Characterization of Malaysian sewage sludge and nitrogen mineralization in three soils treated with sewage sludge

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Abstract
Studies to determine the chemical composition of sewage sludges produced in Malaysia and the potentially mineralizable nitogen *(N_o) and mineralization* rate constant *(k)* of sewage sludge in three Malaysian soils are reported. Analyses of the sludges collected from 10 wastewater treatment plants in Malaysia are acidic in nature and the N. P, Ca, K and Mg contents is variable. The heavy metal (Pb, Cd, Cu, Mn and Ni) concentrations of the sludge, except for Zn are below the European Union Maximum permitted level in sludges. The three soils, Bungor (sandy clay loam), Jawa (silt loam) and Serdang (sandy clay loam) were treated with three rates (0, 140 and 420 kg N ha^{-1}) of dewatered sewage sludge and incubated at 67% of the water holding capacity for 12 weeks. Mineralization of N exhibited a slow initial rate, followed by a rapid increase in rate in week 4 to 8.. Accumulation of mineral N ranged from 50.5 to 147.6 mg kg^{-1} soil. The Bungor and Jawa soils had higher N mineralisation than the Serdang soil, both with and without added sludge. Sludge added at 420 kg N ha^{-1} resulted in the highest concentration of net mineralised N. Values of potentially mineralizable N, $N_{o,}$ and mineralization rate contstant, k ranged from 23.4 to 137.5 mg N kg^{-1} soil and 0.036 to 0.082 week-^{l}, respectively. It was concluded that N mineralization of the sewage sludge treated soils was dependent on the application rate of sludge and soil typel.

Key Words
Sewage sludge characterization, nitrogen mineralization.

Introduction
Malaysia produces about 5 million m^3 of sewage sludge per year. On 9th December 1993, the Government of Malaysia handed over the national sewerage privatization project to Indah Water Konsortium Sdn. Bhd. to manage a more modern and efficient sewerage system for the country. Currently, IWK operates and maintains over 4,300 public sewage treatment plants all over Malaysia, desludges and treats sludge from over 0.8 million septic tanks regularly and monitors effluent samples from sewage treatment plants to ensure they meet the Department of Environment's standards (Indah Water Consortium Sdn. Bhd., 1997).

Recycling sewage sludge on cropland has been considered as one of the possible solutions to the complex problem of sewage sludge disposal. The growing preference for land application of organic wastes, including sewage sludge, to agricultural land has received attention in recent years to reduce cost, environmental problems and regulatory constraints associated with alternative disposal methods of sludge disposal.

The application of sewage sludge to agriculture land is generally the most economic outlet for sludge because there is an opportunity to recycle beneficial plant nutrients and organic matter in soils used for crop production. For example, the N and P fertilizer replacement value of sewage sludge has been reported frequently (Kelling *et al.*, 1977; Sommers *et al.*, 1980; Coker *et al.*, 1987). According to Pagliai *et al.* (1981) and Smith *et al.* (1992), organic matter in sewage sludge can also increase crop productivity by improving soil physical and chemical properties. Fifty to 90 % of the N in sludge is in the organic form (Sommers, 1980). Information on the rate of mineralization rates of organic N in sludge is necessary to predict N availability during a cropping season. However, mineralization of organic N in sewage sludge is a complex process, is dependent on several factors such as soil type, rate or type of waste applied, soil pH, temperature, aeration and moisture (Terry *et al.*, 1981),. Most studies of N-mineralization of sewage sludge have been carried out mainly in temperate soils. Information on N-mineralization of sewage sludge in Malaysia is limited.

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A project was undertaken by the Department of Land Management, Universiti Putra Malaysia, to study the potential use of sewage sludge as a fertilizer in corn cultivation. The study on N-mineralization is part of the long-term study to determine the chemical composition of sewage sludges produced by IWK and N- mineralization potential of a selected sludge in three soil types.

Materials and Methods

Sludge characterization

Sewage sludges were collected from ten different treatment plants throughout Peninsular Malaysia with the co-operation of IWK to represent the various types of sludges produced.

The sludge samples were air-dried and then ground to pass a 1 mm sieve for chemical analyses: pH, organic C, total N, heavy metals and macronutrient content Organic C was determined according to the combustion method (McKeague, 1976). One gram of sewage sludge was placed in a crucible and put into a furnace at 350 °C for an hour. The temperature was then raised to 550 °C and left for 24 hours. The remaining ash was weighed and organic C was calculated from the loss in weight during ashing. Total N was determined using Kjeldhal method (Bremner and Mulvaney, 1982). Total analysis of the heavy metals and macronutrients were determined using the aqua-regia method. The extraction solution was made using HCl and HNO_3 solution (3:1). Heavy metals (Pb, Cd, Cu, Ni, Mn, Zn, and Fe) and macronutrients (Mg and Ca) in the solution were determined using Atomic Absorption Spectrophotometer, whilst with Flamephotometer.

Mineralization of sewage sludge

A laboratory experiment was conducted to determine N-mineralization potential of sewage sludge in 3 Malaysian soils at different rates in an incubation period of 12 weeks. The experiment included three soils: Bungor (Ultisol), Jawa (Inceptisol) and Serdang series (Ultisol) and three rates of dewatered sewage sludge (8 month old): 0 %, l00%, 300 % of recommended fertilizer N rate for maize cultivation (0, 140 and 420 kg N ha^{-1}); replicated 4 times. The topsoil (0 – 20 cm) of the three soils differed in chemical and physical properties (Table 1). The sludge used in the incubation study had a pH of 5.0, and contained 28.4% organic carbon, 37.9 mg kg^{-1} mineral N, 2.0 % total N, 0.21% total P and had a C/N ratio of 13.6.

Table 1. Physical and chemical properties of the three Malaysian soils.

Soil Series	**Size fractions (%)**			**Soil**	**pH (Water, 1:2.5)**	**pH (KCl)**	**Org. C**	**Total N**	**C/N**
	clay	**silt**	**sand**	**Texture Class**			**%**	**%**	
Bungor	28.4	6.9	64.5	Sandy clay loam	4.9	3.6	2.2	0.188	11.9
Serdang	35.8	14.2	50.0	Sandy clay loam	4.7	3.6	1.3	0.154	8.60
Jawa	21.5	71.4	7.0	Silt loam	4.0	3.2	6.4	0.376	17.4

Three hundred grams of air-dried soils in a plastic containers were amended with 3 rates of sewage sludge i.e. 0, 0.5 and 1.5 g (140 and 420 kgN ha^{-1}) of sludge and adjusted to 67% of the water holding capacity with deionized water. The container was closed with a parafilm to enable humified free air to be continuously passing over the soil-sludge mixture. The soils were incubated in a dark cupboard at room temperature. The moisture content was adjusted to 67% of the water holding capacity by regular weighing and addition of distilled water to compensate for the evaporation loss. At 0, 1, 2, 4, 6, 8 and 12 weeks, the soil was thoroughly mixed and a sub-sample of 10 g was removed for extraction of mineral N with 40 ml of 2 M KCl. The sample was shakened for an hour, then 10 ml of the filtered extract was distilled with MgO for NH^+_4-N and with Devarda's alloy for NO^-_3-N and NO^-_2-N, and collected in boric acid. Titration was done with 0.0025 M HC1.

The mineral N data measured at each of the seven incubation periods were statistically analyzed using a nonlinear regression approach described by Smith *et al.* (1980). Estimates for the amount of potentially mineralizable N (N_o) and the first-order mineralization rate constant *(k)* for the 12 weeks incubation period were obtained using the following equation:

$$N_m = N_0 (1 - e^{-kt})$$

Where:

N_m = amount of N mineralized at a specific time (mg kg-1)

N_0 = potentially mineralizable N (mg kg-1)

k = first -order mineralization rate constant (week-1)

t = time of incubation (week)

Results and Discussion

In general, the sludges were acidic (pH 3.57 to 6.43), because no lime is used in the treatment of the wastewater at the treatment plants (Table 2). Higher pH values of sludges had been reported (Chae and Tatabai, 1985; Serna and Pomeras, 1992) due to the addition of CaO and $CaCO_3$ during the sludge treatment.

The highest concentration of organic C was found in sludge 5 (mixture of light industry & domestic type). The variation in organic C seemed to be independent of sludge type. The C/N ratio of the sludges ranged from 4.1 to 38.0 with a mean of 16.6. The organic C content in these sludges were higher than those reported by Hsieh *et al.*, (1981), Parker and Sommers (1983) or Chae and Tatabai (1985).

Total N content ranged from 0.68 to 2.90 %, whereas P was from 0.24 to 1.62 %. Total N content of sludges in this study was higher than reported by Lindemann and Cardenas (1984) and Indah Water Konsortium Sdn. Bhd. (1997) The range of Mg and K concentrations were from 278 to 2902 mgkg^{-1} and 401 to 1209 mgkg^{-1}, respectively. The concentration of Ca varied from 0.16 to 2.16 %. These macronutrients are beneficial for plant growth and the amount in the sludges are of considerable value as a fertilizer replacement. The concentrations of micronutrient reported in this study were similar to those reported by Kala (1998), Phuah (1999) and Christina (1999).

Table 2. pH and nutrient content of 10 selected sewage sludge taken from different wastewater treatment plants (n = 3).

Sewage sludge	pH (H_2O)	%C	%N	C/N	%P	%Ca	K	Mg
							mg kg^{-1}	
1	4.45	48.21	1.67	28.87	0.238	0.627	1205	445
2	3.92	6.13	0.68	9.03	0.321	0.422	1021	521
3	6.43	32.10	1.54	20.84	0.410	1.17	941	1690
4	3.92	11.15	2.70	4.13	0.652	0.323	462	278
5	3.57	56.67	1.52	37.94	0.821	0.160	401	389
6	5.61	41.36	2.27	18.22	0.778	1.12	1209	Aa2
7	5.24	37.41	2.82	13.26	0.634	0.832	728	870
8	5.89	18.28	2.65	6.90	1.20	2.16	621	2062
9	6.02	33.35	2.90	11.50	1.62	0.926	972	2902
10	5.72	41.23	2.64	15.62	0.470	0.640	678	1575
Mean	**5.08**	**32.59**	**2.14**	**16.63**	**0.714**	**0.838**	**824**	**1084**

Sewage sludges 1, 2, 3, 4, 6, 7 and 10 – domestic type

Sewage sludges 5, 8 and 9 – mixture of light industry & domestic type

The concentrations of Pb, Cd and Cu varied from 36 to 308 mg kg^{-1}, 0.51 to 6.49 mg kg^{-1} and 63 to 732 mg kg^{-1}, respectively and the concentration of Mn and Ni ranged from 32 to 420 mg kg^{-1} and 10 to 151 mg kg^{-1} respectively (Table3). Sludge 9 (light industry and domestic type) had the highest concentrations of heavy metals (Pb, Cd, Cu, Mn and Ni). The Fe concentrations in these sludges ranged from 1.22 to 4.01 % whereas Zn varied from 153 to 7012 mg kg^{-1}. According to the Commission of the European Communities 1986 guideline the concentration of heavy metals in all sludge samples did not exceed the maximum permitted concentration of heavy metals, except for the Zn content of sludge 8

Nitrogen mineralization pattern of three application of sewage sludge in the three soils are shown in Figures 1, 2 and 3. Mineralisation of N was slow in all the three soils, initially, and later increased rapidly during week 4 – 8. Mineralization rate declined after week 8 in Bungor and Jawa soils. Figure 3 seems to indicate that mineralization in Serdang soil was still following a linear pattern after week 8 of incubation.; decline in N mineralization may be observed if incubation was continued longer than 12 weeks. The lowest mineralized N was observed in Serdang soil 107.5 mg kg^{-1}

Table 3. Heavy metal content (mg kg^{-1}) of 10 selected sewage sludge taken from different wastewater treatment plants (n = 3).

Sewage sludge	Pb	Cd	Cu	Ni	Mn	Zn	% Fe
1	36	1.57	127	19	101	841	3.22
2	51	0.51	112	20	127	892	4.01
3	47	3.21	141	26	362	997	2.62
4	46	1.22	63	10	32	153	2.54
5	121	2.51	696	15	73	454	2.27
6	60	5.78	110	13	132	1201	2.63
7	68	3.52	178	21	257	1322	1.90
8	189	6.02	223	38	282	7012	1.22
9	308	6.49	732	151	420	3778	3.31
10	72	3.22	190	15	105	3218	3.20
Mean	**100**	**3.41**	**257**	**32**	**189.1**	**1986**	**2.69**

Sewage sludges 1, 2, 3, 4, 6, 7 and 10 – domestic type
Sewage sludges 5, 8 and 9 – mixture of light industry & domestic type

Table 4. Estimates of potentially mineralizable N (N_0) and mineralization rate constant (k) using non-linear regression equation (mean n = 4)

Sewage sludge treatment rates	Observed net N mineralized in 12 weeks	Predicted net N mineralized in 12 weeks (N_o) [a]	Rate constant (k)[a]	$N_o k$	R^2
Kg N ha^{-1}	mg kg^{-1} soil		week $^{-1}$	mg kg^{-1} soil week^{-1}	
		Bungor			
0	107.5	92.3	0.042	3.88	0.977**
140	140.4	137.5	0.036	4.95	0.979**
420	145.8	91.4	0.060	5.48	0.988**
		Jawa			
0	105.5	98.5	0.053	4.23	0.982**
140	127.8	108.8	0.042	4.45	0.984**
420	147.6	124.9	0.042	5.25	0.983**
		Serdang			
0	50.5	23.4	0.090	2.11	0.982**
140	57.6	31.7	0.071	2.25	0.985**
420	65.3	32.2	0.082	2.64	0.985**

a- N_o and k obtained from non-linear regression equation: $N_m = N_0\ (1-e(kt)\}???$
R^2 - Correlation coefficients between observed, predicted total net mineralized N and k values obtained were significant at P<0.01 (**)

The sludge rate of 420 kg N ha^{-1} gave the highest predicted or potentially mineralizable N, N_o value in all three soils treated with sludge. The values of N_o obtained for the Bungor and Jawa ranged from 91.4 to 137.5 mg kg^{-1} soil. For Serdang soil the values were smaller (23.4 to 32.2 mg kg^{-1} soil). The k (rate constant) values ranged from 0.036 to 0.090 week^{-1}. The N availability index, $N_o k$ of the sludges ranged from 2.11 to 5.48 mg kg^{-1}; with the lowest in the Serdang soil.

The high mineralization rates occurred during week 4 to 8 of incubation, and are likely to be associated with the decomposition of labile organic N. After week 8 the more recalcitrant organic N appears to predominates in the organic N pool, as mineralization rates slowed (Lindemann and Cardenas, 1984). The low net mineralized N in Serdang soil compared to the Bungor and Jawa soils could be due to the low amount of organic matter and consequently a low pool of indigenous organic N. The organic matter in the Serdang soil, however, did have a very narrow C:N ratio, suggesting a high potential mineralization potential. Nitrogen immobilization by the heterophic microorganisms of the soil may also be occurring.

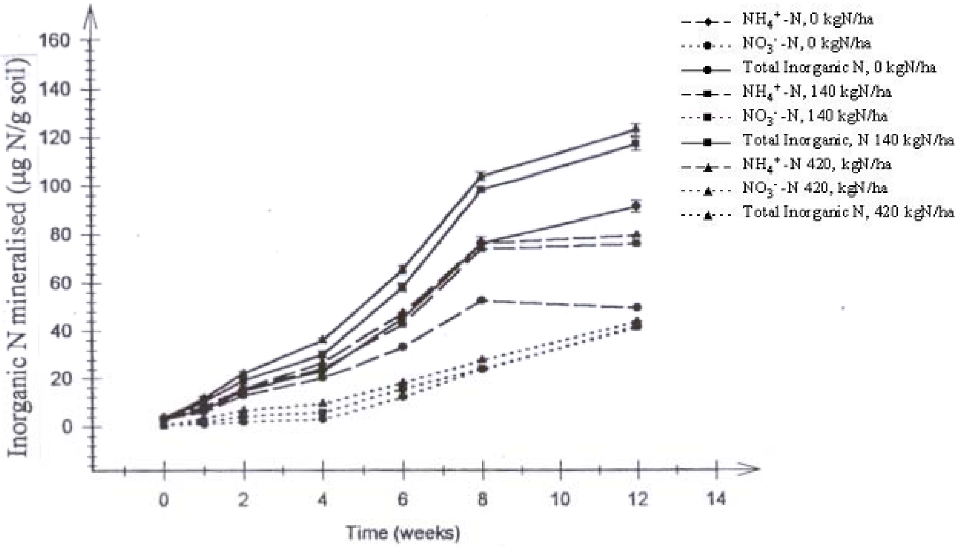

Figure 1. Nitrogen mineralization of different application rate of 8 month old sewage sludge in Bungor soil series (Bars indicate standard deviation of means).

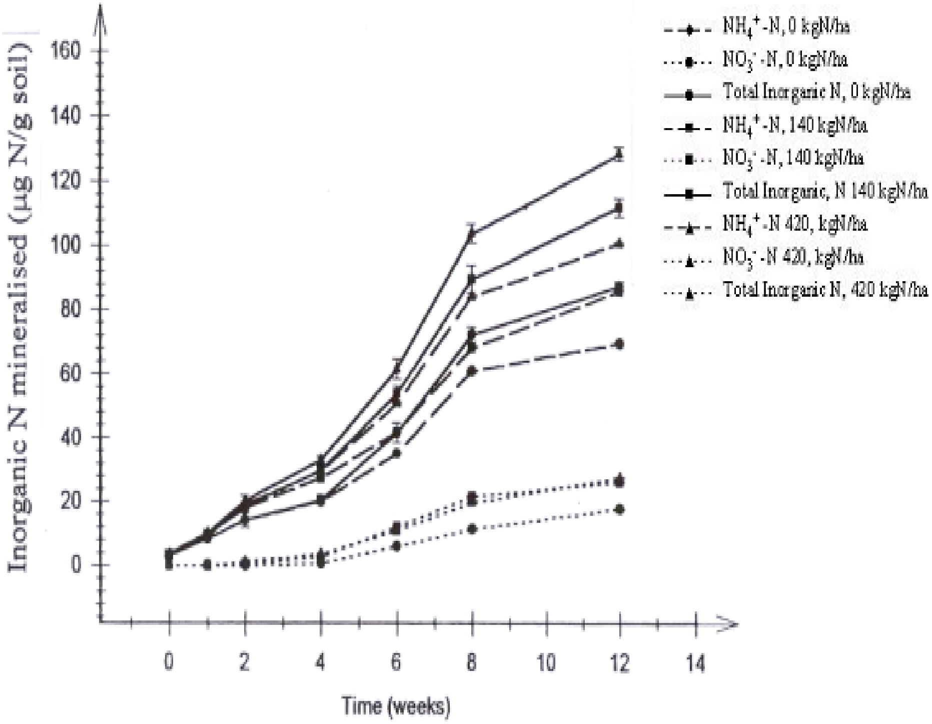

Figure 2. Nitrogen mineralization of different application rate of 8 month old sewage sludge in Java soil series (Bars indicate standard deviation of means).

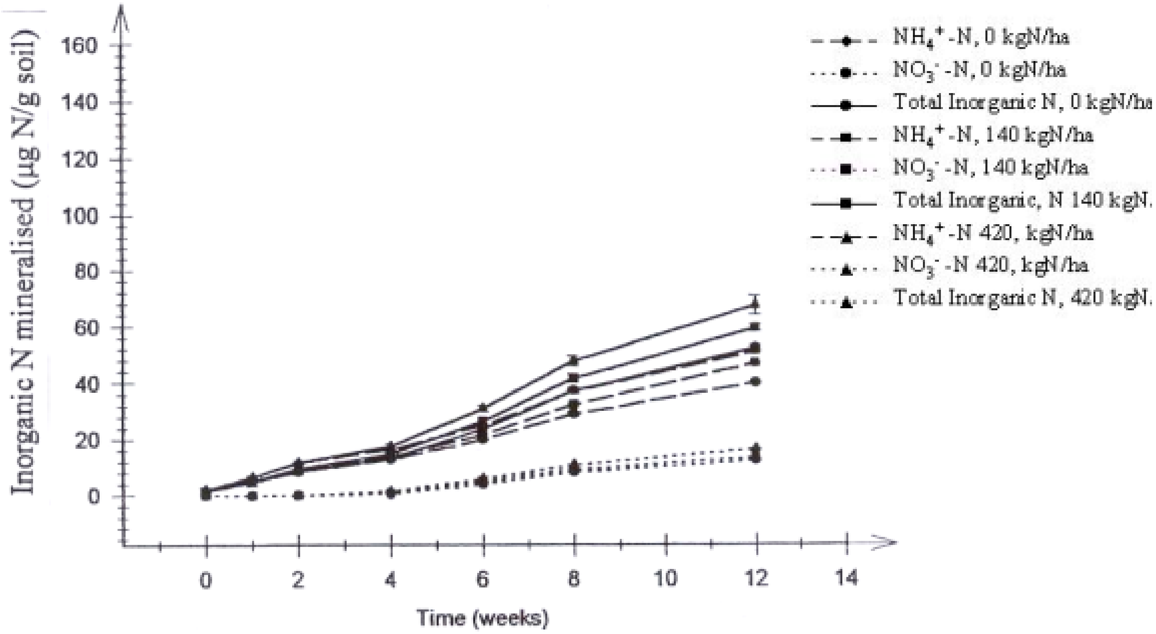

Figure 3. Nitrogen mineralization of different application rate of 8 month old sewage sludge in Serdang soil series (Bars indicate standard deviation of means).

Conclusions

Sewage sludges produced by Malaysian wastewater plants are acidic and have variable chemical compositions. The N-mineralization rate in sewage sludge treated soil is dependent on the sludge application rate and the chemical and physical characteristics of the soil receiving the organic waste. Higher mineralization rates with or without sludge addition were measured in the Bungor and Jawa soils. The third soil had much lower mineralization potentials, even when large amounts of sludge were added. The study highlights the importance of understanding the properties and behaviour of the soil in formulating any sewage sludge based, rather than mineral N fertilizer programme for supply N for plant growth. .

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