

THE EFFECTS OF USING MELALEUCA BIOCHAR ON VEGETABLE PRODUCTION AND N₂O EMISSIONS

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ARTICLE INFO	ABSTRACT
Received: 16/8/2022 Revised: 04/11/2022 Published: 23/11/2022	The Mekong Delta currently has many vegetable production areas, but the habit of using a lot of fertilizers to increase the productivity of farmers has led to an excess of fertilizer. While the majority of N₂O emissions in agriculture are derived from fertilizers. This study aims to evaluate the effect of biochar application on soil nitrous oxide emissions. A pot experiment with broccoli (<i>Brassica juncea</i>) was set up to evaluate the effect of melaleuca biochar on N₂O flux under net house conditions. The current study was conducted four treatments with four levels of ground melaleuca biochar that were mixed in soil (0, 2, 10, and 20 tons. ha⁻¹). N was applied to all treatments in the form of urea at a rate of 70 kg ha⁻¹. The result shows that biochar significantly reduced N₂O emissions by 60% when compared to the urea treatment. Furthermore, broccolis supplemented with biochar produced more biomass than broccolis fertilized solely with inorganic fertilizers, demonstrating that biochar's effectiveness significantly aids plant growth.
KEYWORDS Melaleuca biochar N₂O emissions Vegetable yield Fertilizers Broccolis	

ẢNH HƯỞNG CỦA VIỆC ỨNG DỤNG THAN SINH HỌC TRÀM ĐỐI VỚI SẢN XUẤT RAU VÀ PHÁT THẢI KHÍ N₂O

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Ngày nhận bài: 16/8/2022 Ngày hoàn thiện: 04/11/2022 Ngày đăng: 23/11/2022	Đồng bằng sông Cửu Long hiện có nhiều vùng sản xuất rau màu, tuy nhiên thói quen sử dụng nhiều phân bón để tăng năng suất của nông dân đã dẫn đến tình trạng dư thừa phân bón. Trong khi đó phần lớn lượng khí thải N₂O trong nông nghiệp có nguồn gốc từ phân bón. Mục tiêu của nghiên cứu này là đánh giá ảnh hưởng của việc sử dụng than sinh học đối với sự phát thải khí N₂O từ đất. Thí nghiệm được thực hiện trong chậu trồng cải xanh (<i>Brassica juncea</i>) để đánh giá ảnh hưởng của than sinh học tràm đến phát thải khí N₂O trong điều kiện nhà lưới. Thí nghiệm được bố trí với bốn nghiệm thức tương ứng với bốn mức than sinh học tràm được trộn vào đất (0, 2, 10 và 20 tấn/ha). Phân đạm (ure) được bón cho tất cả các nghiệm thức với tỷ lệ 70 kg/ha. Kết quả nghiên cứu cho thấy than sinh học có thể làm giảm đáng kể 60% lượng khí thải N₂O. Hơn nữa, cải xanh được bổ sung than sinh học tạo ra nhiều sinh khối hơn so với cải chỉ được bón bằng phân vô cơ, chứng tỏ rằng hiệu quả của than sinh học hỗ trợ sự phát triển của cây trồng một cách đáng kể.
TỪ KHÓA Than sinh học tràm Khí N₂O Năng suất rau Phân bón Cây cải xanh	

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1. Introduction

Nitrous oxide (N_2O) and methane (CH_4) are mainly responsible for causing greenhouse gases (GHGs). Meanwhile, agriculture contributes significantly to GHGs emissions in the atmosphere [1]. Nitrous oxide (N_2O) is a greenhouse gas that contributes primarily to global warming. It has a global warming potential 298 times greater than carbon dioxide and contributes to the depletion of the stratospheric ozone layer [1]. N_2O emissions are expected to rise by 35–60% by 2030 due to increased nitrogen (N) fertilizer use in agriculture and animal manure production. One pound of N_2O has nearly 300 times the warming effect of one pound of carbon dioxide [2], [3]. There was a conflict between accelerating demand for crops and the ecological impacts of N_2O emissions. Therefore, it is necessary to find a solution to the above problem.

Recently, soil amendment with biochar, produced by plant materials such as grass, agricultural and forest residues that are decomposed at high temperatures under oxygen-limited conditions has attracted a fair amount of research interest due to its abundant usage and wide potential, which includes improving soil fertility and greenhouse gas sequestration [4]. Applying biochar to soil has been proposed as a means of long-term carbon (C) storage which may be a promising, revolutionary approach for capturing and sequestering carbon and merits serious research and development worldwide [5].

Published results suggest that biochar may play a significant role in reducing GHG emissions from upland agricultural soils. Dejene and Tilahun [6] found that the application of biochar at a rate of 30 tons.ha⁻¹ significantly decreased cumulative N_2O emissions in forest soil by 25.5%. Similarly, Xiao [7] found that applying biochar at a rate of 5 tons. ha⁻¹ to forest soil reduced annual average flux and annual cumulative total soil N_2O emissions by 27.4% and 20.5%, respectively, when compared to untreated soil. Lehmann [8], and Jien [9] reported a 50–80% reduction of N_2O emissions under soybean and grass systems, respectively, because of biochar addition. Biochar application can significantly affect N_2O and CH_4 emissions [3].

Vegetable production is critical in the Mekong Delta, accounting for 30% of total agricultural output. However, data on the effects of biochar amendment on N_2O are scarce. Thus, a pot experiment was carried out with broccoli (*Brassica juncea*) to assess the effects of biochar application on N_2O emission in Can Tho University's screen house. As a result, the current study may be useful in understanding the impact of biochar N_2O emissions on plant biomass. Melaleuca, a common species planted in Vietnam forests, produces approximately 7 million tons of residue per year, with an annual yield of up to 13 tons ha⁻¹ [10]. This is a plentiful, highly absorbent material that can be used to produce large amounts of biochar to supplement the soil.

2. Method

2.1. Soil, broccoli and biochars

Vegetable soil (0–15 cm depth) was collected at Vinh Long province in a typical vegetable agroecosystem (> 10 years). After that, soil is sieved through a 2 mm mesh screen after air drying. The soil was classified as Fimi-Orthic Anthrosols with a bulk density of 1.74 g cm⁻³, and consisted of 62.34% clay (< 0.002 mm), 36.28% silt (0.002–0.02 mm) and 1.38% sand (0.02–2 mm). The main properties of this soil at 0–20 cm are as follows: pH value (1:2.5 H₂O) 6.32, EC value (1:2.5 H₂O) 139 μS , soil organic C (OC) 1.4%, total N 0.2%, total P 0.06%, total K 1.63%. Plastic pots (height 11 cm and diameter 10.5 cm) were filled with about 0.35 kg soil. Three seedlings of *Brassica juncea* were transplanted to each pot.

In the Mekong Delta, broccoli (*Brassica juncea*) is a popular vegetable. Furthermore, broccoli has a short growth period, approximately 30 days to harvest, low water requirements, and is suitable for quite hot (41°C) conditions in net houses. As a result, broccoli was chosen as the experimental object.

Melaleuca biochar samples were made by pyrolyzing melaleuca biomass at 700°C. The melaleuca is cleaned and cut into small pieces after it has been collected. After that, the sawdust

is sawn into the wall. In a mill, sawdust is ground into a fine powder (with a pore size of 0.5 mm). After grinding, the melaleuca powder is pressed into a pellet with a diameter of 5 mm and a length of 10 mm. Before being stored in a desiccator, the pelleted samples were dried at 105°C until their weight remained constant. The biomass samples were carefully weighed before being calcined at 700°C for 2 hours in the VMF165 furnace (Yamada Denky, Japan). In an inert gas atmosphere, the VMF165 reactor is heated at a rate of 10°C/min (nitrogen gas). The primary properties of biochar are listed in Table 1.

Table 1. *Melaleuca* biochar properties at 700°C

Yield (%)	26.75
Ash content (wt.% _{db})	3.00
Fixed carbon content (wt.% _{db})	72.88
Moisture (wt.% _{db})	4.98
VM/FC	0.26
C/N	312.79
HHV (MJ/kg)	26.98
pH	8.67
EC (μS/cm)	146.30
CEC (cmolc/kg)	15.12

(Source: [11])

2.2. Treatment

Melaleuca biochar was applied at three different rates in the treatments (low, medium, and high). Careful mixing was used to incorporate biochar into the soil. Biochar doses of 0 (control), 2, 10, and 20 tons.ha⁻¹ were tested, with three replications for each treatment. For the control without urea and biochar, biochar was carefully mixed into the soil. All treatments received the same total N rate of inorganic fertilizer at 70 kg N ha⁻¹. In addition to precipitation, all pots received equal amounts of water based on vegetable growth. Table 2 shows how much melaleuca biochar was added to each pot.

Table 2. *Layout experiment*

Symbol	Melaleuca biochar mass		Total fertilizer amount (*) g/pot
	tons/ha	g/pot	
DC	0	0.00	173
NT1	2	1.72	173
NT2	10	8.60	173
NT3	20	17.20	173

Note (*) total amount of fertilizer used in the experiment for 1 pot

2.3. Measurement of N₂O fluxes

N₂O was measured by using closed static chambers during the growing period as described by Parkin [12]. Each of these chambers was placed in each pot. PVC was used to make the chambers (33 cm high, 12 cm in diameter, 3.5 L volume). Each chamber was installed with one battery-operated fan to homogenize the air inside the chamber headspace, a thermometer to monitor temperature changes during the gas-sampling period, and a gas sampling port with a neoprene rubber septum at the top of the chamber for collecting gas samples from the headspace. A 60-mL plastic syringe equipped with a 3-way stopcock was used to collect gas samples from the chamber headspace at 0, 10, and 20 min after chamber deployment, and they were stored in 20 mL pre-evacuated vacuum vials crimped with butyl rubber lids and aluminum crowns.

Gas samples were collected once a week and every two days after fertilization for one week. Additionally, gas samples were collected hourly from 8:00 to 11:00 AM to study the diurnal variation of N₂O emissions during the vegetable crop. The collected gas samples were

immediately transferred to bags sealed with a butyl rubber septum and transported to the laboratory (Cuu Long Delta Rice Research Institute, Can Tho) for analysis of N_2O . N_2O concentrations were determined by a gas chromatography (SRI 8610C) equipped with flame ionization detector (FID) and electron capture detector (ECD), respectively.

The gas fluxes were calculated by the formula 1 [12]:

$$f = \left(\frac{\Delta C}{\Delta t} \right) * \left(\frac{v}{A} \right) * \left(\frac{M}{V} \right) * \left(\frac{P}{P_0} \right) * \left(\frac{273}{T_{\text{kelvin}}} \right) \quad (1)$$

Where: F is the gas flux ($\text{mgN}_2\text{O-N m}^{-2} \text{ h}^{-1}$), ΔC : the change in the concentration of gas of interest in the time interval Δt , v : the chamber volume (L), A : the soil surface area (m^2), M : the molecular mass of the gas of interest (i.e. N in $N_2O = 28 \text{ g N mol}^{-1}$), V : the molecular volume occupied by 1 mol of the gas (L mol^{-1}) at standard temperature and pressure, P : the barometric pressure (mbar), P_0 : the standard pressure (1013 mbar) and T : the average temperature inside the chamber during the deployment time.

The cumulative N_2O emissions were calculated by the formula 2 [12]:

$$= (n_2 - n_1) * \frac{(F_{n1} + F_{n2})}{2} + (n_3 - n_2) * \frac{(F_{n2} + F_{n3})}{2} + \dots + (n_c - n_x) * \frac{(F_{nc} + F_{nx})}{2} \quad (2)$$

Where n_1 , n_2 and n_3 are the dates of the first, second and third sampling, n_x is the date of the last sampling and n_c is the date before the last sampling. F_{n1} , F_{n2} , F_{n3} , and F_{nx} are the fluxes of the gas of interest at the n_1 , n_2 , n_3 , n_x and n_c sampling day.

2.4. Plant biomass

For each broccoli (*Brassica juncea*), whole plants were harvested by removing them from the pots. The plants were washed with distilled water before being weighed to determine the fresh weight for vegetable yield.

2.5. Statistical analyses

SPSS 22.0 was used for all statistical analyses in this paper. Unless otherwise stated, all statistical significance was reported at the $p < 0.05$ level.

3. Result

3.1. Cumulative N_2O emissions from vegetable soils

When the daily N_2O emission rate in the experiment is compared between the treatments that include biochar and the control (no biochar), the experimental results show that the daily N_2O emission rate in the experiment includes the following stages: Phase 1 (days 0–7): The N_2O emission rate increased rapidly, with the control emitting the most at $0.66 \pm 0.43 \text{ mg/m}^2/\text{day}$. The biochar treatments produced low emission intensity, with the lowest being NT3 ($0.20 \pm 0.08 \text{ mg/m}^2/\text{day}$) ($p < 0.05$).

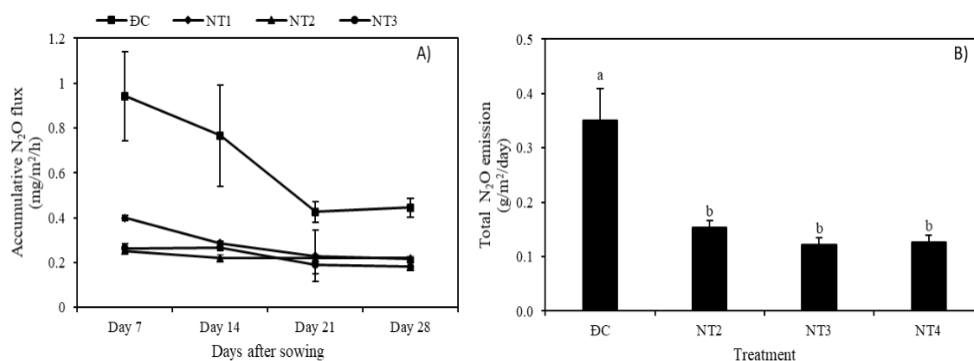


Fig. 1. Accumulative N_2O flux (A), total N_2O emission (B)

Stage 2 (days 7–28): the control still had the highest emission rate, but there was no difference in the N_2O emission rate between the three treatments (NT1, NT2, NT3) ($p > 0.05$). Because the plants began to grow on day 14, the absorption of inorganic fertilizers increased significantly, resulting in a significant reduction in N_2O emission rate, whereas the N_2O emission rate in the control remained unchanged. The mature plants absorbed more fertilizer, increasing growth rates in the biochar-containing treatments but remaining lower than the control ($p < 0.05$).

There was no significant difference in phase 2 between treatments supplemented with 1.72 g of biochar and treatments supplemented with 17.2 g of biochar, possibly due to increased biochar content reducing adsorption efficiency. Previous research discovered that increasing the adsorbent content causes competition for adsorption sites. Nwabanne and Igbokwe [13] discovered that the adsorption efficiency of biochar increased between 0.5 and 2 g/L and remained nearly unchanged when the dose exceeded 2 g/L. Therefore, the use of an optimal dose of biochar to remove adsorbent is critical because it can achieve high efficiency while saving money.

The cumulative N_2O emissions ranged from 114.5 $\text{mg/m}^2/\text{day}$ in the treatment supplemented with biochar to 292.10 $\text{mg/m}^2/\text{day}$ in the control with the same urea fertilization rate of 70 kg N/ha in all treatments (Fig. 1). The results revealed that biochar supplementation significantly reduced N_2O emissions by 60% ($p < 0.05$). Biochar use rates ranging from 2 to 20 tons. ha^{-1} had no effect on N_2O emissions.

Early research has shown that incorporating biochar into soil can change soil properties, potentially improving crop yields and lowering greenhouse gas emissions [6]. Because melaleuca biochar has a C/N ratio of 312.79 [11], the addition of biochar increased the C/N ratio of the soil, which helps to reduce N_2O emissions due to immobilization [14]. Furthermore, denitrification is the best-known mechanism causing N_2O emissions and has received the most attention in biochar research. Because melaleuca biochar has an adsorption efficiency of up to 98 percent, as demonstrated in a previous study [15], when melaleuca biochar is added to the soil, it absorbs nitrate from fertilizers, reducing the nitrification process. Besides, the pH of the experimental soil was 6.32, which was close to neutral, allowing melaleuca biochar to work to its full potential. According to [16], the impact of biochar was greatest in soils close to neutrality, but it did not differ significantly when applied to slightly acidic or alkaline soils.

Furthermore, previous research has shown that increasing soil porosity and aeration is a major factor influencing N_2O generation and diffusion [7]. The addition of biochar to the soil increases the porosity of the soil. This means that as the amount of O_2 increases, the activity of the denitrifier is inhibited, that is the primary cause of N_2O emissions. Aeration was entirely responsible for the initial reduction in nitrate reduction. After the addition of biochar, the soil improved [17]. According to one theory, soil aeration may have a minor impact on N_2O reduction. Several studies have used water content to show that biochar supplementation improves water retention. These have been found to emit less N_2O [18].

Likewise, Cayuela [14] discovered that the presence of biochar reduced total N ($\text{N}_2 + \text{N}_2\text{O}$) in neutral soils. According to some studies, microbial or vegetative NO_3^- fixation in soil following biochar addition may have significantly contributed to the reduction of soil N_2O emissions. Recent research supports this hypothesis and demonstrates that biochar can capture significant amounts of nitrate [18].

When compared to previous studies, the results show that biochar has a high efficiency in reducing N_2O emissions because it was discovered that melaleuca biochar used at a low dose of 2 tons/ha had an effective N_2O emissions reduction of 60%, whereas Bruun [19] discovered that the effect of biochar on soil N_2O emissions was dose dependent, with low doses (15 tons. ha^{-1}) increasing emissions and high doses (45 tons. ha^{-1}) reducing emissions by 47 percent. According to [20], the use of biochar reduced N_2O emissions by up to 53% during the rice and wheat seasons. Similarly, Clough [21] found that applying 5 tons of biochar per hectare of forest land reduced mean annual discharge and total annual cumulative N_2O emissions in soil by 27.4 when

compared to the control group. As a result, understanding why and how the addition of biochar to soil increases or decreases N₂O emissions is a rather complex process [6].

3.2. Veterinary biomass

As a result, it is found that combining melaleuca biochar with inorganic fertilizers will bring optimal efficiency in the accumulation of dry biomass of plants (Fig. 2). Plants supplemented with biochar had a higher biomass than plants only fertilized with inorganic fertilizers ($p < 0.05$), which shows that the effectiveness of biochar helps plants grow significantly better.

The potential of biochar in increasing plant biomass and crop yield has been demonstrated in published studies showing that biochar treatments increase crop yields by an average of 10% [22]. This can be explained by the fact that biochar directly retains nutrients in the soil through its negative charge on its surface, and this negative charge can buffer acidity in the soil, as well as organic matter [6]. The positively charged ions retained by biochar in this case are plant nutrients such as Ca²⁺, K⁺, Mg²⁺ and others, so biochar has increased N uptake for plants.

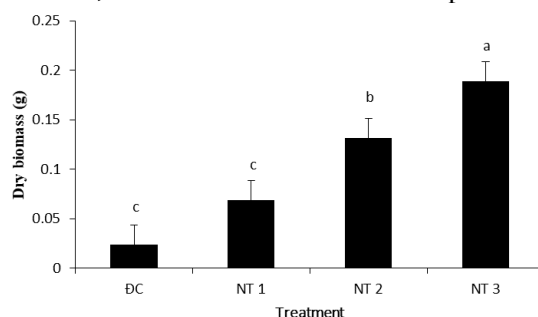


Fig. 2. Dry biomass

Where: The symbols a, b, and c in the same column indicate that there is a difference between the treatments at a 5% significance level using Duncan's test. NT1 = control; NT2 = biochar weight (2 tons. ha⁻¹); NT3 = biochar weight (10 tons. ha⁻¹); NT6 = biochar weight (20 tons. ha⁻¹).

4. Conclusion

In brief, the present study illustrated that the application of melaleuca biochar to upland crops has reduced N₂O emissions by 60%. The addition of biochar at a rate of 2 tons/ha has also yielded positive results. However, long-term biochar in the soil may impair its ability to reduce N₂O emissions, so additional research should look at multiple consecutive rice crops to see if degradation occurs. In conclusion, the melaleuca biomass may be a good source for biochar production for future agricultural applications.

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