Global warming potential from maize cultivation as affected by organic and biochar coated urea fertilizer in rainfed lowland

A Pramono, T A Adriany, H L Susilawati, and M T Sutriadi

Indonesian Agricultural Environment Research Institute, Pati, Indonesia
*Email: ali_pramono@yahoo.com

Abstract. Biochar is a pyrolysis product used for soil amendments and could be applied as organic fertilizer and biochar coated urea. Biochar increased organic matter stability and mitigate climate change by carbon sequestration and reduce N₂O emission. This study aimed to study the effect of biochar coated urea (BCU) fertilizer on global warming potential (GWP) and the economic feasibility of maize cultivation in the rainfed lowland area. The study was carried out at the Indonesian Agricultural Environment Research Institute (IAERI) Pati, Central Java, from July to October 2017. Six treatments were used as follows, 1) FYM+Phonska+Ureaprill, 2) FYM+Phonska+BCU, 3) Biocompost+Phonska+Urea prill, 4) Biocompost+Phonska+BCU, 5) sludge+Phonska+Urea prill, and 6) sludge+Phonska+BCU. All of the treatments were given 3 tons/ha of organic fertilizer and inorganic fertilizer at the same rate. Gas sampling was performed using a closed chamber method. The results showed that BCU application combined organic fertilizer could reduce GWP (CO₂-e) by 12.5% compared to the urea prill application. The highest GWP was determined by the application of Sludge+Phonska+Urea prill by 8.9 ton CO₂-e per ha. The highest maize grain yield was Biocompost+Phonska+BCU application by 7.29 tons per ha. Biochar application in agricultural ecosystems is a potential option to mitigate climate change and supporting food availability.

1. Introduction
Indonesia is the 6th largest producer in the world and contributes 2% of maize (Zea mays L.) production. Maize is the second most important cereal crop after rice, in terms of the percentage harvested area relative to all food crops' total area. In rainfed areas, maize is grown mainly (89%). To meet the maize demands, production has to be increased through technology improvement and the harvested area's extension. Indonesia's harvested area is approximately 3.9 million ha, with a productivity of 5.45 tons/ha. The total production is about 19.6 million tons in 2015 [1], and the targeted production is 34 million tons in 2020. Maize is grown in all provinces in Indonesia. In some provinces, such as East Nusa Tenggara, West Nusa Tenggara, Central Sulawesi, South Sulawesi, Central Java, maize is consumed as a supplement to staple food. East Java, Central Java, and Lampung
are the leading maize producers in Indonesia, while South Sulawesi, North Sumatera, West Java, and Gorontalo are the second important producers [2].

Agricultural greenhouse gas (GHG) emissions and land-use change have doubled over the past 50 years [3] and accounted for 25% of total anthropogenic emissions [4]. Intensive crop production also contributes to GHG emissions. Nitrous oxide ($\text{N}_2\text{O}$) is emitted through agricultural activities and contributed to global GHG emissions [5]. Agricultural management practices can also affect GHG emissions [6]. As one of the first countries to commit to a significant reduction in its GHG emissions, Indonesia has committed to reducing emission levels by 29 percent by 2030, below the business-as-usual scenario, and by 41 percent with international support [7].

Biochar has potential use, making it an effective, economical, and eco-friendly way for soil carbon sequestration [8]. Biochar amendment significantly reduced CO$_2$, CH$_4$, and N$_2$O emission fluxes [9]. Biochar is a product made from organic materials rich in carbon (C) and is found in soils in very stable solid forms, often as carbon stock. Biochar can remain for long terms in the soil at various depths [10]. Biochar combined with bacteria showed an improvement in plant height, biomass production, seed germination, chlorophyll, protein, and carbohydrate content [11]. Biochar was also used for coating material to make slow-release Urea [12]. Organic and inorganic fertilizers play important roles in maintaining soil fertility. Since inorganic fertilizer is often too expensive for the farmer in Indonesia, many have adopted 'integrated soil fertility management', which complements synthetic nutrients with organic inputs obtained by improved waste recycling and crop residue composting, and the incorporation of grain legumes. This study's objective was to know the effect of organic and nitrogen fertilizer management on global warming potential (GWP) and the economic feasibility of maize cultivation in the rainfed lowland area.

2. Materials and Methods

The study was carried out from July to October 2017 at the Indonesian Agricultural Environment Research Institute (IAERI) experimental field site in a rainfed lowland area (6°46'39.7"S and 111°11'53.0" E), located in Pati District, Central Java Province and 11 m above sea level. The area is characterized by an average annual rainfall of less than 1500 mm. The main soil type in the study area is acid endoaquents, which are generally acidic, low in organic matter and deficient in exchangeable cation [13]. This experiment used a randomized complete block design with three replications. The Six treatments were used as follows, 1) FYM+Phonska+Ureapril, 2) FYM+Phonska+biochar coated urea, 3) Biocompost+Phonska+Urea prill, 4) Biocompost+Phonska+biochar coated urea, 5) sludge+Phonska+Urea prill, and 6) sludge+Phonska+biochar coated urea. All of the treatments were given 3 tons/ha of organic fertilizer and inorganic fertilizer at the same rate. The inorganic fertilizer rate was phonska (NPK:15-15-15) 300 kg ha$^{-1}$, urea 200 kg ha$^{-1}$, and urea coated biochar 200 kg ha$^{-1}$ (urea: biochar ratio, 4 : 1). Each replication plot was 30 m$^2$ in size. The plant spacing was 70 cm x 20 cm with two seeds of DK-77 variety per hole. Water irrigation was carried out periodically with water pumps in each experimental plot. The application of organic fertilizer such as farmyard manure, Biocompost, and sludge was applied after planting. Inorganic fertilizer was applied 15 days after planting (1st fertilization), and urea or urea coated biochar are given 50 days after planting (2nd fertilization). Biopesticide was applied every two weeks.

We observed CO$_2$ and N$_2$O emissions and maize grain yield. Gas sampling was done manually using the closed chamber method with 40 cm x 20 cm x 30 cm of size. Chamber headspace of gas samples (10 mL) were collected via syringe five times at 10 min intervals then transferred to storage vials. Gas concentrations in the samples were analyzed in the GHG laboratory within 24 hours by using gas chromatography (Varian GHG 450 Series, a GC System, Varian, Netherlands), which equipped with an electron capture detector (ECD) for N$_2$O analysis and thermal conductivity detector (TCD) for CO$_2$ analysis. The gas chromatography configurations for analyzing N$_2$O concentration were at 50°C column temperature, 350°C ECD temperature, and 100°C injector temperature. The methods for calculating the gas flux were described as below [14]:

\[ \text{Flux} = \frac{\text{Emission - Background}}{\text{Size} \times \text{Time}} \]
\[ E = \frac{\Delta C}{\Delta t} \times \frac{V}{A} \times \frac{mW}{mV} \times \frac{273.2}{273.2+T} \]  

(1)

Where \( E \) is \( \text{N}_2\text{O} \) or \( \text{CO}_2 \) flux (mg m\(^{-2}\) min\(^{-1}\)), \( mW \) is the molecular weight of \( \text{N}_2\text{O} \) or \( \text{CO}_2 \) (g), \( mV \) is the molecular volume of \( \text{N}_2\text{O} \) or \( \text{CO}_2 \) at standard temperature and pressure (22,411), \( C/t \) is changes of \( \text{N}_2\text{O} \) or \( \text{CO}_2 \) concentration over time (ppm per min), \( V \) is chamber volume (m\(^3\)), \( A \) is chamber area (m\(^2\)), and \( T \) is mean the air temperature inside the chamber during deployment (ºC). \( \text{N}_2\text{O} \) or \( \text{CO}_2 \) flux was calculated based on the rate of change in \( \text{N}_2\text{O} \) or \( \text{CO}_2 \) concentration, which was calculated as the slope of the linear regression of the concentration and time. The flux of \( \text{CO}_2 \) and \( \text{N}_2\text{O} \) was then converted as global warming potential (GWP) into kg \( \text{CO}_2 \)-equivalent ha\(^{-1}\) season\(^{-1}\). The GWP of \( \text{CO}_2 \) is 1, and \( \text{N}_2\text{O} \) is 265 [15]. Data obtained analyzed with variance at the 5% level to find out the effect of each treatment. If there was a significant difference, it continued with the Duncan Multiple Range Test level of 5%.

![Image of measurement of \( \text{N}_2\text{O} \) and \( \text{CO}_2 \) emissions with a closed chamber method.](image)

**Figure 1.** Measurement of \( \text{N}_2\text{O} \) and \( \text{CO}_2 \) emissions with a closed chamber method.

3. Result and Discussion

3.1 Effects of fertilization on carbon dioxide (\( \text{CO}_2 \)) and nitrous oxide (\( \text{N}_2\text{O} \)) emission

The gas sampling was taken approximately 11 days after planting and continued once every week until harvest. This study showed that at the pattern and magnitude of \( \text{CO}_2 \) daily flux of several types of organic material application in the soil (Figure 2). Measurement of \( \text{CO}_2 \) fluxes during plant growth showed a very similar pattern among all treatments. The \( \text{CO}_2 \) flux gradually increased during 81 days. The \( \text{CO}_2 \) fluxes tended to be higher in the sludge + Urea plot ranging from 3,344 to 15,027 mg m\(^{-2}\) day\(^{-1}\), so the \( \text{CO}_2 \) emission was highest (Figure 3).
The N\textsubscript{2}O flux measurement during plant growth is presented in Figure 4. A similar pattern of N\textsubscript{2}O flux showed a decreased during plant growth. Generally, the highest N\textsubscript{2}O fluxes happened in the first or second week after N application [13]. The N\textsubscript{2}O flux at the beginning of the vegetative phase is higher than at the end of observation. Fertilization gave a positive response to the value of N\textsubscript{2}O flux. Biocompost+Urea treatments showed the highest flux values. The highest flux value was found in the Biocompost+Urea treatment, which was 2.77 mg N\textsubscript{2}O m\textsuperscript{-2} day\textsuperscript{-1}. The difference in N\textsubscript{2}O flux between treatments was more clearly seen in the cumulative N\textsubscript{2}O flux seen in Figure 5. The N\textsubscript{2}O emissions from the soil were higher in the Biocompost+Urea plot than in the Biocompost+biochar coated Urea, sludge+Urea, FYM+biochar coated Urea, sludge+biochar coated Urea and FYM+Urea, with values of
1.55, 1.44, 1.35, 1.33, 1.32 and 1.28 kg ha\(^{-1}\) season\(^{-1}\), respectively. Urea fertilization affected a higher flux compared to biochar coated urea. The combined application of organic and biochar coated Urea fertilizer has been shown to protect the N from loss by volatilization, leaching, and denitrification, compared with Urea fertilizer applied. This is because of the processes involved in denitrification and nitrification immediately after N application [17]. N input's absorption efficiency is around 50-60\% and 2\% emitted as N\(_2\)O [18]. N\(_2\)O emissions from maize cultivation in this study ranged from 1.28-1.55 kg ha\(^{-1}\) season\(^{-1}\) or 0.9-1.1\% from N applied. The lowest N\(_2\)O emissions were found in the treatment of FYM+Urea, while the highest was in the Biocompost+Urea. Biochar coated urea application controlled nutrient release more slowly, and the N\(_2\)O emission could be reduced by 35\% lower than urea [19].

![Figure 4. N\(_2\)O flux on maize cropping under organic fertilizer application.](image)

3.2 Grain yield, global warming potential (GWP) and economic analysis

The yield-scaled GWP was calculated with GHG emission divided by crop yield production [20]. We found that the combination of organic and carbon-coated urea could reduce GWP by 12.5\% on average compared to the combination of organic and Urea prill (Table 1). Biocompost+biochar coated Urea treatment gave the highest maize grain yield compared to other treatments, so the GWP yield scale was lower. Several management practices and technologies mitigate GHG emissions from soils. Soil conservation techniques reduce CO\(_2\) emissions through the reduction of erosion, protecting the soil surface with crop residues, and increasing the N use efficiency by crops [21].
Figure 5. N$_2$O emission on maize cropping under organic fertilizer application.

Table 1. Global warming potential of maize cropping under organic fertilizer management.

| Treatment                          | GHG Emission (kg ha$^{-1}$ season$^{-1}$) | GWP (kg CO$_2$-e ha$^{-1}$ season$^{-1}$) | Yield (ton ha$^{-1}$) | GWP yield scale |
|-----------------------------------|------------------------------------------|-------------------------------------------|-----------------------|-----------------|
| FYM+Urea prill                    | 8,258$^b$                                | 1.28$^b$                                  | 8,598                 | 7.00$^b$        | 1.23            |
| FYM+biochar coated Urea           | 6,409$^a$                                | 1.33$^b$                                  | 8,565                 | 7.21$^a$        | 1.19            |
| Biocompost+Urea prill             | 7,814$^b$                                | 1.55$^a$                                  | 8,225                 | 6.70$^c$        | 1.23            |
| Biocompost+biochar coated Urea    | 6,817$^c$                                | 1.44$^a$                                  | 7,199                 | 7.29$^a$        | 0.99            |
| Sludge+Urea prill                 | 8,589$^a$                                | 1.35$^a$                                  | 8,947                 | 6.72$^c$        | 1.33            |
| Sludge+biochar coated Urea        | 8,239$^b$                                | 1.32$^b$                                  | 8,589                 | 6.75$^c$        | 1.27            |

Different letters indicate significant differences by Duncan Multiple Range Test at p < 0.05.

The maize grain yield ranges between 6.7-7.3 tons ha$^{-1}$. The highest grain yield was obtained from the Biocompost+biochar coated Urea treatment of 7.3 tons ha$^{-1}$ and increased 9% compared to Biocompost+Urea treatment. Our finding also compatible with the other results, where the yield increase in cereal field biochar experiments ranged from 6.6–11.3% [16]. The results of the economic analysis of the maize cultivation with organic management fertilizer treatments are listed in Table 2. The highest profits were obtained with Biocompost+biochar coated Urea treatment, which amounted to Rp 3,404,048 ha$^{-1}$ with a BC ratio of 0.30.

This study indicated that the grain yield in the study area was high for rainfed areas. The low and lower yields of rainfed lowland rice in Central Java can be attributed to drought, nutrient stress, weed, pests, and disease infestation, or a combination of these factors. In general, maize productivity at the farm level was still low and reached 4.8 t ha$^{-1}$ [22]. At the research level, it could reach 6-10 t ha$^{-1}$, depending on land conditions and the technology applied [23]. Some advantages of land use in the dry season for maize cultivation. First, the yield is quite high. Second, plant biomass (stems and leaves) can be used to forage animal feed, especially cattle. Third, the level of soil fertility can be maintained because of crop rotation. Fourth, land productivity increases so that farmers’ income also increases [24]. Organic matter applications, such as FYM, sludge, compost, and biochar, have increased maize yield and enhanced soil fertility and resilience to climate changes. The biochar-based urea fertilizer can reduce nutrient release rate and improve the efficiency of fertilizers application and environmental
benefits of soil. Our study indicated that organic application could mitigate the negative impacts and maximize the positive effects of climate changes on maize production in Indonesia.

### Table 2. Economic analysis of maize cultivation under organic application.

| No | Treatment | Costs | Unit | Vol       |
|----|-----------|-------|------|-----------|
|    |           | FYM+U | FYM+BCU | Bc+U | Bc+BCU | S+U | S+BCU |
| A  | Labor     | 1     | 6.0 Man | 416,667 | 416,667 | 416,667 | 416,667 | 416,667 | 416,667 |
|    | Organic appl | 2     | 35.7 Man | 1,785,714 | 1,785,714 | 1,785,714 | 1,785,714 | 1,785,714 | 1,785,714 |
|    | Planting  | 3     | 119.0 Hour | 1,785,714 | 1,785,714 | 1,785,714 | 1,785,714 | 1,785,714 | 1,785,714 |
|    | Irrigation | 4     | 6.0 Man | 416,667 | 416,667 | 416,667 | 416,667 | 416,667 | 416,667 |
|    | Fertilizer appl I | 5     | 23.8 Man | 1,190,476 | 1,190,476 | 1,190,476 | 1,190,476 | 1,190,476 | 1,190,476 |
|    | Weeding   | 6     | 6.0 Man | 416,667 | 416,667 | 416,667 | 416,667 | 416,667 | 416,667 |
|    | Fertilizer appl II | 7     | 23.8 Man | 1,666,667 | 1,666,667 | 1,666,667 | 1,666,667 | 1,666,667 | 1,666,667 |
| B  | Materials | 1     | 35.7 kg | 357,143 | 357,143 | 357,143 | 357,143 | 357,143 | 357,143 |
|    | Seed      | 2     | 3000 kg  | 1,500,000 | 1,500,000 | 1,500,000 | 1,500,000 | 1,500,000 | 1,500,000 |
|    | Organic fertilizer | 3     | 300 kg   | 600,000 | 600,000 | 600,000 | 600,000 | 600,000 | 600,000 |
|    | NPK Fertilizer | 4     | 200 kg   | 360,000 | 360,000 | 360,000 | 360,000 | 360,000 | 360,000 |
|    | Urea      | 5     | 200 kg   | 0 | 440,000 | 0 | 440,000 | 0 | 440,000 |
|    | Biochar coated Urea | 6     | 11.9 package | 595,238 | 595,238 | 595,238 | 595,238 | 595,238 | 595,238 |
|    | Pesticide | 7     | 11,090,952 | 11,170,952 | 11,090,952 | 11,170,952 | 11,090,952 | 11,170,952 | 11,170,952 |

Note: The price of maize grain on the farm level was IDR 2,800 (BPS, 2017).

### 4. Conclusions

Biochar coated urea (BCU) application combined organic fertilizer could reduce GWP (CO$_2$-e) by 12.5% compared to urea application. Maximum global warming potential (GWP) (8,947 kg CO$_2$-e ha$^{-1}$ season$^{-1}$) was determined for the combined application of sludge+Urea. The highest maize grain yield was the Biocompost+biochar coated Urea. Biochar application in agricultural ecosystems is a potential option to mitigate climate change and support food availability.

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