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Nitrogen losses (N_2O and NO_3^-) from mustard (*Brassica juncea* L.) cropping applied urea coated bio-charcoal

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Abstract: Most farmers use urea as a nitrogen fertiliser to raise mustard (*Brassica juncea* L.), although its nitrogen (N) content is quickly lost due to its hygroscopic nature. Nitrogen loss in the form of nitrous oxide (N_2O) and nitrates (NO_3^-) has been causing low nitrogen fertiliser efficiency in vegetable cultivation. This investigation aims to assess the impact of urea fertiliser coated with biochar or activated charcoal on losses of N_2O and NO_3^- concentration in the soil during mustard production. The experiment used a randomised block design with five treatments of urea fertiliser coated with biochar/activated charcoal. The observed data included N_2O flux, nitrate, and ammonia content in soil and water. The results showed that urea fertiliser coated with activated charcoal from corn cobs tended to suppress N loss more effectively than urea coated with biochar or activated charcoal from coconut shells. Biochar and activated charcoal from coconut shells suppressed N-N_2O loss as much as 3.1% and 52.5% (7 days after planting (DAP)), respectively, and 68.7% and 71.6% (21 DAP), respectively. Biochar and activated charcoal from corn cob reduce N-N_2O loss by 46.5% and 66.5% (7 DAP), respectively, and by 70.7% and 77.8% (21 DAP). Urea-coated activated charcoal fertiliser increases mustard plant biomass and nitrogen uptake. Biochar and activated charcoal from coconut shells and corncobs increase nitrogen use efficiency by 5, 24, 6, and 17%, respectively. Biochar/activated charcoal coatings are a promising technology for boosting nitrogen use efficiency in vegetable crops, including mustard crops.

Keywords: nutrient; nitrification; greenhouse gas emission; natural charcoal; coating of urea fertiliser

In Indonesia, mustard (*Brassica juncea* L.) is the most popular vegetable and is easily obtained in markets at a relatively low cost. The demand for mustard vegetables always increases along with the increase in the population and awareness of nutritional needs (Sarif et al. 2015). Nitrogen (N) is the most responsive nutrient for the mustard crop (Raghuvanshi et al. 2018). Most farmers generally use the input of urea

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fertiliser to maintain high agricultural crop production, including mustard (*Brassica juncea* L.) vegetable production. Urea is one of the nitrogen fertilisers to ensure the availability of N during plant growth and development. However, agronomic efficiency in mustard crops is still relatively low; for example, in India, it ranges from 14.0–20.1 kg biomass/kg N applied (Keerthi et al. 2017).

Due to its hygroscopic nature, the N content in urea is volatile and is not efficiently absorbed by plants. Plants obtain inorganic nitrogen from the soil, primarily nitrate and ammonium (Hachiya and Sakakibara 2017). The urease enzyme converts urea to ammonium (NH_4^+), which in turn produces nitrate (NO_3^-) and nitrous oxide through microbial nitrification processes (Gao et al. 2022). In aerobic soils, nitrogen exists in the nitrate form rather than ammonia because of nitrification processes; however, N can be lost through nitrate percolation in sandy loam soil texture (Abbruzzini et al. 2019) and nitric oxide emissions (Borchard et al. 2019). Therefore, the excessive use of N fertilisers can also cause problems for the environment and human health (Li et al. 2017) and inefficient N use (Rutting et al. 2018).

However, only 30–40% of N fertilisers like urea are used by crops (Birla et al. 2020, Wang et al. 2022), with the rest being lost in the soil-plant system. This is especially true for food and vegetable crops. N fertiliser losses on horticultural crops might be as high as 60%. Ammonia volatilisation, nitrification-denitrification, runoff, and leaching are all ways in which nitrogen can be lost from an ecosystem (Ishii et al. 2011, Yang et al. 2013, Dominghetti et al. 2016, Ranatunga et al. 2018). Denitrification is the primary mechanism of N loss from agricultural land, with estimates ranging from 22% to 95% across all soil types (Chew and Pushparajah 1995), but N loss by ammonia volatilisation from urea could reach 50% in submerged soils (Zhang et al. 2015). N losses impair fertilisation efficiency, pose a threat to the environment, and may increase pollution and greenhouse gas emissions, particularly from the release of N_2O. To improve the efficiency of nitrogen fertilisers and crop yields, it is essential to decrease N loss. Without inhibitors, nitrogen losses from urea accounted for 10.35% of the total nitrogen administered (for NH_3 and N_2O, respectively) (Guardia et al. 2021). This N-N_2O loss contributes to increased greenhouse gas emissions from agricultural land.

As a percentage of overall agricultural greenhouse gas (GHG) emissions in 2005 (80.179 Gg CO_2-eq), N_2O emissions contributed roughly 30%, below the CH_4 emission share (67%) (Wihardjaka et al. 2013). The management of manure, nitrogen fertiliser, and agricultural soils are the three most significant contributors to the global flux of nitrous oxide. Agricultural soils may account for between 0.2 and 2.1 Tg N_2O emissions worldwide (Snyder et al. 2009). There has been talking of a yearly increase of 0.25 per cent in the atmospheric content of N_2O (Snyder et al. 2009). CH_4 has a shorter lifetime than N_2O in the atmosphere; however, N_2O has a higher global warming potential (GWP) than CH_4. N_2O has GWP 250–310 times that of CO_2, and CH_4 has GWP 27–30 times that of CO_2 for over 100 years. The appropriate cultivation practice can reduce the nitrous oxide emissions from agricultural land.

In balanced fertilisation technology, inorganic fertilisers are used sparingly while organic fertilisers are used maximally (Suhardjadinata et al. 2015), split use of inorganic fertilisers (Liu et al. 2019), and the use of slow-release fertilisers are all methods by which nitrogen fertiliser efficiency can be increased (Chen et al. 2020). Coated urea fertiliser is one type of slow-release fertiliser. Natural charcoal (biochar) or activated charcoal are two examples of possible coating materials. Agricultural waste, such as coconut shells and corn cobs, is abundantly available around cultivated land. In addition to being a carbonaceous material, activated charcoal is also biochar. It has a very excellent nest structure and a large interior-specific surface area, allowing it to hold certain molecules to the inner surface while adsorbing other substances in gas or liquid form. Activated charcoal comprises 87–97% C and includes the components O, H, S, and N (Choma and Jaroniec 2006, Janu et al. 2021). It has been found that both biochar and activated charcoal can increase plant development by enhancing soil structure, water retention, nutrient and organic matter content, and organic matter content (Chen et al. 2020). Due to its porous structure, biochar provides an ideal habitat for beneficial microbes (Ardiwinata 2020). Cation exchange capacity (CEC) can be increased by the presence of biochar/activated charcoal through an electrostatic bonding mechanism on surfaces that contain many functional groups, such as carbonyl, carboxyl, and hydroxyl. The higher CEC value occurs since the carboxyl groups readily deprotonate in water, resulting in a more negative charge on the biochar/activated charcoal surfaces (Huff et al. 2018, Geca et al. 2022). Natural nitrogen loss varies with soil type; however, biochar

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and activated charcoal made from agricultural wastes may improve N utilisation and efficiency (Khan et al. 2021, 2023). In addition, these substrates are perfect for hosting plant-friendly microorganisms and nitrification-inhibiting bacteria (Trupiano et al. 2017, Chen et al. 2021), suppress N_2O emission with a 30.7% reduction for the cumulative emission, and are conducive to the survival of nitrogen-transforming bacteria in water (Xiong 2023). There is still a lack of data on the amount of nitrogen lost as nitrous oxide and nitrate because of mustard growing. This study aimed to determine the effects of mustard (*Brassica juncea* L.) growth with inorganic N fertiliser coated with biochar or activated charcoal on nitrogen loss (nitrate and nitrous oxide) and nitrogen uptake.

MATERIAL AND METHODS

Site and experiment layout. The investigation was performed at the Kajoran vegetable centre in Magelang, Central Java, Indonesia. The experimental location was 7°32'4"S and 110°6'23"E (Figure 1). Andisols in this site were clay loam textural class (37% sand, 32% silt, 31% clay by pipette method), slightly acidic (pH 5.43 by pH meter-electrode method), low available P (8.03 mg P/kg by P Bray method), ammonia content in soil (1.8 mg NH_4^+/kg by Morgan-Wolf method), high cations exchange capacity (CEC = 30.3 $mmol_+$/kg by saturation ammonium acetic 1 mol/L), medium organic C (2.1% by Walkley and Black method), and soil containing allophane with pH (NaF) > 10.

The experiment was conducted in the field using a randomised block design that was replicated three times, with five treatments: T0 – prilled urea as a control; T1 – urea coated with coconut shell bio charcoal; T2 – urea coated with corncob bio charcoal; T3 – urea is coated with coconut shell activated charcoal, and T4 – urea is coated with corncob activated charcoal. The selection of biochar/activated charcoal from coconut shells and corn cobs is based on the relatively high iodine value and surface area compared to rice husks (Ardiwinata 2020).

Biochar and activated charcoal production. Agricultural waste from corncobs and coconut shells was pyrolysed at 300 °C to produce biochar, of which a portion is activated at 800 °C temperature to produce activated charcoal. Biochar and activated charcoal

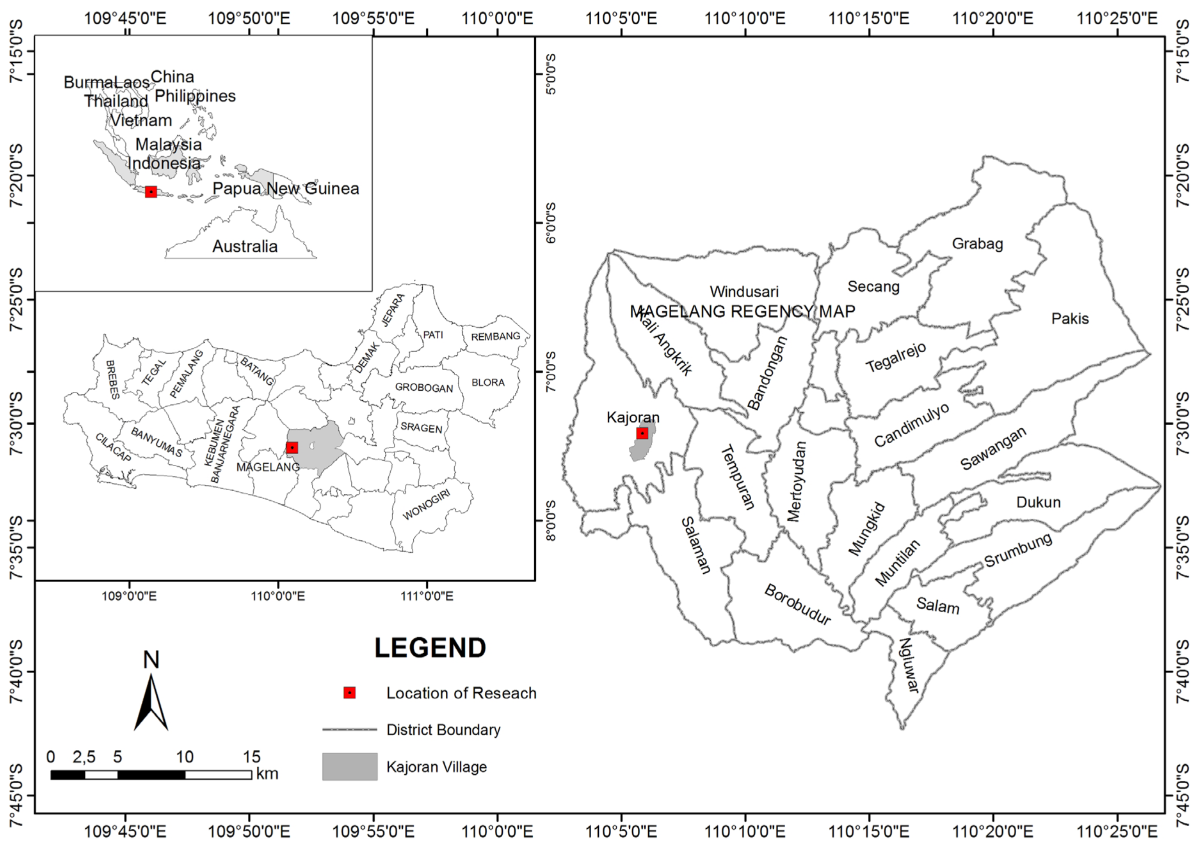

Figure 1. Experimental site in Magelang, Central Java province, Indonesia

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production uses the agricultural waste from corncobs and coconut shells that were pyrolysed at 300 °C to produce biochar, of which a portion is activated at 800 °C temperature to produce activated charcoal. For bio-charcoal production, coconut shells and corncob were cut into small pieces (± 1–2 cm^2) and placed into a stainless steel box with a cover. The carbonisation was conducted in a muffle furnace at 300 °C for 3–4 h. For activated charcoal, coconut shell and corncob charcoal were chemically activated with phosphoric acid (H_3PO_4) and activated at 800 °C for 3 h in a muffle furnace, then filtration by washing with hot water to remove phosphoric compound, including impurities, and dried at l05 °C for 3 h (Ardiwinata and Harsanti 2014). After carbonisation, biochar/activated charcoal was ground using a laboratory jar mill to pass a 50 mesh sieve for urea coating. The adhesive for urea coated with biochar or activated charcoal is tapioca, and the ratio of urea to biochar/activated charcoal is 80:20.

Cultural practices. Mustard (*Brassica juncea* L.), two weeks old from nursery, was planted in every plot with size 2 m × 4 m and a spacing 40 cm × 20 cm plot. Watering is done daily in the afternoon or according to the needs of the plants. A 20 cm depth piezometer was set in each plot to collect water samples. N, P, and K fertilisers were applied at the prescribed rates of 100 kg N, 44 kg P, and 50 kg K per hectare, with N fertiliser applied twice, six days after planting (DAP) and during early crop formation (19 DAP). P and K fertilisers were simultaneously applied with 7 DAP. The method of applying N, P, and K fertiliser is carried out according to recommendations implemented by local farmers.

Parameter observed. Nitrate (NO_3^-) in water and soil, plant biomass, and N_2O flow were observed as parameters. Plant height, number of leaves, and canopy width were measured from 5 plant samples in each plot in the same plant. Plant biomass was determined from an area harvest of 1.2 × 2.4 m square in each plot. Water sample was taken in each plot for nitrate analyses at 7 DAP, 21 DAP, and harvesting (50 DAP). The Morgan-Wolf method was employed to determine nitrate (Eviati and Sulaeman 2012). To determine the nitrate concentration, the percolation water sample was added with a Morgan-Wolf extractor ($NaC_2H_3O_2 \cdot 3\ H_2O$ + DTPA) and shaken for 5 min at a speed of 180 shakes per min. A total of 5 mL of solution was taken, and 0.5 mL of brucine solution and 5 mL of concentrated H_2SO_4 p.a. were while shaking, left for 30 min, and measured with a spectrophotometer at a wavelength of 432 nm (Eviati and Sulaeman 2012). Nitrous oxide flux measurement only employs the closed chamber technique twice (7 and 21 DAP). Before the gas sampling, we planted an anchor to place the polycarbonate chamber of 60 × 20 × 30 cm on each sampling point. Gas samples were taken with 10 mL polypropylene syringes at 10, 20, 30, and 40 min following chamber closure. Aluminium foil was used in the syringes to decrease solar radiation during the gas sampling. The N_2O flux was determined using gas chromatography (Varian GHG 450 Series, a GC System, Varian, Melbourne, Australia) with an electron capture detector (ECD) and a Porapak Q column to analyse the gas sample (Wihardjaka et al. 2013). The gas chromatography configurations for analysing N_2O concentration were at 50 °C column temperature, 350 °C ECD temperature, and 100 °C injector temperature (Ariani et al. 2016).

Nitrous oxide flux was computed using the following IAEA (1992) Eq. 1 (Ariani et al. 2016) as follows:

$$E = \frac{dC}{dt} \times \frac{Vc}{Ac} \times \frac{Wm}{Vm} \times \frac{272.2}{272.2 + T} \quad (1)$$

E = N_2O flux (μg/m^2/min)

$\frac{dC}{dt}$ = N_2O rate per time (mole ppb/min)

where: *Vc* – chamber volume (m^3); *Ac* – chamber area (m^2); *Wm* – N_2O weight (44.02 × 10^3 mg); *Vm* – N_2O volume at 1 bar pressure (22.41 × 10^{-3}/m^3); *T* – mean temperature in the chamber (°C).

Data analysis. The data were examined statistically using Minitab software (Pennsylvania, USA) to analyse variance. When the analysis of variance revealed statistically significant differences between treatments, the pair-wise Duncan's multiple range test (DMRT) (P < 0.05) was employed.

RESULTS AND DISCUSSION

Nitrogen loss from nitrate and nitrous oxide. Nitrate (NO_3^-) and nitrous oxide (N_2O) are two forms of nitrogen loss that can occur when N fertilisers are applied to soil (NO_3^-). Nitrate, the final product of the nitrification process, is mobile and easily leached through percolation, while N_2O gas is the outcome of the nitrification and denitrification processes in the soil. Table 1 displays the N_2O flux 7 and 21 days after planting. There was a statistically significant (P < 0.01) change in N_2O flux after treating urea coated with biochar and activated charcoal. The T_0 treatment showed the maximum N_2O flow at 7 and

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Table 1. The flux of nitrous oxide on vegetative growth of mustard plants

Treatment	N_2O flux (mg/m^2/h)	
	7 DAP	21 DAP
Prilled urea	5.08^a	3.42^a
Coconut shell bio charcoal-coated urea	4.92^a	1.07^b
Corncob bio charcoal-coated urea	2.72^b	1.00^b
Coconut shell-activated charcoal-coated urea	2.41^b	0.97^b
Corncob activated charcoal-coated urea	1.70^{bc}	0.76^b
P-values	0.000	0.000

The mean in the column followed by the same letter is not significantly different at 5% of Duncan's multiple range test. DAP – days after planting

21 DAP. The flux of N_2O at 21 DAP was lower than at 7 DAP. Coating urea with biochar or activated charcoal can decrease the flux of N_2O at the beginning of the growth of the mustard plant (at 7 DAP) and crop formation (at 21 DAP). As a urea coating, biochar and activated charcoal from coconut shells reduced N losses in the form of N_2O by 3.1% and 52.5% (at 7 DAP), respectively, and by 68.7% and 71.6% (at 21 DAP), respectively. The N reduction using biochar and activated charcoal from corn cobs was 46.5% and 66.5% (at 7 DAP), respectively, and 70.7% and 77.8% (at 21 DAP), respectively. Bai et al. (2022) mention that biochar/activated charcoal can improve soil physicochemical characteristics such as nitrous oxide emission.

Nitrate leaching in Indonesia's Andisols of intensive vegetable production regions is hypothesised to be the primary N-loss process (Widowati and Neve 2016). Activated charcoal is more effective as a urea coating with lower nitrous oxide flux than biochar. Biochar or activated charcoal from corncobs tends to emit nitrous oxide at a lower level than from coconut shells. Both biochar and activated charcoal allow for ideal habitation for various microbes, including ammonia-oxidising microbes (Liao et al. 2020, Zhang et al. 2022), so that under favourable conditions such as aerobic conditions, the nitrification process can take place and N_2O is produced as a by-product other than the final product is NO_3^-. Due to its mobile nature and negatively charged, nitrate that young mustard plants have not absorbed will be leached into the subsoil carried by percolation water (Omar et al. 2015).

The amount of nitrate that was leached into the percolation water is tabulated in Table 2. Based on the standard test, the data of nitrate concentration distributes normally at 7 DAP (*P*-value > 0.150), 21 DAP (*P*-value > 0.15), and harvest time (*P*-value > 0.100). At 7 and 21 DAP, the NO_3^- concentration of the water was not significantly affected by the application of biochar/activated charcoal as a coating for urea fertiliser, but it was significant ($P < 0.05$) at harvest time. The lowest nitrate content was seen at harvest in the urea prill treatment only. The nitrate content in the percolation water at the beginning of the mustard plant's growth was high and decreased with the growth period of the mustard plant.

Table 2. Nitrate content in percolated water in mustard cropping

Treatment	Concentration of NO_3^- (mg/L)		
	7 DAP	21 DAP	harvest
Prilled urea	15.10^a	3.30^a	0.20^c
Coconut shell bio charcoal-coated urea	17.20^a	10.17^a	0.29^{bc}
Corncob bio charcoal-coated urea	14.87^a	8.90^a	0.77^{ab}
Coconut shell-activated charcoal-coated urea	15.93^a	6.43^a	0.89^a
Corncob-activated charcoal-coated urea	13.57^a	8.77^a	0.57^{abc}
P-values	0.448	0.259	0.032

The mean in the column followed by the same letter is not significantly different at 5% of Duncan's multiple range test. DAP – days after planting

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Based on data of N_2O flux and NO_3^- content, the highest loss of N in N_2O and nitrate was in the T1 treatment 7 days after planting, 14.1% higher than the control (T0). As shown in Figure 2, the loss of N in the T1 treatment was the highest compared to the control (T0). The loss of N (NO_3^- + N_2O) at 21 DAP and harvesting time in the treatment with activated charcoal was higher than in the prilled urea. The amount of nitrogen lost as NO_3^- and N_2O losses varied from 3.08 to 3.90 kg N/ha at 7 DAP, 0.7 to 2.29 kg N/ha at 21 DAP, and 0.0 to 0.17 kg N/ha at harvest. In the three observations, the mustard crop lost less than 10% of the nitrogen fertiliser supplied to the soil as NO_3^- and N_2O. At 21 DAP, the loss of N from urea-coated biochar and activated charcoal was generally higher than that of prilled urea fertiliser. Assuming that activated charcoal is an ideal habitat for microbes, including nitrifying bacteria, the substrate is available in the form of NH_4^+ from urea fertiliser, aerobic conditions provide sufficient O_2, and activated carbon functions as a catalyst, so the microbial nitrification process can take place, which will produce N in the form of nitrate. According to Przepiorski (2006), the presence of activated carbon can result in a biological nitrification process in which *Nitrosomonas* and *Nitrobacter* bacteria convert ammonia to nitrite and nitrite to nitrate. Ammonia in water is nitrified by bacteria immobilised on the outer surface of activated carbon.

NO_3^- is weakly linked to the soil surface and mobile (Zhang et al. 2023); thus, when NO_3^- production exceeds the needs of plants at specific growth stages, N-NO_3^- will be leached by percolation water (Dechorgnat et al. 2011). Thus, a larger quantity of N-NO_3^- will be extracted. Bandosz and Ania (2006) and Ardiwinata (2020) state that activated carbon provides a high-power adsorption site consisting of both micropores and functional groups and catalyses surface reactions; for example, in oxidation reactions $SO_2 \rightarrow H_2SO_4$, the response of complex catalysis from oxidation of H_2S, the reduction of $NO_x \rightarrow N_2$ in reaction environmental remediation. This also allows activated carbon to play a role in nitrification, especially in catalysing oxidation reactions of NH_4^+ to NO_3^- (Liu et al. 2008).

The raw materials for biochar and activated charcoal used as coatings for urea fertiliser are thought to affect the effectiveness and efficiency of urea fertilisers coated with biochar or activated charcoal. The use of corn cobs as a coating for urea fertiliser at the beginning of mustard plant growth showed high effectiveness in reducing N loss as nitrous oxide gas emitted into the atmosphere and nitrate loss in percolation water. This means that biochar and activated charcoal from corn cobs can delay the nitrification process of urea fertiliser applied at the beginning of plant growth so that the nitrate produced from the nitrification process can be inhibited or delayed (Liao et al. 2020). Then, nitrogen nutrients can be utilised efficiently by plants. Biochar can enhance nutrient availability and reduce nutrient leaching in soils (Schahczenski 2010, Nurhidayati and Mariati 2014).

The availability of nitrogen in soils with NH_4^+ concentrations of more than 1.5 mg/kg from the onset of plant growth to crop formation implies that deep deployment of urea fertiliser can reduce N losses. Timing and integration of urea fertiliser can potentially improve agronomic efficiency since it lowers N loss and increases N availability, particularly during crucial times of plant growth. Incorporating urea fertiliser into aerobic soil prevents N loss due to NH_3 volatilisation (Dominghetti et al. 2016). Zhang et al. (2022) reported the partial substitution of urea with biochar in panicle initiation has a more substantial yield-increasing effect and lowered the risk of nitrogen pollution in silty clay soils and sandy loam soils in paddy fields.

Growth and yield of mustard. The plant height of mustard, number of leaves, and their canopies were better in T2 (corncob bio charcoal-coated urea) than others at 21 days after planting (Figure 3). The number of leaves (P < 0.05), plant height

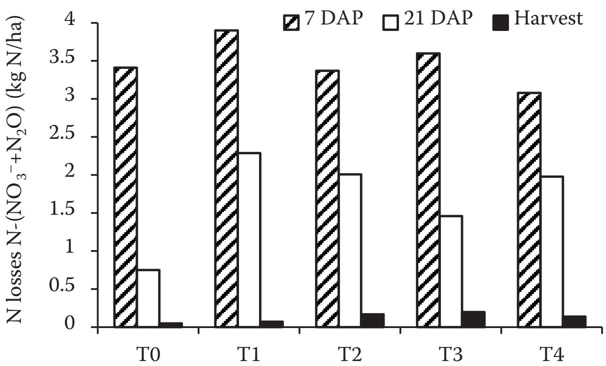

Figure 2. Loss of nitrogen (N) in the form of N-N_2O + N-NO_3^- during the growth of mustard. T0 – prilled urea as a control; T1 – coconut shell bio charcoal-coated urea; T2 – corncob bio charcoal-coated urea; T3 – coconut shell activated charcoal-coated urea; T4 – corncob activated charcoal-coated urea; DAP – days after planting

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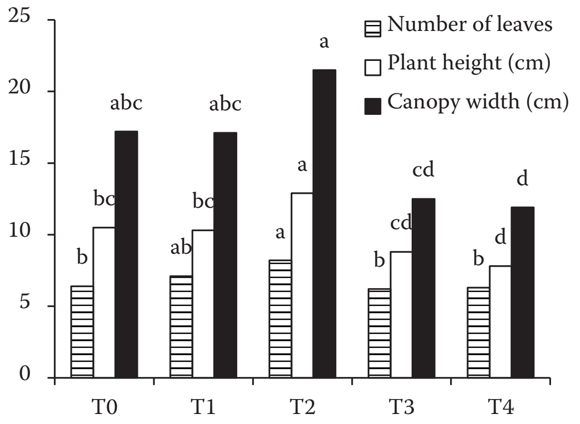

Figure 3. Mustard plant growth at beginning crop formation (21 days after planting (DAP)). The mean in the same colour histogram followed by the same letter is not significantly different at 5% of Duncan's multiple range test. T0 – prilled urea as a control; T1 – coconut shell bio charcoal-coated urea; T2 – corncob bio charcoal-coated urea; T3 – coconut shell activated charcoal-coated urea; T4 – corncob activated charcoal-coated urea. Urea fertiliser coated with activated charcoal was applied in 7 days after planting

(P < 0.01), and canopy width (P < 0.01) were significantly influenced by the application of activated charcoal-coated urea fertiliser at the start of the crop formation phase. Plants treated with T2 and T3 showed the most improvement in 21 DAP. Higher plant yields were achieved using activated charcoal made from corncobs instead of coconut shells.

Treatment with biochar and activated charcoal as a coating for urea fertiliser considerably influenced the dry biomass production of mustard (P < 0.01). Treatments T0 and T4 showed a low biomass output of 0.86 and 0.84 t/ha, respectively. Dry biomass yields for T1, T2, and T3 treatments (t/ha) are 1.24, 1.49, and 1.38, respectively (Figure 4). Dry mustard biomass yields were improved by urea treated with activated charcoal from coconut shells, outperforming those from corncobs.

Mustard biomass weight is positively and significantly related to nitrogen uptake (P < 0.01), as shown by the linear equation:

$$Y = 0.779 + 0.02535X$$

$$(R^2 = 0.4337,\ n = 15,\ P\text{-value} = 0.008)$$

where: Y – dry biomass weight; X – N uptake.

This means that the N nutrients absorbed by plants are effectively utilised in plant growth. Conversa et al. (2019) also reported a similar correlation between broccoli plants and Guo et al. (2021) in tomato plants.

The treatment of biochar and activated charcoal as a urea fertiliser coating significantly affected the N absorption of mustard plants and the utilisation efficiency of N fertiliser (P < 0.01). Nitrogen uptake (kg N/ha) is calculated by multiplying the nutrient concentration by plant biomass dry matter (kg/ha) (Ciampitti et al. 2013). In contrast, nitrogen uptake efficiency is calculated by dividing N absorbed by N applied. Activated charcoal improved nitrogen uptake by 6 to 25 kg N/ha. Biochar from corncobs demonstrated the greatest N uptake (30.93 kg N/ha), followed by microbe-laden activated charcoal made from coconut shells (23.64 kg N/ha), and urea fertiliser without activated charcoal demonstrated the least N uptake (5.93 kg N/ha). Based on Guo et al. (2021), biochar application can significantly increase N uptake in tomato plants because biochar surface area can adsorb nutrients and prolong the retention time of nutrients. Biochar as a coating for urea fertiliser boosts its efficiency by 5% (coconut shell) and 24% (corncobs), while activated charcoal increases it by 6% (corncobs) and 17% (coconut shell) (Table 3). Nitrogen utilisation efficiency (NUE) is crucial for understanding how the crop utilises the provided N (Devika et al. 2018). Treatment T2 demonstrated the maximum efficiency of N fertiliser use, while treatment T1 demonstrated the lowest. Utilising

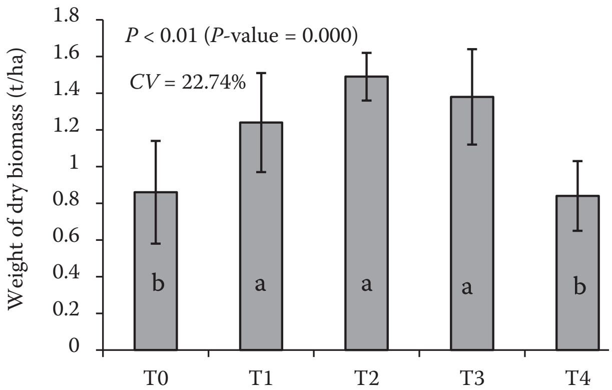

Figure 4. The yield of dry mustard biomass treated with urea coated with biochar and activated charcoal in Magelang. Bars following the same letter are not significantly different at 5% of Duncan's multiple range test. T0 – prilled urea as a control; T1 – coconut shell bio charcoal-coated urea; T2 – corncob bio charcoal-coated urea; T3 – coconut shell activated charcoal-coated urea; T4 – corncob activated charcoal-coated urea; CV – coefficient of variation

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Table 3. Nitrogen (N) uptake and physiological efficiency of urea fertiliser in mustard cultivation in Magelang vegetable fields

Treatment	N uptake (kg N/ha)	N uptake efficiency
Prilled urea	5.93[c]	–
Coconut shell bio charcoal-coated urea	11.96[b]	0.058[b]
Corncob bio charcoal-coated urea	30.93[a]	0.242[a]
Coconut shell-activated charcoal-coated urea	14.81[b]	0.086[b]
Corncob-activated charcoal-coated urea	11.67[b]	0.067[b]
P-value	0.000	0.000
CV (%)	7.16	10.41

The mean in the column followed by the same letter is not significantly different at 5% of Duncan's multiple range test. *CV* – coefficient of variation; – not defined

urea coated with biochar made from coconut shells could boost N efficiency by 24%.

The application of nitrogen fertilisers in conjunction with biochar increased soil nitrogen and improved plant nutrient uptake efficiency (Xia et al. 2022). Utilising biochar and activated charcoal as a coating for urea fertiliser considerably boosts N uptake and the effectiveness of N fertiliser use, allowing mustard plants to consume nitrogen by the plant's growth needs. Biochar or activated charcoal has an abundance of functional groups and exchangeable cations on its surface. After being applied to the soil, it can thereby lower the amount of nitrogen lost through volatilisation and leaching (Basso et al. 2013, Xia et al. 2022). Biochar and activated charcoal are used as homes for microorganisms (Liao et al. 2020), including helpful microorganisms for plant growth like *Azotobacter*, nitrogen-fixing from the air, and nitrifying bacteria. This alters the dynamics of N in plant roots. Due to their porous nature, biochar and activated charcoal can provide ideal conditions for the proliferation of microorganisms, leading to a greater variety of N-cycling-related microbial groups (Xia et al. 2022).

Inefficient use of urea fertiliser often occurs in mustard (*Brassica juncea* L.) cultivation, where N is lost in the form of nitrous oxide and percolated nitrate before it is absorbed by plants. Biochar and activated charcoal from corn cob and coconut shell waste can be used as a urea fertiliser coating. Biochar and activated charcoal significantly suppress N loss in the form of nitrous oxide and percolated nitrate at harvest time and improve biomass weight of mustard and nutrient uptake. As a urea coating, activated charcoal reduced N-N_2O loss relatively higher than biochar from coconut shells or corn cobs.

Applying urea fertiliser coated with biochar and activated charcoal tends to give higher yields of mustard plant biomass than urea prill fertilisation. The use of urea fertiliser coated with biochar and activated charcoal considerably enhanced the N uptake of mustard by 6–25 kg N/ha and the efficiency of urea fertiliser by 5–24% (coated with biochar) and 6–17% (coated with activated charcoal), respectively.

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