Datta, 1987). Young GM materials should be incorporated into the soil before rice transplanting app. after eight weeks of growth or if older then incorporated several months before the transplanting in order to increase decomposition (De Datta, 1987).

Sesbania can in average produce 15 t ha^{-1} of green matter with an N content of 2.67% of the dry weight (Singh, 1984). This would roughly result in 400 kg N ha^{-1} which is a rather large input. However not all N will be plant available as mentioned earlier. Given the percentages Kundu & Ladha (1999) referred to above the *Sesbania* crop would result in 80-120 kg available N ha^{-1}. As *Sesbania* can tolerate anaerobic conditions resulting from flooding (De Datta, 1987), farmers could grow a *Sesbania* crop before transplanting in early wet season app. eight weeks before transplanting. This would provide the farmers with a considerable input of N. The cultivation of a catch crop or a GM crop before the rice transplanting would also reduce the labour of transporting and producing composts on the homestead land. Instead organic biomass would more easily be present to incorporate in the soils, even in fields located far from the homestead lands.

Given the traditional rice yield of 2.19 t ha^{-1} (grain), this would result in a straw dry mass of 3.3 t ha^{-1} with a harvest index of 0.5. In theory farmers have sustained their domestic animal production with an approximate rice straw production of 3.3 t ha^{-1} or less as opposed to the estimated scenario in table 8 where all land would be converted to SRI, resulting in a straw production of 5.25 t ha^{-1} which is a difference of 1.95 t ha^{-1}. This signifies that farmers would be able to return this amount to the field. With uptake rates estimated by De Datta (1987) this would result in a new net balance: N (14.3 kg ha^{-1}), P (14.6 kg ha^{-1}) and K (- 0.7 kg ha^{-1}). The balance of especially K would be quite sustainable if farmers could afford to return the additional production of straw or some of it. This is of course depending on their amount of cows and buffaloes per farmer. One could argue that with additional straw they would be able to sustain more domestic animals thus a trade-off situation is arising.

Table 8. An estimated picture of an annual nutrient budget for the target farmers. All nutrient values are in kg/ha. Kundu & Ladha (1999) refer to Koyama (1981) stating that upon applying organic materials 10-20% of the N is mineralized and thus plant available, and the rest is immobilised and lost. An average value of 15% mineralized N, P and K has been chosen. Nutrient inputs from sediments have not been included as no natural flooding occurred in the target area.

Input	N (Kg/ha)	P (Kg/ha)	K (Kg/ha)	Specifications	References
Precipitation	12	0,2	12		Greenland (1997)
Biological N fixation (BNF): mainly Azolla	30				Dobermann & Fairhurst (2000)
Transplanted seedlings (30 days)	0,6	0,08	1,4		Seedling uptakes estimated to be 2% of straw of 5.25 t/ha. Uptake rates determined from De Datta (1987)
Compost incl. GM	50	25	49,8	3t/ha	N (1,67%), P (0,83%) and K (1,66%) of the compost estimated from Latif *et al*. (2005)
Total	**92,6**	**25,28**	**63,2**		
Output					
Grain	38	7	11	3,5 t/ha grain yield	Uptake rates estimated from De Datta (1987)
Straw	26,6	3,8	67,5	5,25t/ha dry weight	Harvest Index 0,5 estimated from Dobermann & Fairhurst (2000). 5% from stubble not removed. Uptake rates estimated from De Datta (1987)
Leaching (percolation)	20	1	10		Estimated from Dobermann & Fairhurst (2000) and N loss from leaching George *et al*. (1992)
Gaseous loss: Volatalization & denitrification	4				Estimated from Greenland (1997)
Total	**88,6**	**11,8**	**88,5**		
Net balance	**4**	**13,48**	**- 25,3**		

9.6. Can SRI mitigate GHGs and at the same time increase soil quality through C sequestration?

There are large differences between the theoretical concepts of SRI as described by Laulanie (1993), Stoop *et al*. (2002) and Sheehy *et al*. (2004) and the SRI conducted by the farmers in the target area of this study. This section will try to evaluate the consequences of the conceptual SRI and the SRI conducted by the farmers in Prey Veng.

Table 10 is a theoretical model illustrating how a theoretical SRI system as described by Stoop *et al.* (2002) and Sheehy *et al*. (2004) and the SRI practiced by farmers potentially will affect emissions of CH_4, N_2O and CO_2 and influence the soil C pool.

The use of a fluctuating water table resulting in periods of drainage and moist soils (Laulanie, 1993; Sheehy *et al*. 2004) will result in long periods with aerobic conditions reducing CH_4, which though will lead to increased emissions of N_2O but at the same time increase C content. SOM will therefore be increased during times of flooding and slowly decrease when drained (Mitsuchi, 1974). There will however be a trade-off when considering the possibilities of denitrification and emissions of N_2O. Intermittent flooding showed a 17% lower GWP for N_2O and CH_4 than continuous flooding in China (Yue *et al*., 2005) and thus the most favorable would seem to go for a fluctuating water table as with SRI.

The emissions of N_2O are quite large during the dry season – up to three to four times larger than upon the growth season (Dobermann & Fairhurst, 2000) upon aerobic conditions. Denitrification is occurring in situations of lack of oxygen and some bacterial strains will then use nitrate as a source of respiration in stead of oxygen (Patrick & Reddy, 1976). Denitrification can especially occur in wetland soils, poorly drained soils and soils fertilized with nitrate (Borggaard & Elberling, 2003). The theoretical SRI will give fewer rises to denitrification due to the fluctuating water table. The SRI practiced by farmers seems though however to experience some periods with denitrification due to the long drought periods and aerobic conditions.

The farmers in Prey Veng do however not possess the means to control water, they are able to drain their fields but not adjust water levels later on. It is therefore very risky if they drain at one point and not are able to adjust water if a prolonged drought is present. Only 3% of the target farmers use less water, and their fields might in theory build up less C than fields that are flooded according to the findings of Mitsuchi (1974) but it is though doubtful if there will be any significant difference between their C levels and the other participating farmers. Especially when considering that one rice season is very short – a few months followed by a fallow period throughout the rest of the year.

The farmers who are able to adjust water levels (3%) will though be able to reduce CH_4 emissions due to drainage periods resulting in aerobic conditions (Wassmann *et al*., 2000; Yue *et al.*, 2005; Zou *et al*., 2005; Li *et al*., (2009) but will at the same time increase emissions of N_2O and CO_2 and thereby creating a trade-off. The success of the drainage concepts is though depending on the degree of drainage i.e. complete drainage or as in the SRI theories soil is kept moist/wet to dry depending on the farmer and the area. If the soil is just a little too wet/moist there will still be methane emissions due to anaerobic conditions.

The majority of farmers do as mentioned not adjust water levels and their "SRI" fields will emit more CH_4 but less N_2O and CO_2 due to long periods with anaerobic conditions. The question is then which systems are to be preferred considering the present trade-off. Since few farmers use chemical fertilizers which can increase N_2O emissions (Nishimura *et al*., 2004; Mandal *et al*., 2008), drainage periods will not lead to heavy emissions of N_2O.

The other important SRI concept is the use of organic amendments (Laulanie, 1993) which will reduce all three GHGs (Yagi & Minami, 1990; Neue, 1993; Nayak *et al.*, 2007) and increase the C content of the soil (Jarecki & Lal, 2003; Ramesh & Chandrasekaran, 2004; Mandal *et al*., 2008; Rajashekhara Rao & Siddaramappa, 2008). 93% of the farmers follow this SRI concept and their fields will therefore most likely have some influence on GHG emissions and build up of C pools. The fact that farmers remove the rice straw from the fields is removing nutrients, but removal of straw was according to Lou *et al*. (2007) found to decrease the emissions of CO_2 and N_2O. This is linked to the higher cellulose content of straw compared to the roots which will result in a slower decomposition of straw than roots (Lou *et al*., 2007).

The degree of GHG emission reductions and C dynamics will very much depend on the applied amount of organic amendments and as discussed above in “compost production” are farmers able to collect quite a lot of natural fertilizers but they are not able to produce larger amounts of compost.

Estimates are made on the C pool increase per year based on the organic inputs in table 9 and 10. If farmers in average would grow one ha or more with SRI, apply 3t/ha of compost/GM and have an average yield of 3.5 t rice per ha, a yearly input of C would be 348 kg C per ha per year which corresponds to close to 1% of the soil C pool of 49.5 t/ha. It is estimated that app. 1% of the C soil pool is mineralized per year thus resulting in a steady state where losses matches inputs app.
Jarecki & Lal (2003) found similar results from a situation with a rice yield of 3.96 t ha^{-1} and input of crop residues amounting to 2.67 t ha^{-1}. They concluded that the soil C pool was enriched with 401 kg C ha^{-1} annually (Jarecki & Lal, 2003). With the intensions of the ILFARM project to establish 500.000 trees the potential of storing larger amounts of C seems possible. Given the inputs assessed in section 9.5.5, under the nutrient budget, the plantings of e.g. *Sesbania* on 1 ha would yield 15 t ha^{-1} of green matter (Singh, 1984). Assuming a C percentage of 42 % (Brady & Weil, 1999a) this would leave the farmers with an additional C input of 6300 kg/ha where however some parts would be lost due to decomposition especially if the *Sesbania* is added directly and not composted. Conservation tillage or no tillage could increase the C budget in the soil, it is however

doubtful if such measure would work for the RPF as they would have to increase input costs on pesticides which they do not have.

To really affect and increase the C pool, the inputs of biomass must be larger than the losses of C (Lal, 2007) and thus taking the steady state to a new level. Given the amount of trees planted in the ILFARM project (500.000) this would mean 625 trees per participating household (800 in total). The available input of biomass would then app. at least be the double resulting in 6 t ha^{-1} (incl. compost). Such a double input would result in a net balance of 116 kg C ha^{-1} in excess after mineralization per year. For long term effects (20-30 years), assuming farmers would apply at least 6 t ha^{-1}, this would result in a C pool of 51.5 t C ha^{-1} and 53 t C ha^{-1} respectively which is a rather small increase. However farmers will reach a sustainable rice production with high yields (3.5 t ha^{-1}) and a slowly increasing C pool improving soil quality in the long run.

However producing and transporting such large quantities of biomass is very labor intensive and only larger families (richer) will be more likely to cope with such a scenario. It is however unlikely that both small and larger households will convert all their land to SRI, as it requires intensive labor. A more likely scenario is that farmers will use some of the SRI techniques and mix them into their traditional system. Farmers conducting SRI will sometimes stop after a few years and then start mixing their traditional systems with SRI (Ma Veasna, personal communication, 2008).

Table 9. An estimated C budget. It is assumed that farmers convert all their land to SRI and have an annual compost production of 3t/ha and a rice yield of 3.5 t/ha.

Inputs	kg C ha	Specifications	References
Roots	210	Undecomposed	42% C estimated from Brady & Weil, (1999a).Root shoot ratio estimated from Yoshida (1981) to be 0.1
Stubble	110	Undecomposed	42% C estimated from Brady & Weil, (1999a). Stubble estimated to be 5% of the straw mass (5.25 t/ha)
Compost	1050	Undecomposed	C% of the compost is estimated to be 35%
Total	**1370**		
Losses			
Roots	141	67% lost	Estimated from Brady & Weil (1999a)
Stubble	94	85% lost	Estimated from Brady & Weil (1999a)
Compost	788	75% lost	Estimated from Brady & Weil (1999a)
Total	**1022**		
Net balance	**348**	Soil C pool = 49.5 t/ha	

A perfect SRI system as described by e.g. Stoop *et al*., (2002) compared to conventional rice systems will most likely emit less amounts of GHGs and increase C pools due the water management involving several drainage periods. The SRI practiced by the targeted farmers within this project does not seem to possess the means of really affecting a decrease of GHG emissions due to no water management. The potentials of increasing the C pool does however seem more appropriate for the RPF in Prey Veng with the input of 500.000 trees over the next years.

On the basis of the discussion on GHG emissions and C sequestration, it is tempting to state that SRI is moving the target farmers' livelihood sustainability towards a new and higher level. Or as stated by Pretty (2000) on the definition of a sustainable farming system being one that: "..sequesters carbon in soils through organic matter accumulation both contributes to the global good by mediating climate change and the private good by enhancing soil health". RPF can turn a rice based farming system emitting large amounts of GHGs into a sustainable one (such as SRI or other systems) through C storage and develop a beneficial system with long term effects on increased soil quality and productivity. By reducing the emissions of GHGs, soil C is increasing in combination with applied organic materials and soil fertility can increase hence have a large positive influence on their livelihood strategies and future life.

Table 10. Estimated effects of SRI techniques on GHG emissions and SOC changes. Theoretical SRI concepts as described by Sheehy *et al*. (2004) and Stoop *et al*. (2002) are compared with the identified SRI techniques from the 30 interviewed farmers. Numbers in brackets indicate the percentage of practicing farmers. - 1 = increase, 1 = decrease and 0 = no real effect. References are not dealing with SRI specifically but describe similar management tools affecting GHG emissions and C dynamics.

SRI techniques	N_2O	CH_4	CO_2	References	ΔC	References
Compost + organic amendments	1	1	1	Yagi & Minami (1990); Neue (1993); Nayak *et al.* (2007)	1	Jarecki & Lal (2003); Ramesh & Chandrasekaran (2004); Mandal *et al*. (2008); Rajashekhara Rao & Siddaramappa (2008)
Water management (several drainage periods)	-1	1	-1	Wassmann *et al*. (2000); Yue *et al.* (2005); Li *et al*. (2009); Zou *et al*. (2005). Denitrification. Patrick & Reddy (1976).	-1	Mitsuchi (1974); Nishimura *et al*., (2008)
1 seedling per hill	-1	- 1; +1	-1	Yagi & Minami (1990); Lou *et al*. (2007); Yan *et al*. (2009)	1	Lou *et al.* (2007)
Regular hand weeding	0	0	0		0	
SRI techniques practiced by the studied farmers	**N_2O**	**CH_4**	**CO_2**	**References**	**ΔC**	**References**
Use of natural fertilizers (compost+green manure) (93%)	1	1	1	Yagi & Minami (1990); Neue (1993); Nayak *et al.* (2007)	1	Mandal et al. (2008); Ramesh & Chandrasekaran (2004); Jarecki & Lal (2003); Rajashekhara Rao & Siddaramappa (2008)
Use less water (3%)	-1	1	-1	Wassmann *et al*. (2000); Yue *et al.* (2005); Li *et al.* (2009); Zou *et al*. (2005),	-1	Mitsuchi (1974); Nishimura *et al*., (2008).
Plough twice before transplanting (13%)	-1	-1	-1	Harada *et al*. (2007)	-1	West & Post (2002); Jarecki & Lal (2003)
Plant in lines (56%)	0	0	0		0	
Leveling of field before transplanting (3%)	-1	-1	-1	Harada *et al.* (2007)	-1	West & Post (2002); Jarecki & Lal (2003)
Transplant 1 seedling per hill (93%)	-1	1	-1	Yagi & Minami (1990); Lou *et al*. (2007)	1	Lou *et al.* (2007)
Regular weeding (10%)	0	0	0		0	
General care taking (3%)	0	0	0		0	
Chemical fertilizers (6%)	-1	1	1	Nishimura *et al.* (2004)	1	Mandal *et al*. (2008)

10. Conclusion

The farmers participating in the present study have successfully obtained a significant increase in their rice yields by growing SRI on a small piece of their land. The main management difference seems to be the use of one single transplant per hill and not several as in traditional growing. The wider spacing will provide less competition for nutrients in the low fertility soils and hence a higher yield. The farmers did not possess the equipment to control the water level in the fields, but they were still able to increase their yields significantly. This would imply that SRI works properly when farmers just use some of the concepts. The water management implied in the SRI theories is difficult to practice in many resource poor areas, but the results from this survey indicate that it is not necessary to follow all steps of SRI in order to increase yields.

Both poor and rich farmers, in terms of household incomes, have proven equal in adopting and practising SRI to their fields with no correlation found between income and yield. Likewise there was no correlation between C and N content and income. For future aspects of conducting SRI, farmers with higher incomes might though be more likely to continue with SRI and grow larger areas than poorer farmers. Richer farmers will have more land, and thereby be able to produce more biomass for compost making and harvest more manure from domestic animals. SRI is tough still a very sustainable system targeting the poor farmers. The results obtained during this study indicate that the amount of compost/GM did not have any influence on the yield. Thus RPF poor or not so poor, will by using wider spacing be able to increase their yields which must be described as much more sustainable than their traditional system. The farmers have obtained these yields by using less inputs than in their traditional rice systems and their level of sustainability will move to another level, if they would continue with SRI or use some of the concepts.

SRI is a farming system with much potential regarding GHG mitigation and increase in soil C contents if all concepts are followed. The theoretical concepts as described by Laulanie (1993) and Sheehy *et al*. (2004) would be able to reduce emissions of especially methane dramatically due to a fluctuating water table. The SRI practiced by the farmers will not be able to mitigate large amounts of GHGs, mainly because no water management was carried out. This is not a choice made by the farmers but due to no irrigation facilities in the area.

Both the theoretical SRI and the one practiced by the target farmers seem to be able to increase the soil C pool due to the applications of compost/GM. With the amounts applied by the target farmers there is no increase in soil C but a steady state of inputs and outputs of C thus implying a sustainable balance. However with the introduction of the 500.000 trees farmers could in theory increase the C pool with 116 kg C ha^{-1} per year as the planting of trees would provide them with high amounts of biomass. The introduction of trees would also allow the farmers to have enough organic materials to e.g. convert all their land to SRI as their compost production at the moment is very limited.

The fact that CEDAC will not be present for ever in the target area might indicate that farmers will not conduct SRI as described by Stoop *et al*. (2002) or Sheehy *et al*. (2004) but more a mixture between traditionally and SRI. This would also seem to be more sustainable as farmers have learned by participatory doing and thus made their own experiences. Especially the fact that using only one seedling brought higher yields than traditional seems likely that farmers would continue with this. Water management does not seem an option at the moment without any proper irrigation facilities in the area, but it might not be necessary considering the yield increases obtained using only one seedling. It is given the target farmers and their neighbours will use parts of SRI. Given the large roll on effect where farmers shared their experiences on SRI with in average 9 people would imply that the concepts and ideas of SRI are spreading rather fast and will survive in the area. CEDAC has then successfully implemented a sustainable long lasting project which will benefit farmers in many years to come.

SRI has been through many controversial discussions about its potential in rural areas of the rice growing world. It has often been criticised of its alternative ways. This study indicates that by following only a few of the SRI concepts, farmers are able to increase their rice yields and SRI could then be considered very appropriate for the poorest farmers groups with few resources.
In a world with a growing population and risks of food shortages, SRI can provide security for the poorest groups and it should therefore receive more attention in the future regarding research projects and recognition.

11. References

Anthofer, J. 2004. The potential of the System of Rice Intensification (SRI) for Poverty Reduction in Cambodia. Deutscher Tropentag, Berlin. 2004. Conference on International Agricultural Research for Development. German Development Co-operation (GTZ). Available at internet: http://www.tropentag.de/2004/abstracts/full/399.pdf

Antonovics, J. & Levin, D. A. 1980. The ecological and genetic consequences of density-dependent regulation in plants. Ann. Rev. Ecol. Syst. 11: 411-52.

Barrett, C.B., Moser, C.M., Mchugh, O.V., Barison, J. 2004. Better technology, better plots, or better farmers? Identified changes in productivity and risk among Malagasy rice farmers. Amer. J. Agr. Econ 86(4): 869-888.

Berg, H. van den., Jiggins, J. 2007. Investing in Farmers – The impacts of Farmer Field Schools in Relation to Integrated Pest Management. World Development Vol. 35(4): 663-686.

Blaikie, P., Brown, K., Stocking, M., Tang, L., Dixon, P., Sillitoe, P. 1997. Knowledge in action: Local knowledge as a development resource and barriers to its incorporation in natural resource research and development. Agricultural Systems Vol 55(2): 217-237.

Blair, G.J., Lefroy, R.D.B., Lisle, L. 1995. Soil Carbon fractions based on their degree of oxidation, and the development of a Carbon Management Index for agricultural systems. Aust. J. Agric. Res 46: 1459-1466.

Borggaard, O.K. & Elberling, B. 2003. Soil Organic Matter. *In: Biogeochemistry in a pedological context.* pp 101-140. Holte Bogtrykkeri A/S. Holte. Denmark.

Borggaard, O.K. 2006. Environmental Chemistry and Pedology of Tropical Soils. Department of Natural Sciences, Royal Veterinary & Agricultural University, Frederiksberg. Pp 87.

Brady, N.C. & Weil, R.R. 1999a. Soil Organic Matter. In The Nature and Properties of Soils. 12th edition. Prentice Hall, Upper Saddle River, New Jersey, USA. pp: 446-489.

Brady, N.C. & Weil, R.R. 1999b. Soil Reaction: Acidity and Alkalinity. In The Nature and Properties of Soils. 12th edition. Prentice Hall, Upper Saddle River, New Jersey, USA. pp: 446-489.

Bunch, R. 2002. Use of Green Manures and Cover Crops with SRI. A presentation held at the International Conference "Assessments of the System of Rice Intensification (SRI)", Sanya, China, April 1- 4, 2002. Available at internet: http://ciifad.cornell.edu/sri/proc1/sri_43.pdf

CEDAC. 2008a. Improving Livelihood of Small Farmers in Kanhchriech District of Prey Veng Province. ILFARM-KCR. Second Draft Report. CEDAC October 2008.

CEDAC, 2008b. Evaluation Study: Adoption and non-adoption of System or Rice Intensification (SRI) in Cambodia. CEDAC. July 2008.

CEDAC, 2008c. Description of the ILFARM project. http://cedac.org.kh/Ip_pdf02.pdf

Ceesay, M.M. 2002. Experiments with the System of Rice Intensification in The Gambia. A presentation held at the International Conference "Assessments of the System of Rice Intensification (SRI)", Sanya, China, April 1- 4, 2002 Available at Internet: http://ciifad.cornell.edu/sri/proc1/sri_13.pdf

Dawson, J.J.C. & Smith, P. 2007. Carbon losses from soil and its consequences for land-use management. Science of the Total Environment 382: 165-190.

De Datta, S.K. 1987. Principles and practices of rice production. 1st edition 1981. Reprint edition 1987 with corrections. Robert E. Krieger Publishing Company, INC. Malabar, Florida, USA. p. 618.

De Datta, S.K. & Hundal, S.S. 1984. Organic matter management on land preparation and structural regeneration in rice-based cropping systems. In Organic matter and rice. International Rice Research Institute. Manilla, Phillipines. pp: 399-416.

Dobermann, A & White, P.F. 1999. Strategies for nutrient management in irrigated and rainfed lowland rice systems. Nutrient Cycling in Agroecosystems 53: 1-18.

Dobermann, A. & Fairhurst, T. 1999. Nutrient Management. In: Rice. Nutrient Disorders & Nutrient Management. IRRI. Makati City, Philippines. pp. 13-17.

Dobermann, A. & Witt, C. 2000. The potential impact of crop intensification on carbon and nitrogen cycling in intensive rice systems. p. 1-26. In: Carbon and Nitrogen dynamics in flooded soils. Ed: Kirk, G.J.D. & Olk, D.C. pp 188. IRRI, Philippines.

Dobermann, A. 2004. A critical assessment of the system of rice intensification (SRI). Agricultural Systems 79: 261-281.

Follett, R.F. 2001. Soil management concepts and carbon sequestration zin cropland soils. Soil & Tillage Research 61: 77-92.

Frolking, S., Li, C., Braswell, R., Fuglestvedt, J. 2004. Short- and long-term greenhouse gas and radiative forcing impacts of changing water management in Asian rice paddies. Global Change Biology 10: 1180-1196.

George, T., Ladha, J.K., Buresh, R.J., Garrity, D.P. 1992. Managing native and legume-fixed nitrogen in lowland rice-based cropping systems. Plant & Soil 141: 69-91.

Greenland, D.J. 1997. Rice Farming Today. In: *The sustainability of rice farming*. CAB International, Oxon, UK and New York, USA.. IRRI, Manilla, Philippines. p. 273.

Haden, V.R., Duxbury, J.M., DiTommaso, A., Losey, J.E. 2007. Weed Community Dynamics in the System of Rice Intensification (SRI) and the Efficacy of Mechanical Cultivation and Competitive Rice Cultivars for Weed Control in Indonesia. Journal of Sustainable Agriculture 30 (4): 5-26.

Harada, H., Kobayashi, H., Shindo, H. 2007. Reduction in greenhouse gas emissions by no-tilling rice cultivation in Hachirogata polder, northern Japan: Life-cycle inventory analysis. Soil Science and Plant Nutrition 53: 668-677.

Hesse, P.R. 1984. Potential of organic materials for soil improvement. In Organic matter and rice. International Rice Research Institute. Manilla, Phillipines. pp: 35-44.

Husain, AM.M., Chowhan, G., Rahman, ABM. Z., Uddin, R., Barua, P. 2004. Report on the System of Rice Intensification (SP 36 02). Prepared for PETTRA Technology Workshop. BRRI Auditorium, Gazipur. May 23-24, 2004. Available at internet: http://ciifad.cornell.edu/sri/countries/bangladesh/bangpetechrep.pdf

Hutchinson, J.J., Campbell, C.A., Desjardins, R.L. 2007. Some perspectives on carbon sequestration in agriculture. Agricultural and Forest Meteorology 142: 288-302.

IPCC. 2000. Special report on Land Use, Land-Use Change and Forestry.
Available at Internet:
http://www.ipcc.ch/ipccreports/sres/land_use/index.htm

Inoko, A. 1984. Compost as a source of plant nutrients. In: Organic Matter and rice. International Rice Research Institute. Manilla, Phillipines. pp: 137-146.

IRRI. 2006. Available at internet:

http://www.irri.org/science/ricestat/data/may2008/WRS2008-Table01.pdf

http://www.irri.org/science/ricestat/data/may2008/WRS2008-Table02.pdf

http://www.irri.org/science/ricestat/data/may2008/WRS2008-Table03.pdf

Jarecki, M.K & Lal, R. 2003. Crop management for Soil Carbon Sequestration. Critical Reviews in Plant Sciences 22 (5): 471-502.

Javier, E.L. 1997. Rice ecosystems and varieties. In: Rice production in Cambodia. Manila (Philippines): International Rice Research Institute. Ed: Nesbitt, H.J. p. 39-83.

Kabir, H. 2006. Adaptation and Adoption of the System of Rice Intensification (SRI) in Myanmar using the Farmer Field School (FFS) approach. PhD thesis. Final draft. University of Honolulu. p. 124. http://ciifad.cornell.edu/sri/theses/kabirthesis.pdf

Kabir, H. & Uphoff, N. 2007. Results of Disseminating the System of Rice Intensification with Farmer Field School Methods in Northern Myanmar. Expl. Agric 43: 463- 476.

Kawano, K., Gonzalez, H., Lucena, M. 1974. Intraspecific competition, competition with weeds, and spacing response in rice. Crop Science vol. 14: 841-845.

Kimura, M., Murase, J., Lu, Y. 2004. Carbon cycling in rice field ecosystems in the context of input, decomposition and translocation of organic materials and the fates of their end products (CO_2 and CH_4). Soil Biology & Biochemistry 36: 1399-1416.

Koma, Y.S. 2002. Experciences with the System of Rice Intensification in Cambodia. Proceedings of an International Conference on ASSESSMENTS OF THE SYSTEM OF RICE INTENSIFICATION (SRI)
Sanya, China, April 1-4, 2002. Available at internet:
http://ciifad.cornell.edu/sri/proc1/sri_19.pdf

Koma, Y.S. 2007. Experiences with System of Rice Intensification (SRI) in Cambodia from 2000-2007. CEDAC. Available at internet: http://www.cedac.org.kh/SRI%202000-2007.pdf

Koma, Y.S. 2008. Proposed Strategies to Utilize the Potential of Rice Production in Cambodia. Agriculture and Rural Development Discussion Note. Available at internet: www.cedac.org.kh

Kumazawa, K. 1984. Beneficial effects of organic matter on rice growth and yield in Japan. In: Organic Matter and rice. International Rice Research Institute. Manilla, Phillipines. pp: 431- 444.

Kundu, D.K. & Ladha, J.K. 1999. Sustaining productivity of lowland rice soils: issues and options related to N availability. In Resource Management in Rice Systems: Nutrients. Eds: Balasubramanian, V., Ladha, J.K., Denning, G.L. Klüwer Academic Publishers. AA Dordrecht, The Netherlands. pp. 27-44.

Lal, R. 2002. *Why Carbon Sequestration in Agricultural Soils.* Nutrient Cycling in Agroecosystems 61: 1-6.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. Geoderma 123: 1-22.

Lal, R. 2006. Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands. Land Degradation & Development 17: 197-209.

Lal, R. 2007. Soil Physical Properties and Erosion. In Soil Carbon Management. Economic, Environmental and Societal Benefits. Ed: Kimble, J.M., Rice, C.W., Reed, D., Mooney, S., Follett, R.F., Lal, R. CRS Press Boca Raton, Florida, USA. pp 165 – 178.

Larson, W.E. & Clapp, C.E. 1984. Effects of Organic Matter on soil physical properties. In Organic Matter and rice. International Rice Research Institute, Manilla, Phillipines. pp: 363-386.

Latif, M.A., Islam, M.R., Ali, M.Y., Saleque, M.A. 2005. Validation of the system of rice intensification (SRI) in Bangladesh. Field Crops Research 93: 281-292.

Laulanie, H.D. 1993. Le système de riziculture intensive malgache. TROPICULTURA 11 (3) : 110-114.

Li, C., Cao, C., Wang, J., Zhan, M., Yuan, W., Ahmad, S. 2009. Nitrous oxide emissions from wetland rice-duck cultivation sytems in southern China. Arch Environ Contam Toxicol 56: 21-29.

Lou, Y., Ren, L., Li, Z., Zhang, T., Inubushi, K. 2007. Effect of rice residues on carbon dioxide and nitrous oxide emissions from a paddy soil of subtropical china. Water Air Soil Pollut 178: 157-168.

Ma Veasna – personal communication, 2008. CEDAC project coordinator of the ILFARM project. Held 18th of October 2008 in Prey Veng City – CEDAC office, Prey Veng province, Cambodia. See Appendix F.

Mak, S. 2001. Continued innovation in a Cambodian rice based farming system: farmer testing and recombination of new elements. Agricultural Systems 69: 137-149.

Mandal, B., Majumder, B., Adhya, T.K., Bandyopadhyay, P.K., Gangopadhyay, A., Sarkar, D., Kundu, M.C.,Choudhury, S.G., Hazra, G.C., Kundus, S., Samantaray, R.N., Misra, A.K. 2008. Potential of double-cropped rice ecology to conserve organic carbon under subtropical climate. Global Change Biology 14: 2139-2151.

Matteson, P.C. 2000. Insect Pest Management in Tropical Asian irrigated rice. Ann. Rev. Entomol. 45: 549-574.

Mcdonald, A.J., Hobbs, P.R., Riha, S.J. 2006. Does the system of rice intensification outperform conventional best management? A synopsis of the empirical record. Field Crops Research 96: 31-36.

Menete, M.Z.L., Es, H.M.V., Brito, R.M.L., DeGloria, S.D., Famba, S. 2008. Evaluation of system of rice intensification (SRI) component practices and their synergies on salt-affected soils. Field Crops Research 109: 34-44.

Minamikawa, K. & Sakai, N. 2007. Soil carbon budget in a single-cropping paddy field with rice straw application and water management based on soil redox potential. Soil Science and Plant Nutrition 53: 657-667.

Mitsuchi, M. 1974. Characters of humus formed under rice cultivation. Soil Sci. Plant Nutr. 20(3): 249-259.

Moldenhauer, K.A.K. & Gibbons, J. 2003. Rice morphology and development. In Rice. Origen, History, Technology and Production. Eds: Smith, C.W. & Dilday, R.H. John Wiley & Sons, Inc. USA. pp: 103-128.

Morari, F., Lugato, E., Berti, A., Giardini, L. 2006. Long-term effects of recommended management practices on soil carbon changes and sequestration in north-eastern Italy. Soil Use and Management 22: 71-81.

Moser, C.M. & Barrett, C.B. 2003. The disappointing adoption dynamics of a yield-increasing, low external-input technology: the case of SRI in Madagascar. Agricultural Systems 76: 1085–1100.

Mosier, A.R., Duxbury, J.M., Freney, J.R., Heinemeyer, O., Minami, K., Johnson, D.E. 1998. Mitigating agricultural emissions of methane. Climatic Change 40: 39-80.

Nayak, D.R., Babu, Y.J., Datta, A., Adhya, T.K. 2007. Methane Oxidation in an Intensively Cropped Tropical Rice Field Soil under Long-Term Application of Organic Mineral Fertilizers. Journal of Environmental Quality 36: 1577 -1584.

Nesbitt, H.J. 1997. Topography, climate, and rice production. In: Rice production in Cambodia. Manila (Philippines): International Rice Research Institute. Ed: Nesbitt, H.J. p. 15-21.

Nesbitt, H.J. & Phaloeun, C. 1997. Rice-based farming systems. In: Rice production in Cambodia. Manila (Philippines): International Rice Research Institute. Ed: Nesbitt, H.J. p. 31-39.

Neue, H.U. 1993. Methane Emission from Rice Fields. Wetland rice fields may make a major contribution to global warming. Bioscience 43 (7): 466-473.

Neue, H.U. 1997. Fluxes of methane from rice fields and potential for mitigation. Soil Use and Management 13: 258-267.

Nishimura, A., Sawamoto, T., Akiyama, H., Sudo, S. 2004. Methane and nitrous oxide emissions from a paddy field with Japanese conventional water management and fertilizer application. Global Biochemical Cycles 18: 1-10.

Nishimura, S., Yonemura, S., Sawamoto, T., Shirato, Y., Akiyama, H., Sudo, S., Yagi, K. 2008. Effect of land use change from paddy rice cultivation to upland crop cultivation on soil carbon budget of a cropland in Japan. Agriculture, Ecosystems and Environment 125: 9-20.

NORDECO, 2008. Available at internet: www.nordeco.dk Revised 24-04-2008. Visited 8-01-09.

Oberthür, T., White, P.F., Reyes, R.T., Dobermann, A., Sovuthy, P., Rickmann, J.F. 1997a. Major soils of the rice-growing areas. In: The Soils used for rice production in Cambodia. A manual for their identification and management. Ed; White, P.F., Oberthür, R., Sovuthy, P. pp: 20-57. Cambodia-IRRI.Australia Project. IRRI, Manila. Philippines.

Oberthür, T., Dobermann, A., White, P. 2000. The rice soils of Cambodia. II. Statistical discrimination of soil properties by the Cambodian Agronomic Soil Classification system. Soil Use and Management 16: 20-26.

Olk, D.C., Kessel, C.V., Bronson, K.F. 2000. Managing soil organic matter in rice and nonrice soils: agronomic questions. p 27-48**.** In: Carbon and nitrogen dynamics in flooded soils”. Edited by G.J.D. Kirk and D.C. Olk. pp 188. IRRI, Philippines.

Patrick, W.H.Jr. & Reddy, K.R. 1976. Nitrification-Denitrification reactions in flooded soils and water bottoms: Dependence on oxygen supply and ammonium diffusion. J. Environ.Qual. Vol 5 (4): 469-471.

Pheav, S., Bell, R.W., Kirk, G.J.D., White, P.F. 2005. Phosphorus cycling in rainfed lowland rice ecosystems on sandy soils. Plant and Soil 269: 89-98.

Prasad, C.S. 2006. System of Rice Intensification in India. Innovation history and Institutional Challenges. WWF Project “ Dialogue on water, Food and Environment”. ICRISAT, Patancheru, Hyderabad. India. p. 77.

Pretty, J. 2000. Can sustainable agriculture feed Africa? New evidence on progress, processes and impacts. Environment, Development and Sustainability 1:253-274.

Pretty, J.N., Morison, J.I.L., Hine, R.E. 2003. Reducing food poverty by increasing agricultural sustainability in developing countries. Agriculture, Ecosystems and Environment 95: 217-234.

Rajashekhara Rao, B.K. & Siddaramappa, R. 2008. Evaluation of soil quality parameters in a tropical paddy soil amended with rice residues and tree litters. European Journal of Soil Biology 44: 334-340.

Ramesh, K. & Chandrasekaran, B. 2004. Soil Organic Carbon build-up and dynamics in rice-rice cropping systems. J. Agronomy & Crop Science 190:21-27.

Röling, N. 1994. Facilitating sustainable agriculture: turning policy models upside down. In Beyond Farmer First. Rural people’s knowledge, agricultural research and extension practice. Eds: Scoones, I. & Thompson, J. Intermediate Technology Publications. London, UK. pp.245-248.

Röling, N. & van de Fliert, E. 1994. Transforming extension for sustainable agriculture: The case of Integrated Pest Management in Rice in Indonesia. Vol 11(2-3): 96-108.

Sasaki, N. 2006. Carbon emissions due to land-use change and logging in Cambodia: a modelling approach. J For Res 11: 397-403.

Satyanarayana, A. 2004. Correspondence. Rice, research and real life in the field. In the spirit of science, we should ask why studies don’t reflect farmers’ experiences. Nature (429): 803.

Satyanarayana, A., Thiyagarajan, T.M., Uphoff, N. 2007. Opportunities for water saving with higher yield from the system of rice intensification. Irrig. Sci 25: 99-115.

Schlesinger, W.H. & Andrews, J.A. 2000. Soil respiration and the global carbon cycle. Biogeochemistry 48: 7-20.

Scoones, I. 1998. Sustainable Rura Livelihoods: A Framework for Analysis. Institute of Development Studies (IDS) working paper 72. p. 1-22.

Scoones, I. & Thompson, J. 1994. Knowledge, power and agriculture – towards a theoretical understanding. In Beyond Farmer First. Rural people’s knowledge, agricultural research and extension practice. Eds: Scoones, I. & Thompson, J. Intermediate Technology Publications. London, UK. pp. 16-31.

SCW, 2006. Atlas of Cambodia: National Poverty and Environment Maps. Save Cambodia’s Wildlife, Phnom Penn, Cambodia. pp 139 and CD. DANIDA.

Seng, V., Bell, R.W., Willet, I.R., Nesbitt, H.J. 1999. Phosphorus nutrition of rice in relation to flooding and temporary loss of soil-water saturation in two lowland soils of Cambodia. Plant and Soil 207: 121-132.

SerCon Ltd. 2001. The Stable Isotope Company. ANCA-GSL. Users Manual Version 4.0, February 2001.

Sheehy, J.E., Peng, S., Dobermann, A., Mitchell, P.L., Ferrer, A., Yang, J., Zou, Y., Zhong, X., Huang, J. 2004. Fantastic yields in the system of rice intensification: fact or fallacy? Field Crops Research 88: 1-8.

Sinha, S.K & Talati, J. 2007. Productivity impacts of the system of rice intensification (SRI): A case study in West Bengal, India. Agricultural Water Management 87: 55 – 60.

Singh, N.T. 1984. Green manures as sources of nutrients in rice production. In: Organic matter and rice. International Rice Research Institute. Manilla, Phillipines. pp: 217-228.

Stevenson, F.J. & Cole, M.A. 1999. Soil Organic Matter quality and characterization. In Cycles of Soil. Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients. 2nd edition. John Wiley & Sons, INC. Newy York, USA. pp: 78-106.

Street, J. E. & Bollich, P.K. 2003. Rice Production. In: In Rice. Origen, History, Technology and Production. Eds: Smith, C.W. & Dilday, R.H. John Wiley & Sons, Inc. USA. pp: 271-295.

Stoop, A.W., Uphoff, N., Kassam, A. 2002. A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: opportunities for improving farming systems for resource-poor farmers. Agricultural Systems 71: 249-274.

Surridge, C. 2004. Feast or Famine? Nature Vol (428): 360-361.

Tong, L., Yoshida, T., Maeda, T., Kimijima, H. 2007. Effects of Temperature, Sowing Depth and Soil Hardness on Seedling Establishment and Yield of Cambodian Rice Direct-seeded in Flood Paddy Fields. Plant Prod. Sci. 10(1):129-135.

Tong, L. & Yoshida, T. 2008. Genetic Diversity of Cambodian Rice Cultivars. Plant Prod. Sci. 11(3): 366-367.

Tripp, R., Wijeratne, H., Piyadasa, V,H. 2005. What should we expect from Farmer Field Schools? A Sri Lanka Case Study. World Development Vol 33 (10): 1705-1720.

Tsubo, M., Fukai, S., Tuong, T.P., Ouk, M. 2007. A water balance model for rainfed lowland rice fields emphasising lateral water movement within a toposequence. Ecological Modelling 204: 503-515.

Tsujimoto, Y., Horie, T., Randriamihary, H., Shiraiwa, T., Homma, K. 2009. Soil management: The key factors for higher productivity in the fields utilizing the system of rice intensification (SRI) in the central highland of Madagascar. Agricultural Systems 100: 61-71.

Uphoff, N. 1999. Agroecological Implications of the System of Rice Intensification (SRI) in Madagascar. Environment, Development and Sustainability 1: 297-313.

Uphoff & Tefy Sainy. Year unknown. COMMENT FAIRE POUR AVOIR DES PLANTS DE RIZ QUI CROISSENT MIEUX ET QUI PRODUISENT PLUS INFORMEZ-VOUS ET INFORMEZ LES AUTRES. Available at internet: **(http://tefysaina.org/manuelSRI.pdf)**

Soil Survey Staff. 2006. Keys to soil taxonomy. United States Department of Agriculture. 10th edition. p. 323.

Vergé, X.P.C., De Kimpe, C., Desjardings, R.L. 2007. Agricultural production, greenhouse gas emissions and mitigation potential. Agricultural and Forest Meteorology 142: 255-269.

Wade, L.J., George, T., Ladha, J.K., Singh, U., Bhuiyan, S.I., Pandey, S. 1998. Opportunities to manipulate nutrient-by-water interactions in rainfed lowland rice systems. Field Crops Research 56: 93-112.

Wade, L.J. Fukai, S., Samson, B.K., Ali, A., Mazid, M.A. 1999. Rainfed lowland rice: physical environment and cultivar requirements. Field Crops Research 64: 3-12.

Watanabe, I. 1984. Anaerobic decomposition of organic matter in flooded rice soils. In Organic Matter and rice. International Rice Research Institute, Manilla, Philippines. pp: 237-258.

Watanabe, A., Yamada, H., Kimura, M. 2005. Analysis of temperature effects on seasonal and interannual variation in CH_4 emissions from rice-planted pots. Agriculture, Ecosystems and Environment 105: 439-443.

Wassmann, R., Neue, H.U., Lantin, R.S., Buendia, L.V., Rennenberg, H. 2000. Characterization of methane emissions from rice fields in Asia. I. Comparison among field sites in five countries. Nutrient Cycling in Agroecosystems 58: 1-12.

West, T.O. & Post, W.M. 2002. Soil Organic Carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Sci. Soc. Am. J. 66: 1930-1946.

White, P., Dobermann, A., Oberthür, T., Ros, C. 2000. The rice soils of Cambodia. I. Soil classification for agronomists using the Cambodian Agronomic Soil Classification system. Soil Use and Management 16: 12-19.

White, P.F. & Öberthür, T. 1997. Geomorphology and Hydrology of Cambodian Ricelands. In: The Soils used for rice production in Cambodia. A manual for their identification and management. Ed; White, P.F., Oberthür, R., Sovuthy, P. pp: 3-8. Cambodia-IRRI.Australia Project. IRRI, Manila. Philippines.

White, P.F., Oberthür, T., Sovuthy, P. 1997a. Soils and rice. In: Rice production in Cambodia. Manila (Philippines): International Rice Research Institute. Ed: Nesbitt, H.J. p. 21-31.

White, P.F., Reyes, R.T., Oberthür, T., Hobermann. 1997b. Key to the major soils of the rice-growing areas. In: The Soils used for rice production in Cambodia. A manual for their identification and anagement. Ed; White, P.F., Oberthür, R., Sovuthy, P. pp: 15-19. Cambodia-IRRI.Australia Project. IRRI, Manila. Philippines.

White, P.F. & Seng, V. 1997. Response of rainfed lowland rice to phosphorus fertiliser application in Cambodia. In: ACIAR Proceeding No. 77: Breeding Strategies for rainfed lowland rice in drought-prone environments. Eds. ACIAR. pp. 202-208. Australian Centre for International Agricultural Research, Canberra, Australia.

Yagi, K. & Minami, K. 1990. Effect of Organic Matter Application on Methane Emission from Some Japanese Paddy Fields. Soil Sci. Plant Nutr. 36 (4): 599-610.

Yamah, A. 2002. The practice of the System of Rice Intensification in Sierre Leone. A presentation held at the International Conference "*Assessments of the System of Rice Intensification (SRI)*," Sanya, China, April 1-4, 2002.
Available at Internet: http://ciifad.cornell.edu/sri/proc1/sri_24.pdf

Yan, X., Akiyama, H., Yagi, K., Akimoto, H. 2009. Global estimations of the inventory and mitigation potential of methane emissios from rice cultivation conducted using the 2006 Intergovernmental Panel on Climate Change Guidelines. Global Biochemical Cycles 23: 1-15.

Yoshida, S. 1981. Growth and development of the rice plant. In: Fundamentals of rice crop science. International Rice Research Institute. Manilla, Philippines. pp: 1- 63.

Yue, J., Shi, Y., Liang, W., Wu, J., Wang, C., Huang, G. 2005. Methane and Nitrous Oxide emissions from rice field and related microorganism in black soil, northestern China. Nutrient Cycling in Agroecosystems 73: 293-301.

Xu, X., Tian, H., Hui, D. 2008. Convergence in the relationship of CO_2 and N_2O exchanges between soil and atmosphere within terrestrial ecosystems. Global Change Biology 14: 1651-1660.

Zou, J., Huang, Y., Jiang, J., Zheng, X., Sass, R.L. 2005. A 3-year field measurement of methane and nitrous oxide emissions from rice paddies in China: Effects of water regime, crop residue, and fertilizer application. Global Biogeochemical Cycles 19: 1-9.

Zou, J., Huang, Y., Qin, Y., Liu, S., Shen, Q., Pan, G., Lu, Y., Liu, Q. 2009. Changes in fertilizer-induced direct N_2O emissions from paddy fields during rice-growing season in China between 1950s and 1990s. Global Change Biology 15: 229-242.

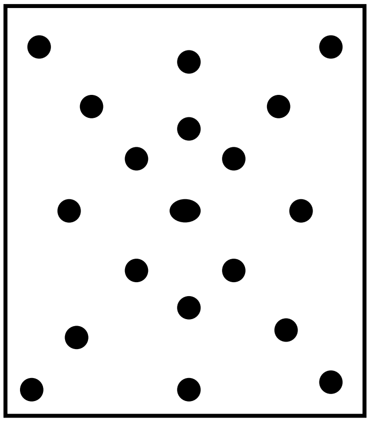
APPENDICES

APPENDIX A. Name, village and sex of interviewed farmers.

Name of farmer	Village	Sex
Ban Bear	Chambork (COP)	M
Huy Ben	Chambork (COP)	M
Hut Sarmean	Kan Dach (COP)	M
Sun Sengly	Kan Dach (COP)	F
Lek Vuthy	Prey Svay (COP)	M
Hom Hort	Prey Svay (COP)	F
Lajh Larch	Prey Svay (COP)	M
Uong Venon	Prey Svay (COP)	M
Chhean Chorn	Prey Svay (COP)	F
Say Srony	Pear Rong (COP)	M
Cheang Him	Pear Rong (COP)	F
Porn Hi	Pear Rong (COP)	F
Chuom Cheat	Pear Rong (COP)	M
Sean Suong	Pear Rong (COP)	M
Chorn Choung	Pear Rong (COP)	F
Yang Mon	Sar Loung (KR)	F
Hi Rum	Sar Loung (KR)	F
Sory Pean	Sar Loung (KR)	F
Reum Seab	Sam Rong (KR)	M
Khim Khorn	Sam Rong (KR)	M
Yorn Sambath	Sam Rong (KR)	M
Vorn Savet	Sam Rong (KR)	F
Hr Chek	Sam Rong (KR)	F
Yean Yenon	Beuny AngChaj (KR)	M
Khorn Euen	Doung Veal (KR)	M
Earn Art	Doung Veal (KR)	M
Chhun March	Doung Veal (KR)	F
Meas Oun	Doung Veal (KR)	F
Pros Yet	Doung Veal (KR)	F
Yan Kim Chheng	Doung Veal (KR)	F

COP = Chorng Om Pil commune KR = Kdeuon Reay commune

APPENDIX B. Soil sampling methodology.



Procedure: The centre of each field was located and marked with a bamboo stick and thereafter the other sampling locations were plotted. 19 subsamples were taken from each field in the same star shaped pattern to form one composite sample for each field. 19 points were chosen due to achieve a systematic sampling procedure for all 30 fields which were shaped very differently. The 19 dotted star shape pattern coped very well with all field sizes and shapes and helped increase the accuracy of the composite sample for each field. As the fields were very heterogeneous the 19 star systems also covers all areas of the field. It would also have been accessible to sample less than 19 subsamples for each field however the level of accuracy is increased with more subsamples.

A vertical core sample from the topsoil/plough layer, 20 cm, was collected with a stainless steel auger tube fabricated at the National School of Agriculture at Preak Leap, Cambodia. The steel tube auger is 3 cm wide and the tube is 50 cm long. At the top is located a handle in order to push the tube into the soil.
Each subsample was sampled by pushing the tube perpendicular down through present water into the soil. Each subsample consisted of 240 cm^3 soil incl. present stones and plant residues.
In order to be able to push the soil out of the tube a small steel spoon was used to press out the soil and then collected in plastic bags. After sampling one field the auger tube and the metal spoon were cleaned with water and then rinsed with rice alcohol 90% vol.

APPENDIX C. SRI farmer questionnaire.

1. General information

Sample Number:....................... Date:...

Village:..

Commune:..

2. Personal information

2.1 Name of farmer....................................... Sex(M/F): ....
Age:……………………..
2.2 Total number of members in your household: ....
2.3 Your annual average income per household (Riel):

From Rice…….............. From Vegetables………………. Chicken and duck raising……….

Cattle and Pig raising……............ Other……………………………………………..

3. Agricultural information

3.1 Total land area (ha/acres):..................... How big is your SRI field?(ha/acres)……………

Total land area with conventional rice (ha/acres):...

3.2 Animals

	Pig	Cow	Buffalo	Chicken	Duck	Horse
Total number						

Other………………

……………………

3.3 What rice cultivar/variety do you use? ....

3.4 How many kg of seeds do you use for your sri field?..

3.6 How many kg seed you use for traditional rice?..

3.7 How old is the SRI rice in this field (days)?..

3.8 What SRI techniques do you apply?...

……………………………………………………………………………………………..

4. What type of fertilizer do you apply to your SRI field?

Type	How much do you apply to your SRI field (kg)?	How many times per year? What time of the year?	How many years have you applied to this field?
Compost			
Green manure			
Chemical fertilizer			

5. How do you make your compost? Animal manure☐ Crop residues☐

Kitchen residues☐ Leaves ☐ Other……………………………………………

6. Do you use any chemical pesticides? ☐ Yes ☐ No

If yes what kind and how much?..

7. Do you want to continue with SRI next year: Yes ☐ No ☐

If yes why?...

8. How big an area will you plant with SRI next year?...

9. What did your wife/husband think about SRI when you began working with SRI?

Very satisfied ☐ Satisfied ☐ Not satisfied ☐

10. What does your wife/husband think about SRI now?

Very satisfied ☐ Satisfied ☐ Not satisfied ☐

11. Have you shared your SRI knowledge with your neighbor? Yes ☐ No ☐

If yes how many?..

APPENDIX D. Soil analysis results.

Farmers	pH KCL	Total C %	Total N %	C:N
Ban Bear	4,6	0,6475	0,07056	9,18
Huy Ben	4,5	0,3044	0,04502	6,76
Hut Sarmean	5,1	0,4003	0,05427	7,38
Sun Sengly	4,8	0,29	0,04123	7,03
Lek Vuthy	4,7	0,2969	0,04483	6,62
Hom Hort	4,2	0,3851	0,05059	7,61
Lajh Larch	4,5	0,2847	0,03935	7,24
Uong Venon	5,2	0,3699	0,04747	7,79
Chhean Chorn	5,2	0,2636	0,03951	6,67
Say Srony	3,9	0,319	0,04343	7,35
Cheang Him	4	0,3268	0,04704	6,95
Porn Hi	3,9	0,4255	0,0554	7,68
Chuom Cheat	4,1	0,4194	0,05728	7,32
Sean Suong	4,2	0,4363	0,05575	7,83
Chorn Choung	4,4	0,4142	0,05546	7,47
Yang Mon	5,3	0,3155	0,04304	7,33
Hi Rum	4,2	0,2809	0,04352	6,45
Sory Pean	5,7	0,2244	0,03948	5,68
Reum Seab	4,3	0,3761	0,04968	7,57
Khim Khorn	4,5	0,3029	0,04305	7,04
Yorn Sambath	4,5	0,4174	0,04995	8,36
Vorn Savet	4,2	0,2795	0,04174	6,7
Hr Chek	5,5	0,2859	0,04625	6,18
Yean Yenon	3,9	0,3161	0,04705	6,72
Khorn Euen	4,4	0,2759	0,03615	7,63
Earn Art	4,6	0,3188	0,04529	7,04
Chhun March	4,4	0,2425	0,03981	6,09
Meas Oun	4,5	0,2459	0,03694	6,66
Pros Yet	4,5	0,1761	0,02887	6,1
Yan Kim Chheng	4	0,2524	0,03904	6,47
Average	**4,53**	**0,3297967**	**0,0459017**	**7,1**
Standard deviation	**0,23**	**0,0894943**	**0,0080691**	**0,72**

APPENDIX E. LIVELIHOOD ASSESTS.

Personal information on the interviewed farmers.

Name of farmer	Village	Sex	Age (years)	Members in HH	Total income $
Ban Bear	Chambork (COP)	M	33	6	1329
Huy Ben	Chambork (COP)	M	65	2	256
Hut Sarmean	Kan Dach (COP)	M	56	6	732
Sun Sengly	Kan Dach (COP)	F	39	4	707
Lek Vuthy	Prey Svay (COP)	M	53	6	683
Hom Hort	Prey Svay (COP)	F	51	5	1098
Lajh Larch	Prey Svay (COP)	M	58	7	146
Uong Venon	Prey Svay (COP)	M	44	7	366
Chhean Chorn	Prey Svay (COP)	F	44	3	98
Say Srony	Pear Rong (COP)	M	53	8	1024
Cheang Him	Pear Rong (COP)	F	43	4	122
Porn Hi	Pear Rong (COP)	F	52	5	317
Chuom Cheat	Pear Rong (COP)	M	28	5	610
Sean Suong	Pear Rong (COP)	M	35	4	756
Chorn Choung	Pear Rong (COP)	F	21	2	488
Yang Mon	Sar Loung (KR)	F	38	5	1805
Hi Rum	Sar Loung (KR)	F	42	4	598
Sory Pean	Sar Loung (KR)	F	33	6	963
Reum Seab	Sam Rong (KR)	M	49	3	280
Khim Khorn	Sam Rong (KR)	M	40	6	976
Yorn Sambath	Sam Rong (KR)	M	34	4	488
Vorn Savet	Sam Rong (KR)	F	30	4	537
Hr Chek	Sam Rong (KR)	F	36	4	732
Yean Yenon	Beuny AngChaj (KR)	M	46	4	171
Khorn Euen	Doung Veal (KR)	M	38	6	683
Earn Art	Doung Veal (KR)	M	52	7	2927
Chhun March	Doung Veal (KR)	F	27	5	500
Meas Oun	Doung Veal (KR)	F	53	3	890
Pros Yet	Doung Veal (KR)	F	25	6	561
Yan Kim Chheng	Doung Veal (KR)	F	50	6	659
Average			**42,27**	**4,9**	**716,67**
Stdev			**+ (-)10,85**	**+ (-)1 ,52**	**+ (-) 561,07**

COP = Chorng Om Pil commune KR = Kdeuon Reay commune

Percentage of households with different domestic animals and the amount per household.

	Pigs	Cows	Buffaloes	Chickens	Ducks	Fish
% of Households	37	57	53	90	30	33
Per Household	4	2	2	8	5	405

Type of fertilizers used by farmers with amount, application per year and total history of application.

Applied materials	% of farmers	Kg/m^2	# of applications year^{-1}	Years of application
Compost	53,33	0.33 + (-) 0.49	1,4 + (-) 0.63	5 + (-) 10
Green manure	73,33	1.90 + (-) 7.24	1.45 + (-) 0.67	9 + (-) 11.79
Organic fertilizers	13,33	0.01 + (-) 0.02	1	1
Chemical fertilizers	13,33	0.004 + (-) 0.02	1.25 + (-) 0.5	7.67 + (-) 10.69

Percentage of farmers combing different kinds of fertilizers.

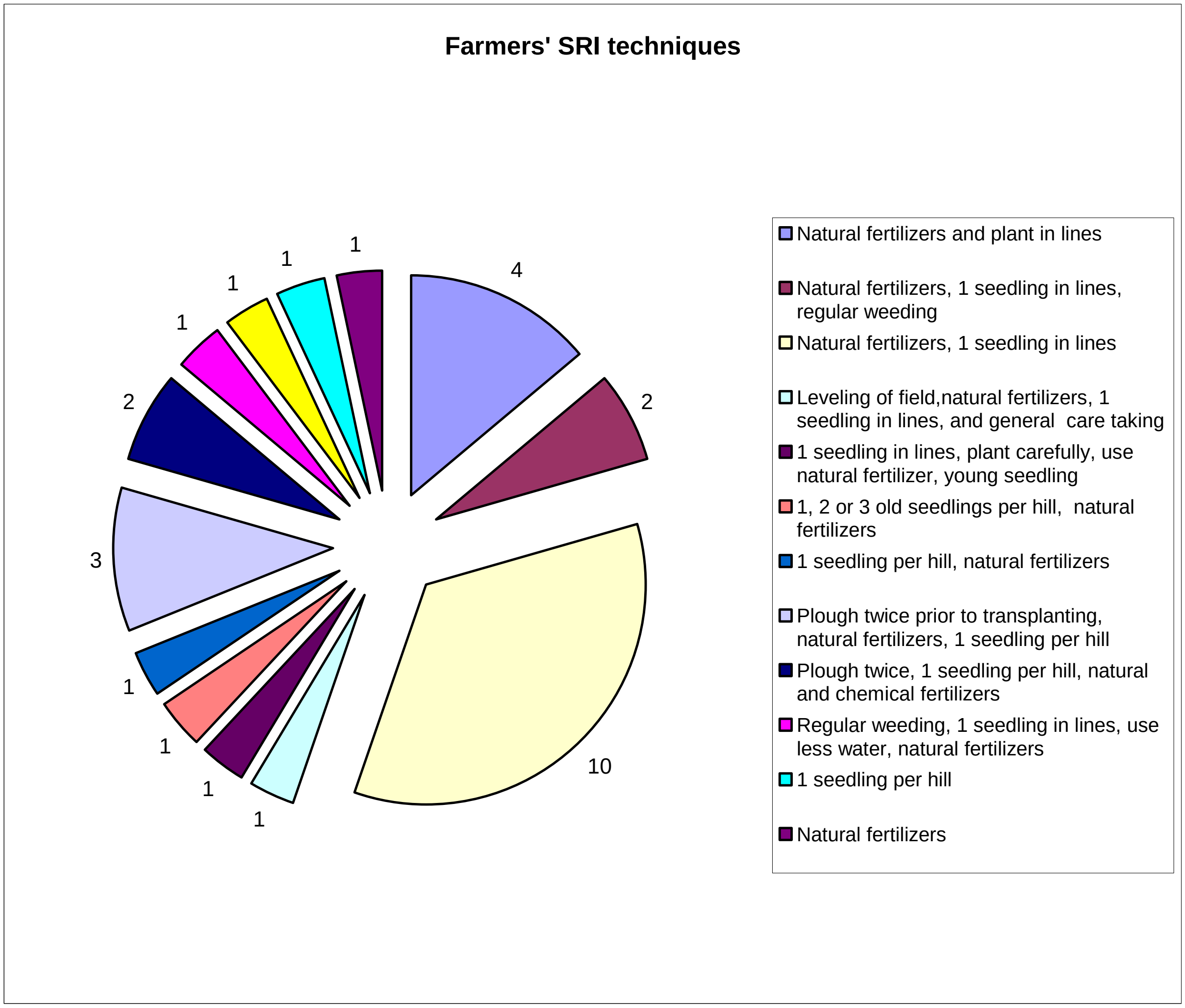
Applied materials	% of total # of farmers	% of group
Compost and Green manure	20	42,67
Compost and Organic fertilizers	10	21,43
Green manure and organic fertilizers	3,33	7,14
Green manure and chemical fertilizers	6,67	14,29
Compost, green manure and organic fertilizer	3,33	7,14
Compost, green manure and chemical fertilizer	3,33	7,14

Rice varieties.

Percentages in brackets indicate the percentage of farmers who cultivated these varieties.

Dorn Neb (80%)	Sorsor	Rang Cheay	Kum Srov	Phakarmodul	Kror Ob
Mrom (70%)	Neang Meas	Torng Chhuk	Chheing Ses	Sen Pidao	Ka Prom
Somaly (45%)	Kro Orb	Phka Ten	Leung Tek	Kror Ya	Orn Lov
Phmor	Moung Many	Pdao Pen	Neang Sar	Thmor	Kror Sang Teab
Neang Kong	Pkar Mlis	Orsar Kro Ourb	UA	Moung Mong	Pdaov
Chom Reuom	Ornoub Thom	Bam Larr	Chmar Tot	Sa Ang	E Aer

Combination of SRI techniques within the target farming community.
Natural fertilizers cover composts and leafy/green manures.



Leafy manures from 5 common trees. The ILFARM plans to plant more trees of especially the five mentioned here but also other multipurpose species.

Scientific name	English name	Cambodian name	Use	Location	Years of production
Cassia *siamea*	Cassia	Angkanh	Fuel wood, fencing and animal feed	Homestead, along roads, pagoda gardens	30 years
Sesbania *bispinosa* & S. *grandifora*	Sesban	Angkea Dey	Fuel wood, fencing, animal feed, construction and green manure	Homestead and along roads	5-6 years
Acacia *auriculiformus*	Acacia	Acasia	Construction and fuel wood	Homestead, along roads, pagoda gardens	Until death
Azadicrachta *indica*	Neem	Sdao	Vegetable, traditional medicine, botanical pesticide, construction, green manure	Homestead, rice dikes bordering rice fields	80 years
Leucaena *leucacephala*	Leucaena	Kamthuthet	Fuel wood, fencing, animal feed, vegetable, green manure	Homestead and along roads	20 years

APPENDIX F. Interview with Ma Veasna project coordinator of the ILFARM project.

Held 18th of October 2008 at the CEDAC office in Prey Veng city, Prey Veng province, Cambodia**.**

Marc Dumas-Johansen: How many SRI concepts do farmers follow in average and which ones?

Ma Veasna: Farmers normally use big seedlings for transplanting, leveling of land, use more compost than in traditional fields, planting the rice plants in strait lines and do weeding. Most farmers carry out all these techniques. Good farmers do like this. Lazy farmers do not do so much.

Marc Dumas-Johansen: What is the disadoption rate of SRI farmers? How many farmers will not practise SRI after some years?

Ma Veasna: Most farmers stop with SRI after three to four years because they are used to working with traditional rice farming and then they mix the two concepts and stop with SRI. SRI also means more work for them, so they gradually go back to traditional rice farming.

Marc Dumas-Johansen: What do farmers feed their animals?

Ma Veasna: Grass and rice straw. They also eat tree leaves. This is mostly for cows.

Marc Dumas-Johansen: How many SRI farmers are there in the in total in the project and how many in each commune?

Ma Veasna: There are 160 farmers in the three target communes but the number is growing. Chourn Ampol commune has 25 SRI farmers and Kdoung Reay commune has 70-78 sri farmers. The most successful farmers are found in this commune. The total land of SRI is 8 ha in these two communes where farmers are medium and small farmers..

Marc Dumas-Johansen: Where do farmers get their seeds from?

Ma Veasna: They use their own seeds and save seeds from last year’s harvest. They keep the seed stocks from their parents. Some farmers buy seeds from outside.

Marc Dumas-Johansen: What trees are used in the project and how many?

Ma Veasna: 500.000 trees in total will be mobilized by the project. Multiple use trees and fruit trees will be used.