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ASSESSING THE ABILITY OF TWO SOIL TYPES IN THE REMOVAL AND RETENTION OF N AND P NUTRIENTS FROM FISH POND EFFLUENTS

[EVALUACIÓN DE LA CAPACIDAD DE DOS TIPOS DE SUELO PARA LA REMOCIÓN Y RETENCIÓN DE N Y P DE EFLUENTES DE ESTANQUES DE PECES]

B.M. Meso[1], W. Wood[2], N.K. Karanja[1*], P.L. Woomer[1], S. M. Kinyali[1] and K. Veverica[3]

[1] Department of Soil Science, University of Nairobi P.O. Box 29053 Nairobi Kenya.
E-mail: ckkgachene@africaonline.co.ke
[2] Department of Agronomy and Soils, Auburn University, Auburn Alabama USA.
E-mail: wwood@acesag.auburn.edu
[3] Pond Dynamics and Aquaculture, Sagana Fish Farm P.O. Box 26 Sagana Kenya.
E-mail kveveric@acesag.auburn.edu
** Corresponding author*

SUMMARY

Effectiveness of two soil types found at Sagana, Kenya, black clay soil (eutric Vertisol) and a red clay soil (chromic Cambisol), in retaining nutrients from pond effluent was investigated. A laboratory experiment was conducted with soil columns containing either of the two soils. Pond effluent application intensities of 31, 81 and 161 mm day^{-1} were tested on both soils. Both soils retained over 60% of total P from pond effluents, with red clay retaining 27% more P than black clay. At the high effluent loading rate, low % N removal was observed in both soils. Total N removal efficiency declined with time after 21 days at the high rate, and after that time no N removal was observed where red clay was used. Black clay was more enriched by N than red clay, while P enrichment was higher in red clay than in black clay. It appears that land application can remove substantial amounts of P and N from pond effluent.

Key words: pond effluent, N and P retention, cambisol and vertisol.

RESUMEN

Se estudio la efectividad de dos tipos de suelo de Sagana, Kenya, suelo arcilloso negro (Vertisol eutrico) y suelo arcilloso rojo (Cambisol crómico), para retener nutrimentos de efluentes de estanques piscícolas. Se desarrollo un experimento de laboratorio con columnas de suelo conteniendo los suelos individuales. Se aplicó efluente de estanque a intensidades de 31, 81 y 161 mm día^{-1}. Ambos suelos retuvieron más del 60% del total de P de los efluentes. El suelo rojo retuvo 27% más P que el suelo negro. A la intensidad de aplicación de efluente alta se observó baja remoción de N en ambos suelos. La eficiencia de remoción de N total descendió con el tiempo después de 21 d en la intensidad alta y después de ese tiempo no se observó remoción de N con el suelo rojo. El suelo negro tuvo un mayor enriquecimiento con N que el suelo rojo, mientras que el enriquecimiento con P fue más alto en el suelo rojo. Se sugiere que el suelo puede ser empleado para remover cantidades substanciales de P y N de los efluentes de lagunas piscícolas.

Palabras clave: efluentes de estanque, retención de N y P, cambisol, vertisol.

INTRODUCTION

Waste effluents from intensive fish culture have been a major concern because they are sources of pollutants to natural waters (Edwards, 1993). Ranges of nitrate N concentration in fish farm effluents of between 0.02 to 12.9 mg L^{-1} with the net output of total N amounting to an annual output of 67.5 t of fish produced have been reported (Solbe, 1982). Alligator farming wastewater was observed to contain a total soluble P and total N concentration of 15 mg L^{-1} and 153 mg L^{-1} respectively (Pardue *et al.*, 1994).

During draining, nutrients are released from sediment solids (Hall *et al.*, 1990) and it has been estimated that as much as 60% P and 80% N from a fishpond end up in the water column (Beverdge, 1996). Changes in recipient fresh water may be apparent in dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), turbidity and secchi disc depth (Pell and Nyberg, 1989). One of the traditional techniques of purifying wastewater is to spread it over the soil surface and then allow it to percolate through the soil profile (Klute *et al.*,1986). Various soil processes attenuate many of the contaminants present in high-strength wastewater. Wastewater application to land resulted in removal on average about 59% BOD, 46% NH$_4$-N, 70% organic-N and 25% total soluble P (Pardue *et al.*, 1994). The effectiveness of land application depends primarily on the time allowed for the soil and soil microorganisms to react with the effluent water (Pardue *et al.*, 1994).

Sagana fish farm in Central Kenya has 20 hectares of ponds which are regularly drained for fish harvest releasing on average 100,000 m3 of enriched effluents into Sagana River. Total N concentration in the effluents ranges from about 3 - 6 mg L^{-1} while total P ranges from 1 - 4 mg L^{-1}, resulting in a possible 450 kg of N and 250 kg of P loading into the river annually. The feasibility of purifying the effluents by land application on the farm prior to releasing in the recipient water was explored in two sites with different types of soils. In well drained parts of the farm, red clay is common, while the lower lying, poorly drained portions are covered with black clay. This study was carried out to assess the effectiveness of the two soil types to retain nutrients from fishpond effluent.

MATERIALS AND METHODS

The experiment was conducted at the Department of Fisheries Fish Farm at Sagana in central Kenya. The farm lies at an elevation of 1231 m above sea level. Rainfall at the farm ranges from 1332 mm yr^{-1} to 1612 mm yr^{-1}, and daily average air temperatures range from 16.3 ^{o}C to 26.9 ^{o}C. Soils at the farm are classified as eutric Vertisol (hereafter referred to as black clay) and chromic Cambisols (red clay), (FAO, 1990). The physical and chemical characteristics of these two soils are presented in Table 1.

Table 1. Initial soil chemical and physical characteristics at the onset of the experiment.

Soil type	Depth	Ksat	Bulk density	PH (water)	Total N	Total C	P	Fe	Al	Mn	K
	cm	cm day^{-1}	Kg m^{-3}	1:1.5	g kg^{-1}	----------------mg kg^{-1}------------------					
eutric Vertisol	0-15	0.98	1160	6.8	0.5	27	8.1	13.4	27.5	28.9	31.0
eutric Vertisol	15-30	0.99	1260	7.3	0.4	20.8	6.2	11.4	25.2	11.3	9.6
eutric Vertisol	30-45	0.99	1322	8.24	0.3	15.7	8.3	13.6	33.2	20.9	7.9
chromic Cambisol	0-15	466	1330	5.32	0.5	16.3	20.6	12.2	31.0	212.2	79.1
chromic Cambisol	15-30	339	1373	5.01	0.4	12.1	7.3	10.7	26.7	110.4	57.9
chromic Cambisol	30-45	337	1447	4.97	0.2	11.7	3.7	10.4	25.2	102.6	44.7

The laboratory experiment was designed with soil columns set up to filter and retain pollutants from fishpond effluents. Two soil samples were obtained, one from an uncultivated field under star grass for the black clay and the other batch from a field previously cultivated with soybean (*Glycine max*) for the red clay by excavation to a depth of 45 cm using a soil auger. For the two types of soils, samples were taken from 0-15 cm, 15-30 cm, and 30-45 cm depths and maintained as individual samples. The soil samples were air dried in the laboratory, crushed and sieved through a 2 mm mesh screen. K, Fe, Mn Al, and available P in a 5 g soil sample were extracted with 20 mL of a dilute double acid mix of 0.05 N HCl and 0.025 N H$_2$SO$_4$ (Russel, 1988). This extract was analyzed by Jarrell-Ash inductively coupled argon plasma (ICAP) spectroscopy (ICAP 9000, Thermo Jarrell Ash, Frankllin, MA). Total C and N in soil were determined by dry combustion with a LECO CHN-600 analyzer (LECO Corp., St. Joseph, MI) (Hue and Evans, 1986).

In the same fields, undisturbed samples were obtained randomly using the core ring method (Russel, 1988). Bulk density and the saturated hydraulic conductivity were determined (Ruseel, 1988). Three portions of pipe (10 cm diameter) were used to simulate a soil profile of three layers depth of 0-15 cm, 15-30 cm, and 30-45 cm. Each portion of 15 cm length was filled with soil taken from each soil layer. Based on the measured bulk densities, 1.56 kg of the red clay and 1.93 kg of the black clay from the 30-45 cm soil layer was pushed down into the lowest portion. The second 15 cm portion of the pipe was fitted on the top side of the first portion already filled with soil from 30-45 cm and fixed by duct tape, then 1.48 kg of the red clay and 1.84 kg of the black clay from the 15-30 cm was packed into this second portion of the pipe. A third portion of the pipe which was longer than the rest (22 cm depth) to hold pond effluent was fitted on the top side of the system and fixed using the same procedure. Red clay (1.51 kg) and 1.63 kg black clay from 0-15 cm was packed into the portion to a depth of 15 cm and compacted by shaking so as to attain the bulk density of the field soils in the same horizon. The three portions fixed together formed an individual soil column which was mounted on a collection pan. Pond water to be purified (Table 2) was collected from the pond receiving 20 kg N ha^{-1} week^{-1} containing on average 5.18 mg L^{-1} N and 0.68 mg L^{-1} P and passed through the soil column filters at varying irrigation depths which served as the treatments. Four treatments were chosen corresponding to varying loading rates of pond effluent to land as shown in Table 3. Three replicates of the soil columns were arranged on the laboratory floor in a completely randomized design.

Table 2. Average nutrient and total suspended solids (TSS) contents of canal and fish pond water.

Source	Season 1			Season 2		
	Total N	Total P	TSS	Total N	Total P	TSS
	---------------mg L^{-1}---------------					
Canal	0.49	0.04	79.7	0.72	0.16	54
Pond	6.03	3.89	330.6	3.16	1.33	193

Table 3. Treatments in the soil column filters

Treatment	I.I. (mm day^{-1})	A.P. (days)	Water (m^3) / land (m^2)
1	0	0	0
2	31	32	1
3	81	62	5
4	161	62	10

I.I.= Irrigation intensity, A.P.= Application period

At the end of experiment, soil was retrieved from the column at the three 15 cm depths, prepared and analyzed for total N and extractable P using the method described above. The effluent of the soil columns was collected on Tuesdays and Fridays and stored at 4 ^{o}C for chemical analysis. Using standard methods, pond effluents and through-flow water were analyzed for total N and P. The difference between the concentration of total N and P in pond effluents and the leachate from the soil column was used to estimate the percentage of nutrient removal by soil columns. Change in soil nutrient content after application of effluents was determined by comparing nutrient contents in soils with and without effluent application.

RESULTS AND DISCUSSION

The two soils used in this study varied considerably in pH value, saturated hydraulic conductivity (K sat), total carbon, manganese and potassium contents (Table 1). On average, in the first two weeks 60-75% of applied N was removed by the black clay, and 20-60% by the red soil (Fig. 1). The highest percent N removal (70% for red clay and 84% for black clay) was observed with application rates of 31 mm/day during the first week, the 161 mm day-1 effluent application rate resulted in 20% N removal in the same period for red clay. The intermediate 81 mm day^{-1} irrigation treatment resulted in 37% N removal from pond effluent added to red clay. High effluent loading resulted in less effective N removal. Black clay was 20%, 42% and 72% more effective than red clay in N removal at 31 mm day^{-1}, 81 mm day^{-1} and 161 mm day^{-1} effluent application intensities, respectively. Total N removal declined rapidly to less than 30% after the third week in 81 mm day^{-1} and 161 mm day^{-1} application intensities.

Table 4 shows total N enrichment in soil after the experiment. Black clay retained 2.7%, 145% and 155% more total N than red clay at 31, 81 and 161 mm day-1 rate of effluent application, respectively. The NH_4^+ ions attraction to the negative changes in surface clays and humus both of which were high in the black clay soils coupled by a possibility that some ammonia cations may have been trapped in the cavities of the crystal structure of 2:1 montimorirotic clays (vertisols) accounted for higher retention of the NH_4^+ cations in the black clay soils (Brady and Weil, 1999). Low saturated hydraulic conductivity of black clay (Table 1) reduced the rate of downward movement of water, increasing contact time between N in effluent with the soil exchange surface, resulting in higher retention. Water was probably transported through the small pores in the soil profile, enhancing retention. With alkaline pH (Table 1), black clay retained more total N than red clay.

Table 4. Increase in total N content in the soil after pond effluent application

Application Intensity (mm day^{-1})	Red clay	Black clay	LSD0.05	SE	C.V
	Soil total N				
	--------------g m-2-------------------				
31	1.1	1.13	0.48	0.16	40
81	0.51	1.25	0.35	0.12	52
161	0.44	1.12	0.38	0.13	44

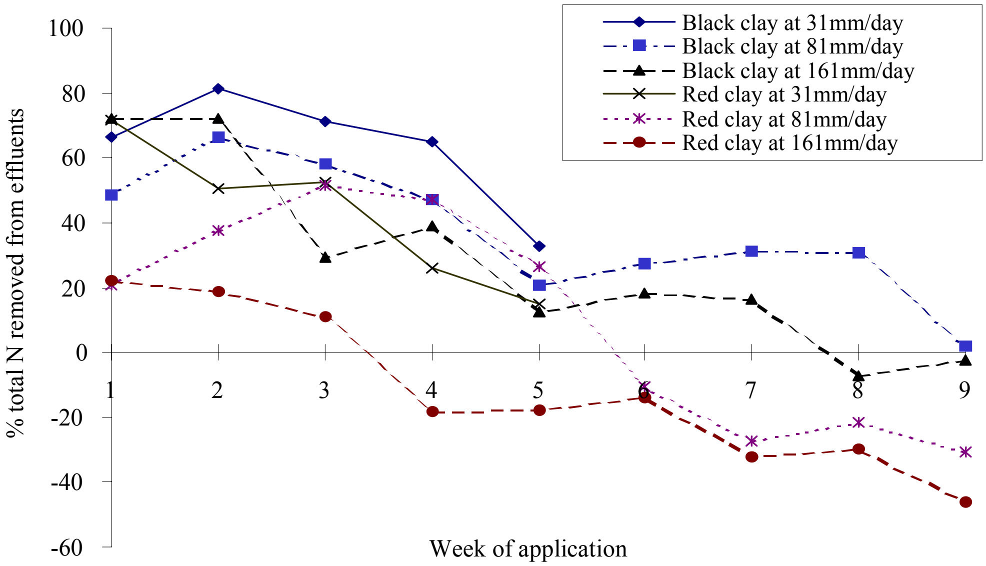

Figure 1. Nitrogen removal by soil in the columns at varying pond effluent application rates.

For red clay, total N in pond effluent was equal to that in the effluent from the soil column after 23 days and 40 days of operation in the 161 mm/day and 81 mm day^{-1} effluent application intensities, respectively, implying zero N removal. However, zero N removal was not observed in the 31 mm day^{-1} application intensity (Figure 1). In black clay, zero N removal was observed at 161 mm day^{-1} application intensity after 54 days, the other two application intensities did not attain zero removal. Any further application of the pond effluents after reaching zero N removal resulted in higher levels of total N in the effluent from soil column than in pond effluent. This negative N budget implies N addition by the soil in the columns to the through-flow water, which can be attributed to displacement of previously sorbed NH_4^+. This observation agrees with other reports by (Chardon *et al.*, 1997 ; Klute *et al.*, 1986).

Over 60% of applied P was removed at all application intensities (Fig. 2). Concentration of P in effluent from soil column remained low from the second week throughout the experimental period. The efficiency of P removal was about 75% in black clay and 80% in red clay at all loading intensities. The acidic red clay soil with a pH 5.3 contained higher Al_3^+ and Mn_2^+ hydroxyl ions contents than the black clay soil with an average pH 7.0. In the presence of Al, Fe and Mn and the low pH in soil solution, the phosphate ions may have replaced the hydroxyl groups to form very stable bridges with these cations as earlier observed by (Bohn *et al.*, 1985). The phosphate could also have reacted with the hydrous oxides of iron, manganese, aluminum to form insoluble compounds. On the other hand adsorption and affinity capacities of the black clay soils tended to be low due to the rather neutral pH 7.0; the negative charged clay surfaces and the high organic matter content which may have formed complex compounds with Al, Fe and Mn ions in soil solution (Duxbury and Peverly, 1978). No tendency for P saturation in the soil column was observed with the loading rates used in this study, contrary to observations made by (Pardue *et al.*, 1994) who used higher influent concentration. Phosphorus retained in the soil was mainly a product of application rate and P concentration; similar observations were made by (Chardon *et al.*, 1997). The fact that very low levels of P were found in soil columns effluent suggests that most of the P was retained by soil particles.

Black clay was more enriched by N than red clay at 81 and 161 mm day^{-1} rates of effluent application (Table 4, while P enrichment was higher in red clay than in black clay at 161 mm day^{-1} rate of effluent application (Table 5).

Table 5. Increase in dilute acid extractable P content in the column soil after pond effluent application.

Application Intensity (mm day^{-1})	Red clay	Black clay	LSD0.05	C.V
	Soil Extractable P ------------------g m^{-2}------------------------			
31	1.03	0.99	0.16	14
81	1.5	1.03	0.83	46
161	1.34	1.02	0.24	23

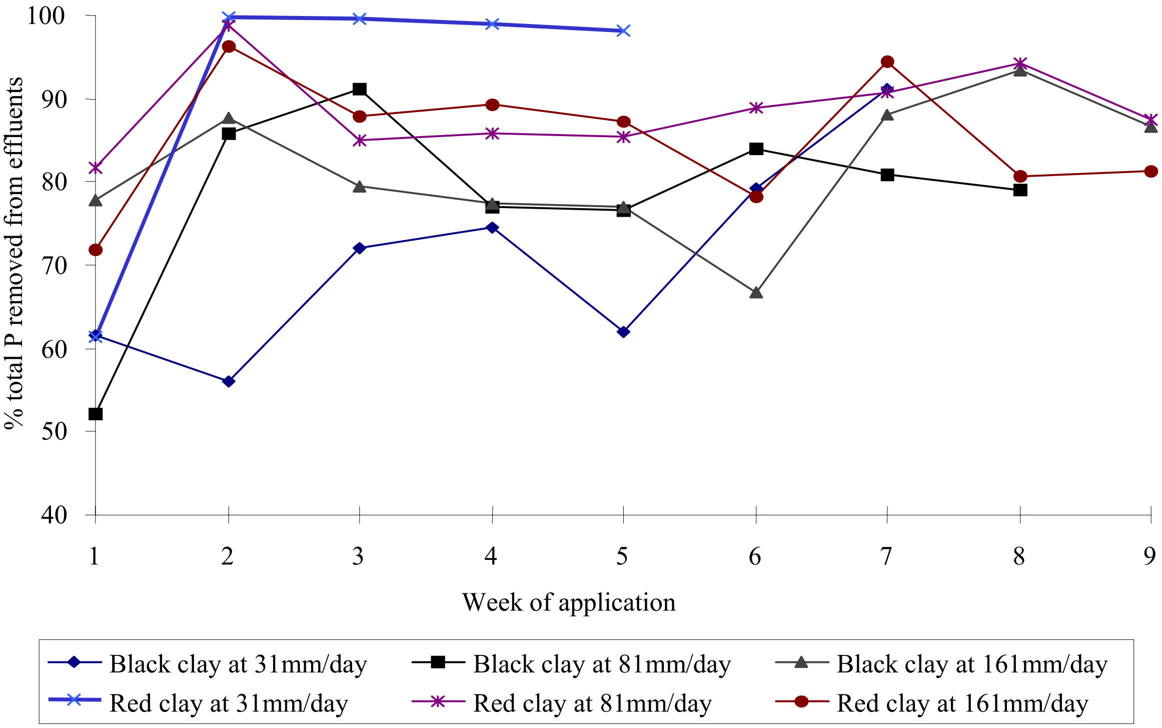

Figure 2. Phosphorus removal by soil at varying pond effluent application rates.

CONCLUSIONS

Removal of N from pond effluent was high in the first three weeks of application, but it rapidly decreased with time. Continuous application of pond effluent at a rate of 81 and 161 mm day^{-1} for a period of 40 and 23 days, respectively saturates the soil's ability to retain N from pond effluent with total N ranging from 1.33 mg L^{-1} to 6.30 mg L^{-1}. Soil treatment resulted in an average 80% removal of total P from pond effluent for up to ten weeks. Pond effluent application at a rate of 81 mm day^{-1} in red clay resulted in the highest soil P enrichment while an application at a rate of 31 mm day^{-1} in black soil had the least enrichment. Black and red clay soils in Sagana, are able to retain substantial amounts of N and P from pond effluent with better effects on P removal. For sustainable utilization of the soils in retention of N and P, further research should be conducted on possible uptake of the retained N and P through crop growth. For example, 10 hectares of growing crops with a P uptake of 25 kg P ha^{-1} year^{-1} on the application area will take up all the 250 kg of P from the 20 hectares fish pond effluents and the crop will benefit from the nutrients.

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