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IMPROVEMENT OF SOIL STRUCTURE AND PLANT GROWTH BY ADDITION OF ALUM SLUDGE

Key Words: Alum sludge, soil structure, plant growth

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ABSTRACT

Addition of the alum sludge to soils in pots decreased both slaking and dispersion of soils and resulted in improved aggregation. Water retention between - 10 and -1000 kPa was increased and the strength of aggregates and the modulus of rupture of moulded briquettes were decreased by the addition of sludge.

The application of sludge to three soils increased the yield of dry matter of maize grown in pots with and without an addition of fertilizer, but high rates of application led to germination problems and decreased phosphate uptake by the maize.

It is concluded that alum sludge may be disposed of in soils with beneficial effects on soil structure and plant growth, but requires testing in the field at rates of the order of 2 t ha^{-1}.

2 tons/ha

Phosphorus

assume metric tons/ha

tons/ac

INTRODUCTION

"Alum sludge" results from the clarification of reservoir waters by addition of solutions of $Al_2(SO_4)_3$. The resultant sludge must be removed from the bed of the reservoir and its disposal can be a problem.

Because the sludge contains considerable amounts of nitrogen, phosphorus and other plant nutrients, it was considered that it might be a useful fertilizer. In addition, the freshly precipitated aluminium hydroxides could improve the physical conditions of the soil. This communication reports the results of mixing alum sludge, as a dry powder and as a suspension, with three soils on some physical properties of the soils and on the yield of maize plants grown in the amended soils.

MATERIALS

The Alum Sludge

The alum sludge was obtained from Happy Valley treatment plant (Adelaide) as a suspension in November 1978. The solid material dried at 105°C for 16 h contained 13.6% carbon determined using a Fisher carbon induction furnace[7] and 0.94% nitrogen determined by the method of Kjeldahl. The elemental composition of the alum sludge was determined by X-ray fluorescence spectroscopy after dissolution of an ignited sample in a lithium borate disc[2]. The composition of the sludge depends on the reservoir sampled and the time of sampling, but compared with soil clays the sludge is richer in carbon, nitrogen and phosphorus (Table 1) in addition to the aluminium which is added.

The pH of the sludge was 6.5 in water and the zero point of charge 3.5. X-ray diffraction studies indicated that except for a small amount of quartz the minerals present were highly disordered and did not yield a diffraction pattern.

TABLE 1

Elemental composition of alum sludge

Oxide	Alum sludge
Fe_2O_3	5.54
MnO	0.22
TiO	0.34
CaO	1.83
K_2O	1.09
P_2O_5	0.80
SiO_2	25.49
Al_2O_3	61.71
MgO	0.47
Total	96.37

TABLE 2

Some characteristics of the soils used

Australian Great Soil Group	Solodic soil	Podzol	Red-brown earth
Key (Northcote 1971)	Dr2.43	Uc2.20	Dr2.23
Soil Taxonomy USDA (1975)	Typic natrixeralf	Typic haplorthod	Calcic rhodoxeralf
Depth sampled (cm)	0-10	0-30	0-10
pHw	7.5	6.1	5.1
<2 μm (%)	43	8	30
2-20 μm (%)	5	3	31
20-53 μm (%)	0	0	16
53-500 μm (%)	40	85	22
>500 μm (%)	4	4	1
Maximum water holding capacity % w/w	56	28	39

The Soils

Three soils were used: a strongly sodic clay with an exchangeable sodium percentage of about 30 resulting from the mixing by tillage of A and B horizons of a solodic soil; a leached lateritic sand from a podzol deficient in trace elements; and the surface horizon of a hard-setting red-brown earth. Further properties of the soils are shown in Table 2.

METHODS

Preparation of Soils

The soils were air dried, gently crushed and sieved <5 mm. The amounts of air dry soil used in each pot for structural and plant growth studies were 3.0 and 2.5 kg respectively.

Application of Sludge

Air dried sludge (13% w/w H_2O) was sieved <100 µm and applied to the soil wetted to near -10 kPa and the samples mixed thoroughly in a cement mixer. Suspensions of sludge were added to wetted soils at the appropriate rates so that the water potential was near -10 kPa, and mixed as above. The rates of sludge added were 2 and 20 t ha^{-1} assuming a depth 0-10 cm and a bulk density of 1 g cm^{-3}. Control samples wetted to -10 kPa to which sludge was not added were mixed in the cement mixer for the same length of time as amended soils.

Treatments of Soils in Pots

(a) Physical characterisation

Soils were saturated with water and allowed to dry in the glasshouse. The wetting and drying process was done five times during a period of two months. Samples from duplicate pots were mixed. Aggregates with diameters 6.7 to 9.5 mm were collected by dry sieving and the rest of the sample passed through a sieve with 2 mm holes.

(b) Plant growth

For plant growth plus and minus fertilizer treatments were imposed. A soluble fertilizer was added in 100 cm^3 per pot and supplied the following elements expressed in mg per pot; N-333, P-167, K-167, S-67, Mn-27, B-7, Zn-13, Cu-13, Mo-0.3. Pots were not drained. Rainwater was added every alternate day for two weeks and then daily. Maize (Zea mays) was sown at a rate of six seeds per pot. After seedlings emerged all but the two strongest plants were removed. The maize plants were harvested ten weeks after sowing by cutting off the tops at soil level and drying at 70°C.

Experimental Design

Pots were arranged in a split plot design with two replicates. Each of the two levels of the split plot was formed by a factorial combination of two of the four treatments. Thus, the 6 whole-plots were formed by combinations of the three soils with two fertilizer treatments. The six split-plots were formed by combinations of the two methods of application of the sludge (dry and suspension) with the three rates of addition. This arrangement of the four treatments enabled greater accuracy for comparisons between the two methods of application and between the three rates of addition and less emphasis on tests between the three soils and the presence or absence of fertilizer.

Analytical Methods

(a) pH

pH values were determined using a glass electrode on a 1:2 soil:water suspension of soils.

(b) Dispersion and slaking

Indices for dispersion and slaking of aggregates were determined using a modification of Emerson's method[4].

(c) Particle size distributions

Particle size determinations were done by sedimentation using Stokes law or sieving. Wet sieving was based on the method described by Kemper and Koch[5].

(d) Water retention

Soil was equilibrated with suctions of -10 and -1000 kPa in pressure plate apparatus. The water contents were determined gravimetrically.

(e) Aggregate strength

The mean force required to crush 15 natural air dry aggregates was determined using a top pan balance and a proving ring.

(f) Modulus of rupture

Briquettes of soil were moulded at 40% water holding capacity and allowed to air dry for one week. The briquettes were ruptured in the apparatus described by Richards[1].

(g) Aluminium and phosphorus contents of maize tissue

Aluminium and phosphorus were determined by X-ray fluorescence spectroscopy using pressed discs of finely ground plant material.

RESULTS AND DISCUSSION

Physical Measurements

The pH of the sludge was 6.5 and the addition of sludge did not cause any marked change to the pH values of the soils.

Slaking and Dispersion

The slaking and dispersion indices (Table 3) show clearly that both slaking and dispersion were decreased by addition of sludge, particularly the high rates applied as a suspension. The decrease in dispersion and slaking were confirmed by particle size analysis which showed a decrease in clay dispersed after 30 min end-over-end

TABLE 3

Slaking and dispersion indices

Soil	Sludge application: Method	Rate t ha^{-1}	Slaking index	Dispersion index
Solodic soil	Control	0	5	7
	Dry	2	4	5
	Dry	20	4	5
	Suspension	2	3	4
	Suspension	20	1	1
Podzol	Control	0	8	No dispersion observed in 24 hours
	Dry	2	8	
	Dry	20	7	
	Suspension	2	7	
	Suspension	20	3	
Red-brown earth	Control	0	7	5
	Dry	2	5	4
	Dry	20	5	4
	Suspension	2	4	3
	Suspension	20	3	1

TABLE 4

Particle sizes obtained by wet sieving

Soil	Sludge application: Method	Rate t ha^{-1}	0.25-0.5mm (% by weight)	0.5-1mm (% by weight)	>1mm (% by weight)
Solodic soil	Control	0	13.8	23.3	5.8
	Dry	2	22.1	31.8	7.2
	Dry	20	21.8	29.7	6.9
	Suspension	2	20.7	28.3	10.8
	Suspension	20	30.8	20.4	28.6
Podzol	Control	0	35.6	18.6	3.1
	Dry	2	39.1	18.4	2.4
	Dry	20	41.7	14.5	2.5
	Suspension	2	50.8	12.6	3.8
	Suspension	20	56.4	9.2	3.8
Red-brown earth	Control	0	24.3	11.7	2.6
	Dry	2	26.8	18.4	3.2
	Dry	20	26.5	18.8	3.2
	Suspension	2	29.2	18.5	7.8
	Suspension	20	34.1	20.4	7.9

shaking, and the presence of more water stable aggregates as shown by a wet sieving procedure (Table 4). Increased water stable aggregation was particularly evident in the solodic soil and red-brown earth.

The increase in aggregation was accompanied by an increase in water retention in pores from about 0.2 to 20 μm in the soils to which suspensions of sludge were added. Water retention between -10 and -1000 kPa was increased by 18%, 85% and 19% in the solodic soil, podzol and red-brown earth respectively, after addition of 20 t ha^{-1} of sludge as a suspension.

Aggregate Strength and Modulus of Rupture

The mechanical properties of the soils to which wet sludge was added were changed markedly. The increased aggregation and porosity resulted in weaker aggregates as shown by the force required to crush large (6.7-9.5 mm) natural air dry aggregates (Table 5). The trend in crushing strengths was confirmed by the results for the modulus of rupture of moulded briquettes of the amended soils.

TABLE 5

Force required to crush aggregates, and modulus of rupture

Soil	Sludge application: Method	Sludge application: Rate t ha^{-1}	Crushing force N (mean of 15 aggregates)	Modulus of rupture Pa x 10^5
Solodic soil	Control	0	34.2	17.4
	Dry	2	32.4	16.0
	Dry	20	34.7	16.7
	Suspension	2	26.8	13.1
	Suspension	20	18.1	12.7
Red-brown earth	Control	0	9.6	6.1
	Dry	2	8.4	5.6
	Dry	20	8.6	6.2
	Suspension	2	4.9	3.9
	Suspension	20	2.7	2.4

PLANT GROWTH

Seedling Emergence

Seedling emergence was limited by poor germination, probably due to anaerobic conditions in those soils to which a suspension of sludge was added. When this was observed, additional samples of the three soils were mixed with suspensions of sludge applied at the rate of 20 t ha^{-1}. The amended soils were then air-dried before being placed in pots. Seedling emergence in all three soils was then close to 100% (Table 6). A similar germination problem has been observed when sewage sludge was added to soils.

TABLE 6

Percentage seedling emergence of maize. (Means of four replicates), six seeds per pot)

Soil	Method of application	Sludge applied (t ha^{-1}) 0	2	20
Solodic soil	Dry	46	83	75
	Suspension	79	88	58
Podzol	Dry	96	88	88
	Suspension	88	83	8
Red-brown earth	Dry	25	46	29
	Suspension	42	25	17

Yield of maize plants (tops only)

The mean dry matter yields of maize tops are shown in Table 7.

The analysis of variance indicates that both interactions between fertilizer x method of application x rate of addition, and, soil x fertilizer x rate of addition, were significant ($P < 0.05$). Such three-way interactions are difficult to interpret but careful examination of the data in Table 7 reveals the following:-

TABLE 7

Yield of maize tops (dry matter, g per pot)

Soil	Method of sludge application	Sludge applied (t ha^{-1})					
		Without fertilizer			With fertilizer		
		0	2	20	0	2	20
Solodic soil	Dry	5.5	8.4	7.2	19.7	30.0	18.4
	Suspension	5.5	9.5	6.4	18.4	38.0	16.7
Podzol	Dry	7.1	9.2	8.2	21.0	32.3	32.5
	Suspension	7.0	8.3	8.5	19.8	24.1	23.1
Red-brown earth	Dry	7.0	17.1	14.0	19.5	29.4	28.3
	Suspension	5.6	14.3	7.2	19.9	24.4	16.0

1. The yield of maize was substantially higher in the presence of fertilizer for both methods of application at all rates of addition of the sludge.
2. While 2 t ha^{-1} of sludge increased the yield of maize 20 t ha^{-1} gave yields intermediate between those given by 2 t ha^{-1} and zero rate.
3. The three-way interaction fertilizer x method of application x rate of addition, appears to have arisen mainly because in the presence of fertilizer the yield obtained with 20 t ha^{-1} of sludge applied in suspension was considerably less than with the same quantity of dried sludge.
4. The interaction, soil x fertilizer x rate of addition, occurred because in the absence of fertilizer the red-brown earth gave much higher yields in reponse to 2 h ha^{-1} of sludge than the other two soils. The reverse occurred in the presence of fertilizer.

Because the three-way interactions were significant, it is inappropriate to present tests using variance ratios for main effects and two-way interactions. Thus, although points 1 and 2 above represent the most important conclusions drawn from the yield trials, and will therefore receive greatest emphasis in any recommendations resulting from this work, points 3 and 4 provide additional information which allows specific modifications of the major conclusions.

Phosphorus Uptake by Maize Plots

The analysis of variance for the phosphorus uptake in mg per pot (Table 8) was consistent with that for yield, except that the interaction, soil x method of application x rate of addition, was also significant ($P < 0.05$). However, the phosphorus uptake by the maize after addition of 20 t ha^{-1} sludge was less than for the nil rate of sludge application. This was probably a result of the high phosphate fixation capacity of the sludge due to the presence of disordered aluminium-rich products. This assumption is supported by the inverse relationship observed between the aluminium and phosphorus contents of the maize tissue (Pearson's correlation coefficient $r = -0.48$; $P < 0.01$).

TABLE 8

Phosphorus uptake in maize tops (mg per pot)

Soil	Method of sludge application	Sludge applied t ha^{-1}					
		Without fertilizer			With fertilizer		
		0	2	20	0	2	20
Solodic soil	Dry	18.2	16.8	14.4	98.5	108.0	62.5
	Suspension	13.2	15.7	8.3	101.2	159.6	33.4
Podzol	Dry	10.7	17.5	12.3	98.7	80.8	78.0
	Suspension	10.5	14.1	17.9	67.3	88.7	62.8
Red-brown earth	Dry	56.7	104.3	44.8	109.2	147.0	98.0
	Suspension	42.0	37.2	9.4	97.5	268.8	48.0

It is not possible from these results to distinguish between improvement in physical conditions of the soil and improved nutrient status as causes for yield responses due to sludge addition. However, the yield increases of almost 30% in the unfertilized podzol were probably due to nutrients added in the sludge. Yield responses to sludge in the presence of fertilizer were most likely due to improved physical conditions in the soils.

CONCLUSIONS

All the physical parameters assessed show improvements due to the application of sludge in suspension.

The application of sludge at a rate of 2 t ha^{-1} to 3 soils increased the yield of dry matter of maize with and without addition of fertilizer. High rates of application of wet sludge (20 t ha^{-1}) caused seedling germination problems, which could be prevented by allowing soils treated with sludge to dry out before planting seeds.

It is concluded that alum sludge may be disposed of by addition to soils and has potential for improving soil structure and plant growth. Field testing of the sludge is required using application of the order of 2 t ha^{-1}.

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