

# Combined effects of nitrification inhibitor and zeolite on greenhouse gas fluxes and corn growth

*by* Hartono Hartono

---

**Submission date:** 21-Jun-2023 01:10PM (UTC+0100)

**Submission ID:** 209265997

**File name:** 5.pdf (732.7K)

**Word count:** 7222

**Character count:** 36185



# 13 Combined effects of nitrification inhibitor and zeolite on greenhouse gas fluxes and corn growth

Oslan Jumadi<sup>1</sup> · Yusminah Hala<sup>1</sup> · R. Neni Iriany<sup>2</sup> · Andi Takdir Makkulawu<sup>2</sup> · Junja Baba<sup>3</sup> · Hartono<sup>1</sup> · St. Fatmah Hiola<sup>1</sup> · Kazuyuki Inubushi<sup>3</sup>

Received: 11 September 2017 / Accepted: 15 October 2019 / Published online: 26 November 2019  
© Springer-Verlag GmbH Germany, part of Springer Nature 2019

## Abstract

Field and incubation experiments were conducted to determine the emission rate of greenhouse gases, nitrogen change, populations of AOB, NOB, and fungi as well as growth of corn in response to amendment of urea granulated with and without nitrification inhibitors and zeolite. The application of urea with neem, urea with zeolite, urea with zeolite + neem, urea with zeolite + dicyandiamide, and urea with dicyandiamide (UD) decreased the N<sub>2</sub>O emissions by 16.3%, 59.6%, 66.8%, 81.9%, 16.3%, and 86.7%, respectively. Meanwhile, patterns of CH<sub>4</sub> fluxes were mostly determined by small emissions. Increase in corn height, weight of cobs, biomass, and chlorophyll leaf contents were not significantly different between urea alone and urea with NIs and zeolite. In the incubation experiment, the highest concentration of NH<sub>4</sub><sup>+</sup> and N<sub>2</sub>O production was detected during the first week and it remained high up to the second week of incubation in the combination of urea with NIs and zeolite treatments, although there was no significant difference compared with urea. During NH<sub>4</sub><sup>+</sup> decrease, the concentration of NO<sub>3</sub><sup>-</sup> started to accumulate from the second to the third weeks. Production of CO<sub>2</sub> showed no significant differences among treatments. The static production of CO<sub>2</sub> could also explain that NIs and zeolite additions did not change AOB, NOB, and fungi activities after the fourth week of incubation.

**Keywords** Emission of N<sub>2</sub>O and CH<sub>4</sub> · CO<sub>2</sub> Production · Dicyandiamide · Neem · Nitrification inhibitor · Zeolite

## Introduction

Urea (CO(NH<sub>2</sub>)<sub>2</sub>) has been widely used by farmers as a major source of nitrogen fertilizer to support corn production which is the second most important cereal after rice in Indonesia. The worldwide demand for urea was forecasted to increase from 148 Mt in 2010 to 171.7 Mt in 2015, representing a growth of 3.2% per annum (IFA 2011). Nitrogen (N) is more substantial in a plant and needs larger quantities than other nutrients and it is estimated that only 30–40% of the application of N fertilizer

is taken up by the crop. Most of it disappears by ammonia volatilization, nitrification, and denitrification. Therefore, the use of urea in the agriculture sector in order to increase the quantity and quality of agricultural food production can generate a negative impact on the environment, such as ozone layer depletion due to enhancement of greenhouse gas emissions, particularly nitrous oxide (N<sub>2</sub>O) gas (Mosier and Kroeze 2000).

Emission of N<sub>2</sub>O gas in agricultural land is determined by the nitrification process in aerobic soil conditions and formed nitrate (NO<sub>3</sub><sup>-</sup>) that has mobility capacity to leach as a pollutant to the environment. The NO<sub>3</sub><sup>-</sup> is susceptible to denitrification loss in anaerobic conditions in soil or water. In addition, that process is also a cause of low use nitrogen fertilizer efficiency in the agricultural sector (Mosier and Kroeze 2000). The process of release of N<sub>2</sub>O from the soil into the atmosphere is influenced by diffusion processes in the soil and the capacity of soil to consume N<sub>2</sub>O, which is determined by several factors such as the production footprint in the soil, soil organic matter, soil texture, and soil water content (Zhang et al. 2017; Majumdar et al. 2002; Jumadi et al. 2014).

Responsible editor: Philippe Garrigues

✉ Oslan Jumadi  
oslanj@unm.ac.id

<sup>1</sup> Biology Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Makassar, Makassar 90224, Indonesia

<sup>2</sup> Plant Breeding, Cereals Research Institute, Maros 90514, Indonesia

<sup>3</sup> Graduate School of Horticulture, Chiba University, Matsudo, Chiba 271-8510, Japan

Efforts have been made to increase nitrogen use efficiency by additional substrates in nitrogen fertilizer, e.g., use of nitrification or urease inhibitors and slow release with coating technologies (Akiyama et al. 2013; Jumadi et al. 2008). The intent of these methods is to increase food production through an optimized fertilizer utilization rate to reduce the negative environmental impact of  $\text{NO}_3^-$  leaching and  $\text{N}_2\text{O}$  losses to the atmosphere. Hence, reduction of nitrogen losses to the environment is the main area of research to increase nitrogen use efficiency (Ruser and Schulz 2015). Nitrification inhibitors (NIs) retard the oxidation of ammonium ( $\text{NH}_4^+$ ) to nitrite ( $\text{NO}_2^-$ ) in soil for a certain time by inhibition of ammonia monooxygenase (AMO, the first enzymatic step of nitrification) (German-Bauer and Amberger 1989). Inhibition of nitrification can be utilized by the addition of synthetic nitrification inhibitors. However, these synthetic NIs are usually expensive and limited in availability in the market, particularly in Indonesia.

Several studies have also considered that organic NIs such as neem (*Azadirachta indica*) and karanja (*Pongamia glabra*) have NI properties to delay nitrification in nitrogen fertilizer (Opoku et al. 2014; Majumdar et al. 2000; Jumadi et al. 2019; Sharma and Prasad 1996; Kumar et al. 2007). Neem has been used in management of pests and disease in plants for a long time in India and besides having insecticidal properties, neem cake has been found to be an effective NI (Mohanty et al. 2008). Neem seeds contain secondary metabolites such as polyphenols, azadirachtin or certain unsaturated fats, and other tetranortriterpenoids that can act as inhibitors of nitrification and urease; therefore, it can improve the efficiency of urea fertilizer (Abbasi et al. 2011; Majumdar (2005)). Another strategy to increase the efficiency of nitrogen contained in the urea is the addition of polymer material to the urea fertilizer to slow release, such as polyolefin, polyethylene, and zeolite minerals (Ahmed et al. 2008; Azeem et al. 2014). Zeolites are naturally occurring aluminosilicate minerals that have a tridimensional porous structure with hollow channels; therefore, they have an extensive surface area that enables them to bind ammonium within the pore structure. In addition, zeolite can reduce ammonia volatilization because of its high CEC and affinity for  $\text{NH}_4^+$ . Furthermore, with small internal holes of zeolite ( $10^{-6}$  m), it will theoretically preserve  $\text{NH}_4^+$  from responsible microbes that drive nitrification, e.g., ammonium oxidizer bacteria or ammonium oxidizer archaea (Kithome et al. 1998).

Methane monooxygenase (MMO) catalyzes methane ( $\text{CH}_4$ ) gas as a substrate to form  $\text{CO}_2$  gas and this process also can be driven by ammonium monooxygenase (AMO) (Hanson and Hanson 1996). A general characteristic of monooxygenase enzymes is a broad substrate range, and in this respect, AMO fits well in this group, as well as over 40 compounds which have been shown to be substrates of AMO which can competitively inhibit  $\text{NH}_3$  oxidation. Hence,

correlation mechanisms between AMO and MMO are affected by the amendment of nitrification inhibitor which can reduce the activity of both enzymes (McCarty 1999). Mohanty et al. (2008) pointed out that under incubation, experimental application of DCD at the time of soil incubation resulted in a substantial reduction in  $\text{CH}_4$  production (31% over that of untreated control), but under field conditions, they suggested that repeat application of DCD with fertilizer N to flooded rice soils might not be effective in controlling  $\text{CH}_4$  production. However, few studies have been conducted in field experiments to explore the effect of organic and chemical nitrification inhibitors combined with urea and zeolite on the rate of greenhouse gas fluxes, population of soil microbes, and growth of corn crops in tropical conditions.

The objective of this study is to evaluate the combined effect of urea granulated with organic and chemical nitrification inhibitors and zeolite on greenhouse gas fluxes under field conditions and production in incubation experiments. We also determined whether the growth of corn and soil microbial population is affected by additional urea granulated with natural slow release (zeolite) and nitrification inhibitors (neem cake and DCD).

## Materials and methods

### Soil sampling and field site

The cornfield experiment was located at the Indonesian Cereal Research Institute, South Sulawesi Province of Indonesia ( $4^\circ 59' 11.3''$  S  $119^\circ 34' 34''$  E). Soil samples were taken from triplicate plots at 0–15-cm depth and sieved through a 2.00-mm sieve for soil properties analysis and incubation experiment purposes. The pH (1 M KCl 1:5), and total carbon (C) and nitrogen (N) were measured by electrode methods and C/N analyzer (MT 700, Yanaco), respectively. Data of daily temperature and precipitation were collected from the Meteorology, Climatology and Geophysical Agency. A field experiment was plotted in an area around of 400  $\text{m}^2$  and each microplot was measured 17.5  $\text{m}^2$  (2.5 m width  $\times$  7.0 m length). Three replicates of seven treatments were conducted with a completely randomized design from June 23, 2014–September 19, 2014. Corn var. B8 seeds were sown in a well-drained field and the distance between one corn crop to another was around 30 cm; therefore, there were around 153 corn crops in each plot. The nitrogen fertilizers were applied in the field by incorporation into soil with seven types of granulated fertilizer, namely (1) control (C; no addition of nitrogen); (2) urea (U; nitrogen content of 45%); (3) urea with neem (UN; neem (*Azadirachta indica* L) cake is a residual waste from the process of neem oil extraction. It was used as an

organic nitrification inhibitor and mixed with urea at a rate of 5% (w/w); (4) urea with zeolite (UZ; zeolite is coarse natural zeolite from a local mine that is used as a natural slow-release fertilizer and mixed with urea at a rate of 10% (w/w)); (5) urea with zeolite and neem (UZN; zeolite and neem cake were mixed with urea at a rate of 10% and 5% (w/w), respectively); (6) urea with zeolite and dicyandiamide (UZD; zeolite and DCD were mixed with urea at a rate of 10% and 5% (w/w), respectively); and (7) urea with dicyandiamide (UD; DCD is chemical/synthetic nitrification inhibitor (Wako Ltd, Special Grade 90.0% and containing about 65% N) and mixed with urea at a rate of 5% (w/w)). The granulations of mixed fertilizers were done using an inclined pan granulator. The total rate of N applied in each treatment was  $120 \text{ kg-N ha}^{-1}$  applied in two splits (60 + 60) on July 1, 2014 (1st fertilizer applied (FA)) and July 23, 2014 (2nd FA). At the second application of nitrogen fertilizer, each of the plot treatments also had an addition of KCl  $100 \text{ kg ha}^{-1}$  and SP-36 (super phosphate)  $100 \text{ kg ha}^{-1}$ . These rates and timing application of nitrogen treatments followed local farming practices.

### Greenhouse gas emission and growth rate of corn measurements

The gas fluxes of  $\text{N}_2\text{O}$  and  $\text{CH}_4$  were sampled using the closed chamber method (Jumadi et al. 2008). The concentration of  $\text{N}_2\text{O}$  and  $\text{CH}_4$  in the samples was quantified using gas chromatographs (Shimadzu, GC 14B) equipped with an electron capture detector and a flame ionization detector, respectively. Percentage ratio of  $\text{N}_2\text{O-N}$  lost per amount of N applied as fertilizer into the field (EF, emission factor) and the percentages of the reduction of  $\text{N}_2\text{O}$  flux emitted from the fields with nitrification inhibitor or CRF was calculated according to Jumadi et al. (2008). The growth rate of the corn crop was sampled randomly using five corn plants from among the 153 corn crops of each plot. The growth parameters measured were plant height (cm) which was measured weekly until 50 days after seedling (DAS). Other plant growth parameters were also observed including leaf chlorophyll content (%) at 60 DAS, cob weight (kg), and the dry weight of corn stalk biomass, which were weighed after harvesting or at the end of the growth period.

### Greenhouse gas production potential and microbial population

The incubation experiment was conducted to assess greenhouse gas production potential and viable microbial soil population with treatments identical to those used in the field experiment above. Forty grams of soil was incubated aerobically at  $27^\circ\text{C}$  in sealed 120-mL bottles for a 4-week incubation in triplicate for each treatment.

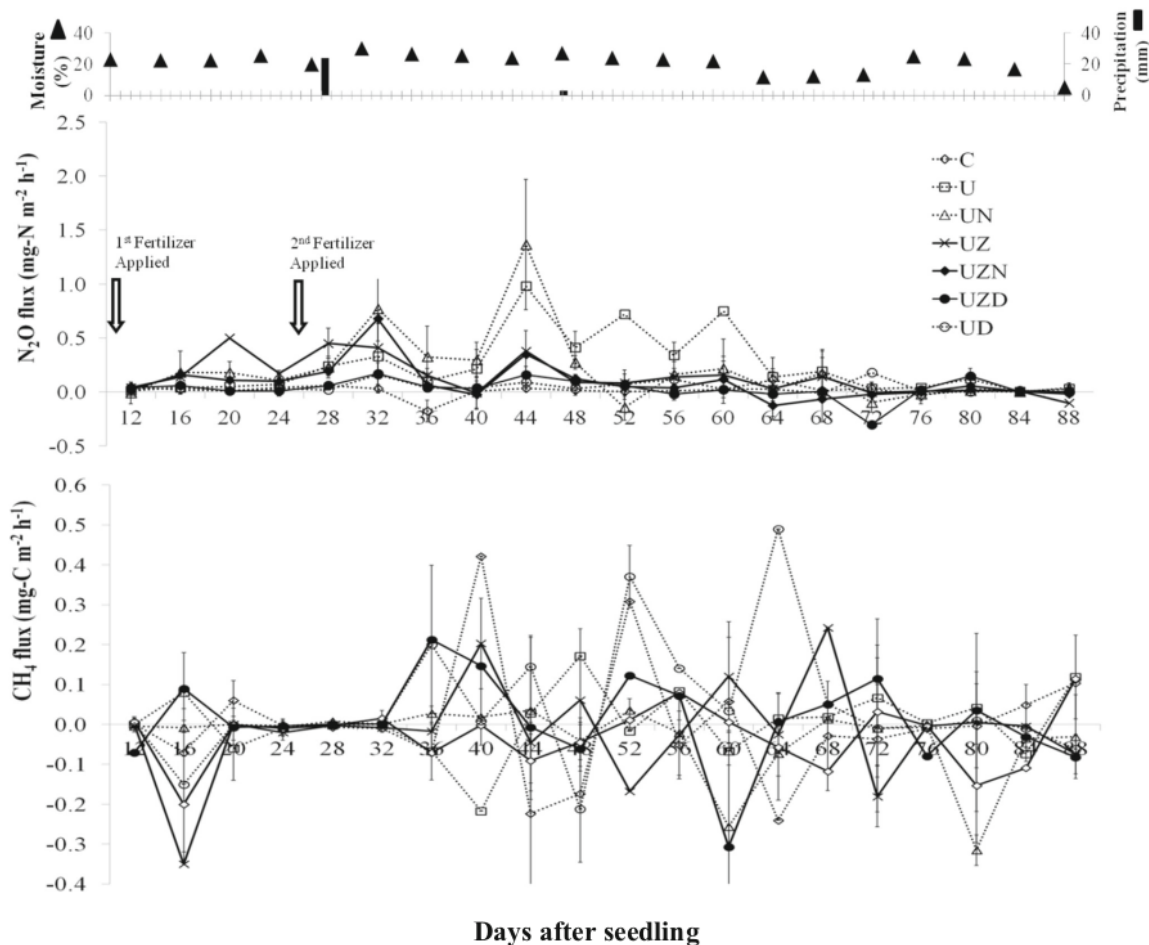
Production potential of  $\text{N}_2\text{O}$  and  $\text{CO}_2$  gases and inorganic N as  $\text{NH}_4^+$  and  $\text{NO}_3^-$  were determined for each soil sample. Every week, the gases in the headspace of each bottle were removed and the incubation bottles were then aerated and resealed for later sampling. Five grams of soil samples was weighed and immediately extracted with 25 mL of 2 M KCl (1:5). The amounts of  $\text{NH}_4^+$  and  $\text{NO}_3^-$  were determined by nitroprusside and hydrazine reduction methods. Gas samples were determined by the concentrations of  $\text{N}_2\text{O}$  and  $\text{CO}_2$  using GC. Determination of soil microbial population was sampled at the end of the soil incubation time of 28 days and then prepared for analysis. Total soil fungus was counted by plate count using potato dextrose agar media. The viable population of nitrifiers; i.e., ammonium oxidizer bacteria and nitrite oxidizer bacteria were estimated by the most probable number technique (Schmidt and Belser 1982). Standard deviations and means of all data were calculated. Each mean was compared with others using the Duncan ( $P < 0.05$ ) value by SPSS software (Ver.20.0 for Windows, SPSS Inc., Chicago, USA).

## Results and discussion

### Soil properties and greenhouse gas fluxes

The soil used was an alluvial soil type. The texture of soil used was 8% sand, 54% silt, and 38% clay, which refers to texture class silty clay loam. The background field soil had a pH of 5.8, CEC of  $28.15 \text{ cmolc/kg}$ ,  $\text{P}_2\text{O}_5$  of  $79.60 \text{ } \mu\text{g g}^{-1}$  contained total carbon of  $11.33 \text{ g-C kg}^{-1}$  dry soil, total N of  $1.40 \text{ g-N kg}^{-1}$  dry soil, and C/N ratio of 8.09. The rainfall was monitored twice during cropping at 29 days after seedling (DAS) and 48 DAS giving measurements 24 mm and 3 mm, while soil moisture ranged from 5.0 to 60.12%. The temperature range during the experiments was  $22\text{--}35^\circ\text{C}$ . The fluxes of  $\text{N}_2\text{O}$  showed a small increase at 20 DAS or 11 days after first nitrogen applied in urea zeolite (UZ) treatment and then decreased at the next measurement. The fluxes of  $\text{N}_2\text{O}$  rose after the second application of fertilizer on 26 DAS for U, UZ, and UN treatments. It was emitted longer with urea (U) treatment from 44 DAS to 60 DAS. The highest peaks of  $\text{N}_2\text{O}$  flux were measured as  $1.36 \text{ mg-N m}^{-2} \text{ h}^{-1}$  with U treatment and  $0.98 \text{ mg-N m}^{-2} \text{ h}^{-1}$  with UN treatment at 44 DAS. The  $\text{N}_2\text{O}$  fluxes for nitrogen additions outside of U treatment commenced a decrease at 48 DAS until the end of measurements and did not vary significantly from the control (Fig. 1).

The sum of  $\text{N}_2\text{O}$  fluxes in a season was highest with U treatment at  $4.67 \text{ kg-N ha}^{-1} \text{ season}^{-1}$ , but statistically comparable with urea neem (UN) at  $3.96 \text{ kg-N ha}^{-1} \text{ season}^{-1}$ . The



**Fig. 1** Change of soil moisture, precipitation,  $N_2O$ , and  $CH_4$  fluxes from cornfields affected by urea granulated with organic and chemical nitrification inhibitors and zeolite treatments during corn cropping

season (June to September 2014). Vertical bars indicate  $\pm$  standard deviations (see “Materials and methods” for abbreviations of symbols)

measurements for the other treatments were  $2.07 \text{ kg-N ha}^{-1} \text{ season}^{-1}$  for urea zeolite (UZ),  $1.75 \text{ kg-N ha}^{-1} \text{ season}^{-1}$  for urea zeolite neem (UZN),  $0.89 \text{ kg-N ha}^{-1} \text{ season}^{-1}$  for urea dicyandiamide (UD), and  $1.10 \text{ kg-N ha}^{-1} \text{ season}^{-1}$  for urea zeolite dicyandiamide (UZD). Meanwhile, control (C) plot was ambient at  $0.31 \text{ kg-N ha}^{-1} \text{ season}^{-1}$ . The emission factor was also highest with U treatment at 2.1% compared with the other treatments: 0.8% (UZ), 1.8% (UN), 0.2% (UD), 0.7% (UZN), and 0.3% (UZD). Among treatments with nitrification inhibitor and zeolite, the lowest reduction of  $N_2O$  flux emitted from field corn was 16.3% with UN treatment. Reductions of  $N_2O$  flux with other treatments were 59.6% (UZ), 66.9% (UZN), 81.9% (UZD), and 86.7% (UD) (Table 1). The pattern of methane ( $CH_4$ ) fluxes from the field was mostly determined by small release and uptake fluctuations across the measurements over one cropping season, except for UD treatment at

64 DAS which had the highest measurement ( $0.4 \text{ mg-C m}^{-2} \text{ h}^{-1}$ ). The seasonal cumulative fluxes of  $CH_4$  were as follows:  $-0.29$  (UZ),  $-0.5$  (UZN),  $-0.63$  (UN),  $0.07$  (C),  $0.14$  (UZD),  $0.30$  (U), and  $0.9$  (UD)  $\text{kg-C h}^{-1} \text{ season}^{-1}$  (Fig. 1).

#### Growth rate of corn crop

All corn crop growth parameters were enhanced by amendment of urea with and without NIs and zeolite compared with control (Table 2). The corn crop growth parameters such as height, cob weight, and chlorophyll rates were comparable for all nitrogen fertilizers (U, UZ, UN, UD, UZN, and UZD), and significantly different from control (C). The dry weight of stalk and leaf (biomass) of the corn crop was also greater with U, UZ, UN, UD, UZN, and UZD treatment compared with C. However, the weight of biomass with UZ ( $1.02 \text{ kg}$ ) was not

**Table 1** The emission factor (EF %) and N<sub>2</sub>O emission reduction in a corn crop season. Means followed by the same letter are not significantly different at (*P* < 0.05) by the Duncan test

Treatments	Total N <sub>2</sub> O (kg-N ha <sup>-1</sup> season <sup>-1</sup> )	EF (%)	Reduction (%)
C	0.31 <sup>a</sup>		
U	4.67 <sup>d</sup>	2.10	
UN	3.96 <sup>cd</sup>	1.80	16.3
UZ	2.07 <sup>bc</sup>	0.80	59.6
UZN	1.75 <sup>b</sup>	0.70	66.8
UZD	1.10 <sup>a</sup>	0.30	81.9
UD	0.89 <sup>a</sup>	0.20	86.7

significantly different from C (0.68%). The treatments of UZ seem to result in lower values of harvest parameters compared with other nitrogen additions. The corncob weight with U (1.42 kg) and UD (1.40 kg) treatments were significantly different from that of UZ (1.27 kg), but not significantly different from weights with other amendments, namely 1.30 kg (UZN), 1.37 kg (UN), and 1.39 kg (UZD). Despite that, UZ treatment has more chlorophyll content (53.64%) compared with other treatments: 38.24% (C), 45.72% (UN), 47.05% (UZN), 49.20% (UD), 50.06% (UZD), and 52.46% (U) (Table 2).

**N<sub>2</sub>O and CO<sub>2</sub> production, nitrogen change, and microbial soil abundance in incubation soil**

The cumulative production of N<sub>2</sub>O in the first week increased by application of U to 0.321 ± 0.099 μg g<sup>-1</sup> dray soil (ds) but was not significantly different from other nitrogen applications except UZN (0.095 ± 0.003 μg g<sup>-1</sup> ds) and C (0.047 ± 0.003 μg g<sup>-1</sup> ds). In the second week of incubation, the N<sub>2</sub>O production of UZN (0.180 ± 0.09 μg g<sup>-1</sup> ds) increased significantly from C (0.013 ± 0.002 μg g<sup>-1</sup> ds), but it was statistically comparable with other treatments. In the third week of incubation, the treatments of UZ produced N<sub>2</sub>O up to 0.185 ± 0.044 μg g<sup>-1</sup> ds, while other treatments slightly decreased afterward to the end of the incubation time (Fig. 2). With

regard to soil respiration, no statistically significant differences were observed among soils treated with urea plus additional NIs and zeolite and control, but amendment of UD seems to stimulate the production of CO<sub>2</sub> up to the second week of incubation and then slightly down to the same rate of CO<sub>2</sub> production as the other nitrogen treatments (Fig. 2).

Soil NH<sub>4</sub><sup>+</sup> concentrations were considerably higher when the soil was treated with all types of nitrogen fertilizers compared with C during the first week of incubation and stayed constant in the second week. In the third week of incubation, the concentrations of NH<sub>4</sub><sup>+</sup> in soils treated with nitrogen were slightly reduced and dramatically decreased in the fourth week of incubation and were not significantly different from C. Soil NO<sub>3</sub><sup>-</sup> concentrations in soil treated with nitrogen were low in the first week and not significantly different from C at 0.041 ± 0.02 μg g<sup>-1</sup> ds except for UN at 0.71 ± 0.02 μg g<sup>-1</sup> ds. The concentration of NO<sub>3</sub><sup>-</sup> was substantially larger beginning in the second week until the end of incubation (Fig. 3). The abundance of ammonium oxidizer bacteria (AOB) ranged from 1.4 × 10<sup>3</sup> to 8.5 × 10<sup>4</sup> cell per dry gram soil (ds), whereas nitrite oxidizer bacteria (NOB) population ranged from 9.2 × 10<sup>2</sup> cell ds<sup>-1</sup> to 8.2 × 10<sup>4</sup> cell ds<sup>-1</sup> in all the soil samples. Soil fungi population in all treatments was not far from 2.6 × 10<sup>3</sup> cell ds<sup>-1</sup> to 4.7 × 10<sup>4</sup> cell ds<sup>-1</sup> (Table 3).

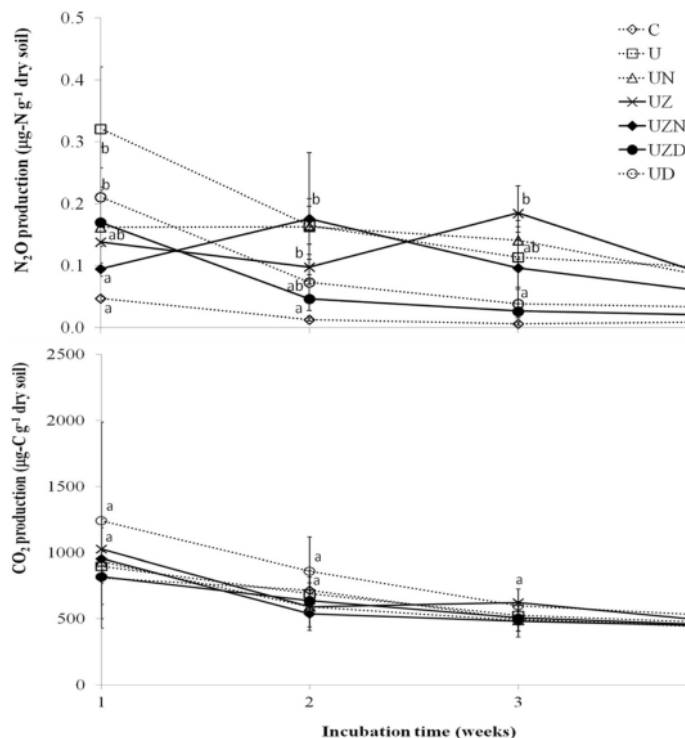
**Discussion**

The measurements of N<sub>2</sub>O flux show the application of urea with nitrification inhibitors (NIs) and zeolite reduces the N<sub>2</sub>O emission range from 16.3 to 86.7% through a corn planting season (Table 1). Our study shows that urea with dicyandiamide (DCD) as a chemical NI has substantial repression on N<sub>2</sub>O flux from cornfields compared with organic NI (neem cake) particularly urea with neem (UN) treatment with the lowest inhibition of 16.3%. This quantity of reduction is very similar to the finding by Akiyama et al. (2013) who used meta-analysis data by integrating results of field measurements showing that NI from neem products could repress N<sub>2</sub>O emission by an average of 14% with the range of

**Table 2** The average of plant height at 50 days after seedling (DAS), weight of cobs, dry weight of corn plants, and chlorophyll content at 60 DAS. Means followed by the same letter are not significantly different at (*P* < 0.05) by the Duncan test

Treatments	Plant height (cm)	Cob weight (kg)	Dry weight of corn plants (stalk and leaf) (kg/plant)	Chlorophyll content (%)
C	182.13 <sup>a</sup>	0.75 <sup>a</sup>	0.68 <sup>a</sup>	38.24 <sup>a</sup>
U	226.13 <sup>b</sup>	1.42 <sup>c</sup>	1.25 <sup>b</sup>	52.46 <sup>bc</sup>
UN	229.00 <sup>b</sup>	1.37 <sup>bc</sup>	1.33 <sup>b</sup>	45.72 <sup>b</sup>
UZ	220.80 <sup>b</sup>	1.27 <sup>b</sup>	1.02 <sup>ab</sup>	53.64 <sup>c</sup>
UZN	226.87 <sup>b</sup>	1.30 <sup>bc</sup>	1.10 <sup>b</sup>	47.05 <sup>bc</sup>
UZD	226.73 <sup>b</sup>	1.39 <sup>bc</sup>	1.14 <sup>b</sup>	50.06 <sup>bc</sup>
UD	218.00 <sup>b</sup>	1.40 <sup>c</sup>	1.20 <sup>b</sup>	49.20 <sup>bc</sup>

**Fig 2** Change in the concentration of  $N_2O$  and  $CO_2$  production during incubation time in weeks. Means followed by the same letter are not significantly different ( $P < 0.05$ )



reduction being 25 to 7%. In the same tropical field experiment, it was observed that there was a substantial repression of  $N_2O$  flux from cornfields in soils with a combination of nitrogen fertilizer with DCD which reduced  $N_2O$  flux by 55.8% compared with urea and also by 11.7% compared with control release fertilizer (LP-30) (Jumadi et al. 2008). This study suggests that the addition of zeolite with urea (UZ) also reduces 59% of  $N_2O$  emission compared with urea alone. Hence, zeolite is apparently a slow-release nitrogen stabilizer and more effective combination with organic NI (neem cake).

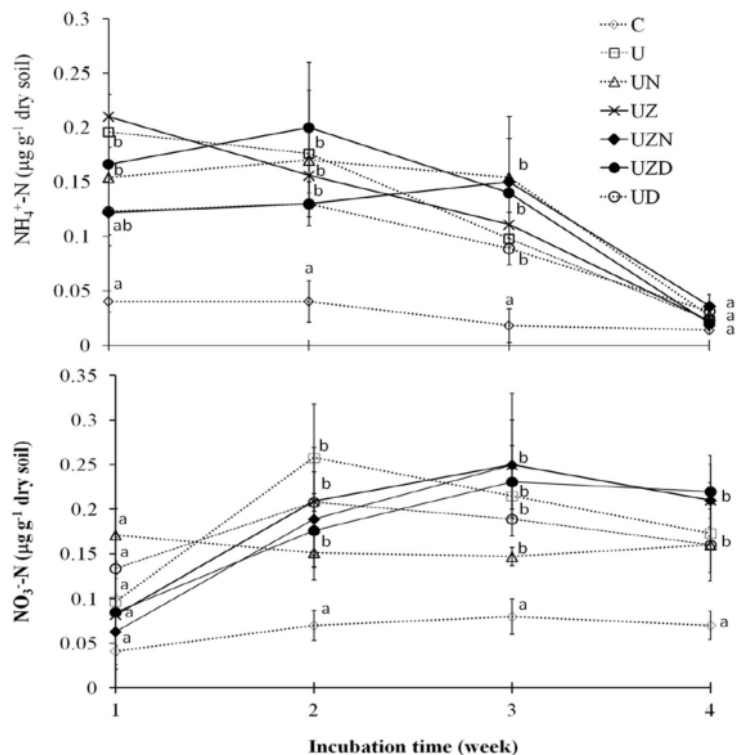
Another experiment that used neem oil as an organic NI, Opoku et al. (2014), resulted in various repressions of  $N_2O$  production, observed a superior inhibitory effect of neem seed oil at 58% at day 30 relative to a lower dose of DCD at 29%, and concluded that neem seed oil, which is less expensive and could be obtained locally in the tropics, has a similar potency as DCD. In addition, organic NI neem could also have activities that inhibit urease in acidic soil and maintain higher concentration of urea for 2 weeks, but it does not occur in typical neutral and alkaline soil (Mohanty et al. 2008). The soil used had a pH of 5.8, which is moderately acid category, which possibly acts to inhibit activity of urease.

The organic NI used in this study was obtained from neem cake, typically a waste product from extracted neem seed oil. It seems to be less effective as a nitrification inhibitor due to the low concentration of secondary metabolites as a function

of substrate substitution to AMO of nitrifying bacteria. In addition, the results that neem cake was less effective for inhibiting nitrification could probably be due to the organic matter including secondary metabolites in neem cake undergoing rapid degradation or being utilized by soil microbes for ammonification to obtain  $NH_4^+$ . Afterward, it continued to transform with nitrification, and thus produced  $N_2O$  as well as  $NO_3^-$ , which was leached from the soil if the efficacy of nitrogen uptake of the plant was less.

Park and Komarneni (1997) tested four types of natural zeolite namely erionite, clinoptilolite, chabazite, and phillipsite that have capacity to store nutrients ( $KNO_3$  and  $NH_4NO_3$ ) and are potential candidates as slow-release fertilizers. Hence, further characterization is required to define the type of natural zeolite used in this study; nevertheless, zeolite has capacity for lowering the emission of  $N_2O$  up to 50% in cornfields. During the experiment, following the addition of urea with and without NIs and zeolite, the highest concentration of  $NH_4^+$  and  $N_2O$  production was detected in the first week, indicating that urea was hydrolyzed and nitrification began within the first week of incubation. The concentration of  $NH_4^+$  remained higher up to 2 weeks of incubation with the combination of urea with NIs and zeolite treatments although there were no significant differences compared with urea. During the  $NH_4^+$  decrease, the concentration of  $NO_3^-$  started to accumulate from the second week to the fourth week, which

**Fig 3.** Change in the concentrations of  $\text{NH}_4^+\text{-N}$  and  $\text{NO}_3^-\text{-N}$  during incubation time in weeks. Means followed by the same letter are not significantly different at ( $P < 0.05$ )



indicates that nitrification was occurring until the end of incubation. Therefore, it showed NIs and zeolite hampered  $\text{N}_2\text{O}$  production under incubation conditions. Similarly, Ahmed et al. (2008) pointed out that applying urea with TSP and zeolite had a significant advantage over urea alone by increasing the formation of  $\text{NH}_4^+$  over  $\text{NH}_3$  and retaining more  $\text{NH}_4^+$  in soil incubation and suggested that  $\text{NH}_4^+$  exchanged in zeolite type clinoptilolite not only served as a slow-release fertilizer in medium-textured porous soil but also reduced volatilization of  $\text{NH}_3$  when urea and zeolite were added to an alkaline coarse texture soil. The retention of  $\text{NH}_4^+$  on the cation exchange sites of the zeolite may also partly explain how the urea with zeolite mixture in granule form can reduce  $\text{N}_2\text{O}$  production compared with urea without zeolite and nitrification inhibitors.

Comparing the influence of urea with NIs and zeolite on  $\text{N}_2\text{O}$  production, our study found no significant difference in  $\text{CO}_2$  production between nitrogen and NIs with zeolite additions and control (Fig. 2). The pattern of  $\text{CO}_2$  produced recorded a slight decrease in the second week of incubation and was constant thereafter. In the first week of incubation with UD treatment, a little more  $\text{CO}_2$  production was detected compared with the second week, which was possibly due to the contribution from the decomposition of urea and DCD. Soil respiration is a reflection of soil microbial metabolism or

biological activity in soil; hence, we speculate that the static production of  $\text{CO}_2$  in this study can also be explained in that the addition of NIs and zeolite to the soil sampled did not cause much change in microbial abundance (AOB, NOB, and fungi) after 4 weeks of incubation (Table 3). Another study shows that the addition of neem cake can reduce the population of nitrifying bacteria with a prolonged time of incubation. Santhi et al. (1986) observes that application of urea mixed with neem cake and neem leaf increases the total microbial count in wetland soil up to the 15th day after the application, but after that, up to the 30th day of incubation,

**Table 3** Microbial population of AOB (ammonium oxidizer bacteria), NOB (nitrite oxidizer bacteria; MPN, cell  $\text{g}^{-1}$  dry soil), and fungi (CFU, cell forming unit,  $\text{g}^{-1}$  dry soil) at 4-week incubation

Treatments	AOB	NOB	Fungi
C	$1.4 \times 10^3$	$9.2 \times 10^2$	$3.3 \times 10^3$
U	$2.0 \times 10^3$	$1.1 \times 10^3$	$4.0 \times 10^3$
UN	$1.9 \times 10^3$	$3.4 \times 10^3$	$4.6 \times 10^3$
UZ	$3.6 \times 10^3$	$8.2 \times 10^4$	$3.3 \times 10^3$
UZN	$2.0 \times 10^3$	$1.1 \times 10^3$	$2.6 \times 10^3$
UZD	$8.5 \times 10^4$	$7.1 \times 10^4$	$3.9 \times 10^3$
UD	$4.0 \times 10^4$	$9.6 \times 10^2$	$4.7 \times 10^4$



the population of *Nitrosomonas*, *Nitrosococcus*, and *Nitrobacter* exhibited a declining trend.

Patra et al. (2006) also reported that natural NIs and DCD retarded *Nitrosomonas*, *Nitrobacter*, and total bacterial and Actinomycete populations. However, the result of this study agrees with Singh et al. (2008) which observed no impact of DCD on soil respiration and microbial biomass in the three soils investigated, while Jumadi et al. (2008) observed microbial soil population (AOB, NOB, and fungi) enhanced by additional urea coated with DCD in the first week and third week of incubation were low with fluctuations decreasing. This is also partly explained by the fact that the mode of action of DCD is a complex reaction which temporarily inhibits the protein bond of AMO to the cell membrane. Amberger (1986) found a specific inhibition of nitrite formation at concentrations of 100 to 300 ppm of *Nitrosomonas europaea* and suggested that DCD is a bacteriostatic agent and not a bactericidal agent. That might also possibly be the mode of action of neem cake as the organic nitrification used in this study.

The initial measurements of the concentrations of CH<sub>4</sub> fluxes were occasionally at a lower level of emission until 32 DAS of the cropping season which might be influenced by field soil being in aerobic condition. However, there was a presence of CH<sub>4</sub> flux after rainfall on 29 DAS and 48 DAS. With UD treatment, CH<sub>4</sub> flux exhibited a temporary positive peak at 52 and 64 DAS (Fig. 1). Urea with organic NIs (neem—UN and UZN) seems to oxidize CH<sub>4</sub>, while urea and urea combined with DCD (UD and UZD) emitted CH<sub>4</sub> from the field with averages of 0.30, 0.9, and 0.14 kg-C h<sup>-1</sup> season<sup>-1</sup>, respectively.

Several studies observed that NH<sub>4</sub><sup>+</sup> or inorganic fertilizer usually inhibits atmospheric CH<sub>4</sub> oxidation due to the competition at the level of nitrification (Le Mer and Roger 2001). Different results by Datta and Adhya (2014) suggested that application of urea + Nimin significantly increased the methanotrophic bacterial population in the soil compared with urea + karanjin, urea + DCD, and control; therefore, it may be attributed to low CH<sub>4</sub> emission released from field. While, Dai et al. (2013) observed methanotroph population abundance and CH<sub>4</sub> uptakes were not significantly affected by the application of DCD and urea-N or animal urine N at different rates. Our observation also confirmed that all urea fertilizers combined with neem cake uptake the CH<sub>4</sub> fluxes in the field while urea with DCD generated CH<sub>4</sub> emission.

Nitrogen is one of the essential nutrients for crop growth and development. Nitrogen can be made available by amending nitrogen in urea with NIs and zeolite. All corn growth parameters observed had no significant differences between urea with and without NIs and zeolite (Table 2). Sharma and Prasad (1996) suggest that the use of nitrification inhibitors (neem and DCD) in split time resulted in a greater increase of nitrogen efficiency in maize-wheat rotations

compared with a single application. Nitrogen is a constituent component of leaf chlorophyll and about 60% functions as enzymes and derivative membrane proteins in plant cells. Therefore, additional nitrogen increases the photosynthetic efficiency of crops which might have resulted in enhancement of corn growth such as plant height, yield, and biomass. Our study results suggest that applying urea fertilizer with organic nitrification inhibitors with and without zeolite in a corn crop of a tropical area has the potential to mitigate N<sub>2</sub>O emission; however, further research is needed on the long-term application of recent type nitrogen fertilizers to better quantify greenhouse gas fluxes from various types of fields.

**Acknowledgments** The authors are very thankful to Indra Pramana, Muh. Dwi Prasetyo, Nurul Mutmainnah, and Ratna Dewi from the Biology Department, Universitas Negeri Makassar.

**Funding information** This work was funded by The Ministry of Research, Technology and Higher Education of Indonesia under grant Penelitian Dasar and Penelitian Terapan.

## References

- Abbasi MK, Hina M, Tahir MM (2011) Effect of *Azadirachta indica* (neem), sodium thiosulphate and calcium chloride on changes in nitrogen transformations and inhibition of nitrification in soil incubated under laboratory conditions. *Chemosphere* 82:1629–1635
- Ahmed OH, Aminuddin H, Husni MHA (2008) Reducing ammonia loss from urea and improving soil-exchangeable ammonium retention through mixing triple superphosphate, humic acid and zeolite. *Soil Use Manag* 22:315–319
- Akiyama H, Morimoto S, Hayatsu M, Hayakawa A, Sudo S, Yagi K (2013) Nitrification, ammonia oxidizing communities, and N<sub>2</sub>O and CH<sub>4</sub> fluxes in an imperfectly drained agricultural field fertilized with coated urea with and without dicyandiamide. *Biol Fertil Soils* 49:213–223
- Amberger A (1986) Potentials of nitrification inhibitors in modern N-fertilizer management. *Z Pflanzenmaehr Bodenk* 149:469–484
- Azeem B, KuShaari K, Man ZB, Basit A, Thanh TH (2014) Review on material and methods to produce controlled release coated urea fertilizer. *J Control Release* 181:11–21
- Dai Y, Di HJ, Cameron KC, He JZ (2013) Effects of nitrogen application rate and a nitrification inhibitor dicyandiamide on methanotroph abundance and methane uptake in a grazed pasture soil. *Environ Sci Pollut Res* 20:8680–8689
- Datta A, Adhya TK (2014) Effects of organic nitrification inhibitors on methane and nitrous oxide emission from tropical rice paddy. *Atmos Environ* 92:533–545
- German-Bauer MP, Amberger A (1989) Degradation of the nitrification inhibitor 1-amidino-2 thiourea in soils, and its action in *Nitrosomonas* pure culture and soil incubation experiments. *Fertil Res* 19:13–19
- Hanson R, Hanson T (1996) Methanotrophic bacteria. *Microbiol Rev* 60:439–471
- IFA (2011) Fertilizer Outlook 2011–2015. 79th Annual Conference International Fertilizer Industry Association (IFA) Montreal
- Jumadi O, Hala Y, Muis A, Ali A, Palennari M, Yagi K, Inubushi K (2008) Influences of chemical fertilizers and a nitrification inhibitor on greenhouse gas fluxes in a Corn (*Zea mays* L.) field in Indonesia. *Microbes Environ* 23:29–34

- Jumadi O, Hiola SF, Hala Y, Norton J, Inubushi K (2014) Influence of Azolla (*Azolla microphylla* Kaulf.) compost on biogenic gas production, inorganic nitrogen and growth of upland kangkong (*Ipomoea aquatica* Forsk.) in a silt loam soil. *Soil Sci Plant Nutr* 60:722–730
- Jumadi O, Hartono H, Masniawati A, Iriyani RN, Makkulawu AT, Inubushi K (2019) Emissions of nitrous oxide and methane from rice field after granulated urea application with nitrification inhibitors and zeolite under different water managements. *Paddy Water Environ* 17: 715. <https://doi.org/10.1007/s10333-019-00724-3>
- Kithome M, Paul JW, Lavkulich LM, Bomke AA (1998) Kinetics of ammonium adsorption and desorption by the natural zeolite clinoptilolite. *Soil Sci Soc Am J* 62:622–629
- Kumar R, Devakumar C, Sharma V, Kakkar G, Kumar D, Panneerselvam P (2007) Influence of physicochemical parameters of neem (*Azadirachta indica* A Juss) oils on nitrification inhibition in soil. *J Agric Food Chem* 55(4):1389–1393
- Le Mer J, Roger P (2001) Production, oxidation, emission and consumption of methane by soil: a review. *Eur J Soil Biol* 37:25–50
- Majumdar D (2005) Crop yield and soil nitrogen dynamics in an intermittently flooded rice field affected by nitrification inhibitors: (Einfluss von Nitrifikationshemmern auf Getreideertrag und Stickstoffdynamik im Boden in einem zeitweilig überfluteten Reisfeld). *Arch Agron Soil Sci* 51(6):645–653
- Majumdar D, Kumar S, Pathak H, Jain MC, Kumar U (2000) Reducing nitrous oxide emission from an irrigated rice field of North India with nitrification inhibitors. *Agric Ecosyst Environ* 81:163–169
- Majumdar D, Pathak H, Kumar S, Jain MC (2002) Nitrous oxide emission from a sandy loam Inceptisol under irrigated wheat in India as influenced by different nitrification inhibitors. *Agric Ecosyst Environ* 91(1–3):283–293
- McCarty GW (1999) Modes of action of nitrification inhibitors. *Biol Fertil Soils* 29:1–9
- Mohanty S, Patra AK, Chhonkar PK (2008) Neem (*Azadirachta indica*) seed kernel powder retards urease and nitrification activities in different soils at contrasting moisture and temperature regimes. *Bioresour Technol* 99(4):894–899
- Mosier AR, Kroeze C (2000) Potential impact on the global atmospheric N<sub>2</sub>O budget of the increased nitrogen input required to meet future global food demands. *Chemosphere-Global Change Sci* 2:465–473
- Opoku A, Chaves B, Neve SD (2014) Neem seed oil: a potent nitrification inhibitor to control nitrate leaching after incorporation of crop residues. *Biol Agric Hortic* 30:145–152
- Park M, Komarneni S (1997) Occlusion of KNO<sub>3</sub> and NH<sub>4</sub>NO<sub>3</sub> in natural zeolites. *Zeolites* 18:171–175
- Patra DD, Kiran U, Pande P (2006) Urease and nitrification retardation properties in natural essential oils and their by-products. *Commun Soil Sci Plant Anal* 37:1663–1673
- Ruser R, Schulz R (2015) The effect of nitrification inhibitors on the nitrous oxide (N<sub>2</sub>O) release from agricultural soils—a review. *J Plant Nutr Soil Sci* 178:171–188
- Santhi SR, Palaniappan SP, Purushotham D (1986) Influence of neem leaf on nitrification in a lowland rice soil. *Plant Soil* 93(1):133–135
- Schmidt EL, Belser LW (1982) Nitrifying bacteria. In: Keeney DR (ed) *Method of soil analysis, part 2*. Soil Sci American, Madison, pp 1027–1042
- Sharma SN, Prasad R (1996) Use of nitrification inhibitors (neem and DCD) to increase N efficiency in maize-wheat cropping system. *Fertil Res* 44:169–175
- Singh J, Saggari S, Giltrap DL, Bolan NS (2008) Decomposition of dicyandiamide (DCD) in three contrasting soils and its effect on nitrous oxide emission, soil respiratory activity, and microbial biomass—an incubation study. *Soil Res* 46:517–552
- Zhang J, Sui Q, Li K, Chen M, Tong J, Qi L, Wei Y (2017) Influence of natural zeolite and nitrification on organics degradation and nitrogen transformation during sludge composting. *Environ Sci Pollut Res* 24:9122. <https://doi.org/10.1007/s11356-017-8918-4>

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

## Terms and Conditions

Springer Nature journal content, brought to you courtesy of Springer Nature Customer Service Center GmbH (“Springer Nature”).

Springer Nature supports a reasonable amount of sharing of research papers by authors, subscribers and authorised users (“Users”), for small-scale personal, non-commercial use provided that all copyright, trade and service marks and other proprietary notices are maintained. By accessing, sharing, receiving or otherwise using the Springer Nature journal content you agree to these terms of use (“Terms”). For these purposes, Springer Nature considers academic use (by researchers and students) to be non-commercial.

These Terms are supplementary and will apply in addition to any applicable website terms and conditions, a relevant site licence or a personal subscription. These Terms will prevail over any conflict or ambiguity with regards to the relevant terms, a site licence or a personal subscription (to the extent of the conflict or ambiguity only). For Creative Commons-licensed articles, the terms of the Creative Commons license used will apply.

We collect and use personal data to provide access to the Springer Nature journal content. We may also use these personal data internally within ResearchGate and Springer Nature and as agreed share it, in an anonymised way, for purposes of tracking, analysis and reporting. We will not otherwise disclose your personal data outside the ResearchGate or the Springer Nature group of companies unless we have your permission as detailed in the Privacy Policy.

While Users may use the Springer Nature journal content for small scale, personal non-commercial use, it is important to note that Users may not:

1. use such content for the purpose of providing other users with access on a regular or large scale basis or as a means to circumvent access control;
2. use such content where to do so would be considered a criminal or statutory offence in any jurisdiction, or gives rise to civil liability, or is otherwise unlawful;
3. falsely or misleadingly imply or suggest endorsement, approval, sponsorship, or association unless explicitly agreed to by Springer Nature in writing;
4. use bots or other automated methods to access the content or redirect messages
5. override any security feature or exclusionary protocol; or
6. share the content in order to create substitute for Springer Nature products or services or a systematic database of Springer Nature journal content.

In line with the restriction against commercial use, Springer Nature does not permit the creation of a product or service that creates revenue, royalties, rent or income from our content or its inclusion as part of a paid for service or for other commercial gain. Springer Nature journal content cannot be used for inter-library loans and librarians may not upload Springer Nature journal content on a large scale into their, or any other, institutional repository.

These terms of use are reviewed regularly and may be amended at any time. Springer Nature is not obligated to publish any information or content on this website and may remove it or features or functionality at our sole discretion, at any time with or without notice. Springer Nature may revoke this licence to you at any time and remove access to any copies of the Springer Nature journal content which have been saved.

To the fullest extent permitted by law, Springer Nature makes no warranties, representations or guarantees to Users, either express or implied with respect to the Springer nature journal content and all parties disclaim and waive any implied warranties or warranties imposed by law, including merchantability or fitness for any particular purpose.

Please note that these rights do not automatically extend to content, data or other material published by Springer Nature that may be licensed from third parties.

If you would like to use or distribute our Springer Nature journal content to a wider audience or on a regular basis or in any other manner not expressly permitted by these Terms, please contact Springer Nature at

[onlineservice@springernature.com](mailto:onlineservice@springernature.com)

# Combined effects of nitrification inhibitor and zeolite on greenhouse gas fluxes and corn growth

## ORIGINALITY REPORT

11%

SIMILARITY INDEX

6%

INTERNET SOURCES

8%

PUBLICATIONS

1%

STUDENT PAPERS

## PRIMARY SOURCES

- 1 M. Kaleem Abbasi, Munazza Hina, Majid Mahmood Tahir. "Effect of Azadirachta indica (neem), sodium thiosulphate and calcium chloride on changes in nitrogen transformations and inhibition of nitrification in soil incubated under laboratory conditions", *Chemosphere*, 2011  
Publication <1%
- 2 Submitted to Monroe College  
Student Paper <1%
- 3 fbmp.info  
Internet Source <1%
- 4 A. Amberger. "Potentials of nitrification inhibitors in modern N-fertilizer management", *Zeitschrift für Pflanzenernährung und Bodenkunde*, 1986  
Publication <1%
- 5 Fatriana, M W Caronge, Y A Djawad, N Bourgougnon, A T Makkulawu, O Jumadi. "Effect of application of algae sp. extract to

corn plants ( L.) and microbial response ", IOP  
Conference Series: Earth and Environmental  
Science, 2020

Publication

---

6	<a href="https://repositorio.unb.br">repositorio.unb.br</a> Internet Source	<1 %
7	Clemens Scheer, Rudolf Meier, Nicolas Brüggemann, Peter R. Grace, Michael Dannenmann. " An improved N tracer approach to study denitrification and nitrogen turnover in soil incubations ", Rapid Communications in Mass Spectrometry, 2016 Publication	<1 %
8	<a href="https://eprints.unm.ac.id">eprints.unm.ac.id</a> Internet Source	<1 %
9	<a href="https://repository.futminna.edu.ng:8080">repository.futminna.edu.ng:8080</a> Internet Source	<1 %
10	Xianglan Li. "Methane and nitrous oxide emissions from rice paddy soil as influenced by timing of application of hydroquinone and dicyandiamide", Nutrient Cycling in Agroecosystems, 01/21/2009 Publication	<1 %
11	<a href="https://mafiadoc.com">mafiadoc.com</a> Internet Source	<1 %
12	<a href="https://nopr.niscpr.res.in">nopr.niscpr.res.in</a> Internet Source	<1 %

---

- |    |  |      |
|----|--|------|
| 13 | <a href="http://ouci.dntb.gov.ua">ouci.dntb.gov.ua</a><br>Internet Source  | <1 % |
| 14 | G. Vinay, B. Padmaja, M. Malla Reddy, G. Jayasree, S. Triveni. "Effect of Natural, Organic and Inorganic Farming Methods on Microorganisms and Enzymes Activity of Maize Rhizosphere", International Research Journal of Pure and Applied Chemistry, 2020<br>Publication | <1 % |
| 15 | <a href="http://krishikosh.egranth.ac.in">krishikosh.egranth.ac.in</a><br>Internet Source  | <1 % |
| 16 | D.D. Yan, Q.X. Wang, Y. Li, C.B. Ouyang, M.X. Guo, A.C. Cao. "Effects of fumigation on mineral nitrogen dynamics in soil profiles from tomato greenhouse", Acta Horticulturae, 2017<br>Publication   | <1 % |
| 17 | P. Pengthamkeerati, A. Modtad. "Nitrification Inhibitor, Fertilizer Rate, and Temperature Effects on Nitrous Oxide Emission and Nitrogen Transformation in Loamy Sand Soil", Communications in Soil Science and Plant Analysis, 2016<br>Publication                      | <1 % |
| 18 | Shingo Matsumoto. "Evaluation of the mineralizable organic nitrogen in soil using an   | <1 % |

immunological technique", Biology and  
Fertility of Soils, 10/2008

Publication

19

[jurnal.unived.ac.id](http://jurnal.unived.ac.id)

Internet Source

<1 %

20

[www.jcancer.org](http://www.jcancer.org)

Internet Source

<1 %

21

D. D. Patra, M. Anwar, Sukhmal Chand, Usha Kiran, D. K. Rajput, Sushil Kumar. " Nimin and oil as nitrification inhibitors for optimum yield of Japanese mint ", Communications in Soil Science and Plant Analysis, 2007

Publication

<1 %

22

Dongdong Yan, Qiuxia Wang, Liangang Mao, Wei Li, Hongwei Xie, Meixia Guo, Aocheng Cao. "Quantification of the effects of various soil fumigation treatments on nitrogen mineralization and nitrification in laboratory incubation and field studies", Chemosphere, 2013

Publication

<1 %

23

[www.openagrar.de](http://www.openagrar.de)

Internet Source

<1 %

24

[worldwidescience.org](http://worldwidescience.org)

Internet Source

<1 %

25

Jishao Jiang, Youwei Pan, Xianli Yang, Juan Liu, Haohao Miao, Yuqing Ren, Chunyan Zhang,

<1 %

Guangxuan Yan, Jinghua Lv, Yunbei Li.  
"Beneficial influences of peledith and dicyandiamide on gaseous emissions and the fungal community during sewage sludge composting", Environmental Science and Pollution Research, 2019

Publication

---

26

Paul D. Brown, Matthew J. Morra.  
"Brassicaceae Tissues as Inhibitors of Nitrification in Soil", Journal of Agricultural and Food Chemistry, 2009

<1 %

Publication

---

27

S MOHANTY, A PATRA, P CHHONKAR. "Neem (Azadirachta indica) seed kernel powder retards urease and nitrification activities in different soils at contrasting moisture and temperature regimes", Bioresource Technology, 2008

<1 %

Publication

---

28

XULI TANG. "Soil-atmospheric exchange of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O in three subtropical forest ecosystems in southern China", Global Change Biology, 3/2006

<1 %

Publication

---

29

[static.frontiersin.org](http://static.frontiersin.org)

Internet Source

<1 %

---

30

[www-gio.nies.go.jp](http://www-gio.nies.go.jp)

Internet Source

<1 %

---



31

[www.dpvta.uniud.it](http://www.dpvta.uniud.it)

Internet Source

&lt;1 %

32

A. Zahoor, T. Honna, S. Yamamoto, M. Irshad, Haytham El-Sharkawi, W.H. Abou El-Hassan, Faridullah. "Wheat ( L.) response to combined organic and inorganic phosphorus fertilizers application under saline conditions ", Acta Agriculturae Scandinavica, Section B - Plant Soil Science, 2007

Publication

&lt;1 %

33

Arti Bhatia, Nicholas J. Cowan, Julia Drewer, Ritu Tomer et al. "The impact of different fertiliser management options and cultivars on nitrogen use efficiency and yield for rice cropping in the Indo-Gangetic Plain: Two seasons of methane, nitrous oxide and ammonia emissions", Agriculture, Ecosystems & Environment, 2023

Publication

&lt;1 %

34

Bhupinder Singh Jatana, Christopher Kitchens, Christopher Ray, Nishanth Tharayil.

"Regulating the nutrient release rates from proteinaceous agricultural byproducts using organic amendments and its effect on soil chemical and microbiological properties", Biology and Fertility of Soils, 2020

Publication

&lt;1 %

35

Cheng, W.. "N<sub>2</sub>O and NO production in various Chinese agricultural soils by nitrification", *Soil Biology and Biochemistry*, 200406

Publication

---

<1 %

36

Deepanjan Majumdar. "Crop yield and soil nitrogen dynamics in an intermittently flooded rice field affected by nitrification inhibitors", *Archives of Agronomy and Soil Science*, 2005

Publication

---

<1 %

37

Jiang, J.. "Nitrous oxide emissions from Chinese cropland fertilized with a range of slow-release nitrogen compounds", *Agriculture, Ecosystems and Environment*, 20100131

Publication

---

<1 %

38

Yanjie Guo, Bowen Li, Hongjie Di, Lijuan zhang, Zhiling Gao. "Effects of dicyandiamide (DCD) on nitrate leaching, gaseous emissions of ammonia and nitrous oxide in a greenhouse vegetable production system in northern China", *Soil Science and Plant Nutrition*, 2012

Publication

---

<1 %

39

Zaman, M.. "Effect of urease and nitrification inhibitors on N transformation, gaseous emissions of ammonia and nitrous oxide,

<1 %

pasture yield and N uptake in grazed pasture system", Soil Biology and Biochemistry, 200906

Publication

40

[bdigital.zamorano.edu](http://bdigital.zamorano.edu)

Internet Source

<1 %

41

[chesapeake.org](http://chesapeake.org)

Internet Source

<1 %

42

[repository.sustech.edu](http://repository.sustech.edu)

Internet Source

<1 %

43

[www.publish.csiro.au](http://www.publish.csiro.au)

Internet Source

<1 %

44

[www.stargate-h2020.eu](http://www.stargate-h2020.eu)

Internet Source

<1 %

45

Alpna Dubey, Damodhara R. Mailapalli. "Development of control release urea fertilizer model for water and nitrogen movement in flooded rice", Paddy and Water Environment, 2017

Publication

<1 %

46

D. Chen. "Prospects of improving efficiency of fertiliser nitrogen in Australian agriculture: a review of enhanced efficiency fertilisers", Australian Journal of Soil Research, 2008

Publication

<1 %

47

Douglas W. Ming, Earl R. Allen. "18. Use of Natural Zeolites in Agronomy, Horticulture and Environmental Soil Remediation", Walter de Gruyter GmbH, 2001

Publication

---

<1 %

48

J. Carneiro. "Effect of the nitrification inhibitor dicyandiamide on microbial communities and N<sub>2</sub>O from an arable soil fertilized with ammonium sulphate", Environmental Chemistry Letters, 03/21/2009

Publication

---

<1 %

49

Sangita Mohanty, C. K. Swain, Rahul Tripathi, S. K. Sethi et al. "Nitrate leaching, nitrous oxide emission and N use efficiency of aerobic rice under different N application strategy", Archives of Agronomy and Soil Science, 2017

Publication

---

<1 %

50

Ahmed Md Motasim, Abd Wahid Samsuri, Arina Shairah Abdul Sukor, Amin Mohd Adibah. "Nitrogen Dynamics in Tropical Soils Treated with Liquid and Granular Urea Fertilizers", Agriculture, 2021

Publication

---

<1 %

51

[digitalcommons.uri.edu](https://digitalcommons.uri.edu)

Internet Source

---

<1 %

---

Exclude quotes On

Exclude bibliography On

Exclude matches Off

# Combined effects of nitrification inhibitor and zeolite on greenhouse gas fluxes and corn growth

---

GRADEMARK REPORT

---

FINAL GRADE

**/0**

GENERAL COMMENTS

**Instructor**

---

PAGE 1

---

PAGE 2

---

PAGE 3

---

PAGE 4

---

PAGE 5

---

PAGE 6

---

PAGE 7

---

PAGE 8

---

PAGE 9

---

PAGE 10

---