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Climate smart agriculture to increase productivity and reduce greenhouse gas emission– a preliminary study

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Abstract. Addressing the climate change on agricultural sector as an approach to increase rice productivity, which at the same time also mitigate the greenhouse gas (GHG) emission, economically feasible, socially acceptable and hence appropriate for policy support, is a special challenge. This study provided Climate Smart Agriculture (CSA) technology to address the multi-dimensional complexity in agriculture system including climate, economic and technology for farmers and the community. The research locations were selected on particularly major irrigated rice fields at three districts in Central Java, i.e. Banjarnegara, Purbalingga and Banyumas District. Demo plots were used to compare the Farmers practice with CSA technology. The CSA technology used were: leaf color chart to apply N fertilizer, paddy soil test kit for determining basic fertilizer, organic matter amendment and intermittent irrigation. This study shows that CSA reduced GHG emissions than Farmers practice between 7-23% of Global Warming Potential and achieved economic benefit between 42-129%. Introducing CSA to the farmers and community is recommended to cope with climate change as the adaptation and mitigation actions. Despite very clear advantages in reducing GHG emission and climate change adaptation, many constraints must be faced by the implementation of CSA in the field.

1. Introduction

Rice is the staple food of the 95% of total Indonesia populations. Ninety five percent (95%) of rice is produced from paddy rice cultivation, mostly involves full wetting period. Technically irrigated paddy rice areas are 4.4 million ha throughout Indonesia, and 60.8% are located on Java island in 2013 [1].

The emission of greenhouse gases (GHG) from paddy rice cultivation per unit area is considerably high and therefore it is suspected to significantly contribute to the total land-based GHG emission in Indonesia. Most of the GHG emission from lowland rice cultivation is methane (CH_4) because of water regime; which emits 58.618 million tons CO_2e year^{-1}. When it is combined with the emission of N_2O (direct and indirect) from fertilizer (47.778 tons CO_2-e year^{-1}), the total GHG emission from paddy rice is indeed high [2].

Several mitigation plans have been described either globally or nationally, including: improvement of water regime (intermittent irrigation), application of matured animal manure to improve soil fertility and soil C sequestration, the introduction of rice variety with low CH_4 emission potential, and avoidance of biomass burning for manure. Effective implementation of the plan needs policy instruments to operate in synergy, though may have to face several barriers. Firstly, being the major staple food for the entire nation, rice is important in food security agenda at the national and local levels. Some decision makers worry that reducing GHG emission from paddy rice cultivation using recommended technologies could cause rice production to decline. Hence, a mitigation action plan needs support data from proper study and analysis, beyond greenhouse and controlled research at the experimental station. Secondly, most of the rice cultivation is practiced by farmers with very limited land holdings and generally, they are quite poor and have no other means to generate income, other than paddy rice farming. They hesitate that the programs on reducing emissions from paddy rice cultivation might not be beneficial. Thirdly, managing water level can only be feasibly conducted for technically-irrigated paddy rice area, that requires a certain management and necessary water scheduling.

Indonesian Agricultural Environment Research Institute claims that climate-smart agriculture (CSA) is a prospective technology. This technology promote a realistic adaptation efforts to be applied in a potential area for rice. It is also an integrative approach to transform and reorient agricultural development to maintain food security and cope with climate change [3]. According to FAO [4] it aims to increase productivity as well as farmers income, building resilience to the changing climate and reduce GHG emission. Expected results of such activities are to increase rice productivity, reduce GHG emission level, economically feasible, and socially acceptable at the same time, hence will be appropriate for policy support.

It is very important to assure that the mitigation technology should not cause any harm to rice yield. This study aims to evaluate the implementation of CSA on GHG emission, rice growth and yield, also the social and economic variables.

2. Materials and method

2.1. Site selection and description

Research location was selected purposively, namely Merden, Senon and Silado villages in Banjarnegara, Purbalingga and Banyumas Districts, respectively. The villages were chosen by considering the farmers already received intensification technologies for the last 5 years, therefore it is presumed that they will have a better understanding on CSA. Field survey was carried out before the experiment. Below are the description of each site.

2.1.1. Banjarnegara district. The dominant soil type of the rice field is alluvial (Endoaquepts associated with Hapluderts) with precipitation type IV/C and V/A. Irrigated rice areas cover almost 2/3 of the total rice field, rice is cultivated twice in a year. The site of demo-plot was located at Merden village.

2.1.2. Purbalingga District. The precipitation type is III/C, which is not adequate for rice fields in November 2015 during land preparation; therefore, irrigation for rice depends on small dam called Mrican reservoir. The dominant soil type is alluvial and red-yellow Podzolik (Eutrudepts associated with Udorhents). The demo-plot site was located at Senon Village.

2.1.3. Banyumas District. The dominant soil type of the rice fields at Banyumas District is alluvial (Endoaquepts associated with Hapludepts) on flat topography, and the red-yellow podzolik (Hapludepts associated with Dystrudepts). The dominant precipitation type is IV/C and V/A, and hence the irrigation water for demo-plot at Silado Village derived from mountains water resources.

2.2. Plot design

There were two demo-plots in each district. One demo-plot applied the mitigation technology and the other one represents custom farmers practice (conventional). The mitigation technology package applied were:

- leaf color chart (LCC) for nitrogen fertilizer application. By determining the leaf color, the N fertilizer dose could be predicted to be more effective and efficient.
- paddy soil test kit for determining basic fertilizer (nitrogen, phosphor and potassium).
- organic amendment application
- the use of seeds certified by National Seed Management Unit (UPBS, Unit Pengelola Benih Sumber)
- water regime management with intermittent irrigation. Many studies has shown that managing water from continuous flooding in wetting and drying or intermittent irrigation will decrease CH_4 emission. That is because methanogen bacteria involved in methane productivity occurs only in anaerobic conditions during flooding, so continuous flooding is critical to methanogenesis [5].

2.3. GHG measurement
Gas samples were collected at 8, 18, 26, 32 and 70 DAT (days after transplanting). DAT representing rice growing stages. The GHGs taken were CH_4 and N_2O using closed chamber technique. There were 4 replications of gas sampling points at each demo-plot. Before the first measurement, the chamber base was immersed at each sampling point. The closed chamber is made of 4mm thick acrylic materials consisted of two parts, a square box and a chamber base. Samples were taken with 20 ml plastic syringes attached to a three-way stopcock at 10, 20, 30, 40, 50 min for N_2O; and 3, 6, 9, 12, 15 min for CH_4, respectively, and then injected into 10 ml evacuated glass vial. The GHG concentrations in the samples were analysed in the laboratory within 24 hours using a gas chromatograph (Varian GHG 450 Series for N_2O and Shimadzu GC 8A for CH_4). The gas chromatography is equipped with an electron capture detector (ECD) for N_2O analysis and flame ionization detector for CH_4 analysis.
The methods for calculating the gas flux were according to IAEA [6]:

$$E = \frac{Bm}{Vm} \, x \, \frac{\Delta C}{\Delta t} \, x \, \frac{V}{A} \, x \, \frac{273.2}{T + 273.2} \tag{1}$$

where E is CH_4/N_2O flux (mg m^{-2} min^{-1}), Bm is molecular weight of CH_4/N_2O (g), Vm is the molecular volume of CH_4/N_2O at standard temperature and pressure (22.41l), $\Delta C/\Delta t$ is changes of CH_4/N_2O concentration over time (ppm min^{-1}), V is chamber volume (m^3), A is chamber area (m^2) and T is mean air temperature inside the chamber during gas sampling (°C).

2.4. Economic analysis
In the present study, the economic feasibility of CSA was evaluated to compare with Farmers practice by comparing costs and revenues. In this study, the social and environmental costs were not taken in consideration like other studies [7].

All necessary monetary costs for the production cycle were calculated on a net basis (excluding taxes). Annual costs and revenues were calculated by assuming the interest rate is constant for the entire period. The revenue-cost ratio (R/C) highlights the revenue per unit of capital invested [8]. In fact, this criterion consists in dividing the sum of the benefits (revenues) for the sum of the discounted costs (outputs), which are also discounted. If R/C is >1, the project is feasible, and the highest R/C is most preferable for multiple projects.

3. Results and discussion

3.1. GHG emission for global warming potential
A measure to express the magnitude of GHG traps in the atmosphere called global warming potential (GWP). GWP using the potential heat trapped by a mass of carbon dioxide to compare with the potential heat trapped by a mass of certain gas. It is commonly calculated over a specific time horizon

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namely 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide (whose GWP is standardized to 1). According to IPCC Fourth Assessment Report GWP value for CH_4 over 100 years time horizon is 23 and 298 for N_2O, respectively.

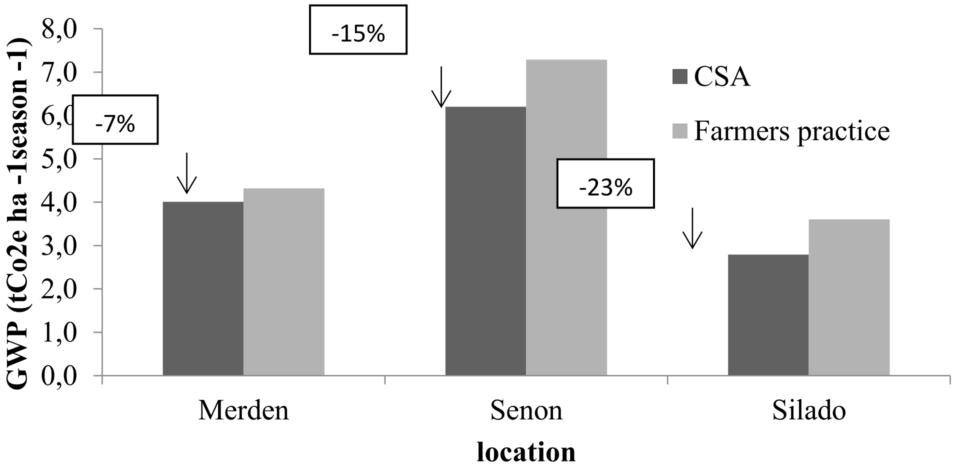

Figure 1. Global warming potential from demo-plots under two cultivation techniques at Merden, Senon and Silado

The GWP from rice field with CSA technology were 7, 15 and 23% lower than farmers practice at Merden, Senon and Silado village, respectively as shown in Figure 1. CH_4 emissions dominated the GWP in rice paddies [9]. This means that water management plays an important role in GHG emission, although water was not likely the only factor affects the GHG emission in paddy field. However, this study performs CSA technologies fulfilled the expectation as stated in Presidential Decree No 61 the Year 2011.

3.2. Rice grain yield and economic analysis

Rice grain yield was determined from samples at 2.5 m x 2.5 m tile size followed by the guideline issued by CRIFC (Central Research Institute for Food Crops). Rice grain yield under organic farming developed by a farmer at Merden village was relatively higher than CSA technology implementation at Senon and Silado villages. That is because the demo-plots soil in Merden village is more fertile than that of Senon and Silado villages. However, in general, rice grain yields under CSA technology at all three demo-plots were higher than farmers practice (Table 1). On the contrary, organic farming at Merden village emitted the lowest GHG than CSA technology at Senon and Silado villages (Table 2), but the soil physical and chemical properties at all demo-plots were nearly similar.

The organic farming in the Merden village resulted in the highest R/C ratio due to the most fertile soil among other demo-plots and tended to produce higher grain yield but lower cost, also low GWP (Table 2). This phenomenon needs further investigation because ideally, the CSA technology should significantly suppress GWP. However, the field observation found that rice plant in Silado village had a very serious pest disease called neck blast during the vegetative stages. This condition brought farmers to apply the pesticide. Therefore, the differences in cultivation techniques among sites lead to materials and labour costs differences. This resulted in the wide range diversities of economic profit.

CSA technologies have clearly concluded to be more environmentally friendly, as it could reduce GHG emission hence promote a sustainable agriculture system. Besides environmental-friendly, a sustainable agriculture system must also be economically viable. However, the economic benefit does not always translated to financial gains. There are also social and environment benefits that can also reflect the economic benefits. The study conducted at Merden, Senon and Silado villages shows that GHG emission mitigation does not always need an additional cost. It is clearly shown that while farmers applying mitigation technologies, they also gain an economic benefit with less cost.

Table 1. Grain yield and economic farming analysis under two cultivation techniques at Merden, Senon and Silado villages

Village	Farming system	Cost (labour & material) (IDR ha^{-1})	Yield (t ha^{-1})	Revenue (IDR ha^{-1})	Benefit	Benefit increase	R/C
Merden	Organic farming	11,584,200	6.7	30,150,000	18,565,800	129%	2.60
	Farmers practice	13,519,000	4.8	21,600,000	8,081,000		1.60
Senon)	CSA	12,086,400	6.3	28,350,000	16,263,600	49%	2.35
	Farmers practice	13,827,175	5.5	24,750,000	10,922,825		1.79
Silado	CSA	11,777,412	5.4	24,300,000	12,522,588	42%	2.06
	Farmers practice	12,307,176	4.7	21,150,000	8,842,824		1.72

Table 2. Yields and GWPs under two cultivation techniques at Merden, Senon and Silado

Village	Farming system	Yield (t ha^{-1})	Yield increase (t ha^{-1})	GWP (t ha^{-1} season^{-1})	GWP decrease (t ha^{-1})
Merden)	Organic farming	6.7	1.9	4.01	0.31
	Farmers practice	4.8		4.32	
Senon	CSA	6.3	0.8	6.20	1.09
	Farmers practice	5.5		7.29	
Silado	CSA	5.4	0.7	2.79	0.81
	Farmers practice	4.7		3.60	

In the present days, research becomes an important element to obtain a beneficial production system. A new technology that might seem environmentally friendly may not be agronomically viable or economically profitable. Farmers will adopt the new technology of agricultural mitigation practices which is profitable.

3.3. CSA technology implementation constraint
The constraints of implementing new technologies, including CSA technology other than the cost according to many studies are: permanence, additional, uncertainty, transaction cost, measurement and monitoring cost, and another constraints [10].

3.3.1. Permanence. Some of the mitigation options are permanent, but some might impermanent. According to West and Post [11], carbon sequestration in soils or terrestrial biomass are impermanent, while CH_4 avoidance from managing manure with biodigester are permanent.

3.3.2. Additional. We need to add an activity to the ongoing activities to reduce GHG emissions in agriculture. The additional cost must be calculated proportionally. Just like managing water regime, it would have added an activity to control the water table.

3.3.3. Uncertainty. There are two points: mechanism uncertainty and measurement uncertainty. Mechanism uncertainty related to processes involved in GHG emissions and carbon storage in agricultural, which are complex. Measurement uncertainty related to the wide variability of seasonal and temporal of GHG emission [12].

3.3.4. Transaction costs. Farmers will adopt the new technology of agricultural mitigation practices which profitable. The less of the participants in the trading process, the more profit farmers will gain.

3.3.5. Measurement and monitoring costs. Measuring on the farm of GHG emission reduction or soil carbon sequestration might be very expensive, thus research is needed to make it more simple with less cost.

3.3.6. Other *constraints.* Other possible constraints or barriers to new technologies implementation as stated by Smith et.al [10] including the availability of capital, the rate of capital stock turnover, risk attitudes, need for new knowledge, availability of extension-service-supported technology dissemination, consistency with traditional practices, pressure of agricultural land and water competition, demand for agricultural products, high costs for certain enabling technologies (e.g. soil tests before fertilization) and the ease of compliance (e.g. farmers prefers to conduct continuous flooding because it is more simple than managing water with intermittent irrigation).

4. Conclusion

The implementation of CSA technology could reduce GHG emission by approx 7-23%, increase yield by 0.7 – 1.9 t ha^{-1}, with R/C ratio >2, hence environmental-friendly and economic feasible. But, since it is still a preliminary research, a further investigation and assessment in multi years and multi locations is required to minimize the uncertainty, especially regarding spatial and temporal of GHG emissions and carbon storage in agricultural systems at large scale.

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References

[1] Ministry of Agriculture 2015 *Agricultural Statistic* (Jakarta: Indonesia Ministry of Agriculture)
[2] UNFCC 2015 *Indonesia First Biennial Update Report Under The United Nations Framework Convention on Climate Change (UNFCCC)* (Jakarta: Kementerian Lingkungan Hidup dan Kehutanan)
[3] Lipper L, Thornton P, Campbell B M, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R, Jackson L, Jarvis A, Kossam F, Mann W, McCarthy N, Meybeck A, Neufeldt H, Remington T, Sen P T, Sessa R, Shula R, Tibu A and Thorquebiau E F 2014 Climate Smart Agriculture for food security *Nature Climate Change* **4** 1068-72
[4] FAO 2013 *Climate Smart Agriculture: Source book* (Rome Italy: Food and Agricultural Organization of the United Nation)
[5] Adhya, Tapan K, Linquist B, Searchinger T and Wassmann R 2014 *Wetting and Drying : Reducing Greenhouse Gas Emissions and Saving Water from Rice Production* Working Paper World Resource Institute 1–28.
Ma K, Qiu Q F and Lu Y H 2010 Microbial mechanism for rice variety control on methane emission from rice field soil *Global Change Biology* **16** 3085-95
Yan X, Yagi K, Akiyama H and Akimoto H 2005 Statistical analysis of the major variables controlling methane emission from rice fields *Global Change Biology* **11** 1131-41
[6] IAEA 1992 *Manual on Measurement of Methane and Nitrous Oxide Emission from Agricultural* (Vienna, Austria: International Atomic Energy Agency) pp 91
[7] Sgroi F, Candela M, Di Trapani M A, Foderà M, Squatrito R, Testa R and Tudisca S 2015 Economic and Financial Comparison between Organic and Conventional Farming in Sicilian Lemon Orchards *Sustainability* **7** 1–15
[8] Daneshvar S and Kaleibar M M 2010 *The minimal cost-benefit ratio and maximal benefit-cost ratio* The 2nd International Conference on Engineering System Management and

Applications (ICESMA) 5542690.

[9] Ma Y C, Kong X W, Zhang X L, Yan X Y, Yang J C and Xiong Z Q 2013 Net global warming potential and greenhouse gas intensity of annual rice–wheat rotations with integrated soil–crop system management *Agric. Ecosyst. Environ.* **164** 209–19

Shang Q, Yang X X, Gao C, Wu P, Liu J, Xu Y, Shen Q, Zou J and Guo S .2011. Net annual global warming potential and greenhouse gas intensity in Chinese double rice-cropping systems: a 3 years field measurement in long-term fertilizer experiments *Glob. Change Biol.* **17** 2196–210

[10] Smith P, Martino D, Cai Z, Gwary D, Janzen H, KumarP, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B and Sirotenko O. 2007 Agriculture *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* ed. B Metz, O R Davidson, P R Bosch, R Dave and L A Meyer (Cambridge: Cambridge University Press)

[11] West T O and Post W M 2002 Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis *Soil Sci. Soc. Am. J.* **66** 1930–46

[12] McCarl B A, Kim M-K, Lee H C, Murray B C, Sands R D and Schneider U A 2009 Insights from agricultural and forestry GHG offset studies that might influence IAM modelling *Integrated Assessment of Human Induced Climate Change* ed M Schlesinger, H Kheshgi, J Smith, F de la Chesnaye, J Reilly, T Wilson and C Kolstad (Cambridge: Cambridge University Press)