Effect of Sodium Chloride Application on Nitrification Rates in Coconut Growing Sandy Regosol

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Abstract

Nitrification is one of the important microbial processes that govern the availability of nitrogen for plants. A pot experiment was conducted to assess the effect of sodium chloride (NaCl) application together with Adult Palm Mixture (APM) on nitrification rates of a coconut growing Sandy Regosol (Aquic Quartzipsamments) and to determine the leaching losses of nitrate. Pots were filled with 15 kg of Sandy Regosol soil and the treatments; T_1 - Zero NaCl and zero APM application (NF), T_2 – APM, T_3- APM + NaCl at the rate of 1kg /palm/year, T_4 - APM + NaCl at the rate of 2 kg /palm/year, T_5 - APM + NaCl at the rate of 3kg /palm/year were imposed with three replicates in a Completely Randomized Design. The pots were maintained with 60% of the water holding capacity. Soil samples were collected at 10 cm depth at two weeks intervals up to 10 weeks and they were analyzed for pH, electrical conductivity, NH_4^+ - N, NO_3^- - N, Na^+, Cl^- and K^+ contents, population of nitrifiers and potential nitrification rates using standard methods. Pots were saturated with distilled water and leachates were collected at 6 and 12 weeks after treatment application (WTA) and they were assessed for NO_3^- - N contents. Soil potential nitrification rates ranged from 1.27 - 2.51 µg /g/h at 2 WTA to 0.13 – 1.15 µg /g/h at 10 WTA. The increase of soil chloride contents with the use of NaCl has reduced soil nitrification rates and a similar trend was observed in soil NO_3^- - N content and the nitrifier population. Among the fertilizer treated soils, the lowest nitrification rate was observed in APM + 3kg NaCl/palm/year. In addition, increasing chloride levels of soil has significantly reduced leaching losses of NO_3^- - N indicating the inhibitory effect of sodium chloride on soil nitrification.

Keywords: *Nitrate leaching, Nitrification inhibitors, Nutrient losses*

INTRODUCTION

Coconut is one of the major plantation crops in Sri Lanka which requires a regular supply of nutrients throughout its life cycle due to the continuous removal of nutrients with nuts and other parts (Somasiri *et al.*, 2003). However, among those nutrients, nitrogen (N) plays a vital role in coconut palms as a component in chlorophyll, protein, vitamins and enzymes. It has been found that approximately 480 g of N is removed from a coconut palm at a production level of 50 nuts per year and therefore it is recommended to supply 800g of urea to adult palms per year in order to compensate the N loss through its products (CRISL, 2016).

Nevertheless, N fertilizers that contribute as the largest part of N supplier in the N cycle, undergo different transformation processes such as leaching losses, volatilization, denitrification, surface runoff, fixation and immobilization of NO_3^- - N, which is formed through nitrification of added NH_4^+(Sahrawat, 2008). Hence, the efficiency of added nitrogen rarely exceeds 50 %. Moreover, as coconut cultivation is mainly distributed in sandy soils, most of the applied nitrogen is lost through leaching under heavy rainfall conditions.

Nitrification is a biological process by which ammonium is oxidized to nitrite and subsequently to nitrate through the activity of ammonium oxidizers and nitrate oxidizers respectively. The rate of these nitrification reactions depend on substrate concentration as well as environmental factors including, oxygen concentration, pH, temperature and presence of toxic or inhibiting substances (Peng and Zhu, 2006).

In addition to supplying of plant preferred product i.e. NO_3^- to the system, nitrification can reduce nitrogen use efficiency to some extent indirectly due to higher leaching losses of negatively charged NO_3^- ions compared to NH_4^+ (Pidwirny, 2006). Therefore, nitrification inhibitors such as Dicyandiamide (DCD), nitrapyrin, N-serve and 3,4-dimethylpyrazole phosphate (DMPP) are widely used in agricultural systems in order to increase N use efficiency by controlling the formation of nitrate via nitrification (Amberger and Germann-Bauer, 1990). However, these inhibitors should be introduced to the coconut growing soils as an external source. Nevertheless, it has been revealed that chloride ion has a detrimental effect on nitrification (Christensen *et al.*, 1986; Golden *et al.*, 1980).

Coconut growers apply Muriate of Potash (KCl) as a potassium source and some growers have a conventional practice of applying different levels of common salt (NaCl) to enhance coconut yield. However, both KCl and NaCl release chloride ion (Cl^-) to coconut growing soils.

Therefore, this study was focused to identify the effect of KCl and NaCl application on nitrification rates of coconut growing soils and to evaluate the NO_3^- -N losses with respect to chloride applications.

MATERIALS AND METHODS

Experimental site

The study was carried out as a pot experiment at Soils and Plant Nutrition Division, Coconut Research Institute, Lunuwila, Sri Lanka. Pots were filled with 15 kg of soil (Aquic Quartzipsamments) which were collected from the center of square of a coconut land in Bandirippuwa estate, Lunuwila (IL1a agro ecological zone) and the treatments; T_1 - Zero NaCl and zero Adult Palm Mixture application (NF), T_2 - Adult Palm Mixture for Intermediate zone [0.8 kg of urea, 0.9 kg of Eppawala rock phosphate and 1.6 kg of Muriate of potash] (APM), T_3- APM+ NaCl at the rate of 1 kg /palm/year, T_4 - APM+ NaCl at the rate of 2 kg /palm/year, T_5 - APM+ NaCl at the rate of 3 kg / palm/year were imposed with three replicates in a completely randomized design. As recommended by the coconut research institute, dolomite was applied at the rate of 1 kg/palm/year (CRISL, 2016) for all treatments except NF. The amount of fertilizer/NaCl application for each treatment was determined based on the mass of soil used in the pot in relation to the mass of soil in the manure circle. Moisture contents of the pots were maintained at 60% of water holding capacity by adding water periodically.

Soil sampling and analysis

Soil samples were collected before treatment application and thereafter at two weeks intervals up to three months. Half of the soil samples were air dried and passed through 2mm sieve and analyzed for pH (soil: H_20 = 1:2.5), electrical conductivity (soil: H_20 = 1: 5), Na^+(Knudsen *et al.*, 1982), Cl^- (Dharmakeerthi *et al.*, 2007) and K^+(Knudsen *et al.*, 1982) contents. The rest of the samples were stored at 4 °C and analyzed for NH_4^+-N (Hinda and Lowe, 1980) and NO_3^--N (Bremner, 1965) contents, population of nitrifiers (Woomer, 1994) and potential nitrification rates (Schmidt and Belser 1994).

Collection of leachate and analysis

The pots were saturated with distilled water and leachates were collected at 6 and 12 weeks after treatment application (WTA) and they were assessed for NH_4^+- N (Hinda and Lowe, 1980) and NO_3^- - N (Bremner, 1965) contents.

Statistical Analysis

Analysis of variance was done with at a significant level of 0.05 using SAS 9.1.3 statistical software and means were compared using Duncan's New Multiple Range test.

Results and Discussion

Variation in soil pH and electrical conductivity

Soil pH and the electrical conductivity are shown in the Figure 1a and 1b respectively. At the beginning of the study, all treatments except NF showed comparable pH values and there after a slight reduction was observed over the time period. However, soil to which none of the fertilizers applied showed significantly lower pH values (4.46 - 4.12) throughout the experimental period. Higher pH values observed in fertilizer treated soils can be due to the dolomite application.

Soil electrical conductivity of none amended soil (NF) ranged from 20.23 to 37.65 µS/cm and it was significantly lower than the fertilizer treated soil (Figure 1b) throughout the experimental period. However, soil electrical conductivity significantly increased with the increase of the applied amount of NaCl due to the increase of the soluble salt concentration.

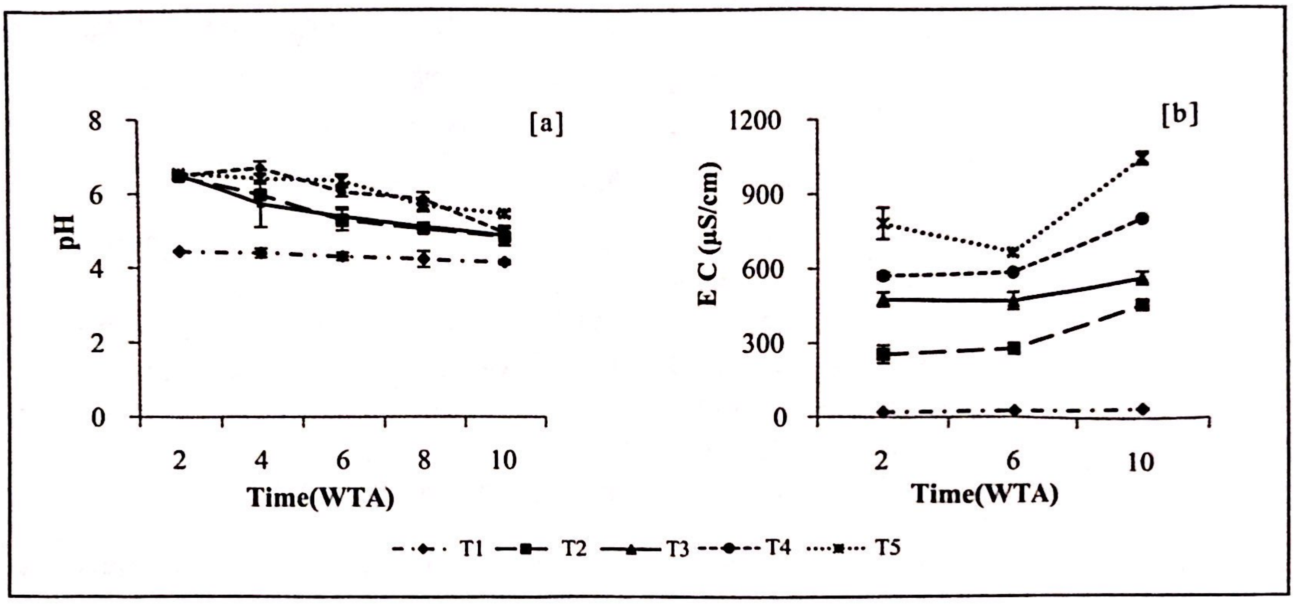

Figure 1. Variation of (a) soil pH (b) soil electrical conductivity (EC)

T_1: Zero NaCl and zero Adult Palm Mixture application (NF), T_2: Adult Palm Mixture for Intermediate zone (APM), T_3: APM + NaCl at the rate of 1kg /palm/year, T_4: APM + NaCl at the rate of 2 kg /palm/ year, T_5 : APM + NaCl at the rate of 3 kg /palm/year, WTA: Weeks after treatment application, bars indicate ± Standard Error (SE) of mean.

Variation of exchangeable sodium (Na^+) and potassium (K^+) contents

Significantly high Na^+ content was observed in soil treated with APM + 3 kg NaCl/palm/year followed by APM + 2 kg NaCl/palm/year and APM + 1 kg NaCl/palm/year respectively and it was in accordance to the amount of Na added in those treatments (Figure 2a) . However, NF and APM treatments to which NaCl was not added showed significantly low Na^+ content throughout the experimental period.

Application of similar quantities of MOP has caused same quantities of exchangeable potassium contents in all treatments except NF over the studied time period (Figure 2b). Nevertheless, NF to which none of the fertilizers were added showed significantly lower exchangeable potassium ion content throughout the experimental period.

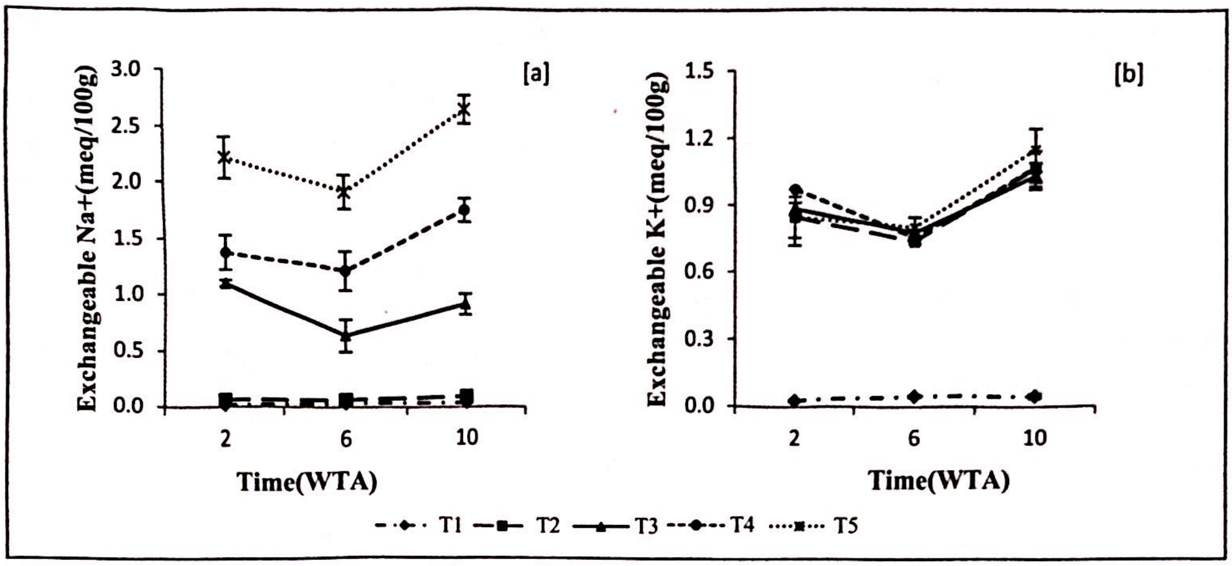

Figure 2. Variation of (a) Exchangeable sodium (Na^+) (b) Exchangeable potassium (K^+) contents in soil

T_1: Zero NaCl and zero Adult Palm Mixture application (NF), T_2: Adult Palm Mixture for Intermediate zone (APM), T_3: APM + NaCl at the rate of 1 kg /palm/year, T_4 : APM + NaCl at the rate of 2 kg /palm/ year, T_5 : APM + NaCl at the rate of 3 kg /palm/year, WTA: Weeks after treatment application, bars indicate ±Standard Error of mean.

Variation in chloride (Cl^-) content in soil

Fluctuation of soil Cl^- contents is shown in the Figure 3 and the trend observed for changes in soil Cl^- contents over time was similar to that of soil Na^+ contents (Figure 2a). Application of higher doses of NaCl has caused high Cl^- ion concentration in soil. Nevertheless, the lowest chloride content was found in the NF treated soil.

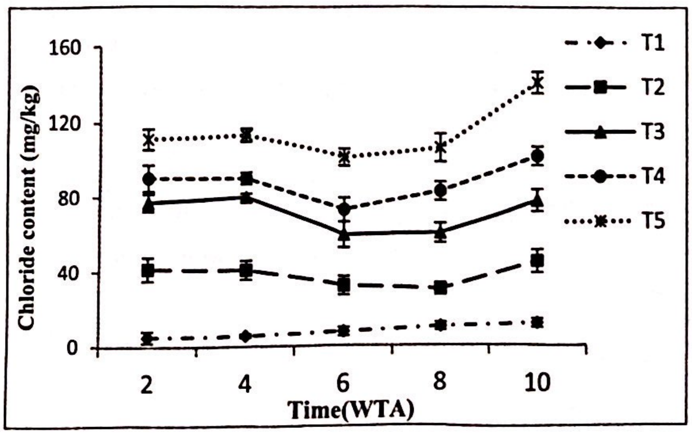

Figure 3. Variation of chloride contents in soil

T_1: Zero NaCl and zero Adult Palm Mixture application (NF), T_2: Adult Palm Mixture for Intermediate zone (APM), T_3: APM + NaCl at the rate of 1kg /palm/year, T_4 : APM + NaCl at the rate of 2 kg /palm/ year, T_5 : APM + NaCl at the rate of 3 kg /palm/year, WTA: Weeks after treatment application, bars indicate ±Standard Error of mean.

Variation in Ammonium – N (NH_4^+ – N) content in soil

A gradual reduction was observed in the soil NH_4^+ – N content over time (Figure 4a). Soil treated with APM + 2 kg NaCl/palm/year and APM + 3 kg NaCl/palm/year [illegible] NH_4^+ – N content throughout the experimental period and this can be due to the lower NH_4^+ oxidizer population in these treatments (Table 1). However, positive correlation [illegible] could be observed between the soil Cl⁻ and NH_4^+ – N content in soil indicating the inhibitory effect of chloride on nitrification. [illegible] et al. (2014) has found that the addition of ammonium chloride combined with KCl [illegible] soil [illegible] ammonium concentration after [illegible] days of incubation than the application of ammonium chloride alone and it has been explained by the inhibitory effect of chloride on nitrifiers.

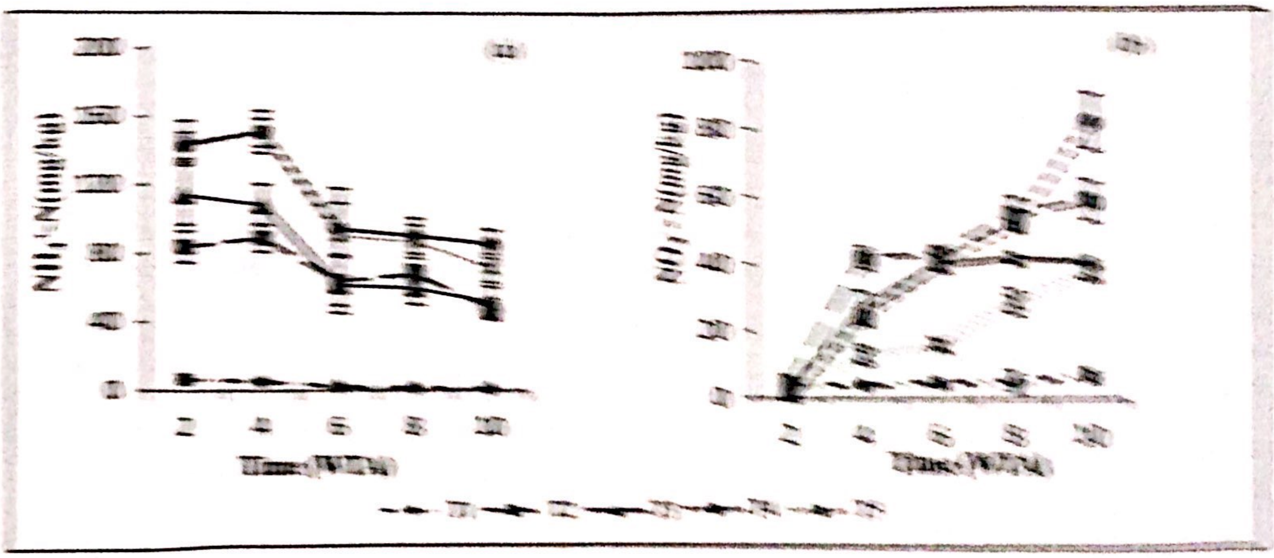

Figure 4. Variation of (a) ammonium (NH_4^+ – N) and (b) nitrate (NO_3^- – N) contents in soil

T_1 - Zero NaCl and zero Adult Palm Mixture application (NF), T_2 - Adult Palm Mixture for Intermediate zone (APM), T_3 - APM + NaCl at the rate of 1 kg/palm/year, T_4 - APM + NaCl at the rate of 2 kg/palm/year, T_5 - APM + NaCl at the rate of 3 kg/palm/year. WTA: Weeks after treatment application. Bars indicate ±Standard Error of mean.

Variation in nitrate – N (NO_3^- – N) content in soil

Soil NO_3^- – N content increased over the experimental period (Figure 4b). The NO_3^- – N content of soil was not significant in all treatments at 2 WTA. However, APM showed the highest NO_3^- – N content during the whole period of the experiment except in 10 WTA and this could be due to the high nitrifier population in APM treated soil in which there was lower Cl⁻ contents among the chloride added treatments (Table 1). Moreover, lower nitrifier population in soil treated with NF and APM + 3 kg NaCl/palm/year has caused lower NO_3^- – N contents in NF followed by APM + 3 kg NaCl/palm/year throughout the experimental period. Similarly, in an incubation study conducted by Megda et al. (2014), reduction in nitrate contents was observed in soil treated with NH_4Cl + KCl when compared with the soil treated with ammonium chloride alone, suggesting a detrimental effect of chloride on the activity of nitrifying microorganisms.

Golden *et al.*, (1981) has found that chloride ion concentration effectively retard nitrification because high salt concentrations in soil excessively produce oxygen-reactive species (Thompson *et al.*, 1987) and these species may have a cytotoxic effect on nitrifiers creating oxidative damage to lipids (Wise and Naylor, 1987), proteins and nucleic acids (Imlay and Linn, 1988). Similarly, lower nitrifier population (Table 1) and high soil NH_4^+ - N contents in soils treated APM together with NaCl suggest the inhibitory effect of Cl^- application on soil nitrification. However, even with addition of NaCl, APM + 2 kg NaCl /palm/ year showed higher nitrifier population at 10 WAT and this can be due to the higher availability of the substrate (NH_4^+) in soil (Figure 4 a). Nevertheless, irrespective of the NaCl addition, higher nitrifier population and nitrification rates may have caused contradictory results in NO_3^- - N content in soil treated with APM + 2 kg NaCl/palm/year.

Table 1. Population of nitrifiers in soil

Treatment	Ammonium oxidizer population (Cells/g soil)		
	2 WTA	6 WTA	10 WTA
T_1	230^c	230^c	230^c
T_2	738^b	738^a	919^a
T_3	919^a	425^b	230^c
T_4	425^{bc}	425^b	738^b
T_5	230^c	230^c	230^c

T_1: Zero NaCl and zero Adult Palm Mixture application (NF), T_2: Adult Palm Mixture for Intermediate zone (APM), T_3: APM + NaCl at the rate of 1 kg /palm/year, T_4: APM + NaCl at the rate of 2 kg /palm/year, T_5 : APM + NaCl at the rate of 3 kg /palm/year, WTA: Weeks after treatment application, Means with the same letters are not significantly different at $P<0.05$.

Potential nitrification rates of soil

Soil potential nitrification rates ranged from 1.27 to 2.51 µg/g/h at 2 WTA and 0.13 – 1.15 µg /g/h at 10 WTA (Table 2). However, NaCl applied soil showed significantly high potential nitrification rates than APM applied soil at 2 WTA and this can be due to the higher availability in NH_4^+ -N as their substrate (Figure 4a). Nevertheless, even with significantly different nitrification rates, soil NO_3^- - N contents were comparable at 2 WTA. Moreover, at 6 WTA all treatments except NF and APM + 3kg NaCl/palm/year showed higher potential nitrification rates compared to that of 2 WTA and similar trend could be observed in the nitrifier population (Table 1). This can be the reason for lower NO_3^- - contents in NF and APM + 3 kg NaCl/palm/year upto 6 WAF. Nevertheless, potential nitrification rates reduced further from 0.68 - 3.65 µg /g/h at 6 WTA to 0.13 - 1.15 µg /g/h at 10 WTA. However, irrespective of high NaCl content, APM + 2 kg NaCl/palm/year showed the highest potential nitrification rate. The lowest was found in the APM + 3 kg NaCl/ palm/year followed by APM + 1 kg NaCl/palm/ year due to significantly low nitrifier population in those treatments. Among the fertilizer treated soil, APM + 3 kg NaCl/palm/year maintained the lowest potential nitrification rate throughout the experimental period.

Table 2. Potential nitrification rates of soil

Treatment	Potential nitrification rate (µg NO_3^--N/g dry soil/h)		
	2 WTA	6 WTA	10 WTA
T_1	1.28[b]	0.68[c]	0.21[b]
T_2	1.27[b]	3.65[a]	0.26[b]
T_3	2.51[a]	3.41[a]	0.18[b]
T_4	2.29[a]	2.87[a]	1.15[a]
T_5	1.84[ab]	1.40[b]	0.13[b]

T_1: Zero NaCl and zero Adult Palm Mixture application (NF), T_2: Adult Palm Mixture for Intermediate zone (APM), T_3: APM + NaCl at the rate of 1 kg /palm/year, T_4: APM + NaCl at the rate of 2 kg /palm/year, T_5 : APM + NaCl at the rate of 3 kg /palm/year, WTA: Weeks after treatment application, Means with the same letters are not significantly different at P<0.05.

Leaching losses of NO_3^- - N in soil

In 6 WTA, the highest NO_3^- - leaching was found in APM treated soil followed by APM + 1 kg NaCl/palm/year, APM + 2 kg NaCl/palm/year and APM + 3 kg NaCl/palm/year respectively and this trend was similar to the NO_3^- - N content in soil (Figure 5). Leaching losses increased over the time and this can be due to increasing availability of NO_3^- - N in soil (Figure 4b) over the experimental period. However, at 12 WTA, T_2 and T_4 showed the highest leaching losses and this was in accordance to the nitrate contents in soil.

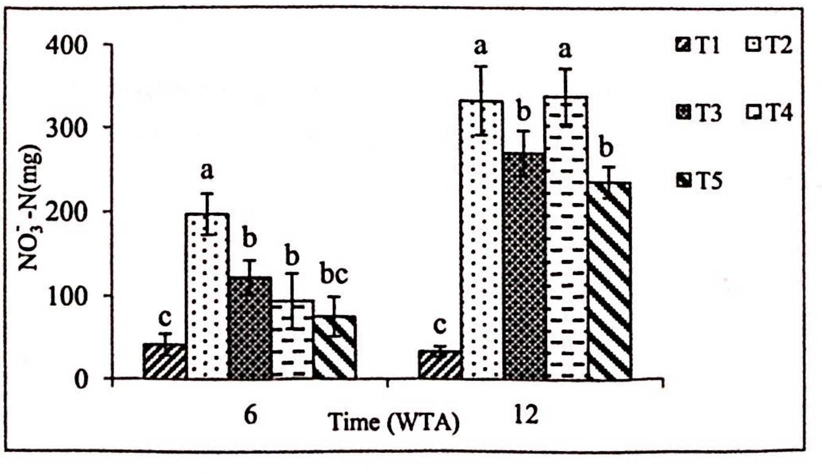

Figure 5. Leaching losses of NO_3^- - N during the experimental period

T_1: Zero NaCl and zero Adult Palm Mixture application (NF), T_2: Adult Palm Mixture for Intermediate zone (APM), T_3: APM + NaCl at the rate of 1 kg /palm/year, T_4 : APM + NaCl at the rate of 2 kg /palm/year, T_5 : APM + NaCl at the rate of 3 kg /palm/year, WTA: Weeks after treatment application, Means with the same letters are not significantly different at P<0.05. Bars indicate ± Standard Error of mean.

Conclusion

Among the fertilizer treated soil, APM + 3 kg NaCl/palm/year showed the lowest nitrification rate throughout the experimental period and the lowest NO_3^- leaching losses suggesting the inhibitory effect of sodium chloride on nitrification.

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