



Application of litters to inhibit nitrification in Vertisols on sweet corn (*Zea mays* S.)

Supriyadi^{1*}, Adiprasetya Widyatama², Gadis Mona Prinandhika², Purwanto¹, Sri Hartati¹

¹Department of Soil Science, Faculty of Agriculture, Sebelas Maret University, Indonesia

²Undergraduate Program of Soil Science, Faculty of Agriculture, Sebelas Maret University, Indonesia

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* Corresponding Author

Email address:
supriyadi_uns@staff.uns.ac.id

ABSTRACT

Nitrification, or the process of oxidation of ammonium to nitrate in the soil, needs to be inhibited because it reduces the efficiency of nitrogen fertilizers. Vertisols have 2:1 minerals and have a high negative charge, so ammonium is more absorbed by soil particles, whereas nitrate is free to move in the soil and diffuses into the plant tissue or is leached with gravity water. This study aimed to determine the litter treatment that can inhibit the nitrification process in Vertisols on sweet corn plants. This research was conducted from June until November 2019 in the Greenhouse of Plesungan, Gondangrejo, Karanganyar, Indonesia. This study used a basic completely randomized design with a single factor (litter type) as an immobilizer. The types of litter used in this study were *Gliricidia maculata*, *Albizia falcataria*, *Senna siamea*, and *Tithonia diversifolia*. The parameters observed were ammonium content, potential nitrification, average nitrate content, actual nitrification, plant height, number of leaves, and plant dry weight. *Tithonia diversifolia* gave the highest actual nitrification of 23.26%. *Senna siamea* has the lowest actual nitrification of 12.36%, followed by *Gliricidia maculata* with 17.39% and *Albizia falcataria* with 17.67%. This shows that the *Tithonia diversifolia* litter has the highest value in inhibiting nitrification. Sweet corn plants treated with the *Tithonia diversifolia* litter had the best plant growth compared to the other treatments. Therefore, among the treatments used, the *Tithonia diversifolia* litter was more optimal for inhibiting nitrification in Vertisols.

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1. Introduction

Nitrification, or the process of oxidation of ammonium to nitrate in the soil, needs to be inhibited because it reduces the efficiency of nitrogen fertilizers. The application of excessive amounts of N fertilizer raises various problems, for example, the biochemical change from an immobilized nitrogen form, ammonium, to a more mobile form, nitrite or nitrate, by chemoautotroph bacteria during the nitrification process could be harmful to the environment (Purwanto et al., 2014). Nitrification is a critical step in the nitrogen cycle and has significant agricultural and environmental consequences for the availability of nitrogen as a plant nutrient (Yao et al., 2011). This process is highly detrimental to plants because it causes the efficient use of nitrogen by plants to decrease, thus limiting crop production. For sweet corn, for example, the absorption of nitrate requires energy of 20 ATP, whereas the absorption of ammonium needs 6

ATP. In the environment, nitrification also has a negative impact, because it produces NO_3^- , which is very dangerous when absorbed by plants. About 53% of NO_3^- easily leaches with groundwater, and through denitrification, NO_3^- is converted to N_2O , NO , and N_2 gases (Liu et al., 2014). The suppression of soil nitrification can be an important strategy for minimizing N losses from agricultural systems (Gong et al., 2013).

Nitrification is a more important source of NO and N_2O than is denitrification when water-filled pore space (WFPS) is at <60%, and the reverse is true when WFPS is at >60% (Macdonald et al., 2011). The nitrification activity after N fertilizer application is the main driver of N loss during the aerobic upland season because of nitrate leaching. Nitrification is also considered as an indirect driver of N loss during the flooded rice-growing season because the

denitrification rate in flooded soil is controlled by the nitrification rate instead of the activities of denitrification enzymes (Lan et al., 2017). In environments unfavorable to autotrophic nitrifying bacteria, nitrification may result from the activity of heterotrophic microorganisms (Dolinšek et al., 2013) since ammonia-oxidizing bacteria are weaker competitors for ammonium than ammonia-assimilating heterotrophs when ammonium is limited (Faeflen et al., 2016).

The important factors that control soil N mineralization and nitrification include soil C/N ratio (Urakawa et al., 2016), moisture and temperature (Yu et al., 2010), fertilization (Zhang et al., 2015), vegetation and stand age (Nishizawa et al., 2016), and land-use change (Norton & Ouyang, 2019). Nitrification inhibitors are chemicals that slow down the process of nitrification, i.e., the transformation of NH_3 to nitrite. This slowdown in nitrification is due to the inhibition of the activities of the *Nitrosomonas* bacteria group, which transforms ammonium to nitrite; the formation of nitrate is thus slowed down. Leaching, as well as volatilization losses, are reduced because the nitrogen remains in the ammonium form (Ransom et al., 2020).

Within the N cycle, nitrification, the oxidation of ammonium to nitrate via an intermediate step that generates nitrite, is of exceptional interest as it modifies the relative availability of the two forms of ammonium and nitrate that are most readily available for plant N nutrition (Veresoglou, 2012). Nitrate leaching is followed by the leaching of base cations in the soil, thereby reducing base saturation and increasing soil acidity, which ultimately worsens the chemical nature of the soil (Goulding, 2016). In general, nitrification must be inhibited because nitrate that is leached into water bodies can cause eutrophication, which can reduce levels of dissolved oxygen, increase concentrations of greenhouse gases, and thus contribute to environmental pollution.

Vertisols are a type of soil that is dark gray to black, are clay textured, have slickenside, and have fractures that can periodically shrink and swell (Dudek et al., 2019). The composition of Vertisols is always dominated by type 2:1 clay minerals, particularly montmorillonite (Rajamuddin et al., 2013). Vertisols have relatively rich nutrient reserves, although they are not yet available for plants (Dudek et al., 2019). Soil Vertisols have a high negative charge, so ammonium is more absorbed by soil particles, whereas nitrate moves freely in the soil and diffuses into the plant tissue (Scherer et al., 2014). Ammonium content in Vertisols' stagnant soil water is lower than the nitrate because Vertisols has variable minerals that can adsorb ammonium and nitrate. This occurs because soil has a more negative charge so that more ammonium is absorbed by soil particles while NO_3^- is freer to move in the soil and diffuses into the plant tissue. The more problems in Vertisols management are on the physical properties rather than on the chemical properties. Its because Vertisols have relatively rich nutrient reserves, although they are not yet available for plants. The problems related to the physical properties of the soil are in the form of heavy clay texture, swelling and shrinking properties, low infiltration

rates, and slow water drainage. Inhibition of nitrification offers the potential for decreasing soil nitrate losses via retarding the microbial transformation of soil ammonium to soil nitrate (Ruser & Schulz, 2015). Efforts to inhibit nitrification and increase the utilization of nitrogen include maintaining the amount and diversity of litter input quality so that the immobilization of ammonium (nitrification substrate) and O_2 competition between heterotrophic bacteria and nitrifying bacteria are increased (Wati et al., 2020). Inhibition of the nitrification process is done by adding litter as a natural nitrification inhibitor.

Nitrification inhibitor compounds are relatively expensive, no effective nitrification inhibitor compound has been found against the target of *Nitrosomonas* bacteria and nitrification inhibitor does not harm the non-target bodies (Purwanto & Supriyadi, 2014). Efforts to inhibit nitrification are carried out by maintaining the amount and variety of the quality of litter input, it will increase ammonium immobilization (nitrifying substrate) and O_2 competition between heterotrophic bacteria and nitrifying bacteria (Wati et al., 2020). Thus, in the present research, the process of nitrification in the soil is inhibited with the addition of litter as a natural nitrification immobilizer. The addition of litter is intended to reduce the concentration of NO_3^- in the soil so that there is competency in the use of ammonium and NO_3^- by heterotrophic microbes during the decomposition of organic matter. Previous research showed that low-quality litter decreased potential nitrification by 77.35% and high-quality litter decreased by 25.05% (Wati et al., 2020). The types of litter used in this study are *Gliricidia maculata*, *Albizia falcataria*, *Senna siamea*, and *Tithonia diversifolia*. This study aims to determine the litter treatment that can inhibit the nitrification process in Vertisols on sweet corn plants.

2. Material and Methods

2.1. Experimental Site and Soil Properties

This research was conducted from June to November 2019 in the Greenhouse of Plesungan, Gondangrejo, Karanganyar. Laboratory analysis was carried out in the Chemistry and Soil Fertility Laboratory and the Soil Biology Laboratory in the Faculty of Agriculture, Sebelas Maret University, Surakarta. Vertisols as soil samples were taken from Jatikuwung, Gondangrejo, Karanganyar, Indonesia (7°31'3"S, 110°50'52"E) used simple random purposive sampling, which was taken from a depth of 0–20 cm. The soil was composited and dried. The pot size for each treatment was 35 cm × 26 cm. Ten kilograms of soil, with a volume of 22,759 cm³, was put in the pot.

Based on the results of the initial soil analysis, the chemical properties of Vertisols were as follows: 6.805 pH H₂O, organic C of 0.869%, organic matter content of 1.49%, total N of 0.477%, C/N ratio of 1.82, and moisture content of 7.77%. The plant litter species used were *Gliricidia maculata*, *Albizia falcataria*, *Senna siamea*, and *Tithonia diversifolia*. These were chosen because they are easy to obtain, grow fast, have abundant biomass, and have varying content

Table 1. Initial chemical characteristics of each litter

| No. | Litter type | Chemical content | | | | Litter quality class |
|-----|------------------------------|-----------------------|------------|-----------------|-------------------------------|----------------------|
| | | Carbon/nitrogen ratio | Lignin (%) | Polyphenols (%) | Lignin + polyphenols/nitrogen | |
| 1 | <i>Gliricidia maculata</i> | 10.00 | 20.02 | 9.24 | 7.33 | High |
| 2 | <i>Albizia falcataria</i> | 7.00 | 30.10 | 15.11 | 9.00 | High |
| 3 | <i>Senna siamea</i> | 16.95 | 16.10 | 1.87 | 6.83 | High |
| 4 | <i>Tithonia diversifolia</i> | 18.75 | 20.84 | 4.37 | 18.35 | Low |

Note: Litter quality class is based on content (lignin + polyphenol)/nitrogen (Wati et al., 2020).

Table 2. ANOVA test of parameters affected by various types of litter for 30 days on Vertisols and plant growth

| Parameter | p-value (Significance) |
|-------------------------|------------------------|
| Ammonium | 0.011 |
| Nitrate | <0.001 |
| Potential nitrification | 0.002 |
| Actual nitrification | 0.538 |
| Organic C | 0.080 |
| Total N | 0.921 |
| C/N ratio | 0.175 |
| pH H ₂ O | 0.006 |
| Plant height | 0.991 |
| Number of leaves | 0.946 |

quality (polyphenol, lignin, and C/N ratio), thus causing the results in terms of the inhibition of nitrification to vary also. These plants were air-dried and then mashed and filtered with a sieve having a diameter of 0.5 mm. There were five treatments, namely, G1 (control treatment), G2 (*Gliricidia maculata*), G3 (*Albizia falcataria*), G4 (*Senna siamea*), and G5 (*Tithonia diversifolia*), with a completely randomized design variable approach consisting of one factor with three replications.

2.2. Crop Management and Treatments

Each type of litter with a dry weight of 28.125 g pot⁻¹ was immersed and mixed evenly with the soil in the pot. Litter was given 5 days of incubation before sweet corn seeds were planted. (NH₄)₂SO₄ fertilizer with a dose equivalent to 200 kg ha⁻¹ was given in the appropriate form of treatment (Tabri et al., 2018). Basic fertilization with the manure of 200 t ha⁻¹, or equivalent to 8 g pot⁻¹, was carried out. SP-36 fertilizer with a dose of 147 kg ha⁻¹, or equivalent to 0.735 g pot⁻¹, and KCl fertilizer at a dose of 100 kg ha⁻¹, or equivalent to 0.5 g pot⁻¹, were prepared (Sofyan et al., 2019). SP-36 and KCl fertilizers were added 5 days after incubation or together with the planting of sweet corn seeds. Three sweet corn seeds were planted in each pot, and after a week, one sweet corn plant grew in each pot. Potential nitrification measurements were carried out on 0, 6, 12, 18, 24, and 30 days after planting. Soil samples were taken every 5 days around the roots of the sweet corn plant. Harvesting was done at the age of about 50 days or in the vegetative phase of the plant. The parameters

observed were plant height, number of leaves, and plant weight.

Soil samples were analyzed for organic C, total N, C/N, and pH, measurements on 0, 6, 12, 18, 24, and 30 days after planting. The electrometric pH measurement method (using a pH meter), using air-dried soil (a diameter of 0.5 mm and a weight of 10 g), was used to measure the actual pH using H₂O. According to an analysis of organic C using the Walkley and Black method, carbon as an organic compound can reduce the orange Cr₆⁺ to the green Cr₃⁺ in an acidic atmosphere. The intensity of the green color formed is equivalent to that of the carbon content and can be measured by a spectrophotometer at a wavelength of 561 nm. Analysis of organic C using 0.5 mm air-dried soil, 1 N K₂Cr₂O₇, concentrated H₂SO₄, standard solution 5000 ppm C. Total N of soil, analyzed using the Kjeldahl method, in the form of organic nitrogen compounds was oxidized in a concentrated sulfuric acid environment with a catalyst mixture of selen to form (NH₄)₂SO₄. The ammonium content in the extract was determined by distillation. In the distillation method, the extract is alkalized by adding NaOH solution. Furthermore, the liberated NH₃ was bound by boric acid and trapped with a standard solution of H₂SO₄ using a Conway pointer. Total N of soil using air-dried soil 0.5 mm, concentrated H₂SO₄, CuSO₄, and K₂SO₄, Aquadest, H₂SO₄ 0.1 N or H₂BO₄ 10%, Indicator Methyl red, NaOH 0.1 N or NCl 0.1 N and Zn Grains. The C/N ratio was obtained by dividing the organic carbon content by the total N of soil.

2.3. Litter Quality

Table 1 presents the content of C/N, lignin, polyphenols, and (lignin + polyphenol)/N and litter quality classes. High-quality litter is litter that has a C/N ratio of <20 or a (lignin + polyphenol)/N ratio of <10. *Gliricidia maculata* has a (lignin + polyphenol)/N ratio of 7.33; *Albizia falcataria*, 9; *Senna siamea*, 6.83; and *Tithonia diversifolia*, 18.35. These results indicate that *Tithonia diversifolia* is a low-quality litter, whereas *Gliricidia maculata*, *Albizia falcataria*, and *Senna siamea* are high-quality litter types.

2.4. Measurement of Potential Nitrification, Ammonium, and Nitrate

Potential nitrification was measured using the Berg and Rosswall method from the amount of NO₂⁻, which was formed from soil samples after being added with (NH₄)₂SO₄ and incubated at 25°C for 5 h (Ward, 2011). The formed nitrite was extracted with KCl and measured colorimetry at 520 nm. The oxidation process of NO₂⁻ to NO₃⁻ during incubation was

inhibited by the addition of NaClO₃. The calculation for potential nitrification was carried out using Formula [1].

$$\frac{(S-C)25 \times 1 \times 1000 \times 100}{5 \times 5\%dm} = ngN \frac{1}{g} dm \frac{h}{5} \dots\dots\dots [1]$$

where S is the average sample value (mg N), C denotes the control value (mg N), 25 × 1 indicates the extract volume (ml), 1000 is the conversion factor (1 mg N = 1000 ng N), 5 is the aliquot filtrate value (g), 5 is the original soil weight (g), and 100%⁻¹dm is the factor for soil dry matter.

Ammonium in the soil can be measured directly by colorimetry using the indophenol blue method (Ngibad, 2019) and using Formula [2].

$$\text{Concentration of ammonium (mg N kg}^{-1}\text{)} = \text{ppm curve}/\text{ew N} \times \text{df} \dots [2]$$

where ppm curve indicates the sample levels obtained from the relationship curve between the standard series levels with their readings after being corrected by a blank solution, ew denotes the equivalent weight, N is 14, and df denotes the dilution factor (if any).

Nitrates in the soil can be measured spectrophotometrically using brucine dye reagents (Iklima AS et al., 2019) and using Formula [3].

$$\text{Concentration of nitrate (mg N kg}^{-1}\text{)} = \text{ppm curve}/\text{ew N} \times \text{df} \dots\dots [3]$$

where ppm curve means the sample levels obtained from the relationship curve between the standard series levels with their readings after being corrected by a blank solution;

ew denotes the equivalent weight, N is 14, and df denotes dilution factor (if any).

2.5. Statistical Analysis

The data were analyzed using ANOVA with α = 5% and 1%, followed by the Duncan multiple range tests, to determine statistically significant differences between treatments, and Pearson’s correlation test to determine the relationship between parameters. Data analysis was performed using IBM SPSS Statistics 24 software.

3. Results

3.1. Ammonium

Table 2 shows the ANOVA test results of parameters affected by various litter types for 30 days on Vertisol and plant growth. The modified treatment affected the concentration of ammonium in the soil (p = 0.011) (Table 2). Ammonium concentration and the average ammonium concentration are presented in Figure 1a and Figure 2a, respectively. Ammonium concentration experienced dynamics during the 30 days of observation. The dynamics on day 0 to day 6 indicate that all treatments experienced a decrease in ammonium concentration; for 12 days after day 6, *Tithonia diversifolia* and *Senna siamea* treatments experienced an increase and other treatments experienced a decrease in ammonium concentration (Figure 1a).

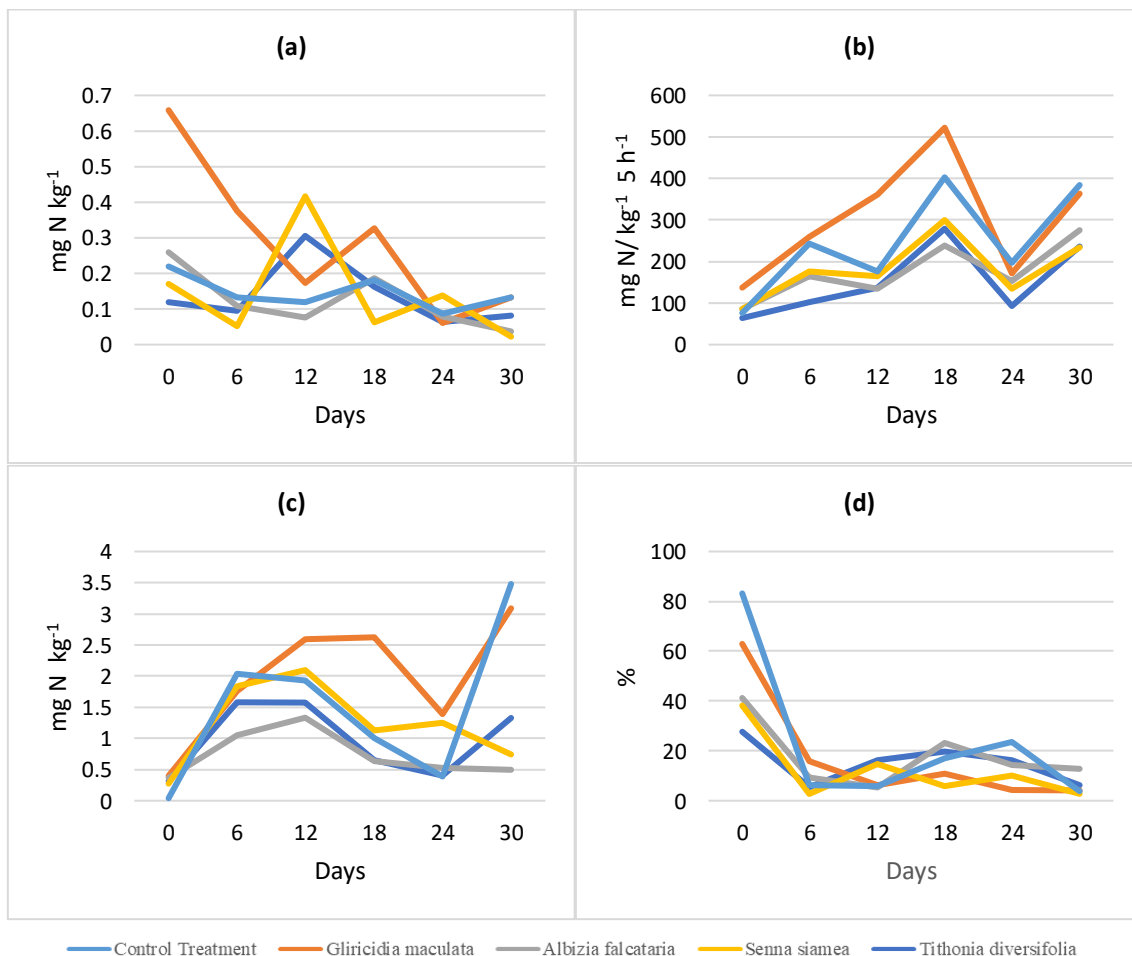


Figure 1. Dynamics of (a) ammonium, (b) potential nitrification, (c) nitrate, and (d) actual nitrification for 30 days.

Table 3. Pearson's correlation (r) between parameters

| Correlations | Ammonium | Nitrate | Potential Nitrification | Actual nitrification | C organic | Total N | C/N | pH | Plant height | Number of leaves |
|-------------------------|----------|----------|-------------------------|----------------------|-----------|----------|----------|----------|--------------|------------------|
| Ammonium | 1 | 0.044 | 0.098 | 0.539** | -0.256* | -0.344** | 0.087 | 0.143 | -0.335** | -0.309** |
| Nitrate | 0.044 | 1 | 0.516** | -0.567** | 0.171 | 0.048 | 0.028 | 0.091 | 0.204 | 0.412** |
| Potential Nitrification | 0.098 | 0.516** | 1 | -0.322** | 0.249* | 0.114 | -0.027 | 0.077 | 0.404** | 0.388** |
| Actual nitrification | 0.539** | -0.567** | -0.322** | 1 | -0.384** | -0.315** | 0.034 | 0.078 | -0.518** | -0.612** |
| C organic | -0.256* | 0.171 | 0.249* | -0.384** | 1 | 0.735** | -0.141 | -0.351** | 0.754** | 0.734** |
| Total N | -0.344** | 0.048 | 0.114 | -0.315** | 0.735** | 1 | -0.585** | -0.523** | 0.744** | 0.738** |
| C/N | 0.087 | 0.028 | -0.027 | 0.034 | -0.141 | -0.585** | 1 | 0.238* | -0.299** | -0.302** |
| pH | 0.143 | 0.091 | 0.077 | 0.078 | -0.351** | -0.523** | 0.238* | 1 | -0.198 | -0.248* |
| Plant height | -0.335** | 0.204 | 0.404** | -0.518** | 0.754** | 0.744** | -0.299** | -0.198 | 1 | 0.880** |
| Number of leaves | -0.309** | 0.412** | 0.388** | -0.612** | 0.734** | 0.738** | -0.302** | -0.248* | 0.880** | 1 |

Remarks: ** Correlation is significant at $\alpha = 0.01$; * Correlation is significant at $\alpha = 0.05$

The treatment of *Tithonia diversifolia* and *Senna siamea* at day 18, showed a decrease in ammonium concentration, but the other treatments showed an increase in ammonium concentration. On day 24, all treatments showed that ammonium concentration decreased, except for *Senna siamea*. At day 30, the treatment of *Gliricidia maculata* and *Tithonia diversifolia* had an increase in ammonium concentration, and other treatments had a decrease. For 30 days, the average ammonium concentration kept decreasing (Figure 2a). The *Gliricidia maculata* treatment had the highest ammonium concentration of 0.288 mg N kg⁻¹, and the *Albizia falcataria* treatment had the lowest of 0.124 mg N kg⁻¹. Ammonium has a significantly positive correlation with actual nitrification ($r = 0.539$) (Table 3).

3.2. Potential Nitrification

The treatment modification significantly affected the potential nitrification in the soil ($p = 0.002$) (Table 2). The potential nitrification and its average are presented in Figure 1b and Figure 2b, respectively. The potential nitrification from day 0 to day 6 increased in all treatments and decreased except for *Gliricidia maculata* and the control treatment at day 12 (Figure 1b). On day 18, the potential nitrification in all treatments increased, and then it decreased at day 24 and again increased at day 30. The *Gliricidia maculata* treatment has the highest potential nitrification of 302.52 mg N kg⁻¹ 5 h⁻¹, and the control treatment has the lowest of 152.05 mg N kg⁻¹ 5 h⁻¹ (Figure 2b). Potential nitrification was positively correlated with nitrate ($r = 0.516$) (Table 3).

3.3. Nitrate

The treatments significantly affected the concentration of nitrates in the soil ($p < 0.01$) (Table 2). Nitrate concentration and its average are presented in Figure 1c and Figure 2c, respectively. Nitrate concentration from day 0 to day 6 experienced a rapid increase in all treatments (Figure 1c). This is due to the formation of nitrate at day 0. Concentration nitrate on control and *Tithonia diversifolia*, from day 6 to 12

were decreased but in the other treatments were increased. On day 18, the nitrate concentration of all treatments was decreased, except the *Gliricidia maculata*. On day 24, all treatments had a decrease nitrate concentration, except the *Senna siamea*, and on day 30, the treatment of *Senna siamea* and *Albizia diversifolia* showed a decreased nitrate concentration, whereas the other treatments had an increased nitrate concentration. The *Gliricidia maculata* treatment had the highest nitrate of 1.975 mg N kg⁻¹, and the *Albizia falcataria* treatment had the lowest nitrate of 0.735 mg N kg⁻¹ (Figure 2c). Nitrate has a significant correlation with potential nitrification ($r=0.516$) and actual nitrification ($r=-0.567$) (Table 3).

3.4. Actual Nitrification

Treatment had no significant effect on the actual nitrification ($p = 0.538$) (Table 2). The actual concentration and its average are presented in Figure 1d and Figure 2d, respectively. The mean of actual nitrification of all treatments was highest at 0 day incubation time, and then it decreased at sixth days incubation. Some experienced an increase and decrease in actual nitrification from incubation to day 30 (Figure 1d). The *Tithonia diversifolia* treatment had the highest actual nitrification of 23.26%, and the *Senna siamea* treatment had the lowest actual nitrification of 12.36% (Figure 2d). Actual nitrification was significantly correlated with plant height ($r=-0.518$) and the number of leaves ($r=-0.612$) (Table 3).

3.5. Plant Growth

The analysis of the sweet corn crop yields is presented in Table 4. Plant height was not significantly different in any treatment (Table 4). The highest plant height was *Tithonia diversifolia* treatment (133 cm), whereas the lowest plant was found in the *Albizia falcataria* (124 cm) (Table 2). The number of leaves of the sweet corn was not significant for the treatments (Table 4).

The highest number of leaves was found in the *Senna siamea* treatment (12), and the lowest was in the *Albizia falcataria* and *Tithonia diversifolia* (10). Plant dry weight was significant ($p < 0.01$) (Table 4), the highest was found in the *Tithonia diversifolia* treatment (27.49 g), whereas the lowest was *Gliricidia maculata* treatment (22.89 g). Plant height significantly correlated with organic C by 0.754, total N by 0.744, and the number of leaves by 0.880. The number of leaves significantly correlated with organic C ($r=0.734$) and total N ($r=0.738$) (Table 5).

3.6. Organic C, Total N, C/N Ratio, and Soil pH

Soil pH values were significantly different in all treatments, whereas the values of organic C, total N, and C/N ratio were not significantly different in all treatments (Table 2). The analysis of organic C, total N, C/N ratio, and soil pH are presented in Table 5. Table 5 shows that the highest of organic C is *Senna siamea* treatment (2.26%) and the lowest is *Albizia falcataria* treatment (1.48%). The highest total N value is found in *Albizia falcataria* (0.25%), and the lowest is in the control treatment (0.21%). The highest C/N ratio is found in *Senna siamea* (13.14%), and the lowest is in *Albizia falcataria* (7.78%). The highest soil pH value is in *Tithonia diversifolia* (7.66), and the lowest is in *Senna siamea* (7.43).

4. Discussion

Tithonia diversifolia can inhibit nitrification because it has a high actual nitrification value (Figure 2d) and is a low-quality litter type (Table 1). Organic matter quality was correlated with nitrification (Ryals et al., 2014), and organic matter quality is often mediated by tree species (Kelly et al., 2011). The litter quality factor that most influenced the release of ammonium and the formation of soil nitrate (nitrification) was the (lignin + polyphenol)/N ratio, not lignin content, polyphenols, or the C/N ratio (Ma et al., 2016). Based on this result, the (lignin + polyphenol)/N ratio of *Tithonia diversifolia*

indicates that it is a low-quality litter, whereas the *Gliricidia maculata*, *Albizia falcataria*, and *Senna siamea* are high-quality litter types. *Tithonia diversifolia* is one of the main sources of soil organic matter, which improves the physical and chemical properties of the soil. Organic matter can provide complete nutrients, including both macro and microelements, although the amount is relatively low, so in practice, it still has to be balanced with the use of inorganic fertilizers. Soil with organic matter can also bind and store nutrients (Mahmood et al., 2017). High-quality litter is litter that has a C/N ratio of <20 or a (lignin + polyphenol)/N ratio of <10 . High-quality litter should have a lignin content of $<15\%$ and polyphenols of $<3\%$ so that it decomposes more quickly and frees ammonium for plants (Rahman et al., 2013).

Ammonium concentration kept decreasing, for example, at 0–6 days (Figure 1a). This indicates that the concentration of ammonium in the soil will continue to decrease over time because of plant use, microbial immobilization, and nitrification. Ammonium is utilized by plants and changes into other compounds because of the decrease in ammonium concentration (Hachiya & Sakakibara, 2017). Ammonium concentrations also increase, for example, in the *Senna siamea* treatment at 6–12 days, because ammonium, which is originally immobilized by microbes, will experience mineralization and thus make ammonium available again in the soil. High ammonium concentrations can also be caused by immobilization not yet occurring as a whole (Roviqowati et al., 2014). Figure 2a, the overall average for the highest ammonium concentrations was found in the *Gliricidia maculata* treatment and the lowest was in the *Albizia falcataria* treatment. The high concentration of ammonium in the soils is caused by *Gliricidia maculata* and other high-quality litter types that decomposes quickly. Faster decomposition occurred when lignin + polyphenols get smaller because lignin and polyphenols can bind N to litter (Rahman et al., 2013).

Table 4. Plant growth parameters with various litter treatments for 30 days

| Treatment | Plant height (cm) | Number of leaves (leaves) | Plant dry weight (g) |
|------------------------------|-------------------|---------------------------|----------------------|
| Control | 126 | 11 | 23.46 |
| <i>Gliricidia maculata</i> | 132 | 11 | 22.89 |
| <i>Albizia falcataria</i> | 124 | 10 | 25.00 |
| <i>Senna siamea</i> | 132 | 12 | 25.93 |
| <i>Tithonia diversifolia</i> | 133 | 10 | 27.49 |

Table 5. Organic C, total N, C/N ratio, and pH H₂O of soil with various litter treatments for 30 days

| Treatment | Organic C(%) | Total N (%) | C/N (%) | pH H ₂ O |
|------------------------------|--------------|-------------|---------|---------------------|
| Control | 1.55 | 0.21 | 11.61 | 7.61 |
| <i>Gliricidia maculata</i> | 1.97 | 0.23 | 10.75 | 7.52 |
| <i>Albizia falcataria</i> | 1.48 | 0.25 | 7.78 | 7.45 |
| <i>Senna siamea</i> | 2.26 | 0.23 | 13.14 | 7.43 |
| <i>Tithonia diversifolia</i> | 1.79 | 0.22 | 9.72 | 7.66 |

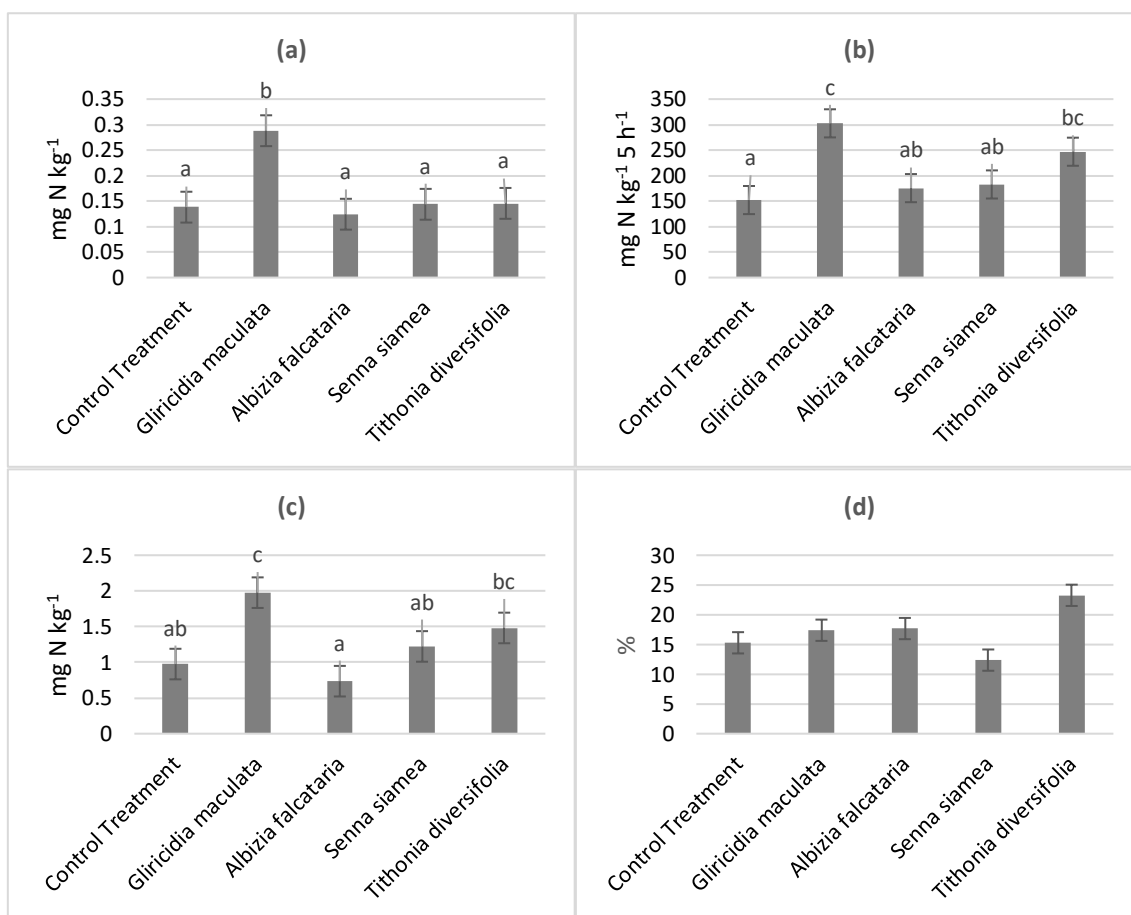


Figure 2. Average concentration of (a) ammonium, (b) potential nitrification, (c) nitrate, and (d) actual nitrification for 30 days. Bar lines indicate standard error. Bar followed by the same letter is not significantly different at $\alpha = 0.05$

Ammonium concentration has a positive correlation with actual nitrification, which means that the higher ammonium concentration will be followed by actual nitrification. High actual nitrification means that the efficiency of nitrogen utilization is also high. It is because the actual nitrification is obtained from the ammonium/N mineral ratio (ammonium + nitrate). A high ammonium/N mineral ratio means that the ammonification process is higher than the nitrification process in the soil (Wang et al., 2018). The *Gliricidia maculata* treatment has the highest potential nitrification, and the control treatment has the lowest (Figure 1b). *Gliricidia maculata* is a high-quality litter type with a low C/N ratio. This causes an imbalance of ammonium mineralization with ammonium immobilization, and so the potential nitrification is high (Wang et al., 2018). Potential nitrification increased because of the availability of ammonium, which is not used by plants and microorganisms. The potential nitrification in the control treatment is supported by the low concentration of ammonium.

Nitrate concentrations increased owing to high potential nitrification. This is reinforced by the correlation between nitrate concentration and potential nitrification ($r = 0.516$) (Table 3). The formation of nitrates is inseparable from the nitrification process (Sanders & Laanbroek, 2018). Nitrate concentration also correlates with actual nitrification, with $r = -0.567$ (Table 3). This means that the nitrate concentration is inversely proportional to the actual nitrification. High nitrate concentrations cause low nitrogen utilization efficiency

because most of the ammonium has been deformed to nitrate. Nitrate synthesis will continue to increase along with the availability of the ammonium substrate in the soil (Hachiya & Sakakibara, 2017). Ammonium is abundant but not balanced against the absorption of plant nitrogen needs at the same time, so there is residual ammonium that changes into nitrate (Hachiya & Sakakibara, 2017). The data in Figure 2c are identical to the ammonium data in Figure 2a, indicating that nitrate concentration is also influenced by ammonium concentration.

The actual nitrification ratio is the ammonium/N concentration of minerals in the soil. The actual nitrification is obtained by calculating the ratio of the concentration of ammonium to the amount of N minerals. As can be seen in Figure 2d, the *Tithonia diversifolia* litter has the highest actual nitrification, indicating that the *Tithonia diversifolia* litter has the highest nitrogen utilization efficiency when compared to other litter types and has low nitrification, because nitrogen can be maintained in the form of ammonium. The higher the ammonium/N mineral ratio, the higher the proportion of ammonification processes compared to nitrification in the soil or the higher the efficiency of nitrogen utilization in the soil (Purwanto & Supriyadi, 2014). It means that *Tithonia diversifolia* treatment has the highest nitrogen utilization efficiency.

Plant height is a plant size often observed as an indicator of growth as well as a parameter to measure environmental influences or treatments applied because plant height is the

most easily measured growth measure (Wardhani & Kusumastuti, 2014). Sweet corn plants with the *Tithonia diversifolia* litter treatment have the best plant growth compared to those with other treatments. *Tithonia diversifolia* litter also has the highest actual nitrification, indicating that the litter has the highest utilization of N efficiency. This proves that the efficiency of nitrogen utilization can increase crop yields. Plant dry weight shows the effect of water content and nutrients on plant metabolism and growth. Rapid nutrient uptake occurs in the vegetative phase of plants, wherein the N element reaches the points where leaves, stems, and male flowers have grown and then fills the seeds (Ciampitti et al., 2013). Plant height and the number of leaves correlated with organic C and total N. This means that plant height and the number of leaves are influenced by organic C and total N. Organic C and total N describe the state of soil organic matter. The organic material content is in line with organic C. Soil organic carbon (SOC) and total N are important soil components for agricultural production. Soil quality is related to the total amount of SOC and total N sequestered in the soil (Xue & An, 2018). Organic matter increases soil fertility and exchangeable nutrients that are slowly provided to plants (Aziz et al., 2017). Organic C and low total N cause low availability of N for plants, which consequently inhibits plant growth (Mahmood et al., 2017). Studies have shown that nitrification rates in soils are dependent on the nitrifying organisms and various environmental factors such as pH and substrate concentrations (Le et al., 2019) and may be significantly affected by nitrogen fertilizer management (Fan et al., 2011).

5. Conclusion

The *Tithonia diversifolia* litter treatment was more optimal for inhibiting nitrification in Vertisols compared to *Gliricidia maculata*, *Albizia falcataria*, and *Senna siamea*. Sweet corn plants treated with the *Tithonia diversifolia* litter had the best plant growth compared to the other treatments because the *Tithonia diversifolia* litter had the highest actual nitrification value, indicating that *Tithonia diversifolia* litter had the highest N utilization efficiency. The decomposition process of *Tithonia diversifolia* is slow, so the supply of ammonium is slow and the microorganisms can live longer to compete with nitrifying bacteria; therefore, nitrification is slowed down. For further research, we suggest direct application in the field without equalizing the size of the litter.

Declaration of Competing Interest

The authors declare no competing financial or personal interests that may appear and influence the work reported in this paper.

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