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Effect of Clay and Organic Matter Amendments on Water and Nutrient Retention of Sandy Soils: Column Leaching Experiment

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Abstract
Two types of clay and an organic matter was used to investigate the potential of combined application of clay and organic matter (OM) to improve water and nutrient retention of sandy soils. Sandy soils are generally known to be problematic because of poor water and nutrient retention resulting in economic losses and environmental pollution. A laboratory column leaching experiment was conducted using a pure sand (PS) and a sandy loam (SL). Soils were amended with Kaolin (K) and bentonite (B) at 0, 2.5 and 5% (w/w) and peat (Pt) at 0, 10, 20, and 30% (v/v). Water and nutrient retention was simulated using ammonium nitrate at 150 kg N /ha in RO water. Water retention increased with the rate of each amendment applied, except for the SL amended with 2.5%K. Pt-clay combinations were more effective than either Pt or clay alone at the same rate. Combined application retained more water than the additive effect of Pt and clay for corresponding treatment except for 2.5%B in PS soil. For nutrient retention, all the clay amendments reduced nitrate and ammonium nitrogen losses in PS. Application of Pt, 2.5%K with or without Pt and 5%B with >20%Pt reduced nitrate leaching in SL. The results demonstrate that amending sandy soils with both clay and organic matter has potential to improve their water and nutrient retention.

Keywords: *sandy soils; bentonite; kaolin; water retention; nitrogen losses*

1. INTRODUCTION

Sandy soils are found all over the globe from tropical to temperate, and from humid to arid zones. They are significant in terms of global food production and therefore food security due to their wide distribution (FAO, 1993). In many areas, sandy soils represent a significant proportion of land being cultivated for food (Hartemink and Hunting, 2005). However, they can be problematic due to their inherent physical, chemical and biological properties, which can result in soil that is low in water and nutrient holding capacity (Eslinger and Pevear, 1988; Dixon, 1991; Reuter, 1994; Franzluebbers et al., 1996). Sandy soils are also prone to leaching, which can lead to water loss and associated contamination of groundwater (by nutrients or pesticides). Sandy soils have low cation exchange capacity (CEC), poor buffering capacity, high rates of organic matter decomposition and reduced microbial biomass (Kramer, 1983; Bruandi et al., 2005; Blanchart et al., 2007).

Sandy soils are by definition low in clay content, which is the origin of fundamental problems associated with this soil group. Clay and organic matter (OM) are the most active and reactive part of a soil (Kramer, 1983; Hillel, 1998). These colloidal particles have relatively large, negatively charged specific surface areas that bind together and retain water and mineral nutrients (Yong et al., 2001). The cations held by these small soil fractions are the source of some of the key nutrients for plants. The potential fertility of a given soil is determined by the amount and type of clay particles, and the organic matter present in the soil.

Laboratory column leaching experiments have been identified as one way to simulate water and solute movements in soils and mimic processes that occur under natural conditions (Yong et al., 2001). This method allows study and monitoring of complex soil processes and provides an insight into processes occurring under field conditions (Zachara and Streile, 1990). Column leaching experiments have been used to study heavy metal retention in soils (Yong et al., 2001); nutrient release from compressed fertilizers (Fernández-Sanjurjo et al., 2014); monitoring water pollution from cattle slurry (Nunez-Delgado et al., 2002); investigation of nitrogen leaching in the plant root zone (Nakamura et al., 2004); and the effects of localized soil heterogeneity on solute transport in soils (Stagnitti et al., 2001).

Previous work has focused on amending sandy soil with either clay or organic matter. However, recently, the use of combined applications of these two materials has been suggested (Djajadi et al., 2012; Nguyen and Marschner, 2013). One of the major benefits of combining clay and organic matter is the synergy or interactions that overcome the limitations of the individual materials when used separately. It has been reported that the benefits of amending sandy soils with organic matter alone do not persist in the absence of enough clay particles (Kramer 1983). Therefore, the objective of this experiment is to examine the optimal combination of clay and organic matter that will enhance water and nutrient retention of sandy soil in the presence or absence of inherent soil clay using free-draining soil columns. Also, the study will quantify the amount of water and nutrients that can be held within the amended soil and how this varies with the different clay, as well as the combination of the clay and organic matter amendment.

2. MATERIAL AND METHODS

2.1 Soils

The study was conducted at the University of Warwick, Wellesbourne Campus, UK. Two soils and three amendment materials were used to explore the relationships between soils and their water retention/leaching potential. The soils were a pure sand (PS) and a sandy loam (SL). The PS was horticultural grit sand (supplied by William Sinclair Horticulture Ltd), which is predominantly quartz (>98%), with particle sizes of ≤5mm. The grain density is 2 g cm^{-3} and pH is 7.9. The SL was from the Wick series, a typical brown earth developed from Triassic rocks (Whitfield, 1973). The SL is 65% sand, 18% clay and 17% silt. pH in water is 6.1 and total N is 0.12%.

The SL soil sample was excavated from the 0-20cm topsoil layer from the Warwick Crop Centre Experimental field (Latitude 52 12 18 N; Longitude 1 36 00 W), Wellesbourne, United Kingdom. The sample was air dried and then sieved (10mm) to remove stones. Both the PS and the SL were oven dried at 80^0C for 24 hours before the start of the experiment, to ensure the uniform initial moisture content of the soils and to standardise the measurement of water retention capacity of the amendments. Fernández-Sanjurjo et al. (2014) adopted a similar method in a column experiment to study nutrients released from compressed fertilizers.

2.2 Amendments

The two types of clay used as amendments were calcium bentonite (B) and kaolin (K). The typical mineralogy of the bentonite is 88% montmorillonite, 5% mica and 5% feldspar. The kaolin is a medium sized china clay, consisting of 47% silica and 37% aluminium oxide by mass. The organic matter (OM) amendment (Pt) was a medium grade, pure sphagnum peat, sourced from Klasmann-Deilmann Ireland Ltd. The peat has >90 % OM, up to 5.0 g g^{-1} water capacity and pH of 4.2.

2.3 Leaching Experiment

The method employed in this project is the vertical column method using sieved soil to keep the soil column as homogeneous as possible, so treatment effects were easier to observe. Leaching was conducted under unsaturated conditions using static, intermittent applications of nutrient solution (400 ml increments), which were allowed to flow through the column. Zachara and Sterile (1990) and Kim (2005) have suggested this as a suitable way of mimicking vadose zone hydrology and found it to be effective in achieving uniform fluid distribution.

The PS and SL were amended separately. The treatments were three rates of K and B (0, 2.5% and 5% w/w), 4 Pt rates (0, 10%, 20%, and 30% v/v) and combinations of both clay types with Pt at all rates. This adds up to 20 treatments for each soil, as described in Table 1. In addition to this, another 16 control treatments (PS alone, SL alone; PS+10Pt, PS+20Pt, PS+30%Pt, SL+10Pt, SL+20Pt, and SL+30%Pt; PS+2.5, PS+5%, SL+2.5 and SL+5% of each clay) were also set up. The experimental design was completely randomized with three replicates, giving a total of 168 experimental units.

Table 1: Treatment table

	Treatment name	Treatment description
1	Soil only	Soil only
2	10%Pt	Soil + 10% peat
3	20%Pt	Soil + 20% peat
4	30%Pt	Soil + 30% peat
5	2.5%K	Soil + 2.5% kaolin
6	2.5%K+10%Pt	Soil + 2.5% kaolin +10% peat
7	2.5%K+20%Pt	Soil + 2.5% kaolin + 20% peat
8	2.5%K+30%Pt	Soil + 2.5% kaolin + 30% peat
9	5%K	Soil + 5% kaolin
10	5%K+10%Pt	Soil + 5% kaolin + 10% peat
11	5%K+20%Pt	Soil + 5% kaolin + 20% peat
12	5%K+30%Pt	Soil + 5% kaolin + 30% peat
13	2.5%B	Soil + 2.5% bentonite
14	2.5%B+10%Pt	Soil + 2.5% bentonite + 10% peat
15	2.5%B+20%Pt	Soil + 2.5% bentonite + 20% peat
16	2.5%B+30%Pt	Soil + 2.5% bentonite + 30% peat
17	5%B	Soil + 5% bentonite
18	5%B+10%Pt	Soil + 5% bentonite + 10% peat
19	5%B+20%Pt	Soil + 5% bentonite + 20% peat
20	5%B+30%Pt	Soil + 5% bentonite + 30% peat

The soil columns used were acrylic tubes of 50 cm high and 11.7 cm diameter. The bottom part of the column was filled with the dried PS or SL to a depth of 10 cm to encourage proper drainage, while the top 20 cm was filled with either PS or SL manually mixed with the appropriate amendment treatment. The whole column was then vibrated gently to allow natural and uniform settlement of all material, and left to equilibrate for 24 hrs before the leaching process was simulated.

Each column received a solution of ammonium nitrate at the rate equivalent to 150 kg N /ha (15 g m^{-2}) in 2L of reversed osmotic (RO) water. Available nitrogen in soil occurs as nitrate or ammonium ions. The fertilizer chosen yields nitrate and ammonium ions in solution, and allows to measure the leaching rate of nitrate components in the test soils that could be related to the field condition. The solution was applied by slowly pouring in 400ml at a time; then the whole column was allowed to drain for 24 hrs. The amount of solution leached through each column passed through a filtering system consisting of a stainless-steel metal mesh and fine cloth mesh and was collected in polyvinylchloride (PVC) cylinders, then measured. Furthermore, the 16 control treatments were also leached with 2L RO water without ammonium nitrate to correct for nitrate present in the used soil and amendments. Water retention was calculated as the difference between total water added and total water released after 24 hrs. A 20 ml subsample of the leachate was filtered using 150 mm Whatman filter paper and analysed for nitrate N concentrations using the FIASTER 5000 Analyser (FOSS Company), and N loads in the leachate were calculated. The result was corrected for water retention in the amended layer only assuming that water retention was uniform in the 30cm layer of the soil column. Nitrate from the control treatments was subtracted from the equivalent treatments that received ammonium nitrate solution before analysis.

Percentage water retained due to the amendment treatment (WRA) was calculated as:

$$\% \, WRA = \left(\frac{water\ retained\ in\ amended\ soil - water\ retained\ in\ unamended\ soil}{(water\ retained\ in\ amended\ soil - water\ retained\ in\ subsoil\ layer)} \right) * 100$$

2.4 Statistical Analyses

Significant differences among the means of the treatments were determined at $p \leq 0.05$ using ANOVA. Means of data with homogeneous variances were separated using Least Significant Differences (LSD), using SPSS v.24. Main effects of clay and OM and their interactions were measured using the General Linear Model (GLM). The relationship between soil water and nutrient leachate was measured using the Pearson correlation test ($p \leq 0.01$).

3. RESULTS

3.1 Effect of Amendment on Water Retention

In the SL, the addition of amendments increased water retention in all treatments compared to soil alone (except for 2.5%K), and the differences were significant at $p < 0.05$. The reason for the lower volume of water retention for 2.5%K in SL is not clear but could be associated with the larger particle size of K which might have increased pore sizes of the amended SL. For the PS, the treatment with 10%Pt retained the least volume of water. The 30%Pt+5%B treatment retained the highest for both SL and PS (Table 2). The water retention of the SL increased with increasing Pt rate, both in Pt alone and in Pt-clay amendment combinations (Table 2), indicating that more water would be retained as the OM content of the soil increases. The order of effectiveness of the Pt rate was 30% > 20% > 10% > 0%.

Table 2: Water retention capacity of amended sandy loam (SL) and pure sand (PS). Mean differences have been corrected for the effects of the unamended subsoil

	Treatment Name	SL (ml) Mean	SL (ml) Mean difference	PS (ml) Mean	PS (ml) Mean difference	WRA (%) SL	WRA (%) PS
1	Soil only	1,247	-	674	-	0.0	. 0.0
2	10%Pt	1,292*	44.7	678	4	5.1	0.9
3	20%Pt	1,362*	114.7	688	14	12.2	3.0
4	30%Pt	1,380*	133.0	753*	79.3	13.8	15.0
5	2.5%K	1,217*	-29.7	719*	45.3	-3.7	9.1
6	2.5%K+10%Pt	1,279*	31.7	817*	143.0	3.7	24.1
7	2.5%K+20%Pt	1,363*	115.7	835*	160.7	12.2	26.4
8	2.5%K+30%Pt	1,385*	138.0	894*	219.7	14.2	32.9
9	5%K	1,280*	33.0	828*	154.3	3.8	25.5
10	5%K+10%Pt	1,371*	124.3	895*	221.3	13.0	33.0
11	5%K+20%Pt	1,421*	174.0	921*	246.7	17.3	35.5
12	5%K+30%Pt	1,468*	221.0	981*	307.3	21.0	40.6
13	2.5%B	1,271*	23.7	852*	178.0	2.8	28.4
14	2.5%B+10%Pt	1,347*	100.3	833*	159.0	10.8	26.1
15	2.5%B+20%Pt	1,482*	235.3	856*	182.0	22.0	28.8
16	2.5%B+30%Pt	1,550*	303.0	928*	253.7	26.7	36.1
17	5%B	1,365*	118.0	944*	270.0	12.4	37.5
18	5%B+10%Pt	1,455*	208.3	1,060*	386.0	20.0	46.2
19	5%B+20%Pt	1,545*	298.3	1,071*	397.0	26.4	46.9
20	5%B+30%Pt	1,594*	346.7	1,131*	456.7	29.5	50.4
	LSD	19.52		29.86			
	SE	7.23		11.06			

Means with an asterisk (*) in the same column are significantly different from the unamended soil ($p < 0.05$). LSD = Least significant difference; SE = Standard error; WRA = Water Retention due to the Amendment

Water retention increased with clay rate. Comparing the main effect of the two clay amendments, clay B was more effective than clay K in terms of water retention when applied alone or in combination with Pt. The higher water retention of clay B is likely to be associated with its large surface area and higher CEC.

In the amended SL, for both clays, application of Pt-clay in combination was more effective than peat and clay alone or their additive effect at the same application rate (Figure 1). An exception to this was the 2.5%K treatment when Pt application was 10%; possibly due to the inability of 2.5%K to offset the low water retention capability of 10Pt rate in SL. The interaction between Pt and clay was significant ($p < 0.001$), indicating that there was a change in response from the combined application of Pt and clay on water retention. On a weight for weight of clay basis, the water retention potential of K in the SL soil was less effective than that of B in any Pt-clay combination (Figure 3a).

In the PS, all treatments increased water retention, and the difference between amended PS and PS alone was significant, except for PS amended with 10 and 20%Pt. Like SL, PS amended with 10%Pt retained the least amount of water, while 5%B+30%Pt had the highest retention

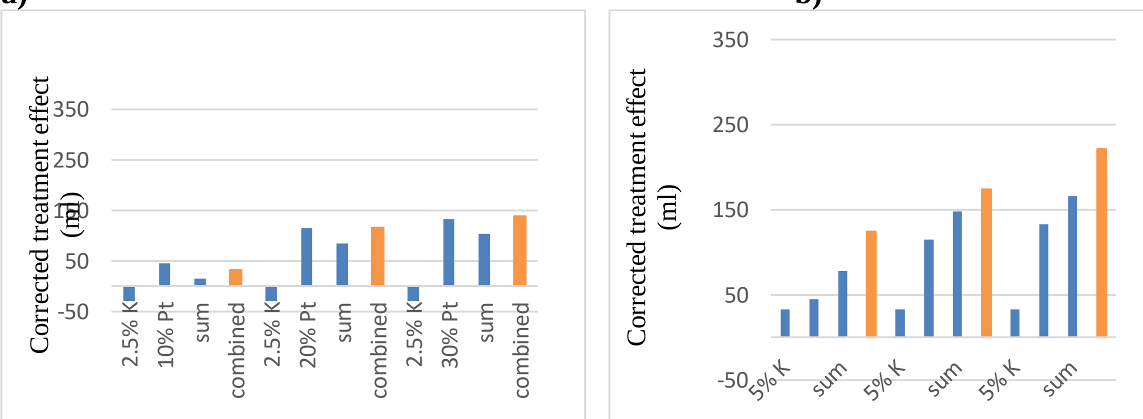
(Table 2). For the PS amended with Pt only, the treatment effect showed that only 30%Pt was able to increase water retention significantly over the unamended PS ($p < 0.001$), suggesting that significant amounts of water would only be retained in soil with little or no inherent clay, if OM application is above 20% of the soil volume (Table 2).

The clay amendments (K and B) increased water retention of the PS. The highest retention was recorded in PS amended with 5%B, while 2.5%K had the lowest retention, although they all significantly increased water retention compared to PS receiving no clay (Table 2). The data also show that water retention increased with clay amendment application rate in PS. The main treatment effect of clay shows that in PS 5%B had the significantly highest effect, followed by 2.5%B and 5%K, while 2.5%K had the least effect on water retention (Figure 3b), suggesting that under the same conditions, PS amended with 2.5%B and 5%K would hold a similar amount of water. Weight for weight, the clay treatments with B retained more water than K. Amounts of water retained in combined Pt-clay treatments were higher than the individual and sum of the effects of Pt and clay at the same application rate except for 2.5%B soils (Figure 2). Interactions between clay and Pt on water retention in PS were also significant ($p < 0.001$), suggesting that the Pt-clay applications have synergistic effects on water retention of PS.

3.3 Percentage WRA

The percentage WRA was different for both SL and PS at the same amendment application rate (Table 2). For SL, the percentage WRA increases with the Pt or clay amendment rate, except where 2.5%K is applied alone. For 5%K, 2.5%B and 5%B, the combined application of Pt and clay increased water retention more than Pt or clay amendment alone. The combined 5% B and 30%Pt had the highest WRA value for both soils. For PS, percentage WRA for all the treatments was greater than the soil only. The pattern of increase was similar to that observed in SL, except for 2.5%K. With the exception of the 10%Pt, 20%Pt and 2.5%K amended PS (where the percentage WRA was smaller than for SL), all other treatments had a higher percentage WRA in PS. In the clay-amended treatments, the percentage WRA was up to two-fold higher in PS compared to SL, irrespective of the presence or absence of Pt. This suggests that the potential of the amendment to improve water retention of a sandy soil would be greatly influenced by the percentage inherent clay content of that soil.

a) **b)**



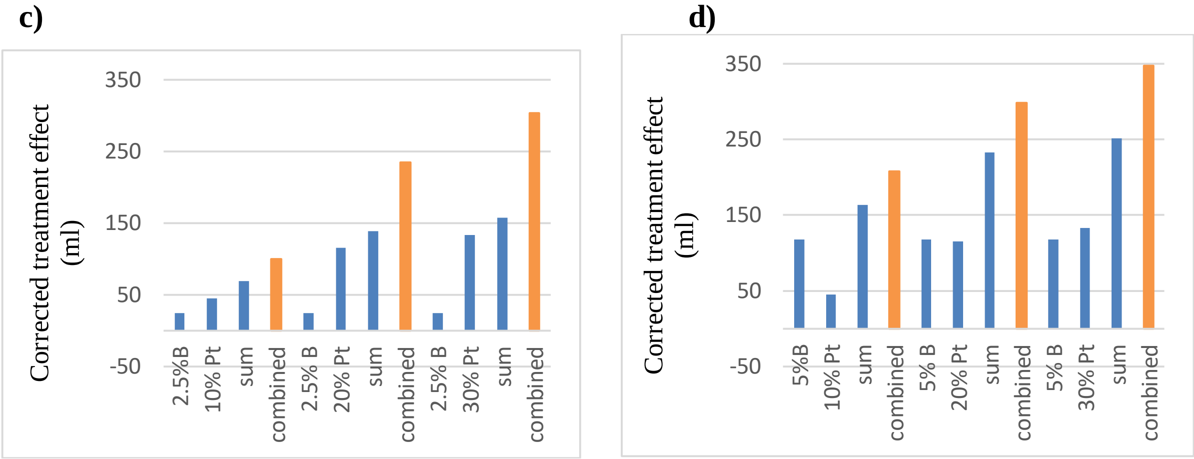


Figure 1: Comparison of the effect of the singly and combined application of clay and OM on water retention in sandy loam (a) 2.5%K, (b) 5%K, (c) 2.5%B and (d) 5%B.

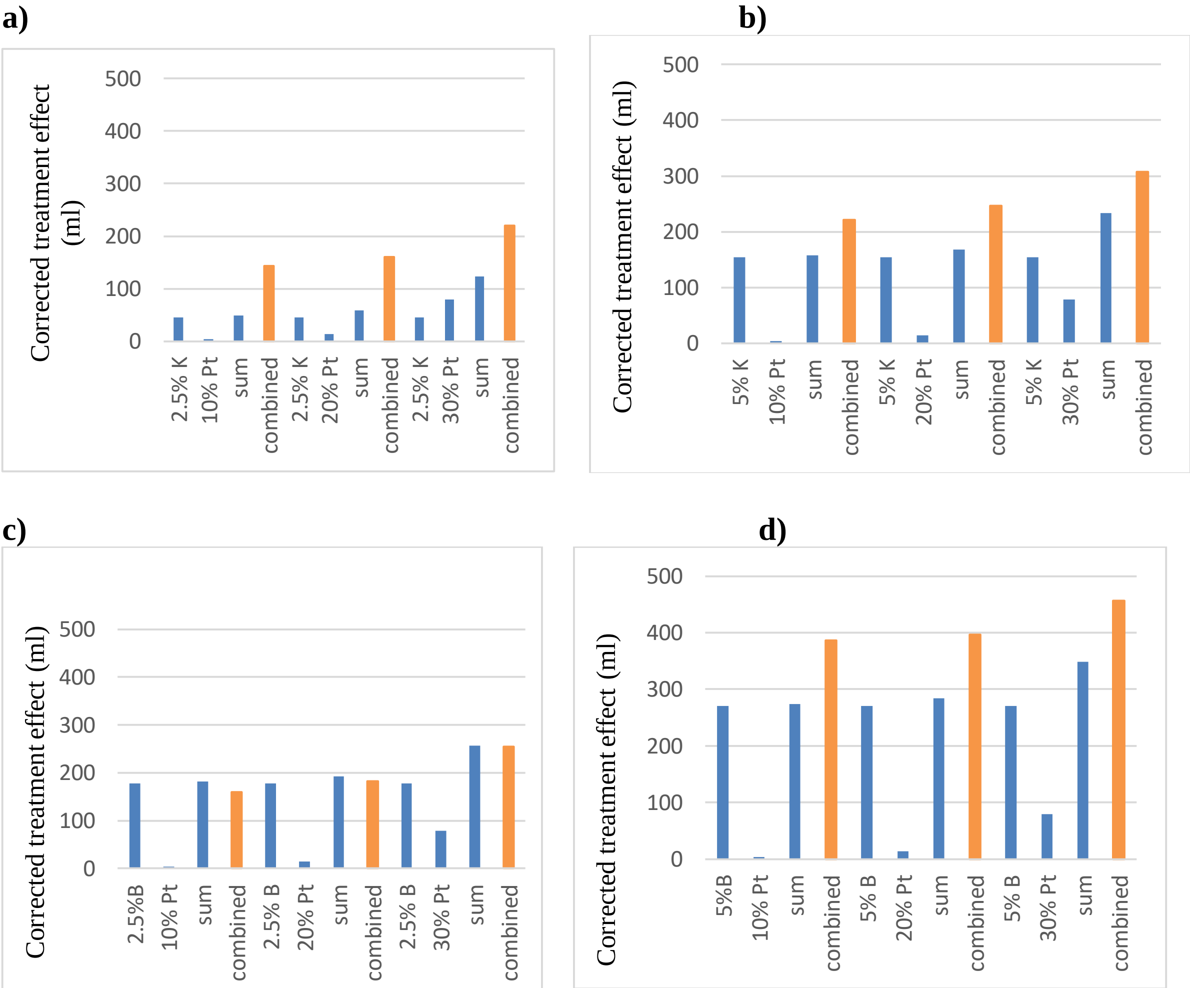
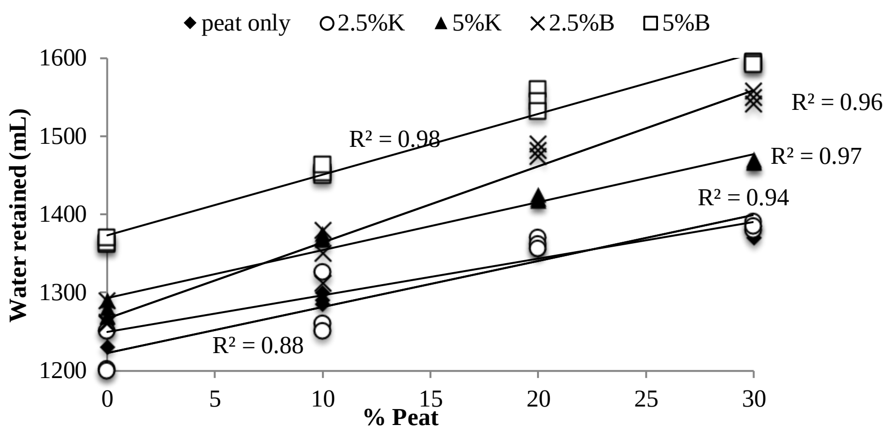


Figure 2: Comparison of the effect of the singly and combined application of clay and OM on water retention in pure sand (a) 2.5%K, (b) 5%K, (c) 2.5%B and (d) 5%B.

3.2 Interaction Effects of the two Amendments

The response of water retention to the clay and Pt additions in SL and PS was examined using a simple linear regression. For SL, the result showed that a weak, but significant, positive relationship exists between water retention and peat rate when Pt is added alone, and a stronger one when Pt is used in combination with the different clay types at each application rate (Figure 3). For PS, the increase was approximately linear except (possibly) above 2.5% clay in the 30% OM treatment. The application of Pt alone was less effective than either of the Pt-clay treatments on a percentage amendment basis. Peat-clay combinations were more effective than either OM or clay alone at the same rate in improving water retention. This shows that the more organic matter added, the higher the water retention in both SL and PS, irrespective of type and amount of added clay present. The R^2 values were higher in SL than PS in all the corresponding treatments (Figure 3). For SL, there was relatively little difference in the R^2 values between treatments (Figure 3a), whereas, for PS, the highest R^2 value was found in the 5%K treatment and the lowest for Pt amendment only (Figure 3b). In both SL and PS, 5%B significantly held more water than the other treatments, both when applied alone and in combination with Pt, at all rates (Figure 3). For the PS, water retention was higher for B than for K at the same application rate, with 5%K showing only a slightly higher retention than 2.5%B. However, in SL, clay B at 2.5% held more water than 5%K. For Pt application rates higher than 10%, water retention of the Pt-clay mixture is: peat = 2.5%K < 5%K < 2.5%B < 5%B. In both PS and SL, water retention potential of 2.5%B and 5%K were similar when approximately 8-10% peat is added (Figures 3).

a)



b)

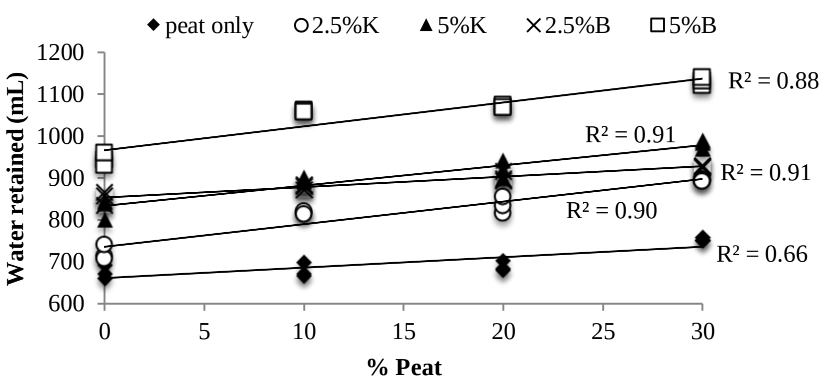


Figure 3: Relationship between water retention and peat rate in clay amended (a) SL (Sandy loam) and (b) PS (Pure sand) ($p \leq 0.05$; n = 3).

3.5 Effect of Amendment on Retention of Nitrate Nitrogen

Table 3 shows the nitrate concentration (mgL^{-1}) leached in PS and SL. The amount by mass (i.e. load; mg) of nitrate leached in each treatment was calculated as a product of the volume of water leached and nitrate concentration and presented in Figure 4.

3.5.1 Effect of amendments on nitrate concentration

In SL, the amended treatments reduced nitrate leaching compared to the unamended soil, except for 5%K+30%Pt, 2.5%B, 2.5%B+30%Pt, 5%B and 5%B+10%Pt. Pt alone at all rates reduced nitrate leaching compared to the unamended SL. Clay K reduced nitrate leaching on its own and in combination with peat, except when peat rate was 30% in the 5%K amended SL. In clay B treatments, nitrate losses were higher at the two B application rates (2.5% and 5%). The addition of 10 and 20%Pt to 2.5%B reduced nitrate losses compared to soil amended with 2.5%B and 2.5%B+30%Pt. On the other hand, the addition of Pt to 5%B reduced nitrate losses as the Pt application rate increased. Among the treatments, 5%K+10%Pt has the highest effect on nitrate N retention (Table 3).

In PS, all the amendments reduced nitrate concentration compared to PS only, except 10%Pt. Addition of 10%Pt slightly increased nitrate leaching, while 20 and 30%Pt reduced it compared to that of PS only, but none of these differences was significant. The means of the three Pt rates were not significantly different, suggesting that their effects on nitrate leaching were similar. Application of K and B at 2.5% and 5% significantly reduced nitrate leaching, but the difference between the two clay rates was not significant for either K or B.

Table 3: Nitrate concentration in the leachates of amended sandy loam (SL) and pure sand (PS)

	Treatment Name	SL (mg L^{-1})		PS (mg L^{-1})	
		Mean	Mean difference	Mean	Mean difference
1	Unamended soil	67.9	-	114.3	-
2	10%Pt	44.1*	-23.8	115.1	0.8
3	20%Pt	56.3	-11.6	107.1	-7.2
4	30%Pt	47.9*	-19.9	105.0	-9.2
5	2.5%K	44.6*	-23.3	70.1*	-44.2
6	2.5%K+10%Pt	45.2*	-22.7	82.0*	-32.3
7	2.5%K+20%Pt	25.2*	-42.7	93.1*	-21.2
8	2.5%K+30%Pt	55.9	-12.1	83.7*	-30.6
9	5%K	26.7*	-41.2	79.3*	-35.0
10	5%K+10%Pt	3.8*	-64.1	91.8*	-22.5
11	5%K+20%Pt	69.2	1.3	79.9*	-34.4
12	5%K+30%Pt	137.9*	70.1	60.9*	-53.4
13	2.5%B	81.9*	14.0	82.2*	-32.1
14	2.5%B+10%Pt	68.4	0.5	85.4*	-28.9
15	2.5%B+20%Pt	77.1	9.2	76.8*	-37.5
16	2.5%B+30%Pt	151.3*	83.4	92.1*	-22.2
17	5%B	84.9*	16.9	79.4*	-34.9
18	5%B+10%Pt	103.9*	36.1	76.3*	-37.9
19	5%B+20%Pt	49.4*	-18.5	84.9*	-29.4
20	5%B+30%Pt	70.7	2.8	97.3	-17.0
	LSD	14.20		18.63	
	SE	6.79		8.90	

Means with an asterisk (*) in the same column are significantly different from the unamended soil ($p < 0.05$). LSD = Least significant difference; SE = Standard error of the means; SL = Sandy loam; PS = Pure sand # Negative (-) mean difference indicates lower nitrate concentration in the leachate compare to the control; positive (+) mean difference indicates higher nitrate concentration in the leachate compare to the control.

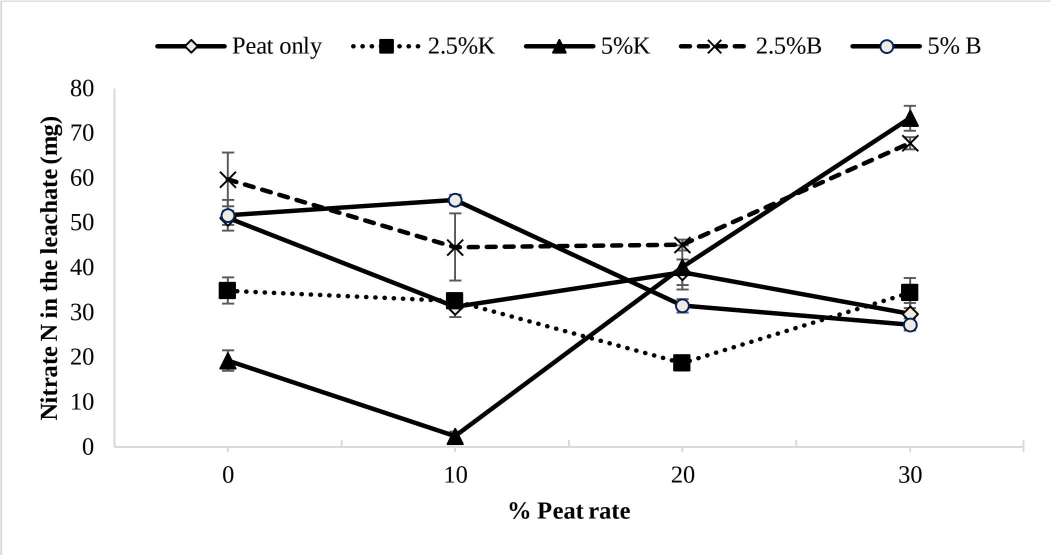
The application of clay K at 2.5% was more effective than combined Pt and K. Above 10%Pt, 5%K + Pt combined held more nitrate than 5%K only. For clay, B amended PS, only 2.5%B+20%Pt was able to reduce nitrate loss compared with 2.5%B amended soil alone. However, at 5%B rate, Pt addition at 10 and 20% rates reduced nitrate loss in the leachate, compared with 5%B only, but the difference was not statistically significant (Table 3). At the same application rate, nitrate retention was lower in PS than SL except for 5%K+30%Pt (Table 3), suggesting that more nitrate is leached in PS than SL. The effectiveness of the amendments on nitrate retention in the two soils is possibly due to the effect of the inherent clay in the SL.

3.5.2 Effect of combined clay and peat on nitrate load

Figure 4 shows the response of SL and PS to Pt rate with respect to nitrate load in the leachates. In SL, 5%K greatly reduced nitrate load when co-applied with 10%Pt, but nitrate load rapidly increased when Pt was more than 20%. Pt addition up to 20% reduced nitrate leaching in the 2.5%K treatment. Addition of Pt improved nitrate retention of B. At 5%B, a significant increase in nitrate retention was observed when more than 10%Pt was added; while in 2.5%B, Pt addition reduced nitrate retention when application rate was above 20% (Figure 4a). Both 2.5%K and 5%K + Pt show that K's ability to increase nitrate retention increased with the Pt rate. Clay B, when applied alone, reduced nitrate retention compared to the unamended SL. However, when mixed with Pt, nitrate-leaching load in the leachate of B amended SL reduced, with the exception of 2.5%B+30%Pt (Figure 4a). For the two clay amendments, 2.5%K reduced nitrate leaching more than 2.5%B, both when applied alone and with Pt. 5%K reduced nitrate leaching more than 5%B, but when Pt rate was $\geq$ 20%, nitrate retention potential of 5%B became higher than 5%K (Figure 4a).

In PS, 5%B showed the lowest nitrate-leaching load when Pt rate was less than 30%. All clay amended soils significantly increased nitrate retention compared to Pt, except when Pt rate was 30%. When co-applied with Pt, nitrate retention of 5%K was significantly highest at the 10%Pt application rate but reduced as Pt rate increases thereafter. Nitrate retention ability of 2.5%B and 5%K were similar, except when Pt was increased to 30% (Figure 4b). The effect of the two clay amendments on nitrate leaching load in SL and PS was influenced by Pt rate. For instance, at 5% clay rate in SL, nitrate leaching increased with Pt rate in K but reduced in B amended soil. However, in PS, both clay amendments seem to reduce leaching as Pt rate increased, except a slight increase in 5%B + 30%Pt in PS. In all, the effect of clay addition to reduce leaching was more pronounced in PS than SL.

a)



b)

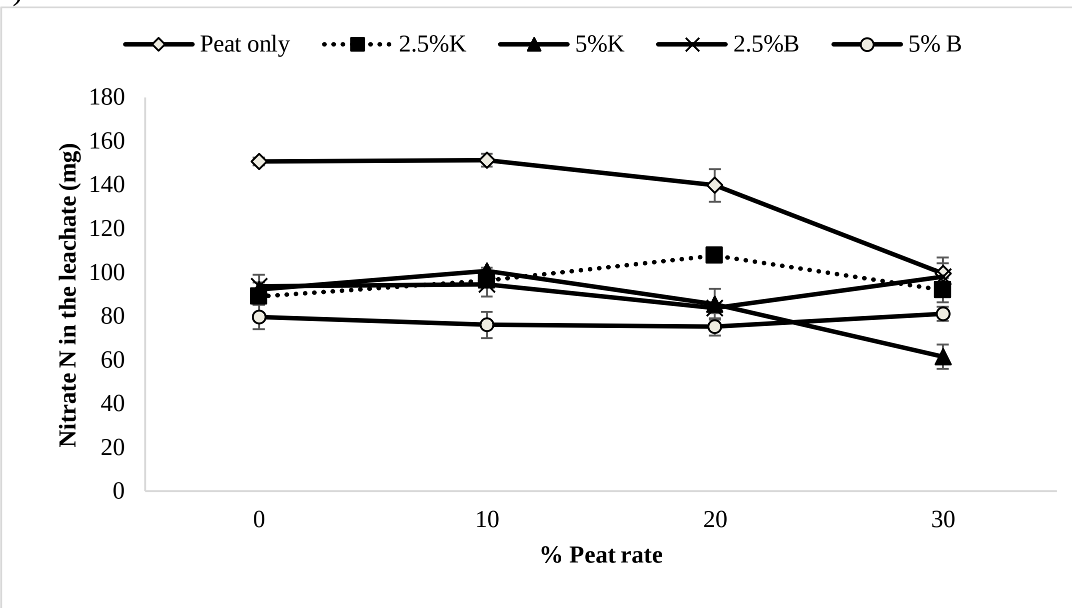


Figure 4: Effect of peat rate on nitrate load (a) SL (Sandy loam) and (b) PS (Pure sand) amended with two clays (K: kaolin; B: bentonite) and Pt. Error bar = ± s.e.m.

Comparing the two soils, the result also showed that interactions between Pt and clay amendments were significant for both SL ($p < 0.0005$) and PS ($p = 0.044$), suggesting a positive interaction between clay amendment and OM. However, the interaction effect was more pronounced in SL than PS. In both soils, the effect of amending soils with the clays was significant, however, in SL only 2.5%K significantly reduced nitrate leaching compared to no clay amendment, but in PS, all clay amendments reduced leaching. The results are similar to those of water retention (Table 2) suggesting that the inherent clay content of SL might have reduced the effectiveness of any added clay (K or B). This suggests that the beneficial effect of claying in sandy soil will increase with decreasing inherent clay content. In this experiment, the main effect of OM was not significant in PS but was in SL, suggesting that in terms of reducing nitrate leaching, OM will work only when in combination with clay.

Deductions from correlation analyses showed that mechanisms responsible for nitrate leaching in SL might be different from that of PS. Correlation between volume of leachate and nitrate load in SL was weakly and non-significant ($p < 0.15$; $r = 0.19$). In PS, this correlation was strongly positive and significant ($p < 0.001$; $r = 0.74$). Thus, it could be inferred that the more the water leached, the higher the load of N losses in PS. This could mean that N retention in PS is largely controlled by water retention while other soil processes control or influence its retention in SL.

4. DISCUSSION

4.1 Water Retention Capacity of the Amended Soil and Sand

All amendments and their combinations increased the water-holding capacity of the two soils compared to the unamended controls. The results/outcomes were similar in SL and PS, except for 2.5%K. The inherent clay present in the SL has been identified as bentonite (Whitfield, 1973), which is known to be smaller in particle size than kaolin (Murray, 1999). The water retention in 2.5%K is likely to be partly associated with K particle size, which is possibly larger than the SL inherent clay size, and might have increased the porosity of SL, and partly due to the quantity used which its water retention could not offset the increase in soil pore effect. The reason for this suggestion is that in PS (with no inherent clay and with particle sizes larger than K), the addition of 2.5%K increased water retention by 6%. Also, in SL, when 2.5%K was mixed with 10% peat, the amended soil's water retention slightly decreased compared to soil amended with 10%Pt alone. However, at 5%K application rate, this was not observed, and the major difference between the two K application rates is the quantity of clay material added. Thus, it can be concluded that at 5%K application rate, the quantity is large enough to offset any increased soil pore sizes resulting from the K amendment.

The percentage increase in water retention as a result of the amendments ranges from 0.6% in the PS amended with 10%Pt, to 40.4% in the PS treatment 30%Pt + 5%B. For the Pt, the amount of water held increases with the percentage of the Pt. Water retention of Pt is largely associated with the dead-end pore spaces found in the cortical layer of plant stems and hyaline cells in the leaves (and stems) which have openings at one end for water storage (Rezanezhad, et al., 2016). A typical peat could hold water up to 18 times of its dry weight (Hobbs, 1986). The water holding capacity of the peat used is 5g/g dry weight, so, in principle the more the quantity of peat added, the more the water that could be retained. The result agrees with the findings of Wang et al. (2014) who reported that in a laboratory experiment in Florida, fermented bioethanol and paper mill wastes at 10% loading increased water retention of a sandy soil by 150 and 300% respectively, compared to the unamended control. Li et al. (2004) showed in a three-year field experiment in Quebec, that amending sandy soil with peat increased water retention and total porosity.

Both bentonite and kaolin increased water retention of SL and PS, but their effect was dependent on the medium being amended. The ability of both clay amendments to increase water retention could be the result of their potential to reduce pore sizes or to their surface charges compared to sand particles (Dixon, 1991; Reuter, 1994; Murray, 1999). A comparison of the two clays showed that B has a higher water holding capacity than K when applied at the same rate. This difference is largely associated with the properties of the clays. Bentonite is a 2:1 clay mineral and the calcium bentonite used in this experiment has 88% montmorillonite, suggesting higher specific surface area compared to kaolin, whose mineralogical composition is mainly of low activity, 1:1 kaolinitic clay. The water holding action of clay occurs in two ways: (1) bonding of water to clay either through electrostatic forces or reactions between water hydrogen ions and oxygen atoms of clay, and (2) by hydration of cations attached to the clay micelle. Thus, clay minerals with higher CEC and charge densities will hold more water. This phenomenon could explain why B with higher activity holds more water than K. Suzuki et al. (2007) also reported an increase in soil available water when a sandy soil in Northern Thailand was amended with termite mound and bentonite compared to the control and attributed the result to the alteration of pore size distribution by the amendments.

Some synergy was observed for the clay amendments when mixed with peat in that, the percentage water held by each clay-peat combination is higher than the sum of the equivalent clay and peat application rate when applied separately in both SL and PS. It was observed that water retention could be increased at the same clay level with increased Pt rate. The synergistic effect observed in this experiment could be related to the formation of clay-organic matter complexes, which possibly could have stimulated stronger van der Waal forces. Theng et al. (1986) suggested that this kind of interaction is possible between clay and organic polymers.

4.2 Nitrogen Leaching In Amended Soils

The effect of Pt rate on ammonium retention varies with the soil. In PS, ammonium retention follows a pattern similar to water retention, thus it could be concluded that reduction in ammonium losses occurred mainly because it was retained in the soil solution. For SL, ammonium retention appears to result from a porosity effect, as losses increased with an increase in OM (Pt), especially in B amended soils. For the two clay amendments, B reduced ammonium leaching more than K. This is expected, as B has higher CEC than K, and could attract more positively charged ions such as ammonium. Sitthaphanit et al. (2010) also reported higher ammonium retention in soil amended with bentonite, while the clay had no effect on nitrate mobility. The findings from the current investigation agree with their results as B reduced leaching of ammonium in both test soils. However, contrary to their findings, K when applied alone reduced nitrate leaching in SL and both clays in PS. The difference might be due to methods of fertilizer application. Sitthaphanit et al. (2010) mixed the fertilizer with the top 2.5kg soil before leaching, while the current experiment used nutrient solution.

Cation retention in soil follows simple electrostatic force mechanisms. While the quantity of anion retained in soil by clay is small compared to cations, the mechanism is quite complex. Some factors such as (1) charge repulsion (2) water extraction from solution to form double layers by clay (3) clay colloid charge density (4) charge density and concentration of the anion (5) soil pH and (6) specific anion reactions (CTAHR, 2015) have been identified to affect anion retention capacity. In this work, amending sandy soils with K only reduced nitrate loss, compared to B only. This could be a result of several factors, such as charge repulsion and clay colloid charge density (factors 1 and 3 above). Bentonite is a clay with a substitution reaction (exchanging structural cations with others of lower valency, thereby creating a charge deficit), so is expected to have a more negative charge on its surface than K that is less reactive. Coupled with that, nitrate is negatively charged and as like charge repels, B will attract less nitrate. Additional support for less nitrate retention by B is that the clay requires more water to form a double layer (factor 2); this condition will cause an increase in nitrate concentration in the soil solution of soil amended with B. This increase in nitrate (anion) concentration (factor 4 above) in turn increases repulsion, hence more nitrate is leached in B amended soil. Pamukcu and Wittle (1993) showed similar results. Shanmugam et al. (2014), Nguyen and Marschner (2013) and Djajadi et al. (2012), in short-time incubation experiments, also reported a reduction in nutrient losses of sandy soil amended with kaolin and organic matter.

The high nitrate retention in K amended soil in current study could also come from the ability of K to modify the anion retention characteristics of the inherent soil clay (Sivachidambaram and Rao, 2012), which was high in montmorillonite, while addition of B could have stimulated or increased repulsion of nitrate; and this may be responsible for wider variability in nitrate retention in kaolin treated SL compared to PS without inherent clay content.

The impact of adding more than 20% Pt to SL was negative in that the OM did not reduce nitrate leaching. This observation is likely to be associated with increased porosity and permeability in the OM used (peat), as the amount of OM increased, resulting in loss of more nitrate in the leachate. The response of the clay amendments and their application rate to organic matter varies and is complex with respect to N retention in this experiment, especially in the SL.

Reuter et al. (1994) suggested that kaolinites should not be used in amending sandy soil due to their low activity and CEC. In contrast, however, a reduction in water repellency when sandy soil is amended with kaolinite has been reported (Hall et al., 2010; Shanmugam et al., 2014). The current study has shown that kaolin has higher potential to reduce nitrate leaching (especially in sandy soil with low inherent clay content) possibly due to less repulsion of this negatively charged molecule compared to bentonite. So, where anion retention is at stake, kaolin may be considered more beneficial.

5. CONCLUSION

The current investigation showed that water retention was enhanced by the addition of clay B; clay K (when application rate is above 2.5%); and clay-peat combinations. In all, the combined application of 5% clay (either K or B) and peat at ≥ 20%Pt rates appear to be most effective in increasing the water retention. The water retention by the added amendments (WRA) was higher in soil with no inherent clay (PS) compared to the sandy loam (SL) that has 18%, thereby confirming that the effectiveness of the added clay on water retention will reduce as inherent soil clay increases. The effect of amendments on nutrient retention was more easily elucidated in PS than SL; all amendments reduced nutrient leaching in PS but the response was varied in SL. Kaolin demonstrated better nitrate retention ability, especially when applied alone or at 2.5% in combination with peat in the sandy loam. Clay B showed higher CEC while K demonstrated higher anion exchange capacity. These results suggest that application of clay and organic materials has the potential to mitigate most of the physical and chemical factors militating against the productivity of sandy soils.

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