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Original Article

Effect of Methane Emission from Fertilizer Application

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ABSTRACT

Agriculture is a major source of greenhouse gas. Despite what many might think, the effect of greenhouse gas emission from fertilizer application is well known across hundreds of nations all over the world. This effect from fertilizer application has been around for several centuries and has a very important meaning in the lives of many. It would be safe to assume that effect of methane emission from fertilizer application is going to be around for a long time and have an enormous impact on the lives of many people in Indonesia. About 85% of Indonesian workers are engaged in agriculture, which accounts for 3% of GDP in 2001. Some 91 million ha (76.6 million acres) are under cultivation, with 35% to 40% of the cultivated land devoted to the production of export crops. Some 88% of the country's cultivated land is in Java. This study calculated the greenhouse effects from fertilizer application, in the term of global warming potential (GWP) associated with CH_4 emissions in Indonesian croplands. The results show that the GWP of CH_4 emissions was 223.456Tg CO_2–eq yr^{-1} during year 2009.
Keywords: Indonesia, urea, rice, coconut, social economic, global warming

1. INTRODUCTION

Despite what many might think, the effect of methane emission from fertilizer application is well known across hundreds of nations all over the world. The effect of methane emission from fertilizer application has been around for several centuries and has a very important meaning in the lives of many. It would be safe to assume that effect of methane emission from fertilizer application is going to be around for a long time and have an enormous impact on the lives of many people. Despite its crucial role in providing food, agriculture remains the largest driver of genetic erosion, species loss and conversion of natural habitats. Globally, over 4,000 assessed plant and animal species are threatened by agricultural intensification, and the number is still rising. Over 1,000 (87%) of a total of 1,226 threatened bird species are impacted by agriculture. Overfishing and destructive fishing methods along with eutrophication caused by high nutrient run-off from agricultural areas are among the major threats to inland and marine fisheries.

Modern agricultural methods and technologies brought spectacular increases in food production, but not without high environmental costs. Efforts to boost food production, for example, through direct expansion of cropland and pastures, will negatively affect the capacity of ecosystems to support food production and to provide other essential services. Food production will undoubtedly be affected by external factors such as climate change, but the production and distribution of food is itself is also a major cause of climate change.

Agriculture is a major source of greenhouse gases (GHGs), especially of methane (CH_4) and nitrous oxide (N_2O). The effect of methane emission from fertilizer application has a large role in Indonesian Culture. Many people can often be seen taking part in activities associated with effect of methane emission from fertilizer application. This is partly because people of most ages can be involved and families are brought together by this. Generally a person who displays their dislike for effect of methane emission from fertilizer application may be considered an outcast.

Application of nitrogen fertilizer to soils often enhances N_2O production and emission. It has been projected that the N_2O emissions from agricultural land will further increase by 35–60% by 2030 due to increased use of nitrogen fertilizer and manure production (FAO, 2003). Agriculture is also the major source of atmospheric CH_4. Methane is a principal GHG driving climate change. Its warming potential is about 20 times more powerful than carbon dioxide. Global methane emissions amount at present to about 540 million tonnes p.a., increasing at an annual rate of 20-30 million tonnes. Rice production currently contributes about 11 percent of global methane emissions. Around 15 percent comes from livestock (from enteric fermentation by cattle, sheep and goats and from animal excreta). The livestock contribution can be higher or lower at the national level depending on the extent and level of intensification. In the United Kingdom and Canada the share is over 35 percent. The production structure for ruminants in Indonesia is expected to increasingly shift towards that prevalent in the industrial countries. The major share of cattle and dairy production will come from feedlot, stall-fed or other restricted grazing systems and by 2030 nearly all pig and poultry production will also be concentrated in appropriate housings. Much of it will be on an industrial scale with potentially severe local impacts on air and water pollution.

The Permanent cropland (% of land area) in Indonesia was 10.49 in 2009, according to a World Bank report, published in 2010. The Permanent cropland (% of land area) in Indonesia was reported at 10.10 in 2008, according to the World Bank. Permanent cropland is land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee, and rubber. This category includes land under flowering shrubs, fruit trees, nut trees, and vines, but excludes land under trees grown for wood or timber. Indonesia is the largest national economy in Southeast Asia. It has a market-based economy in which the government plays a significant role by owning more than 164 state-owned enterprises. The government administers prices on several basic goods, including fuel, rice, and electricity.

Numerous studies have been carried out on fertilizer use in Indonesia. At the International Conference on Nutrient Management for Sustainable Food Production in Asia held in Bali, Indonesia, concluded that Indonesia had become self-sufficient in rice thanks to fertilizer use. Today only a small increment of rice production can be expected from the shrinking area of lowland rice. The main challenge is to develop productive agricultural systems in the underdeveloped, rained uplands, which are currently poorly fertilized.

The official fertilizer recommendations date from 1984. Some overall estimates of fertilizer use by crop in Indonesia are given in the publication Fertilizer use by crop, FAO et al. (2002). According to this publication, 52 percent of the fertilizers consumed in Indonesia are applied to rice, 12 percent to maize, 13 percent to oil-palm, 5 percent to vegetables and 4 percent to fruits, the remaining 14 percent to various other crops. Information on the quantities of fertilizer used by each crop in each province and island is not available. In the absence of reliable information on fertilizer use on crops and up-to-date recommendations, it is not possible to assess reliably the relationships between fertilizer use and development of crop production.

The aim of this paper is to estimate the amount greenhouse gas emissions in terms of the synthetic GWP from N_2O and CH_4 emissions and SOM accumulations in Indonesian croplands between 1990 and 2010.

2. MATERIALS AND METHODS

2.1 Emission calculation

2.2

2.1.1 N_2O emission from croplands

Nitrous oxide (N2O) is the other powerful GHG for which agriculture is the dominant anthropogenic source. Mineral fertilizer use and cattle production are the main culprits. N2O is generated by natural biogenic processes, but output is enhanced by agriculture through nitrogen fertilizers, the creation of crop residues, animal urine and faeces, and nitrogen leaching and runoff. N2O formation is sensitive to climate, soil type, tillage practices and type and placement of fertilizer. It is also linked to the release of nitric oxide and ammonia, which contribute to acid rain and the acidification of soils and drainage systems. The current agricultural contribution to total global nitrogen emissions is estimated at 4.7 million tonnes p.a., but there is great uncertainty about the magnitude because of the wide range in estimates of different agricultural sources

The national N_2O emission in Indonesia was estimated in three ways in the present study:

I. IPCC Tier 1 method

To calculate the fertilizer-induced direct emission ($E_{N2O\text{-}N}$) from croplands, the IPCC (2006) gives the general equation:

$$E_{N2O\text{-}N} = EF \times N_{input} \quad (1)$$

where N_{input} is the total annual nitrogen input in the form of synthetic fertilizer, farm manure (including compost) and crop residue(s) applied to croplands. Sewage, rendering waste and other kinds of organic matter applications were not included in the present study due both to the lack of sufficient data and the negligible importance of these kinds of fertilizers in crop cultivation in Indonesia. EF is the emission factor, which indicates the fraction of the input nitrogen that is emitted as N_2O. The default value of EF is 0.01 (0.003–0.03) for upland crop cultivation and 0.003 (0.000–0.006) for rice cultivation, respectively (IPCC, 2006).

II. Modified emission factors

Modifying the emission factors based on observation allows for more reliable estimations of the national N_2O emission from croplands. The emission factors in Table 1 were compiled from data acquired from peer-reviewed journal papers and field observations concerning N_2O emissions from Indonesian croplands (Zheng et al., 2004). Instead of using the default emission factor for all crop fields in Equation 1 of the IPCC Tier 1 method, different values were used for different crop categories (Table 1), i.e., rice growing season in rice paddy, upland growing season in rice paddy and uplands planted with upland crops year-round.

III. Regression equation

An empirical equation between fertilizer-induced direct N_2O emissions ($E_{N2O\text{-}N}$, N_2O–N) and nitrogen inputs (N_{input}, same as in Equation 1) and precipitation (P, in meter) for upland crop cultivation:

$$E_{N2O\text{-}N} = (0.0186 \pm 0.0027) \times P \times N_{input} \quad (2)$$

In the regression equation, the fertilizer-induced N_2O emission factor was corrected for by including precipitation. To account for the impacts of upland irrigation on the N_2O emission by using this method, we compiled data for irrigation water consumption into equivalent precipitations as described in section 2.2.2. The N_2O emission from rice paddies during the rice growing period was calculated with Equation 1, and the default N_2O emission factor of 0.003±0.003 of the IPCC (2006) was used for all water management regimes, though the emission factor of rice cultivation may change with the evolution of water management in rice paddy irrigation.

Table 1. Fertilizer-induced direct N_2O emission factors in croplands of Indonesia

Category	Crop cultivation	Emission factor	
		Mean	Uncertainty range
I	Rice season in rice paddy	0.0075	0.0029 – 0.0131
II	Upland crop season in rice paddy§	0.0251	0.0071 – 0.0431
III	Other uplands planted with upland crops year round	0.0086	0.0031 – 0.0141

2.1.2 CH_4 emission from rice paddies

In the present study, the CH_4 emission from irrigated rice cultivation in Indonesia was computed using three methods:

I. IPCC Tier 1 method

The IPCC Tier 1 method recommends a default rice paddy CH_4 emission factor of 1.3 kg CH_4 ha^{-1} d^{-1} for a continuously flooded water regime without any organic amendment. To account for the impacts of various water regimes, organic matter applications and soil types, corresponding scaling factors are provided (IPCC, 2006). In the present study, the scaling factors for water regimes and organic matter applications were adopted. The equation for calculating the CH_4 emission ($E_{CH4\text{-}C}$) from a rice paddy is therefore expressed as follows:

$$E_{CH4\text{-}C} = 0.75 \times 1.3 \times D_{rice} \times SF_w \times SF_o \times A_{rice} \quad (3)$$

where the constant 1.3 (kg CH_4 ha^{-1} d^{-1}) is the default CH_4 emission factor recommended by the IPCC (2006) and the constant 0.75 used to convert CH_4 into C. $E_{CH4\text{-}C}$ (kg CH_4–C) is the CH_4 emission. D_{rice} (days) is the duration of the rice growing period. A_{rice} (hectare) is the rice cultivation area and SF_w and SF_o are, respectively, the scaling factors for the water regime and organic matter applications used for rice cultivation. As mid-season drainage has been widely adopted in rice cultivation since 1980 (Zou et al., 2009), SF_w takes a value of 0.52 (0.41–0.66) (IPCC, 2006; Yan et al., 2003). The duration of rice growing is, on average, 80–120 days for early and late rice and 110–140 days for single rice (Bachelet et al., 1995; Yan et al., 2003). Organic fertilizer comprises various types of organic matter, e.g., farm manure, crop straw, biogas residue(s) and green manure, but the majority is farm manure and crop residue(s), while the others account for less than 8–10% of the total. For simplicity, the SF_o is calculated by Equation 4 (IPCC, 2006), which considers farm manure and crop residual incorporation:

$$SF_o = (1 + R_{cr} \times CR_{cr} + R_{fm} \times CR_{fm})^{0.59} \quad (4)$$

where R_{cr} and R_{fm} are the application rates (t ha^{-1}, dry weight) of crop residue(s) and farm manure (t ha^{-1}, fresh weight), respectively. CR_{cr} and CR_{fm} are the conversion factors of crop residual and farm manure into CH_4–C and have values of 1.0 (0.97–1.04) and 0.14 (0.07–0.20), respectively (IPCC, 2006).

II. Fraction of rice net primary productivity (NPP) emitted as CH_4

Rice production in Indonesia has undergone significant advances in the decades from 1980 to 2009, but the IPCC Tier 1 method does not account directly for the impacts of long-term improvements in rice production on CH_4 emissions. In previous studies (Taylor et al., 1991; Aselman and Crutzen, 1989), a certain fraction of rice NPP was used to estimate the CH_4 emissions from flooded rice paddies. This approach was used as a second method in the present study. The rice NPP was calculated with data for annual statistical rice yields (NBSC, 1981–2010), and the CH_4 emission ($E_{CH4\text{-}C}$) was calculated by Equation 5:

$$E_{CH4\text{-}C} = Y_{rice} \times 0.85 \times (1+R_{s/g}) \times (1+R_{r/s}) \times 0.40 \times F_{CH4} \times SF_w \quad (5)$$

where Y_{rice} is the statistical rice grain yield. The constants 0.85 and 0.40 are the average dry matter proportion of rice grain and the carbon content of the rice biomass, respectively (Huang et al., 2007). $R_{s/g}$ is the straw/grain ratio and has changed with rice cultivar evolution from 1.3 in the 1980s to 0.92 at present (Yang and Zhang, 2010; Yoshida, 1981). $R_{r/s}$ is the root/shoot ratio of a rice plant at harvest and takes a value of 0.10 (Huang *et al.*, 2007; Neue et al., 1990). F_{CH4} represents the fraction of rice NPP converted into CH_4 emissions. Taylor et al. (1991) assumed that 5% of the rice NPP might be transformed into CH_4 emissions, and Aselman and Crutzen

(1989) used a fraction ranging between 3% and 7%. Analogous to that in the IPCC Tier 1 method (Equation 3), SF_w is the scaling factor for using a mid-season drainage regime in rice cultivation.

III. TIKUS model

TIKUS is a semi-empirical model that simulates CH_4 emissions from rice paddies that are subject to various agricultural practices. It is one of the models recommended by the IPCC (2006) for compiling national rice paddy CH_4 emission inventories. This model consists of two modules: the derivation of the methanogenic substrates and the processes of CH_4 production and emission. The former module simulates the production of the methanogenic substrates that are primarily derived from rice root exudation and organic matter additions. The latter module simulates the CH_4 production from the available methanogenic substrates and the fraction of emissions via rice plants and bubbles. The daily changes in the soil redox potential (Eh) were calculated according to various water manipulations performed in rice paddies, and in the model, the influences of environmental factors are expressed as specific coefficient functions. Inputs into the TIKUS include the daily temperature from transplanting to harvesting, percentage of sand (0.2–2mm) in the paddy soils, the rice grain yield, the type and amount of organic matter applied to the soils and the water management regime used for rice irrigation.

2.1.3 Contribution of organic matter amendments to SOM storage in cropland soils

The budget for SOM storage is the balance between the SOM gain from organic matter application and the SOM loss via respiration. The decomposition processes occurring in soils turn a large portion of the input organic matter into carbon dioxide (CO_2), and only a small portion is converted into SOM. Environmental factors may affect the speed at which organic matter decomposes, but most studies have found that the fraction of organic matter converted into SOM (F_{cvs} in Equation 6) is within the range of 0.14–0.22 (e.g., Balesdent and Balabane, 1996; Bolinder et al. 1999; Rasmussen and Collins, 1991). In some biogeochemical models, the fraction of organic matter converted into SOM is related to the clay content of the soil by an empirical function (Jenkinson et al., 1992). To assess the contribution of organic matter incorporation to SOM storage, we calculated the amount of the organic matter that was converted into SOM (referred to as SOC_{in} hereafter) while decomposing, without considering the respiration of SOM pool. Using the equations from Lee et al. (2012), the SOC_{in} was calculated as follows:

$$SOC_{in} = (Y_{crop}\times F_{id}\times ((1+R_{s/g})\times R_{r/s}+R_{s/g}\times F_{ir})\times F_{icr}+M_{fm}\times F_{icf})\times F_{cvs} \qquad (6)$$

where Y_{crop} is the statistical yield of a crop (Zhou et al., 2011) and M_{fm} is the amount (dry organic matter) of farm manure application to the cropland. F_{cvs} is the fraction of applied organic matter that is eventually retained in the SOM pool after decomposition. F_{id}, $R_{s/g}$ and $R_{s/r}$ are, respectively, the dry matter fractions of the yield, the ratio of straw/yield and the ratio of root/shoot. Values of the crop-specific parameters, i.e., F_{id}, $R_{s/g}$ and $R_{s/r}$, were taken from Huang et al. (2007) and Zhou et al. (2011) without considering their temporal changes from the 1980s to the present for simplicity. F_{icr} and F_{icf} are the average carbon contents in crop residue(s) and farm manure, respectively, and were assigned values of 0.43 (0.38–0.47, Huang et al., 2007) and 0.35 (0.23–0.41), respectively. F_{ir} is the fraction of crop residue(s) that is amended into croplands and was set at a constant value of 0.25, assumed that 15% of crop residue(s) were returned to cropland during the 1990s, but an analysis of the national survey data showed that this fraction might be as high as 36.6%. By compiling data from the literature and surveys, we summarised the fractions of crop straw retention in different regions of Indonesia during different periods between 1980 and 2009 (Table 2).

Table 2. Decadal averages of the fraction of crop straw retention, %

Region	Period		
	1980-1989	1990-1999	2000-2009
I	17.50	22.39	31.50
II	20.52	26.25	36.93
III	24.62	31.49	44.31
IV	25.77	32.97	46.38
V	16.73	21.40	30.11
VI	13.30	17.01	23.94

2.1.4 Combining GHG estimations made by different methods

The GWP of CH_4 and N_2O was converted into its CO_2 equivalent (Equation 7) with 100-year time horizons, that is, using values of 25 and 298 (Equation 7), respectively (Forster et al., 2007). Only the fertilizer-induced direct N_2O emission was incorporated into the calculated GWP. Because the accumulation of SOM has the effect of mitigating the global warming caused by CH_4 and N_2O emissions, the SOC_{in} was treated as having a negative impact on the GWP.

$$GWP = E_{CH_4-C}\times\frac{16}{12}\times 25 + E_{N_2O-N}\times\frac{44}{28}\times 298 - SOC_{in}\times\frac{44}{12} \qquad (7)$$

where E_{CH4-C}, E_{N2O-N} and SOC_{in} are, respectively, the CH_4 emission (in terms of C), N_2O emission (in terms of N) and SOC_{in} (in terms of C).

3. RESULTS

3.1 Temporal changes in GHG emissions from croplands of Indonesia

The five-year averages of the national CH_4 and N_2O emissions and SOC_{in} are shown in Fig 1. In spite of the decrease in rice harvest area from 33.3 M ha in the early 1980s (1980–1984) to 29.3 M ha in the late 2000s (2005–2009), CH_4 emissions increased from 4.2 to 4.8 Tg CH_4–C yr^{-1} (Fig 2–a), which corresponds to an increase of 138.1 to 161.0 Tg CO_2 - eq yr^{-1} (Table 3). The increase in CH_4 emissions was mainly attributed to the enhanced rice production and organic matter incorporation (Fig 1–d), but in contrast to the increasing crop residual retention, farm manure applications in rice cultivation decreased due to both the promotion of mineral N fertilizer applications (Fig 1–c) and the expanding vegetable area (Fig 1–a) that competed for farm manure along with staple crops. In 1980, the amount of farm manure applied to rice fields was 26.5 Mt C yr^{-1}, and in 2009, it was 19.7 Mt C yr^{-1}, representing a decrease of 25.7%.

From the early 1980s to the late 2000s, the total N input into the croplands of Indonesia increased from 18.7 to 41.0 Mt N yr^{-1} (1 Mt = 10^6 tons) (Fig 1–c), of which mineral fertilizer accounted for 58–69%. The application of mineral fertilizer increased, astonishingly, by more than 133%, and owing to the increasing livestock population, the application of farm manure N also increased by 57%. In concert with the rapidly increasing amount of N applications, the annual fertilizer-induced direct N_2O emission more than doubled from 0.15 Tg N_2O–N yr^{-1} in the early 1980s to 0.38 Tg N_2O–N yr^{-1} in the late 2000s (Fig 2–b).

During the period from 1980 to 1984, the total organic matter retention in croplands, including farm manure and crop residue(s), was, on average, 195.5 Tg C yr^{-1}. Subsequently, due to the increasing livestock population and enhanced crop biomass together with the increasing fraction of crop straw incorporation, the amount of organic matter applied to croplands increased to 332.6 Tg C yr^{-1} (Fig 1–d) in the late 2000s. As a result, the SOC_{in} increased from 44.3 Tg C yr^{-1} in the early 1980s to 74.2 Tg C yr^{-1} in the late 2000s (Fig 2–c).

Combining the CH_4 and N_2O emissions, the GWP of the two greenhouse gases was 223.456Tg CO_2–eq yr^{-1} in the early 1980s and increased to 355.9 Tg CO_2–eq yr^{-1} in the late 2000s. Compared to N_2O, CH_4 accounted for the majority of the total GWP in the early 1980s (Table 3, Fig 2–d), but by the 2000s, the GWP of N_2O overtook that of CH_4 and became the major contributor (Table 3, Fig 2–d).

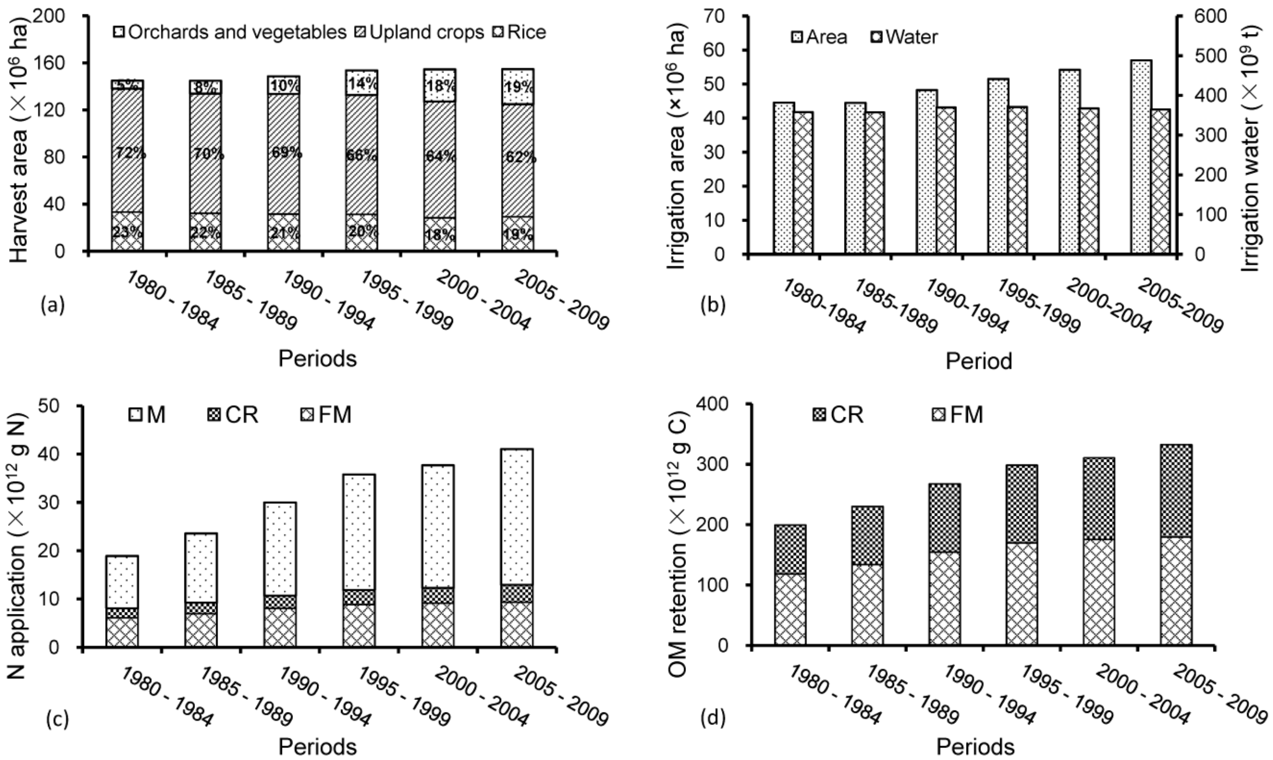

Fig 1. Long-term change in crop cultivation in Indonesia. a) Harvest areas and the proportions of rice, upland crops (vegetable fields and orchards excluded), vegetable fields (including pisang) and orchards (including kacang); b) Irrigated area and water consumption due to irrigation; c) Application of mineral fertiliser, farm manure and crop residue(s) in terms of nitrogen; d) Application of farm manure and crop residue(s) in terms of carbon.

Table 3. GWPs of Indonesia's croplands during different periods

Periods	Rice (Tg CO_2_eq yr^{-1})			Upland crops (Tg CO_2_eq yr^{-1})			Total (Tg CO_2_eq yr^{-1})
	CH_4	N_2O	SOC_{in}	CH_4	N_2O	SOC_{in}	
1980—1984	138.1 (105.9—172.5)[a]	11.9 (7.9—19.7)	43.3 (33.5—53.2)	NA[b]	69.1 (55.5—85.6)	119.3 (91.1—146.5)	**56.6 (−29.7—142.6[c])**
1985—1989	144.0 (112.6—177.5)	16.4 (10.9—27.2)	46.6 (36.0—57.2)	NA	81.6 (65.9—100.0)	140.8 (108.7—172.9)	**54.7 (−39.6—148.9)**
1990—1994	133.7 (119.2—183.4)	18.1 (12.0—30.0)	49.5 (38.2—60.7)	NA	111.6 (89.6—138.3)	169.0 (130.5—207.6)	**62.0 (−45.6—168.5)**
1995—1999	159.2 (124.9—192.8)	17.2 (11.4—28.4)	51.8 (40.1—63.5)	NA	143.8 (115.0—178.5)	193.6 (149.4—237.7)	**74.8 (−48.0—194.8)**
2000—2004	152.2 (112.9—190.1)	15.4 (10.2—25.4)	50.0 (38.7—61.3)	NA	159.9 (127.0—198.6)	204.6 (159.3—253.5)	**77.0 (−62.3—201.6)**
2005—2009	**161.0 (117.8—201.2)**	**15.0 (10.0—24.9)**	**52.3 (40.5—64.0)**	**NA**	**179.8 (141.5—222.8)**	**219.8 (169.7—270.0)**	**83.8 (−62.1—225.8)**

[a] Values in parentheses indicate differences among different estimation methods; [b] NA: not available; [c] The lower limit was calculated by summing the corresponding lower limits of CH_4 and N_2O emissions and subtracting the upper limit of SOC_{in}. The upper limit was calculated by summing the corresponding upper limits of CH_4 and N_2O emissions and subtracting the lower limit of SOC_{in}.

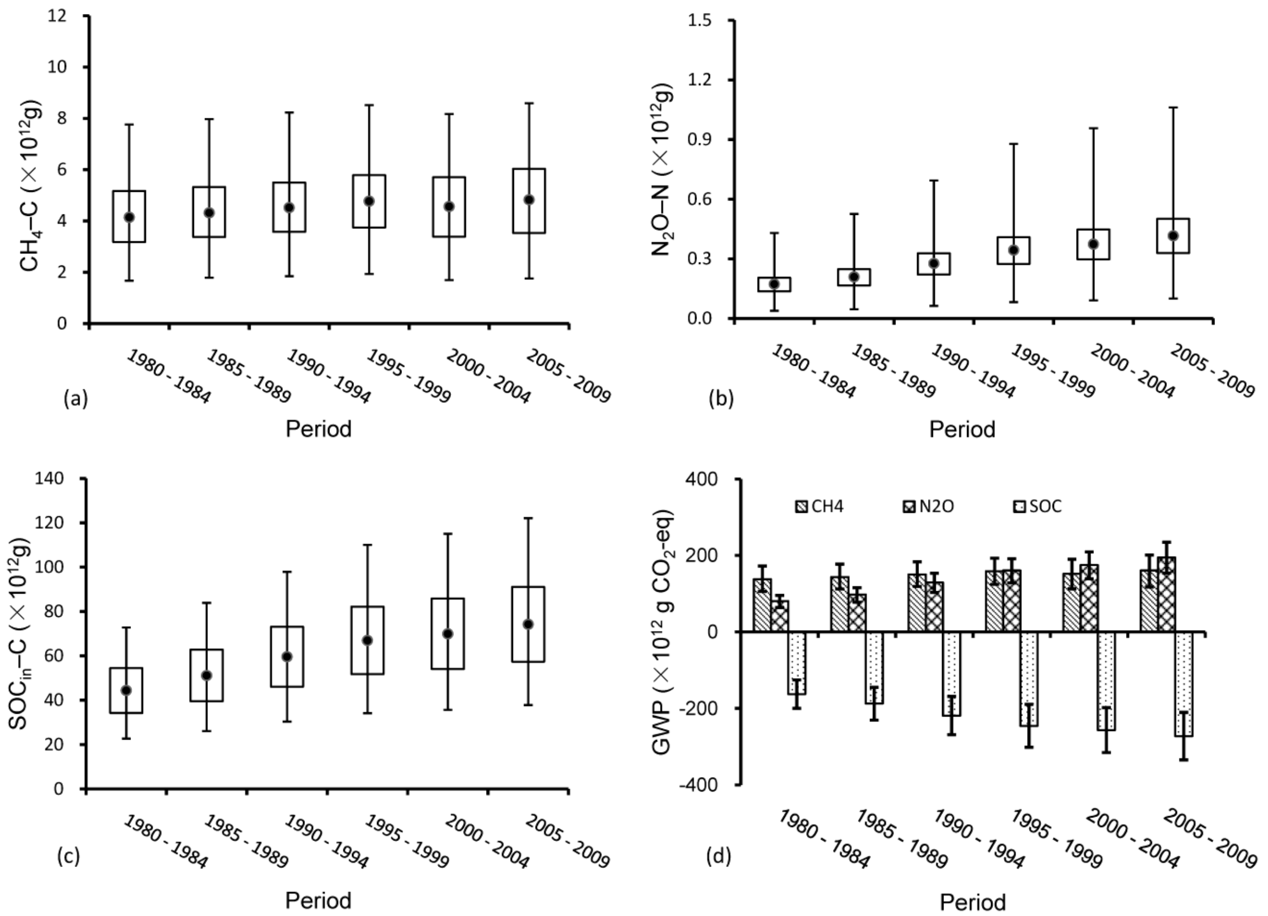

Fig 2. Greenhouse gas emissions and their global warming potentials associated with crop cultivation in Indonesia. a) CH_4 emission from rice cultivation; b) N_2O emission from rice and upland crop cultivation; c) SOM acquisition due to organic matter amendment; d) Global warming potentials (CO_2 equivalent for a 100 year horizon) of CH_4 and N_2O emissions and carbon acquisition in croplands. The dashed lines in a, b and c represent the overall uncertainties caused by the estimation methods, parameters and coefficients of the methods. The boxes in a, b and c represent the uncertainties caused by the application of different estimation methods. The dashed lines in d represent the uncertainties corresponding to the boxes in a, b and c.

4. DISCUSSION

4.1 Economic Factors

It is not common practice to associate economics with effect of methane emission from fertilizer application. Generally, effect of methane emission from fertilizer application would be thought to have no effect on our economic situation, but there are in fact some effects. The sales industry associated with fertilizer application is actually a 2.3 billion dollar a year industry and growing each year. The industry employs nearly 133,000 people in Indonesia alone. It would be safe to say that effect of methane emission from fertilizer application play an important role in Indonesian economics and shouldn't be taken for granted. After a three month long research project, I've been able to conclude that effect of methane emission from fertilizer application doesn't negatively affect the environment at all. An effect of methane emission from fertilizer application seem to result in waste products and couldn't be found in forests, jungles, rivers, lakes, oceans, etc... In fact, effect of methane emission from fertilizer application produced some positive effects on our sweet little nature.

Oh does effect of methane emission from fertilizer application ever influence politics. Last year 5 candidates running for some sort of position used effect of methane emission from fertilizer application as the primary topic of their campaign. A person might think effect of methane emission from fertilizer application would be a bad topic to lead a campaign with, but in fact with the social and environmental impact is has, this topic was able to gain a great number of followers. These 5 candidates went 4 for 5 on winning their positions.

Animal manures are a mixture of water, salt and minerals. Depending on the animal species and feeding nutrition, the chemical compositions of animal manures differ remarkably. The N_2O emission factors for different manures can range between 0.005 and 0.139, depending on the mineral N and total C contents of the applied manures and the application techniques (Velthof et al., 2003). After their application into soils, the manures with higher contents of easily mineralisable N and C, e.g., liquid pig manure, emit more N_2O, and their emission factors can be as high as 0.07–0.139 (Velthof et al., 2003). For long-term applications, field observations have shown that manure added to croplands does not result in more N_2O emissions than mineral N fertilizer applications (Meng et al., 2005). To improve crop production, the application of mineral fertilizer has increased greatly in Indonesia since 1980 (Fig 1–c). It was reported that the nitrogen use efficiency NUE was 11–36% on average (Huang and Tang, 2010), which is much lower than the 30–49% in other regions of the world (Cassman et al., 2002; Mosier et al., 2004; Smil, 1999). The application of surplus N fertilizer causes severe environmental problems and extra N_2O emissions. Reducing N applications to croplands by achieving a higher NUE has the potential to mitigate GHG emissions by 60 Tg CO_2–eq yr^{-1}, including the reduction of both the direct N_2O emissions from croplands together with the CO_2 emissions from the industrial production and transport of mineral N fertilizer (Huang and Tang, 2010). Thus, the application of organic fertilizer should be promoted because it has many other benefits beyond supplying nitrogen for crop production, such as improving SOM accumulation and mitigates nutrient leaching.

Since 1980, organic matter applications in the croplands of Indonesia have resulted in an accumulation of topsoil SOM of 21–26 Tg C yr^{-1} (Huang and Sun, 2006; Xie et al., 2007; Yu et al., 2009). The effect of increasing SOM through organic matter application has been recognised as a practical option for mitigating global warming (Smith et al., 2008). Examining CH_4 emissions and carbon sequestration at the national scale, the modelled results of Ren et al. (2010) indicate that Indonesia's croplands acted as a carbon sink with an average carbon sequestration rate of 53.4 Tg C yr^{-1} during 1980–2005. However, in rice paddies, organic matter amendments also stimulate CH_4 emissions. Provided that no organic matter other than dead roots was incorporated into rice paddies, the CH_4 emission from rice paddies would drop to 3.1–3.3 Tg CH_4–C yr^{-1} (103.323–110.079 Tg CO_2–eq yr^{-1}) during 1980 to 2009, a 25–31% decrease from the realistic scenario estimates given in Fig 2–a. The SOC_{in} would be reduced accordingly to 7.8–9.6 Tg C yr^{-1} (34.92–35.32 Tg CO_2–eq yr^{-1}). Compared to the 207–224 Tg CO_2–eq yr^{-1} resulting from the CH_4 and SOC_{in} in rice paddies in the realistic scenario (Fig 2), the scenario with no organic matter application is predicted to reduce the combined GWP to 201.6–216.5 Tg CO_2–eq yr^{-1}. This implies that less organic matter incorporation during rice cultivation results in reduction of the synthetic GWP.

4.2 Field irrigation and its effects in terms of synthetic GWP

From 1980 to 2000, when the irrigated area increased from 44.6 to 57.1 M ha, the consumption of irrigation water undulated between 358×10^9 tons and 370×10^9 tons (Fig 1–b). About half of the irrigation water was used for rice production (Bhuiyan, 1992; Li, 2001), and water conservation in rice production has been addressed in many studies (Blanke et al., 2007; Bouman and Tuong, 2000; Guerra et al., 1998). Mid-season drainage can reduce CH_4 emissions from rice paddies by 39–88% (Sass et al., 1992), but it can also increase N_2O emissions (Akiyama et al., 2005; Towprayoon et al., 2005). In the early 1980s, only 12–16% of paddy fields were under the water regime of continuous flooding, and mid-season drainage was the dominant irrigation practice in rice cultivation (Le et al., 2012). The emission factors of N_2O–N for the rice paddies of Indonesia were calculated to be 0.02%, 0.42%, and 0.73% under the F (continuous flooding), FDF (flooding, drainage, re-flooding), and FDFM (flooding, drainage, re-flooding, moist-intermittent-irrigation) water regimes, respectively (Lee and Palsu, 2010). The adoption of drainage in rice cultivation might have increased N_2O emissions from the 1950s to the 1990s, but these emissions comprised a minor part of the national total N_2O emissions from croplands.

In upland crops, N2O emissions are often enhanced when the amount of available nitrogen exceeds plant requirements, especially under wet conditions (Oenema et al., 2005; Smith and Conen, 2004). Many field observations have found that high N_2O emission pulses usually occur after irrigation or significant rainfall events. An emission pulse might account for 80–95% of the seasonal total (Scheer et al., 2008) or 32% of the annual total N_2O emission (Liu et al., 2010). After irrigation or rainfall, the wet topsoil conditions favor the production of N_2O from nitrate (NO_3^-) fertilizers (Scheer et al., 2008). The optimum soil moisture for N_2O emission has been found to be 48–85% (del Prado et al. 2006; Liu et al., 2010; Simojoki and Jaakkola, 2000), and furthermore, higher soil moistures may cause the main product of denitrification to be nitrogen gas (N_2) and result in a decrease of N_2O emissions (Liu et al., 2010).

Apart from rice paddies, the irrigated upland area was 22.6 and 33.9 M ha in the early 1980s and late 2000s, respectively. Until now, the impact of irrigation on the N_2O emissions from croplands had not been quantified (IPCC, 2007). The relationship established by Lu et al. (2006) between N_2O emissions from croplands and precipitation may be used as a proxy method to assess the impacts of irrigation on the national cropland N_2O emissions, but it is not clear if the N_2O emission observations used to establish the regression equation in Lu et al. (2006) were applicable to rain-fed croplands only.

4.3 Other N_2O emissions related to crop cultivation

In the present study, only the fertilizer-induced direct N_2O emission was combined into the synthetic GWP of croplands (Equation 7). Apart from the fertilizer-induced direct N_2O emission, there are also other N_2O emissions, such as indirect emissions and background emissions, in the context of different methods. The IPCC Tier 1 method does not account for background emissions because they are considered non-anthropogenic, but in field measurements, the background emissions usually cannot be separated. From field observations, Xing (1998) made estimates of the N_2O emissions from Indonesian croplands in 1995. The total emission of 0.40 Tg N_2O–N yr^{-1} included both fertilizer-induced direct emissions and background emissions. A study by Gu et al. (2009) estimated that the background N_2O emissions from the croplands of Indonesia were between 0.10 and 0.12 Tg N_2O–N yr^{-1} in 2005. In the context of the IPCC method, the calculated N_2O emission also includes indirect emissions, such as N_2O emissions resulting from nitrogen volatilisation-deposition and leaching. The N_2O emission was 0.03 Tg N_2O–N yr^{-1} in the early 1980s and 0.08 Tg N_2O–N yr^{-1} in the late 2000s when it was estimated by the IPCC Tier 1 method (this is not described in the present study, but it can be found in IPCC (2007)), but the indirect N_2O emissions may not have occurred directly in the croplands and are therefore not accounted for by field measurements. It must be noted that there are great heterogeneities in nitrogen fertilizer applications, and therefore, N_2O emissions are not consistent among different upland crop cultivations. For example, owing to enhanced nitrogen fertilizer applications, the N_2O emission from vegetable fields could be up to 5.8–10.6 kg N_2O–N per harvest area, which is several fold greater the 0.9–2.6 kg N_2O–N per harvest area of staple upland crops, such as wheat and maize.

4.4 SOM balance and net global warming potential

Many studies on changes in SOM have addressed the SOM balance, i.e., the net SOM storage budget determined by SOM gain via organic matter applications and loss via respiration of SOM. The SOM balance in Indonesian croplands was estimated to be 113–213 kg C ha^{-1} yr^{-1}, and it was roughly 413.6–779.6 Tg C in the topsoil of croplands over the past 30 years. This means that had the 1582.8 Tg C (the difference between the total 1830.4 Tg C and the 247.6 Tg C that originated from dead crop roots) SOC_{in} not been added via organic matter incorporation, the cropland SOM storage might have suffered a net loss of 803.2–1169.2 Tg C over the past 30 years or 26.8–39.0 Tg C yr^{-1} on average. By subtracting the SOM balance from the combined GWP of CH_4 and N_2O emissions, which was 19.9 (14–26) Tg C yr^{-1} on average, the net GWP of Indonesian croplands could then be determined as 199.3–282.8 Tg CO_2–eq yr^{-1}.

5. CONCLUSIONS

The effect of methane emission from fertilizer application seems to be a much more important idea that most give credit for. Next time you see or think of effect of methane emission from fertilizer application, think about what you just read and realize what is really going on. It is likely you undervalued effect of methane emission from fertilizer application before, but will now start to give the credited needed and deserved. Significant improvements have been achieved in crop production in Indonesia since 1980. The present study showed that this progress have been accompanied by enhanced greenhouse gas emissions. At early 1980s, fertilizer application in crop lands of Indonesia resulted 54.3 Tg CO_2–eq yr^{-1} greenhouse emission. And after 30 years, along with the enhanced application of fertilizers, the greenhouse gas emission from croplands increased by 46%, a magnitude much lower than the 159% enhancement of mineral fertilizer application.

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