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RESEARCH ARTICLE

Assessment of Nitrogen Volatilization and Greenhouse Gas Emissions from Urea with N-stabilizer in a Productive Oil Palm Plantation (*Elaeis guineensis* Jacq.)

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Abstract

Nitrogen fertilization plays a crucial role in supporting plant growth. However, nitrogen in the soil can be lost through rainwater leaching. To address this issue, the concept of fertilizing N-stabilizer-coated urea was proposed. The aim is to reduce nitrogen loss on the field due to vaporization and minimize greenhouse gas (GHG) emissions. The study was conducted to assess the effectiveness of this N-stabilizer-coated urea in reducing nitrogen loss through vaporization, improving GHG emissions, and its impact on plant growth and leaf quality. The research was conducted at IPB-Cargill Jonggol, Bogor, West Java, oil palm education and research station from August 2021 to March 2022. The experimental design employed a completely randomized block design. The fertilizer treatments included four types of nitrogen fertilizers: urea (46% N), coated urea with N-stabilizer (46% N), ZA (21% N), and NPK (15-15-15, 15% N). Additionally, a control treatment without any fertilizer application was included. All treatments were replicated three times. Data analysis was done using the SAS (Statistical Analysis System) 9.0 program. The F-test was conducted, followed by DMRT (Duncan Multiple Range Test) advanced tests at a 5% error level. The results revealed that urea with N-stabilizer fertilization significantly reduced NH_3-vaporization by 53% in the first week compared to the application of normal urea. NH_3-vaporization level from ZA and NPK was < 1% compared to urea application. Field application of urea with N-stabilizer showed no significant difference in greenhouse gas emission (GHG) compared to the other nitrogen fertilizer types. The GHG values ranged from 7.10 to 7.29 g CO_2-e.m^{-2} per day. The use of N-stabilizer-coated urea could be an effective approach to minimize nitrogen loss through vaporization and reduce greenhouse gas emissions while maintaining comparable results to other nitrogen fertilizer types in terms of GHG emissions on the field.

Keywords: urea vaporization, slow-release fertilizer, urease inhibitor, nitrification inhibitor

Introduction

Oil palm plantations have grown significantly over the years, leading to expansion and increased production. Between 2015 and 2019, the area of oil palm plantations grew from 11,260,277 ha to 14,456,611 ha, with production increasing from 31,070,015 tons to 47,120,247 tons (Directorate General of Estate Crops, 2021). However, such expansion may impact the ecosystem positively or negatively, depending on management practices. Poor plantation management can result in land degradation and reduce productivity.

One of the key macronutrients essential for plant growth is nitrogen, which plants absorb in the form of NO_3^- or NH_4^+ from the soil. Nitrogen deficiency can lead to stunted growth and negatively affect chloroplast development and function, resulting in the hydrolysis of proteins into amino acids, which are then translocated to young leaves. Initial symptoms of nitrogen deficiency manifest in old leaves, which turn pale green, pale yellow, or bright yellow (chlorosis) and may experience necrosis (Bala and Fagbayide, 2009). Studies have shown that N fertilizer application can increase N levels in the top 0–20 cm of the soil by 0.21%, but at greater depths (20–60 cm), nutrient

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levels decrease due to plant uptake and nutrient leaching (Albari et al., 2018). Nitrogen loss from the soil occurs primarily through drainage water, vaporization, and plant absorption (Patty et al., 2013).

To improve fertilizer efficiency, reduce nitrogen losses, and minimize greenhouse gases, researchers have focused on developing Advanced Fertilizers (AF), which offer various advantages, including environmental friendliness and higher efficiency. To reduce nitrogen fertilization losses, additional active ingredients such as NBPT (N-(n-butyl)thiophosphoric triamide) intended to limit the release of nitrogen-containing gases following fertilization (Rose et al., 2018), NPPT (N-(n-prophyl)thiophosphoric triamide) reduce the risk of nitrogen loss in the form of ammonia emission after urea fertilizer application, thereby improving nitrogen use efficiency (Modolo et al., 2018), and DCD (dicyandiamide) DCD temporarily inhibits nitrification by deactivating the enzyme ammonia monooxygenase (AMO) in ammonia-oxidizing microbes (Di et al., 2010) have been incorporated into N fertilizer formulas.

Studies have demonstrated that urea fertilizer without NBPT addition experiences significant NH_3 loss after fertilization, primarily due to rapid hydrolysis after minimal rainfall. Including NBPT as an active ingredient can reduce NH_3 loss by 35%, as it inhibits the hydrolysis process of urea (Martin et al., 2017). Additionally, urea treated with NBPT significantly cut NH3 emissions by approximately 60% to 80% compared to regular urea, with these effects lasting up to 10 days after application (Smith et al., 2021). Furthermore, applying urea enriched with additives such as DCD can significantly reduce N_2O emissions compared to urea without stabilizers. The addition of DCD reduced N_2O emissions by up to 97.1% compared to standard urea application (An et al., 2021).

The primary objective of this study is to assess the improvement in greenhouse gas emissions in oil palm plantations resulting from using urea with N-stabilizer compared to urea, ZA, and NPK fertilizers. By evaluating the impact of different fertilizers on greenhouse gas emissions, we can identify more environmentally friendly and efficient options for oil palm cultivation.

Materials and Methods

The experiment was conducted at the IPB-Cargill Jonggol Teaching Farm, Jonggol District, Bogor Regency, West Java, and the Laboratory of Ecotoxicology, Waste, and Bioagents, IPB University. The study used 12-year-old productive oil palms and lasted from August 2021 to March 2022.

A closed gas chamber method (IAEA, 1992) was employed to sample greenhouse gases. A manually assembled 12-inch PVC pipe at 30 cm height formed the gas chamber, with a transparent acrylic glass (12 inches in diameter) glued to the top for clear visibility of measurement tools inside the chamber. A small fan ensured homogenous gas mixing. Ammonia gas vaporization from the soil was measured using the AR8500-5133423 ammonia gas detector, while carbon dioxide emitted from fertilizer application sites was measured using the HT-2000 CO_2 gas detector. Gas samples were collected with a 100 ml syringe and sent to the Laboratory of the Indonesian Agricultural Research Institute, Pati Regency, Central Java, for N_2O and CH_4 analyses using Gas Chromatography.

The experimental design utilized a completely randomized block design with nitrogen type as a factor, which consisted of four types of nitrogen fertilizer and one control treatment without any fertilizer application. Each treatment involved three oil palm trees, making a total of 45 samples. Nitrogen fertilization was applied at a dose of 1.1 kg N per tree. The treatments included control (without nitrogen fertilizer), Urea (46% N), Urea with N-stabilizer (46% N) containing NBPT and DCD as supplementary ingredients, ZA (21% N), and NPK (15-15-15, 15% N). Fertilizer was spread in a circular area with a radius of 1.5 m, preceded by clearing weeds from the oil palm circle.

The close gas chambers were positioned at different distances from the tree: 0.5 m (circle area), 1.85 m (active path area), and 5.85 m (center representative area among the oil palm trees). The observed greenhouse gases were CO_2, CH_4, and N_2O. Gas sampling occurred 10 minutes after closing the chamber, and measurements were made on days 1, 2, 3, 5, 7, 14, 30, and 45 after fertilizer application.

The potential greenhouse gas e-CO_2 was calculated using the formula adapted from the second assessment report of IPCC (1995):
Potential CO_2 emissions equivalent (CO_2-e)
= (total CO_2 emission x 1)+(total CH_4 emission x 21)+(total emission N_2O x 310)

Where
- Total CO_2 emissions = sum of CO_2 emissions at circle area, active path area, including center representative area among the oil palm trees ($g.m^{-2}$ per day)
- Total CH_4 emissions = sum of CH_4 emissions at circle area, active path area, including center

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representative area among the oil palm trees (g.m^{-2} per day)

- Total N_2O emissions = sum of N_2O emissions at circle area, active path area, including center representative area among the oil palm trees (g.m^{-2} per day)

Climate data, including rainfall and the number of rainy days, were collected manually using an ombrometer placed at the study site. The data obtained were analyzed using the F-test. If the F-test was significant, a Duncan Multiple Range Test (DMRT) follow-up test was performed at a 5% level using the SAS software (Statistical Analysis System).

Result and Discussion

The timing and intensity of rainfall can significantly affect the microclimatic conditions of the study site and subsequently impact various processes, such as the hydrolysis of urea, nitrification, and nutrient leaching. The research was conducted during the onset of the rainy season in October; therefore, the study site experienced frequent rainfall during the study period, particularly in the afternoon. The first rain occurred on the 5th day after the application of fertilization, and it measured 5.7 mm (Figure 1).

The rainfall can positively affect water availability in the soil, which is essential for the dissolution and hydrolysis of urea. Water is required for the urease enzyme to break down urea into NH_3 and bicarbonate ions. Therefore, the rain on the 5th day after fertilization could have facilitated hydrolysis and increased ammonium availability in the soil. On the other hand, rainfall may have also affected nutrient leaching, which refers to the process where nutrients, including nitrogen, are washed away from the soil surface and carried deeper into the soil profile or even lost to the surrounding environment. Heavy rainfall can cause excessive leaching of nutrients, including nitrate (NO_3^-), a soluble form of nitrogen. This leaching can lead to nutrient losses and reduce the overall efficiency of the fertilizer application.

Moreover, rainfall can influence nitrification, which is the conversion of ammonium to nitrate by nitrifying bacteria. Excessive rain and waterlogging can slow down nitrification, thereby reducing the loss of nitrogen through N_2O emissions.

The results of the study indicate that the application of N-stabilizer-coated urea effectively reduces the loss of urea fertilizer through NH_3-vaporization. The N-stabilizer urea demonstrated a remarkable 58.8% reduction in NH_3-vaporization during the first five days after application compared to regular urea (Table 1). The presence of urease and nitrification inhibitors in the N-stabilizer urea contributed to this significant suppression of NH_3-vaporization. The peak of NH_3 vaporization occurred on the second day after application (9.290 g.m^{-2} per day) and gradually decreased until it was no longer detected on the 14th day after application. The results of this study are comparable to those of Gricke et al. (2011), who reported nitrogen losses of up to 21% through NH_3 volatilization on the 3rd day after fertilizer application. Yuan et al. (2021) Recent research has shown that incorporating dicyandiamide (DCD) into nitrogen

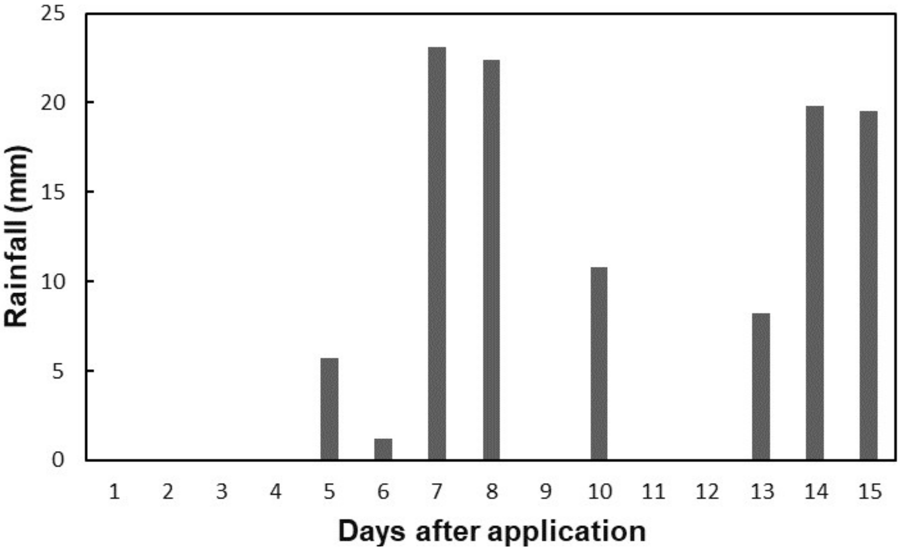

Figure 1. Daily rainfall after fertilization application. Daily rainfall was measured from the first day after fertilization application.

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Table 1. Ammonia NH_3 volatilization from different types of nitrogen fertilizers.

Treatment	1 DAA	2 DAA	3 DAA	5 DAA	7 DAA	14 DAA	30 DAA	45 DAA
Unit					g.m^{-2} per day			
Control	0.000^{b}	0.000^{c}	0.000^{b}	0.000^{a}	0.007^{b}	0.000	0.000	0.000
Urea	7.842^{a}	9.290^{a}	6.967^{a}	0.114^{a}	0.033^{a}	0.000	0.000	0.000
Urea with N-stabilizer	4.873^{ab}	5.054^{b}	1.386^{b}	0.091^{a}	0.019^{ab}	0.000	0.000	0.000
ZA	0.015^{b}	0.000^{c}	0.000^{b}	0.012^{a}	0.031^{a}	0.000	0.000	0.000
NPK	0.000^{b}	0.010^{c}	0.005^{b}	0.028^{a}	0.030^{a}	0.000	0.000	0.000

Note: values followed by the same letter in the same column are not significantly different based on the 5% test of variance; DAA = days after application; nitrogen vaporization data on staple disks, control (no nitrogen fertilization), urea (nitrogen fertilizer 1.1 kg N per tree); urea with N-stabilizer (nitrogen fertilizer 1.1 kg N per tree) with a mixture of nitrification inhibitors and urease inhibitors; ZA (ammonium sulfate fertilizer 1.1 kg N per tree, 21%N); NPK 15-15-15 (nitrogen fertilizer 1.1 kg N per tree).

fertilization significantly decreases ammonia (NH_3) volatilization by about 45-55% and can delay the peak NH_3 flux by 2-4 days compared to controls. Clay et al. (1990) reported similar results where the peak post-fertilization NH_3 volatilization flux occurred on day 2, then continued to decline until day four after application.

Furthermore, gas chromatography tests revealed that the N-stabilizer urea application resulted in higher CH_4 gas emissions on the second day after application compared to regular urea treatment at 0.067 g.m^{-2} per day (Table 2). Urea fertilization increases nitrogen availability in the soil, leading to increased emissions of CH_4 and N_2O gases. The presence of ammonium in the soil from urea fertilization increases the likelihood of nitrification, leading to the production of nitrate, which can be lost more easily than ammonium. However, the addition of nitrification inhibitors and urease inhibitors in the N-stabilizer urea helps prevent this nitrogen loss.

Regarding N_2O gas emissions, there were no significant differences among the various nitrogen fertilizer types, including the N-stabilizer urea (Table 3). The highest N_2O gas emissions were measured 5 to 30 days after application, with levels ranging from 0.0140 to 0.0143 g.m^{-2} per day. The peak on day five was influenced by rain at the study site, which increased N_2O gas emissions. However, the N-stabilizer urea did not show a reduction or increase in N_2O gas emissions compared to other nitrogen fertilizers. Research results of Rahman et al. (2019) also showed significant increases in N_2O gas emissions in the urea treatment during a rain simulation. Other studies have reported reductions in N_2O gas emissions using nitrification inhibitors in nitrogen fertilization, but in this study, the N-stabilizer urea did not show such reductions. Dong et al., (2021) reported a reduction in N_2O gas emissions due to the addition of DCD on nitrogen fertilizing. Earlier studies (Wang et al., 2020) reported a reduction in N_2O gas emissions in nitrification inhibitor treatment in nitrogen fertilization.

In summary, the application of N-stabilizer urea effectively reduces NH_3 vaporization during oil palm fertilization, potentially leading to improved nitrogen use efficiency and reduced nitrogen loss. However, N_2O gas emissions were not significantly affected by the application of N-stabilizer urea. Further research may be required to explore additional factors that influence greenhouse gas emissions and assess the environmental impact of different nitrogen fertilizer types in oil palm plantations.

The results indicate that the CO_2 gas emissions were highest in the urea with N-stabilizer fertilization treatment and the regular urea fertilization treatment up to the third day after application (Table 4). The emissions decreased significantly on the fifth day after application to 1.584 g.m^{-2} per day and 1.470 g.m^{-2} per day, respectively. These CO_2 gas emissions originate from various sources, including palm root activity, weed activity, microorganism activity, and the hydrolysis process of urea. The urea hydrolysis process leads to bicarbonate production, which subsequently becomes CO_2 gas, resulting in increased CO_2 emissions in the first few days after application. This value of CO_2 gas emissions will then be added up with N_2O gas emissions and CH_2 gas emissions to get a CO_2 equivalent potential greenhouse gas (GHG) emission value.

With the urea with N-stabilizer treatment, there was a slowdown in CO_2 gas emissions due to the presence of urease inhibitors, which suppress the hydrolysis rate of urea and reduce the activity of heterotrophic microorganisms, such as NH_3 oxidizing bacteria, responsible for CO_2 emissions. This led to lower CO_2 gas emissions on the seventh day after application than the regular urea treatment. Previous studies have

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Table 2. CH_4 gas emissions from different types of nitrogen fertilizers.

Treatment	0 DAA	1 DAA	2 DAA	3 DAA	5 DAA	7 DAA	14 DAA	30 DAA	45 DAA	Total (g.m^{-2})
Unit	g.m^{-2} per day									
Control	0.056c	0.054a	0.063a	0.059a	0.067b	0.066a	0.062a	0.061a	0.071a	3.029a
Urea	0.058b	0.061a	0.066a	0.062a	0.061c	0.063a	0.062a	0.053a	0.070a	2.866a
Urea N-stabilizer	0.056c	0.063a	0.067a	0.062a	0.065bc	0.066a	0.058a	0.061a	0.072a	3.000a
ZA	0.059ab	0.056a	0.059a	0.067a	0.063bc	0.063a	0.065a	0.056a	0.071a	2.950a
NPK	0.060a	0.063a	0.061a	0.065a	0.073a	0.064a	0.063a	0.075a	0.069a	3.125a

Note: values followed by the same letter in the same column are not significantly different based on the 5% test of variance; DAA = days after application; nitrogen vaporization data on staple disks, control (no nitrogen fertilization), urea (nitrogen fertilizer 1.1 kg N per tree); urea with N-stabilizer (nitrogen fertilizer 1.1 kg N per tree) with a mixture of nitrification inhibitors and urease inhibitors; ZA (ammonium sulfate fertilizer 1.1 kg N per tree, 21% N); NPK 15-15-15 (nitrogen fertilizer 1.1 kg N per tree); the amount represents the total emission for 45 days.

Table 3. N_2O gas emissions from different types of nitrogen fertilizers.

Treatment	0 DAA	1 DAA	2 DAA	3 DAA	5 DAA	7 DAA	14 DAA	30 DAA	45 DAA	Total (g.m^{-2})
Unit	g.m^{-2} per day									
Control	0.011a	0.011a	0.012a	0.012a	0.014a	0.012a	0.014a	0.014a	0.012a	0.599a
Urea	0.010a	0.012a	0.012a	0.012a	0.014a	0.012a	0.013a	0.014a	0.012a	0.598a
Urea N-stabilizer	0.010a	0.012a	0.012a	0.012a	0.014a	0.012a	0.014a	0.014a	0.012a	0.612a
ZA	0.011a	0.011a	0.012a	0.012a	0.013b	0.012a	0.014a	0.014a	0.012a	0.598a
NPK	0.011a	0.012a	0.012a	0.012a	0.014a	0.012a	0.014a	0.014a	0.012a	0.599a

Note: values followed by the same letter in the same column are not significantly different based on the 5% test of variance; DAA = days after application; nitrogen vaporization data on staple disks, control (no nitrogen fertilization), urea (nitrogen fertilizer 1.1 kg N per tree); urea with N-stabilizer (nitrogen fertilizer 1.1 kg N per tree) with a mixture of nitrification inhibitors and urease inhibitors; ZA (ammonium sulfate fertilizer 1.1 kg N per tree, 21% N); NPK 15-15-15 (nitrogen fertilizer 1.1 kg N per tree); the amount represents the total emission for 45 days.

Table 4. CO_2 gas emissions from different types of nitrogen fertilizers.

Treatment	1 DAA	2 DAA	3 DAA	5 DAA	7 DAA	14 DAA	30 DAA	45 DAA	Total (g.m^{-2})
Unit	g.m^{-2} per day								
Control	0.822d	2.120c	2.493b	1.781b	2.465ab	0.985a	0.511c	2.610a	66.145
Urea	3.173b	4.867a	4.431a	1.469c	2.759a	0.760c	1.438b	1.495b	74.306
Urea N-stabilizer	4.720a	4.957a	4.985a	1.584bc	2.287b	0.598c	1.542b	1.384b	72.166
ZA	1.582cd	2.726bc	2.984b	0.865d	1.245c	2.029a	2.475a	1.540b	80.511
NPK	1.880c	2.919b	2.372b	2.288a	1.252c	1.839a	1.560b	1.314b	73.416

Note: values followed by the same letter in the same column are not significantly different based on the 5% test of variance; DAA = days after application; nitrogen vaporization data on staple disks, control (no nitrogen fertilization), urea (nitrogen fertilizer 1.1 kg N per tree); urea with N-stabilizer (nitrogen fertilizer 1.1 kg N per tree) with a mixture of nitrification inhibitors and urease inhibitors; ZA (ammonium sulfate fertilizer 1.1 kg N per tree, 21%N); NPK 15-15-15 (nitrogen fertilizer 1.1 kg N per tree); the amount represents the total emission for 45 days.

also demonstrated that adding urease inhibitors can effectively reduce CO_2 gas emissions from nitrogen fertilization. CO_2 gas emissions measured under the canopy of oil palm plants can come from palm root activity, weed activity, microorganism activity, and the urea hydrolysis process (Uning et al., 2020). Byrne et al., (2020) also underlined that nitrogen fertilizer increases CO_2 gas emissions.

Calculation of total CO_2 gas emissions over the first 45 days after application showed that the urea with N-stabilizer fertilization treatment had the lowest CO_2 gas emissions compared to other nitrogen fertilizer

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Table 5. Potential CO_2-e gas emissions from different types of nitrogen fertilizers.

Treatment	1 DAA	1 DAA	3 DAA	5 DAA	7 DAA	14 DAA	30 DAA	45 DAA	Total (g eq-CO_2.m^{-2})
Unit	g eq-CO_2.m^{-2} per day								
Control	4.976	6.795	7.127	7.132	7.316	6.287	5.763	7.604	315.444
Urea	7.835	9.575	9.143	6.722	7.585	6.105	6.536	6.435	319.928
Urea N-stabilizer	9.640	9.906	9.729	6.842	7.068	5.765	6.722	6.554	324.848
ZA	5.753	7.300	7.777	5.986	5.931	7.247	7.640	6.441	327.971
NPK	6.666	7.719	7.203	19.031	5.948	7.039	7.144	6.247	324.645

Note: values followed by the same letter in the same column are not significantly different based on the 5% test of variance; DAA = days after application; nitrogen vaporization data on staple disks, control (no nitrogen fertilization), urea (nitrogen fertilizer 1.1 kg N per tree); urea with N-stabilizer (nitrogen fertilizer 1.1 kg N per tree) with a mixture of nitrification inhibitors and urease inhibitors; ZA (ammonium sulfate fertilizer 1.1 kg N per tree, 21%N); NPK 15-15-15 (nitrogen fertilizer 1.1 kg N per tree); the amount represents the total emission for 45 days.

types (Table 5). This indicates the effectiveness of the urease inhibitors in the N-stabilizer urea in reducing CO_2 gas emissions. The highest total CO_2 gas emissions were observed in the ZA fertilization treatment. However, when considering the potential greenhouse gas (GHG) emissions, the urea with N-stabilizer treatment showed the highest value on the first day after application (9.640 g CO_2-e.m^{-2} per day). It remained high until the third day after application (9.729 g CO_2-e.m^{-2} per day). The regular urea fertilization treatment had the second-highest GHG emission potential (7.835 g CO_2-e.m^{-2} per day), remaining high until the third day after application (9.143 g CO_2-e.m^{-2} per day).

Interestingly, urea's potential greenhouse gas emissions with N-stabilizer began to decrease on the fifth day after application and were lower than the potential emissions from regular urea fertilization starting on the seventh day after application. This indicates that the N-stabilizer urea's effects on greenhouse gas emissions became more favorable after the initial days following application.

Overall, the total potential greenhouse gas emissions from the N-stabilizer urea fertilization treatment over 45 days was 324.8 g CO_2-e.m^{-2}, or 7.2 g CO_2-e.m^{-2} per day. The values of GHG emissions on the field due to the application of urea with N-stabilizer were not significantly different from those of regular urea, ZA, and NPK fertilizer applications, ranging from 7.10 to 7.29 g CO_2-e.m^{-2} per day. It's important to note that these values were measured during the rainy season, which may have influenced the higher CO_2 gas emissions compared to other studies conducted during different seasons. Harimurti et al., (2021) found that the average greenhouse gas emission generated in oil palm cultivation was 0.486 g CO_2-e.m^{-2}.day^{-1}. According to earlier studies, there is a higher variability in the result of greenhouse gas emissions rate from nitrogen fertilization in oil palm cultivation from various agro-climatological diversities, i.e. 0.3 g CO_2-e.m^{-2}.day^{-1} (Kusin et al., 2015), 6.4 g CO_2-e.m^{-2} per day (Manning et al., 2019), and 2.5 g CO_2-e.m^{-2}.day^{-1} (Susilawati et al., 2021). The higher value of CO_2-e emission potential result obtained in this study was associated with the measurement in the rainy season. Anokye et al., (2021) reported, that an increase in CO_2 gas emissions from oil palm plantations was detected as more than 352% higher during the wet season. According to Manning et al. (2019), soil temperatures may decrease slightly during the rainy season. However, the high soil moisture still supports the activity of heterotrophic microbes responsible for organic matter decomposition. As a result, there is an increase in CO_2 emissions due to the faster decomposition process, even though the soil is cooler compared to the dry season.

In conclusion, the N-stabilizer urea effectively suppressed NH_3 vaporization and reduced CO_2 gas emissions during the initial days after application. However, it did not show a significant effect on N_2O gas emissions. The N-stabilizer urea treatment showed promising results in reducing greenhouse gas emissions compared to other nitrogen fertilizer types. Further research and analysis are necessary to fully understand the environmental impact and benefits of using N-stabilizer urea in oil palm cultivation, considering different agro-climatological conditions and seasonal variations.

Conclusion

In conclusion, the study demonstrated that using N-stabilizer-coated urea can effectively reduce NH_3-vaporization during oil palm fertilization, potentially leading to a more sustainable and environmentally friendly fertilization practice. Using N-stabilizer-coated

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urea for oil palm fertilization significantly reduced NH_3 $_V$aporization during the first week after application. It demonstrated a 53% suppression of NH_3 $_V$aporization compared to the application of regular urea. NH_3 $_V$aporization levels for ZA and NPK fertilizers were considerably lower, each showing < % compared to regular urea application. The greenhouse gas emission was not significantly affected by applying urea with N-stabilizer compared to normal urea, ZA, and NPK fertilizer. GHG emissions on the field ranged from 7.10 to 7.29 g CO_2-e.m^{-2} per day for all nitrogen fertilizer types, including urea with N-stabilizer. Further studies should be conducted to evaluate other factors and conditions that could influence emissions and assess the environmental impact of different nitrogen fertilizer types in oil palm plantations.

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