Effect of clay amendments on nitrogen leaching and forms in a sandy soil

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Abstract
Nitrogen (N) leaching in sandy soil decreases fertiliser use efficiency and may depress plant production. Application of high cation exchange capacity (CEC) materials (e.g. high activity clay minerals) is hypothesized to reduce N leaching and increase plant N uptake in sandy soils. However, the mechanism of leaching in sands with clay amendment is not understood. A column experiment was conducted to determine N leaching and N concentration in soil solution in a sandy soil (1.4 % clay) with three soil amendments (nil, clay soil and bentonite clay) and three fertiliser rates (0, 28 N 17 P 22 K kg/ha and 56 N 34 P 44 K kg/ha). Soil amendments were applied at the rate of 50 Mg/ha. The soil columns were leached with de-ionised water equivalent to 50 mm rainfall every 4 days. Concentrations of soil solution extracted by Rhizon samplers indicated that NH_4 leaching was decreased 38-43 % by bentonite addition but little of the soil solution N was in NO_3 form and bentonite had no effect on mobility of this form of N. The application of bentonite was able to hold NH_4 in soil solution of top soil. Leaching of NH_4 was delayed to 15 day after fertiliser application in bentonite-amended sand.

Key Words
Nitrogen, leaching, soil solution, bentonite, sand soil.

Introduction
Sands with low content of low activity clays are dominant soils of northeast Thailand. In general, these sandy soils are characterised by low organic matter content, low CEC, and high risk of leaching (Blanchart *et al.* 2007; Noble *et al.* 2000). Nutrient leaching in agricultural land affects plant nutrient use efficiency and yield. Fertiliser strategies such as split application, delayed basal application and varied timing of application to synchronise with plant demand have improved plant production by minimising nutrient leaching (Sitthaphanit *et al.* 2009). However, the efficacy of fertiliser strategies may be limited in rainfed areas by high intensity rainfall immediately after fertiliser application. Soil amendment with high CEC materials such as high activity clay minerals (e.g. bentonite) increased CEC and improved plant biomass on sand soils (Croker *et al.* 2004; Noble *et al.* 2001). However, the nutrient loss in clay-amended sands needs further investigation to determine the mechanism of leaching losses under nutrient management strategies in high rainfall regime sandy soils. The aims of this study were: (1) to assess N leaching in a sand soil amended with either a bentonite clay or a clay soil; (2) to investigate N concentration in soil solution in the sandy soil amended with bentonite and clay soil.

Methods
The column experiment was conducted in a glasshouse using 15 cm diameter x 40 cm height columns containing 10 kg of a soil that contained 98 % sand, 0.6 % silt and 1.4 % clay. A factorial experiment was arranged in a randomized complete block design with three replicates, three soil amendments (nil, clay soil and bentonite clay) and three fertiliser levels (0, 28 N 17 P 22 K kg/ha and 56 N 34 P 44 K kg/ha). The soil amendments were applied at the rate of 50 Mg/ha. The initial CEC was 26.5 and 34.3 $cmol_c$/kg for clay and bentonite, respectively. Fertiliser and amendments were mixed with 2.5 kg of sandy soil and packed into the top 10 cm of soil columns. Sufficient deionised water was applied to raise water content to field capacity and allowed to drain for 2 days. Water equivalent to 50 mm of rainfall, representing a heavy rainfall event, was applied to the top of columns at 3, 7, 11, 15 and 19 days after fertiliser application (DAA). Soil solution samplers (Rhizon) were set at 8, 15 and 30 cm depths. Leachate at 40 cm depth and soil solution were collected after each watering event and analysed for NO_3-N and NH_4-N using colorimetric methods by a flow injection analyser. Soil before and after the experiment were extracted with 0.01 M $CaCl_2$ and NH_3 and NO_3 were determined by the phenate method and nitrate electrode, respectively.

Table 1. Properties of experimental sandy soil with and without amendment materials. Values are means of 3 replicates, ± standard errors.

Properties of amended soils	NO_3 (mg/kg)	NH_4 (mg/kg)			
No amendment	4.2	10.1			
Bentonite	7.1	8.8			
Clay	5.5	12.0			
	Soil depth (cm)				
Properties of soil at the end of the experiment	0-5	5-10	10-20	20-30	30-40
	NO_3 (mg/kg)				
No amendment	2.3 ±0.2	3.6 ±0.2	6.1 ±0.6	8.4 ±0.6	8.8 ±1.1
Bentonite	5.0 ±0.7	7.8 ±0.8	7.7 ±1.2	11.3 ±0.8	9.0 ±0.9
Clay	2.2 ±0.2	3.9 ±0.3	5.3 ±0.4	10.6 ±0.8	10.2 ±1.0
	NH_3 (mg/kg)				
No amendment	0.1 ±0.04	0.4 ±0.06	0.8 ±0.20	2.8 ±0.78	3.4 ±0.59
Bentonite	0.2 ±0.05	0.3 ±0.08	0.2 ±0.03	1.5 ±0.39	0.9 ±0.51
Clay	0.4 ±0.11	0.4 ±0.06	0.5 ±0.15	1.4 ±0.36	1.2 ±0.14

Results

Leaching loss

Total NO_3 leached from columns ranged from 24.3-24.6 mg/column but neither bentonite nor clay significantly affected the leaching of NO_3 N (Table 2). Fertilisation increased NO_3 leached relative to the control, by 73 – 83 %. However, NO_3 leaching was not significant different between the two levels of fertilisation. Fertilisation significantly increased NH_4 leaching when compared with the control, and the rate of fertiliser applied significantly affected the total NH_4 leaching. Bentonite addition decreased NH_4 in leachate to 44 % and 49 % less than clay and control treatments, respectively, but clay soil amendment had no significant effect relative to control. Overall, the bentonite addition reduced N leaching by 52-67 % when compared with control and clay treatments.

N in soil solution

At 3 DAA, the bentonite addition had the highest soil solution NO_3 concentration at 8 cm depth (about 20.7 mg l^{-1}) while in clay and control treatments NO_3 leached to 30 cm depth (Figure 1a). Nitrate concentration in bentonite treatment was still higher than control and clay amended sand at 8 cm depth at 7, 11 and 15 DAA, respectively. At 15 DAA, NO_3 in the bentonite treatment leached to the subsoil. At 19 DAA, the NO_3 concentration of bentonite and clay treatments declined to the level of control. The soil solution NH_4 from control and clay treatments promptly leached to 15 and 30 cm depth when water was applied. At 7 DAA, soil solution NH_4 was highest at 30 cm depth in clay amended sand and control indicating leaching to the subsoil (Figure 1b). However, bentonite treatment had highest NH_4 level at 8 cm depth. After 15 DAA, the soil solution NH_4 level declined to the same level as control in all treatments.

Discussion

Bentonite addition was effective in decreasing N loss through leaching especially the NH_4-N form. Bentonite addition increases soil CEC which may result in cation sorption on its surface and explain reduced NH_4 leaching (Gillman, 2007). Increasing CEC can also retain other cations such as Ca^+, K^+ and Mg^+ in soil (Berthelsen *et al.* 2007) The bentonite is a 2:1 clay and was clearly more effective than the mixed clay soil added in retaining NH_4 against leaching. Berthelsen *et al*. (2007) reported bentonite increased CEC in the top 20 cm of soil equivalent to 0.27 $cmol_c$/kg for every 10 t of bentonite added/ha. The soil solution NH_4 remained high until 11 DAA and 15 DAA for NO_3 and then both declined after 15 DAA in bentonite-amended sand. The response of soil solution NO_3 suggested that bentonite reduced leaching by slowing release of NO_3-N from the soil solution in capillary pores to macropores. Several studies show increased in plant nutrient uptake after bentonite addition to sandy soil (Croker *et al.* 2004; Berthelsen *et al.* 2007). The slow release mechanism after bentonite addition could explain the advantage in plant nutrient uptake by postponing leaching.

Table 2. Effect of soil amendment and fertiliser application rate on total leaching loss of NO_3 and NH_4.

	Leaching loss (mg/column)		
Amendment (A)	NO_3	NH_4	NO_3+NH_4
No amendment (control)	24.6	175	200
Bentonite	24.7	89.5	114
Clay	24.3	160	185
Fertiliser rate(F)			
0[a]	16.1	101	117
1[b]	27.9	148	176
2[c]	29.6	176	206
Source of variation			
A	ns	**	**
F	**	**	**
A × F	ns	ns	ns
LSD A	ns	22.2	23.3
LSD F	4.3	22.4	23.8
LSD A × F	ns	ns	ns

[a] No fertiliser. [b] Fertiliser application at the rate of 38N 18P 50K kg/ha.[c] Fertiliser application at the rate of 76N 36P 100K kg/ha.

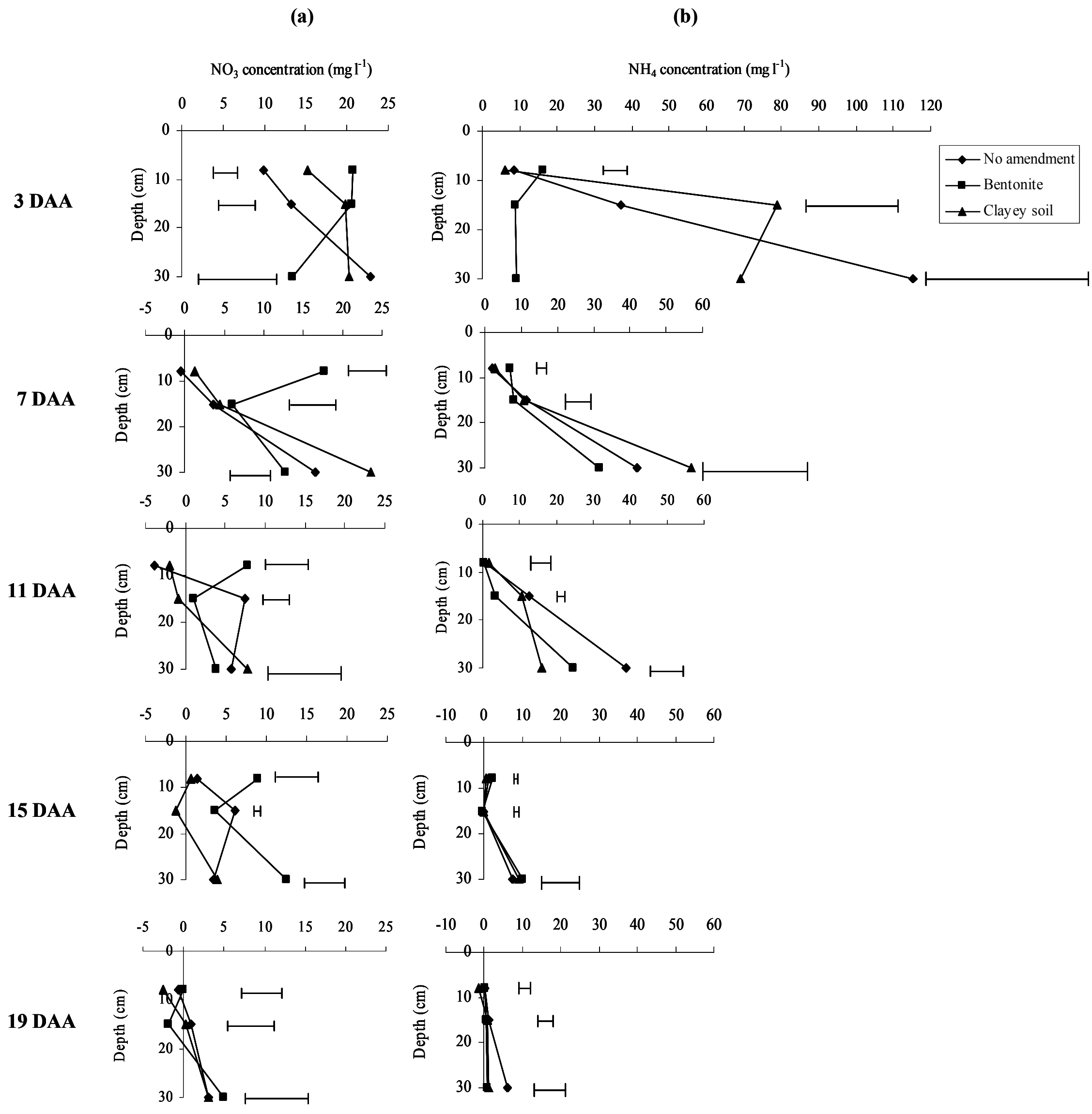

Figure 1. Increase in NO_3 concentration (a), or NH_4 concentration in soil solution (b) at 3, 7, 11, 15 and 19 days after addition (DAA) of fertiliser. The increase in concentration was calculated by subtracting values for unfertilised columns from those in fertilised columns. *Bars* represent LSD ($p < 0.05$).

Conclusions

The application of bentonite clay at 50 t/ha on sandy soil can slow and reduce N leaching. However, bentonite was most effective in retaining N in NH_4 form. By postponing N leaching for up to 15 DAA, bentonite addition may decrease the risk of N leaching in the period soon after fertiliser application and hence increase the probability of plant N uptake. Most of the N leached as NH_4 rather than NO_3 suggesting that nitrification in this sand was slow possibly due to low pH (4.92 with 0.01 M $CaCl_2$), low organic matter (0.71%) and limited microbial activity.

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