SYSTEM OF RICE INTENSIFICATION: AN ALTERNATIVE MITIGATION STRATEGY TO GREENHOUSE GAS EMISSIONS FROM PADDY FIELDS IN INDONESIA

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ABSTRACT

The agricultural system has been influenced by regional climate change particularly its water resource. Precipitation pattern has changed in which extreme events such as La-Niña and El-Niño frequently occur during the last ten years. Increasing greenhouse gas concentration in the atmosphere has increased the average air temperature that affected planting season and water availability in the fields. To deal with this regional climate change, adaptation and mitigation strategies are urgent mainly for rice farming with less water input. The system of Rice Intensification (SRI) is alternative rice farming for climate change adaptation and mitigates greenhouse gas emission from paddy fields. At least, there are three major benefits of SRI dealing with climate change, i.e. minimum greenhouse gas emission, more efficient water irrigation and reduced chemical fertilizers application. Although some critics were dismissed, the beneficial effects of this set management have been demonstrated and confirmed in 60 countries in Africa, Latin America and Asia. A long-term field experiment of SRI was conducted in Indonesia with significant yield increases and reduced water use as well as greenhouse gas emissions. SRI is a set of crop management for plants, soil, water, and nutrients simultaneously in producing more rice with less water input. It has six basic elements, i.e. young seedlings, single transplanting, wider spacing, transplanting quickly and carefully, applying intermittent irrigation and use of compost as much as possible. Here, water *management is key management to reduce greenhouse gas emission. By applying intermittent irrigation, the field is conditioned wet (saturated level without flooding) and dries in particular time and continous flooding is avoided. According to previous studies, this irrigation regime was effective to minimize global warming potential at different levels up to 46.4% depending on field conditions. For optimum SRI water management, we found that moderate regime was an alternative option for mitigating greenhouse gas emission without reducing yield significantly. In this regime, the soil moisture was kept at saturated level from the beginning to generative stage (one week before harvesting) and then it is conditioned dry until harvesting. This regime released greenhouse gas emission 80.1% lower than that of continous flooding irrigation (control). However, the experiment was conducted only in one planting season with specific weather condition. For future work, more experiments should be conducted to find optimal water management under varying weather conditions to mitigate greenhouse gas emission without lowering land productivity.*

Keywords: Greenhouse gas emission, paddy fields, system of rice intensification, water management

INTRODUCTION

The agricultural system has been influenced by regional climate change particularly its water resource. Precipitation pattern has changed in which extreme events such as La-Niña and El-Niño frequently occur during the last ten years. Increasing greenhouse gas concentration in the atmosphere has increased the average air temperature that affected planting season and water availability in the fields. Some negative impact of climate change e.g., crop failure, degradation of agriculture land resources, increasing dryness frequency, area and intensity, increasing the threat of pests and diseases (OPT) (Las *et al*. 2008). Adaptations to regional climate change and mitigation greenhouse gas emission strategies are urgent to address this problem. In Indonesia, paddy fields commonly supplied more water by applying continuous flooding in which standing water 2-5 cm are kept to reduce weed growth with minimum water supply frequency and avoidance of water shortage due to the unreliable water supply system. This method is not effective, because water is supplied more than its actual plant requirement. Also, this method caused in water lost for deep percolation, seepage through bunds and runoff from the soil surface (Bouman 2001).

In addition, flooding condition in the fields caused limited oxygen and others gasses such as sulfates in that soil environment. This situation promotes methanogenesis activities that will relaease more methane (CH_4)

emission to the atmosphere (Bouwman 1990). Methane is one of most important greenhouse gases that contributes to global warming. Therefore, the conventional paddy field with continous flooding irrigation is known as a major source of methane emission (Cicerone *et al.* 1992; Nueu *et al.* 1990). Further, paddy fields also emitted other greenhouse gas, i.e., nitrous oxide (N_2O) and CO_2. Although nitrous oxide concentration is smaller than methane emission and can be negligible according to Smith *et al*. 1982, nitrous oxide contributed 298 times greather than CO_2 in global warming potential (IPCC 2007). Thus, nitrous oxide emission should be considered and reduced in its concentration from the atmosphere. Nitrification and denitrification processes in the soil are main source of realeasing nitrous oxide in the atmosphere as well as microbial process in the soil (Mosier *et al.* 1996).

The characteristic methane and nitrous oxide emissions are different and have opposite trend (Cai *et al.* 1997). Sometimes nitrous oxide emission reduces when flooded condition occurs in the paddy field, on the other hand, its release more at the beginning of the disappearance of flooding water. Also, its emission increased significantly when nitrogen fertilizer was induced to the field (Akiyama *et al.* 2005). On the contrary, methane emission increased during flooding (anaerobic condition) and limited when water was drained from the field (Setyanto *et al*. 2000). Therefore, irrigation system is one of the most important tools in rice farming and is the most important effort for methane and nitrous oxide mitigation (Tyagi *et al*. 2010). We should introduce alternative irrigation system instead of continuous flooding since this irrigation is not effective from environment perspective as well as water resource.

System of Rice Intensification (SRI) is alternative rice farming for climate change adaptation and mitigates greenhouse gas emission from paddy fields. At least, there are some major benefits of SRI dealing with regional climate change, i.e. minimum greenhouse gas emission, more efficient water irrigation and reduced chemical fertilizers application by applying compost/organic fertilizer as well as increasing farmer's net income (Uphoff and Dazzo 2016). SRI is a set of crop management for plants, soil, water, and nutrients simultaneously that are different from common practices by farmers in Indonesia to produce more rice with less water input. Although some researchers have different view points of SRI e.g. Sinclair and Cassman 2004, Sheehy *et al.* 2004, the benefits effects of this set management system have been demonstrated and confirmed in 60 countries in Africa, Latin America and Asia (http://sri.ciifad.cornell.edu/countries/index.html). Many scientific papers have reported the benefits of SRI application in many countries in term of water irrigation, yield and greenhouse gas emission. For example, SRI application can save water irrigation up to 28%, 38.5% and 40% in Japan, Iraq and Indonesia, respectively (Chapagain and Yamaji 2010; Sato *et al.* 2011; Hameed *et al*. 2011). For rice yield, SRI demonstration plot increased yield in China, Iraq, Afghanistan, Indonesia and Madagascar for 11.3% , 42%, 65%, 78% and 100%, respectively (Lin et al. 2011; Hameed et al. 2011; Thomas and Ramzi 2011; Sato *et al*. 2011; Barison and Uphoff 2011). Further, SRI also reduced greenhouse gas emission that is represented by reducing global warming potential up to 37.5% in Indonesia (Hidayah *et al*. 2009) and 40% in India (Gathorne-Hardy *et al*. 2016).

SRI was introduced in Indonesia in 1999 by the Agency for Agricultural Research and Development in dry season, and then it was spread out to some areas through several programs in Indonesia. The data in 2014 showed that SRI has been applied in 29 provinces and 247 districts with total areas during 2010-2015 were 450,855 ha. Ministry of Agriculture supports SRI by many programs such as inputs production (fertilizers, seeds and pesticides), irrigation pump, hand tractor and composting unit. The current study proposed review SRI basic concepts and its application in Indonesia, greenhouse gas emissions from paddy fields and its mitigation strategy particularly by determining optimal option of water management from SRI paddy fields.

SYSTEM OF RICE INTENSIFICATION: AN OVERVIEW

First, SRI was observed and introduced in Madagascar in the early 1980s by Fr. Henri de Laulanié. Recently, SRI is spread out over the world to 60 countries by Professor from Cornell University, Norman Uphoff (http://sri.ciifad.cornell.edu/countries/index.html). In short definition, SRI has six basic elements that are different with farmer's practices in Indonesia and it can be summarized by following points (Uphoff *et al.* 2011):

1. Young seedling (7-14 days after sowing) is transplanted while still at the 2–3 leaf stage. Young seed is selected because it has more potential for roots and shoots growing (Nemoto *et al.* 1995).
2. Avoiding trauma to the roots, seed is transplanted quickly and carefully with lower depth approximately 1 cm depth
3. One seed in one hill (single transplanting) with wider spacing to give more space for plant growing
4. Apply intermittent irrigation instead of continuous flooding.
5. Doing weeding early and regularly. It is recommended using rotary weeder to eliminate weed and increase soil aeration at the same time.
6. Apply compost and others organic fertilizer as much as possible to enhance soil organic matter instead of chemical fertilizer.

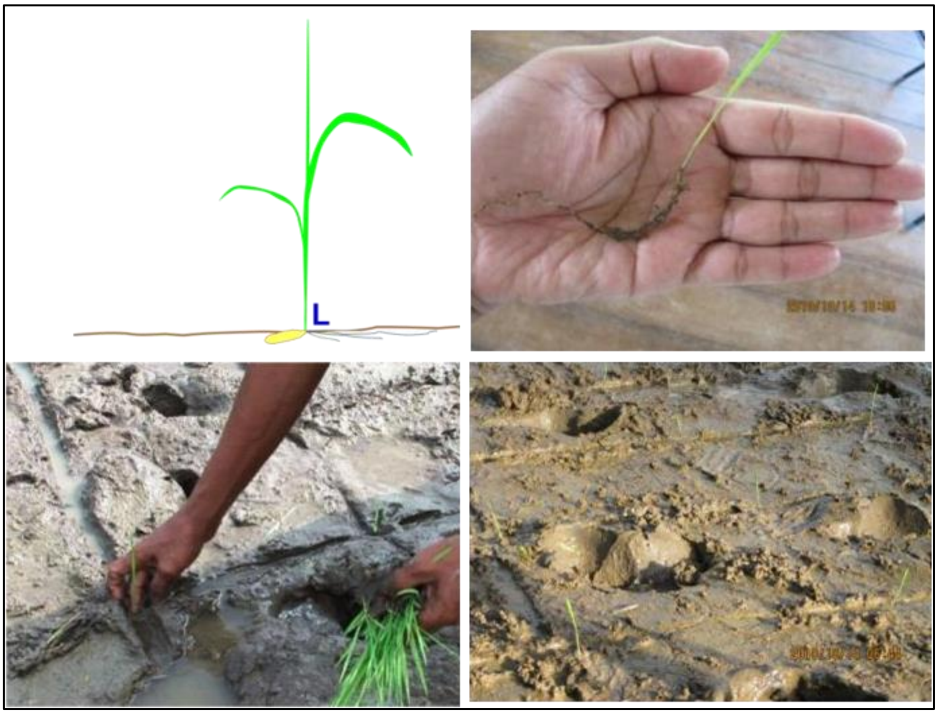

Fig. 1. Some basic elements of SRI: young seed, single transplanting and wider spacing.

By integrated plant, soil, water, nutrient and agro-ecological approach in irrigated rice farming, SRI allowed farmers to realize yields of up to 15 tons/ha with less water input and chemical fertilizers input by participatory on-farm experiments demonstrated in Madagascar (Stoop *et al.* 2002). However, contrary results were obtained and stated that SRI has no inherent benefits over the conventional rice farming (Sheehy *et al.* 2004). Thus, SRI is like an ‘‘unidentified flying object’’ (UFO) or “unconfirmed field observation”, as vehement criticism by Sinclair and Cassman 2004.

In early 2000, SRI became controversial and there were some constraints in spreading out SRI in Indonesia, such as determining optimum water management and then developing irrigation-drainage water control system to inhibit weed growth (Gani *et al.* 2002). By applying intermittent irrigation, the field is conditioned wet (saturated level without flooding) and dry in particular time and avoiding continuously flooding. Based on previous studies, intermittent irrigation saves more water input from 28% to 40% compared to conventional rice farming and it increases rice yield up to 100%. The key is to keep soil moist enough to sustain plant growth because flooding water sometimes caused the plant became suffocate. Irrigation water control system for SRI has been developed in Indonesiausing fuzzy logic algorithms and its performance was good as indicated by lower error. This system can save water irrigation up to 42.54% without reducing yield (Arif *et al.* 2018).

GREENHOUSE GAS EMISSIONS FROM PADDY FIELDS

Recently, two hot issues i.e. global warming and climate change have became considerable scientific debate and public concern. Global Warming Potential (GWP) is known as the potential of some greenhouse gasses that emitted to the atmosphere trapping heat relative to carbon dioxide (CO_2) over a specific time horizon. GWP is computed by multiplying the amount of gas by its associated GWP to carbon dioxide equivalent (CO_2 eq) value (Smith and Wigley 2000). In agricultural fields, methane (CH_4) and nitrous oxide (N_2O) gasses are known as main source of greenhouse gas emission that contribute to GWP at 25 and 298 times greater than carbon dioxide, respectively (IPCC 2007). Thus, those gasses have attracted considerable attention because of their effects to global warming (Neue *et al.* 1990).

As previously mentioned that paddy fields release two kinds of greenhouse gasses. Many research findings have been published regarding methane and nitrous oxide emissions from paddy fields over the past 25 years in regard both continuous flooded irrigation and intermittent irrigation. There are clear findings that methane emission enhances when anaerobic soil condition is developed under flooded water; on the other hand, nitrous oxide emission dramatically increase under aerobic condition with non-flooded water in the fields. One studies showed that a SRI paddy field with intermittent wetting-drying irrigation reduced methane emission by up to 32% (Rajkishore *et al.* 2013), but nitrous oxide emission increased by an insignificant 1.5% (Dill *et al.* 2013). Commonly, methane gas is formed by methanogens bacteria when the field condition was limited oxygen and sulfate during decomposition process (Epule *et al.* 2011). Methane gas is produced as final process of CO_2 reduction in the anaerobic soil. Meanwhile, nitrous oxide is formed by nitrification and denitrification process in the soil. Nitrification is converting process of ammonium ion (NH_4^+) to be nitrate ion (NO_3^-) in three step processes by autotroph bacterial in aerobic condition. N_2O is formed as by product of that process. Then, denitrification process occurs to reduce nitrate ion to be nitrogen in anerobic condition with intermediate products of NO_2^-, NO and N_2O.

Previous studies on greenhouse gas emission in Indonesia

Here, we report some greenhouse gas emission studies in Indonesia that have been conducted in some location with various field conditions:

a. Greenhouse gas emission from paddy fields in Central Java (Setyanto and Bakar 2005)

   This research was conducted at the Agricultural Environmental Research Institute, Jakenan, Pati, Central Java during the dry season of March - June 2002 to determine the effect of different irrigation systems on methane gas emissions. The results showed that intermittent irrigation systems produced methane gas emissions of 136 kg/ha, while flooding irrigation systems with 0-1 cm standing water released total methane emission of 254 kg/ha. This shows that intermittent irrigation systems that are usually applied in SRI cultivation can significantly reduce methane gas emissions up to 46.5%.

b. Greenhouse gas emission from irrigated paddy field in West Java (Hidayah *et al.* 2009)

   The experiment was conducted in paddy fields with tertiary irrigation in Cimanuk watershed, West Java in 2009. They compared emission from conventional and SRI paddy fields and their results were presented in Table 1.

Table 1. Comparison greenhouse gas emission from conventional and SRI paddy fields

Rice cultivation	Emissions (kg/ha/season)			GWP ($t\ CO_2$ eq)
	CH_4	N_2O	CO_2	
Conventional Practices	189.3	1.42	15,752	20.5
SRI				
Plot 2	22.0	4.88	14,380	16.3
Plot 3	142.5	1.36	11,192	14.9
Plot 4	128.2	1.41	12,672	16.0
Plot 5	208.9	1.39	26,655	31.9
Plot 6	90.2	1.64	15,282	17.8
Average	118.4	2.14	16,036	19.4

Table 1 shows that SRI is able to significantly reduce methane gas emissions from 189.3 kg/ha to 118.4 kg/ha. This means that SRI is able to reduce methane gas emissions by 37.5%. However, the reduction in methane gas emissions is not accompanied by a decrease in N_2O and CO_2 gas emissions. In fact, the emissions of these two gases increase by 50.7% for N_2O and 1.8% for CO_2 emissions. However, in general, SRI cultivation contributes less to greenhouse gas emissions with an indication of the lower value of Global Warming Potential (GWP). SRI's GWP value is 5.3% smaller than conventional rice cultivation.

c. Greenhouse gas emission from Paddy Fields in South Kalimantan (Hadi *et al*. 2010)

Here, greenhouse gas emissions from two different water irrigation regimes with different rice variety were compared. Table 2 shows the comparison between those regimes

Table 2. Greenhouse gas emissions from paddy fields with different water irrigation regimes in South Kalimantan (Hadi *et al*. 2010)

Rice Variety	Irrigation Regime	Emissions (kg C/ha/season)			GWP (kg CO_2 eq/ha/season)
		CH_4	CO_2	N_2O	
Local 2004	Flooding	1,251	810	8.9	32,217
	Intermittent	1,065	556	-50.3	10,162
Hybrid 2004/2005	Flooding	1,318	193	26.6	38,381
	Intermittent	1,129	198	5.9	27,911
Local 2005	Flooding	1,585	1,191	-29.6	28,884
	Intermittent	1,217	1,043	-14.8	24,653
Average 2004/2005	Flooding	1,384	731	1.97	33,161
	Intermittent	1,137	599	-19.73	20,909

Intermittent irrigation reduced greenhouse gas emissions for all gasses. For the average, methane emission can be reduced to 17.8%, while CO_2 was reduced up to 18.6%. Intermittent irrigation does not released N_2O as indicated by its negative value as shown in Table 2. In addition, intermittent irrigation can minimize GWP in which its value was 36.9% lower than that flooding irrigation regime.

d. Greenhouse gas emission from tertiary irrigation fields in East Java (Utaminingsih and Hidayah 2012)

The research was conducted during one planting season from April to August 2010 with three plots and total areas of 133 ha. Two irrigations system were also compared as presented in Table 3.

Table 3. Greenhouse gas emissions from paddy field in East Java (Utaminingsih and Hidayah 2012)

Irrigation regime	Total Emissions (kg/ha/season)			GWP ($t\ CO_2$ eq)
	CH_4	N_2O	CO_2	
Flooding	306.89	0.24	1,084.32	8.84
Intermittent				
Plot 1	61.89	0.68	1,234.28	2.98
Plot 2	33.59	0.50	1,796.75	2.78
Plot 3	277.02	0.77	1,296.09	8.45
Average	124.17	0.65	1,442.37	4.74

In this case, intermittent irrigation can reduce methane emission of 59.5%, on the other hand, nitrous oxide and CO_2 gases increased significantly. Overall, GWP value can be reduced up to 46.4%.

MITIGATION STRATEGY

Field experiments and measurements

According to previous studies, it is clearly explained that SRI with intermittent irrigation can reduce greenhouse gas emission from paddy field significantly. However, optimal SRI water management is still questionable for its application in Indonesia as well as its effect on plant growth performance and yield. Therefore, we conducted field experiment to find optimal water management with two main objectives, i.e. reduce greenhouse gas emissions and produce more rice with minimum water irrigation input.

The field experiment was conducted in paddy fields located in Bogor, West Java, Indonesia during 26 March – 24 June 2015. On 26 March 2015, we planted rice (*Oryza sativa* L) with the variety of *Ciherang*. Some SRI elements practiced consist of young seeds (5 days sowing) and one plant in one hill (single transplanting) with wider space of 30 cm × 30 cm. Here, the three plots were supplied with different irrigation regimes with two replications. The first plot was continuous flooding regime (FL) as control in which standing water at 2 and 5 cm water depth was managed from the beginning of cultivation period (vegetative) to one week before harvesting (generative), and then the field was conditioned dry before harvesting. The second plot was moderate irrigation regime (MD) in which the soil moisture was kept at saturated level from the beginning to generative stage (one week before harvesting) and then it is conditioned dry until harvesting. The last plot was dry irrigation regime (DR) to save more water in extreme condition in which the saturated condition of soil was managed only 20 days after transplanting, then dry condition was formed by manage water level at -5 cm water depth (5 cm under soil surface) until harvesting time.

Greenhouse gas emissions, i.e., CH_4 and N_2O, were measured manually using closed chamber box. The size chamber was 30 cm x 30 cm x 120 cm and it's was equipped with the fan to circulate the air inside the box during measurement. During measurement, one hill of paddy rice was closed by the chamber, and then the gas sample is taken every 10 minutes within 30 minutes. We got 4 different gas concentrations that were analyzed using a gas chromatograph (Micro GC CP 4900) with flame ionization detector (FID) in the lab. Based on the change of its concentration, we determined greenhouse gas emission.

Plant perfomances

Table 4 shows the effects of irrigation regime on the plant performances. Plant height, number tillers/hill and number panicles/hill were comparable among the regimes and not significantly different. DR treatment produced the highest plant and number panicles/hill as well as root length. This condition also corresponded to biomass yield in which DR regime produced the heaviest biomass. These results revealed that under SRI practices when the field was not flooded continuously, the root can growth optimally. In addition, when the water was limited, the plant enhanced root length to find the water in soil under the driest condition (Fig. 2).

Table 4. Plant performances under different water regimes

Plant Performances	Irrigation Regimes		
	FL	MD	DR
Plant Height (cm)	85.0 ± 2.6	84.4 ± 3.1	88.5 ± 2.6
Number tillers/hill	25.7 ± 8.0	26.1 ± 0.7	24.3 ± 2.6
Number panicles/hill	17.4 ± 2.8	16.9 ± 1.2	19.3 ± 1.2
Root length (cm)	13	15	16
Grain yield (ton/ha)	4.16 ± 0.68	2.96 ± 1.02	2.64 ± 1.02
Biomass yield (ton/ha)	12.96 ± 1.81	10.4 ± 0.91	13.36 ± 0.57
Irrigation water (mm)	510.4	447.3	434.6

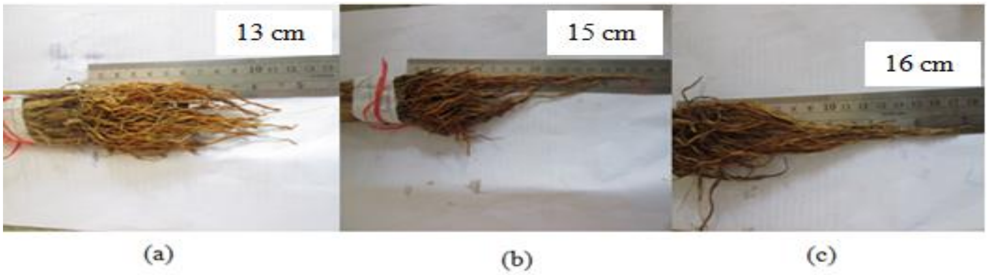

Fig. 2. Root length of each treatment: a) FL, b) MD and c) DR.

However, the production of more biomass was not linear correlated with grain yield. DR regime, in contrast, produced the lowest grain yield. It was indicated that under limited water more spikelet sterility occurred particularly around flowering time. FL regime produced the highest yield in which the yield was 28.8% and 36.5% higher than that MD and DR regimes, respectively. It was revealed that to obtain optimal grain yield, water stress should be avoided.

Optimal water management

In total, greenhouse gases, i.e., methane and nitrous oxide were emitted at different levels under three water management regimes (Table 5). FL regime with maintaining higher water level released more methane emission particularly in the early growth stage to mid-season stage. Methane emission released to the atmosphere during flooding condition when soil moisture was in saturated level. Meanwhile, DR regime released the highest nitrous oxide emission when drought condition occurred by maintaining water level at -5 cm below the soil surface starting from 20 days after transplanting. From this results indicated that CH_4 and nitrous oxide emission has opposite trend. Therefore, global warming potential (GWP) is used as an indicator to represent total greenhouse gas emission.

Table 5 shows that DR regime has lowest GWP, but it decreased significant rice yield being 36.5% lower than that FL regime as shown in Table 4. Meanwhile, MD regime released greenhouse gas emission 80.1% lower than that FL regime. In addition, it saved more water irrigation being 12.4% lower than FL regime and decreased 28.8% rice yield as well. Therefore, MD regime may be an effective option for water management regime in West Java for mitigating greenhouse gas emission.

Table 5. Total greenhouse gas emissions in each water regime

Water Management	Greenhouse Gas Emission		
	CH_4 (kg/ha/season)	N_2O (kg/ha/season)	GWP* (kg CO_2 -eqv/ha/season)
Flooded (FL)	65.3	3.2	2591.7
Moderate (MD)	-16.7	3.1	516.2
Dry (DR)	-163.4	4.2	-2821.8

*GWP: Global Warming Potential at the 100-year time horizon of 25 and 298 for CH_4 and N_2O, respectively (IPCC, 2007)

CONCLUSION

The System of Rice Intensification (SRI), is an alternative rice farming to mitigate greenhouse gas emissions from paddy fields. It has six basic elements wherein water management is the key managemen to reduce greenhouse gas emission. By applying intermittent irrigation as water management, the field is conditioned wet (saturated level without flooding) and dry at a particular time and continuous flooding is avoided. According to previous studies, this irrigation regime was effective to minimize global warming potential at different levels up to 46.4% depend on field conditions. For optimum SRI water management, we found that moderate regime was alternative option for mitigating greenhouse gas emission without reducing yield significantly. In this regime, the soil moisture was kept at saturated level from the beginning to generative stage (one week before harvesting) and then it is conditioned dry until harvesting. This regime released greenhouse gas emission 80.1% lower than that continous flooding irrigation. However, the experiment was conducted only in one planting season with specific weather condition. For future works, more experiments should be conducted to find optimal water management under varies weather condition to mitigate greenhouse gas emission without lowering land productivity.

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REFERENCES

Akiyama, H, K. Yagi, and X.Y. Yan. 2005. Direct N_2O emissions from rice paddy fields: Summary of available data. *Global Biogeochem Cy* 19 (1).

Arif, C., F.M. Ilmi, S.K. Saptomo, B.I Setiawan, and M. Mizoguchi. 2018. Developing Automatic Water Table Control System for Reducing Greenhouse Gas Emissions from Paddy Fields. IOP Conf. Series: Earth and Environmental Science 147: 012040.

Barison, J., and N. Uphoff. 2011. Rice yield and its relation to root growth and nutrient-use efficiency under SRI and conventional cultivation: an evaluation in Madagascar. *Paddy Water Environ* 9 (1):65-78.

Bouman, B.A.M. 2001. Water-efficient management strategies in rice production. International Rice Research Note 26.2.

Bouwman, A.F. 1990. Introduction. In: Bouwman AF (ed) Soil and the Greenhouse Effects. John Wiley & Sons, New York, United States.

Cai, Z.C, G.X. Xing, X.Y. Yan, H. Xu, H. Tsuruta, K. Yagi, and K. Minami. 1997. Methane and nitrous oxide emissions from rice paddy fields as affected by nitrogen fertilisers and water management. *Plant Soil* 196 (1):7-14.

Chapagain, T. and E. Yamaji. 2010. The effects of irrigation method, age of seedling and spacing on crop performance, productivity and water-wise rice production in Japan. *Paddy Water Environ* 8 (1):81-90.

Cicerone, R.J, C.C. Delwiche, S.C. Typer, and P.R. Zimmermann. 1992. Methane emissions from California rice paddies with varied treatments. *Global Biogeochem Cy* 6 (3):233-248.

Dill, J., G. Deichert, and L.T.N. Thu. 2013. Promoting the System of Rice Intensification: Lessons Learned from Trà Vinh Province, Viet Nam

Epule, E.T., C. Peng and N.M. Mafany. 2011. Methane Emissions from Paddy Rice Fields: Strategies towards Achieving a Win-Win Sustainability Scenario between Rice Production and Methane Emission Reduction. *Journal of Sustainable Development* 4 (6): 188-196.

Gani, A., T.S. Kadir, A. Jatiharti, I.P. Wardhana, and I. Las. 2002. The System of Rice Intensification in Indonesia. In: Uphoff N, Fernandes E, Yuan LP, Peng JM, Rafaralahy S, Rabenandrasana J (eds) Assessments of the System of Rice Intensification (SRI), Sanya, China, 1-4 April 2002. Cornell International Institute for Food, Agriculture and Development, Ithaca, NY, pp 58-63.

Gathorne-Hardy, A.D.N. Reddy, M. Venkatanarayana, and B. Harriss-White. 2013. A Life Cycle Assessment (LCA) of greenhouse gas emissions from SRI and flooded rice production in SE India. Taiwan *Water Conserv* 61: 110–125.

Hadi, A., K. Inubushi, and K. Yagi. 2010. Effect of water management on greenhouse gas emissions and microbial properties of paddy soils in Japan and Indonesia. *Paddy Water Environ* 8: 319–324.

Hameed, K.A., A.K.J. Mosa, and F.A. Jaber. 2011. Irrigation water reduction using System of Rice Intensification compared with conventional cultivation methods in Iraq. *Paddy Water Environ* 9 (1):121-127.

Hidayah, S., D.A. Agustina, M.D. Joubert, and Soekrasno. 2009. Intermittent irrigation in System of Rice intensification potential as an adaptation and mitigation option of negative impacts of rice cultivation in irrigated paddy field. Royal Irrigation Department (Thailand) website.

IPCC. 2007. Climate Change 2007: The Physical Scientific Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; Solomon, S., Qin,D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (Eds.).; Cambridge, UK, Cambridge University Press; 2007.

Las, I., E. Surmaini, and A. Ruskandar. 2008. Antisipasi Perubahan Iklim: Inovasi Teknologi dan Arah Penelitian Padi di Indonesia. Proceeding National Seminar on Rice 2008: Inovasi Teknologi Padi Mengantisipasi Perubahan Iklim Global Mendukung Ketahanan Pangan, BB. Padi.

Lin, X.Q., D.F. Zhu, and X.J. Lin. 2011. Effects of water management and organic fertilization with SRI crop practices on hybrid rice performance and rhizosphere dynamics. *Paddy Water Environ* 9 (1):33-39.

Mosier, A.R., J.M. Duxbury, J.R. Freney, O. Heinemeyer, and K. Minami. 1996. Nitrous oxide emissions from agricultural fields: Assessment, measurement and mitigation. *Plant Soil* 181 (1):95-108.

Nemoto, K., S. Morita, and T. Baba. 1995. Shoot and Root Development in Rice Related to the Phyllochron. *Crop Sci* 35 (1):24-29.

Neue, H.U., P.B. Heidmann, and H.W. Scharpenseel. 1990. Organic matter dynamics, soil properties, and cultural practices in rice lands and their relationship to methane production. In: Bouwman AF (ed) Soil and the Greenhouse Effect. John Wiley & Sons, New York, United States, pp 457-466.

Rajkishore, S.K., P. Doraisamy, and K.S. Subramanian, M. Maheswari. 2013. Methane Emission Patterns and Their Associated Soil Microflora with SRI and Conventional Systems of Rice Cultivation in Tamil Nadu, India. *Taiwan Water Conservancy* 61(4): 126-134.

Sato, S., E. Yamaji, and T. Kuroda. 2011. Strategies and engineering adaptions to disseminate SRI methods in large-scale irrigation systems in Eastern Indonesia. *Paddy Water Environ* 9 (1):79-88.

Setyanto, P., A.K. Makarim, A.M. Fagi, R. Wassman, and L.V. Buendia. 2000. Crop management affecting methane emissions from irrigated and rainfed rice in Central Java (Indonesia). *Nutr Cycl Agroecosys* 58:85-93.

Setyanto, P., and R.A. Bakar. 2005. Methane Emission from Paddy Fields as

Influenced by Different Water Regimes in Central Java. *Indonesia Journal of Agricultural Science* 6 (1): 1-9.

Sheehy, J.E., S.Peng, A. Dobermann, P.L. Mitchell, A. Ferrer, J.C. Yang, Y.B. Zou, X.H. Zhong, and J.L. Huang. 2004. Fantastic yields in the system of rice intensification: fact or fallacy? *Field Crop Res* 88 (1):1-8.

Sinclair, T.R. and K.G. Cassman. 2004. Agronomic UFOs. *Field Crop Res* 88 (1):9-10.

Smith, C.J., M. Brandon, and W.H. Patrick. 1982. Nitrous-Oxide Emission Following Urea-N Fertilization of Wetland Rice. *Soil Sci Plant Nutr* 28 (2):161-171.

Smith, S.J., and M.L. Wigley. 2000. Global warming potentials: 1. Climatic implications of emissions reductions. *Climatic Change* 44 (4):445-457.

Stoop, W., N. Uphoff, and A. Kassam. 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. *Agr Syst* 71:249-274.

Thomas, V., and A.M. Ramzi. 2011. SRI contributions to rice production dealing with water management constraints in northeastern Afghanistan. *Paddy Water Environ* 9 (1):101-109.

Tyagi, L., B. Kumari, and S.N. Singh. 2010. Water management - A tool for methane mitigation from irrigated paddy fields. *Sci Total Environ* 408 (5):1085-1090.

Uphoff, N. and F.B. Dazzo. 2016. Making Rice Production More Environmentally-Friendly. *Environments* 3: 12.

Uphoff, N., A. Kassam and R. Harwood. 2011. SRI as a methodology for raising crop and water productivity: productive adaptations in rice agronomy and irrigation water management. *Paddy Water Environ* 9:3-11.

Utaminingsih, W. and S. Hidayah. 2012. Mitigasi Emisi Gas Rumah Kaca Melalui Penerapan Irigasi Intermittent di Lahan Sawah Beririgasi. *Jurnal Irigasi* 7(2): 132-141.