AGRONOMIC ISSUES WITH ALUM SLUDGE

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ABSTRACT

A two year field experiment was established to investigate the use of alum sludge from wastewater treatment for cereal production. Alum sludge (5.0% N, 3.7% P, 7.5% Al) was applied at six rates (0, 3.4, 6.7, 10.1, 13.5 and 20.1 Mg DS ha^{-1}) on a P deficient sand, supplying up to 744 kg P ha^{-1} at the highest rate. In addition, one rate of inorganic fertiliser at district practice was applied, containing 72 kg N ha^{-1} and 20 kg P ha^{-1}, this was reapplied in the second year. The inorganic fertiliser treatment yielded 44-58% higher than the nil fertiliser treatment at final grain harvest, demonstrating the requirement for applied N and P on this site for crop production. Alum sludge was an adequate source of nitrogen (N) for crop growth as indicated by plant tissue N content, and supplied sufficient residual N to meet crop requirements in the second year. However, grain yield in alum sludge treatments was reduced to 62% (year 1) and 69% (year 2) of the yield in the inorganic fertiliser treatment, though greater than the nil fertiliser treatment in both years. Plant shoot tissue analysis at 9 weeks after establishment at the tillering stage of development indicated that plants sown in alum sludge-amended soil and in the nil fertiliser treatment were P deficient, whereas P was adequate in the inorganic fertiliser treatment. There was no evidence of any other nutrient deficiency in plant shoot samples besides P. Therefore, it is suggested that on this P deficient soil, the ability of alum sludge to provide P for plant production was limited in the two years after application.

INTRODUCTION

The addition of alum ($Al_2(SO_4)_3$) in wastewater treatment is an alternative to biological phosphorus removal (BPR) or dosing with ferric chloride ($FeCl_3$) as a P removal mechanism. As a consequence the sludge has a relatively high concentration of aluminium (Al) and P compared to sludge (or biosolids) produced without chemical treatment. Agricultural land application is frequently regarded as a sustainable long-term solution for biosolids to take advantage of nutrients and soil improving propertiest; however, alum sludge/biosolids has not been widely used for crop production, and little is known about the implications of the high aluminium (Al) content for crop growth and impacts on soil properties.

Research into land application of alum residuals from drinking water treatment (WTR) has indicated P immobilisation in some cases, especially in acidic soils (Heil and Barbarick, 1989; Stevens et al., 2003; Ippolito et al., 2006). There has been little research into land application of alum sludge, although findings to date have indicated low availability of P in alum sludge-amended soil (Kuile et al., 1983; Stevens et al., 2003).

Several Western Australian inland country wastewater facilities dose sewage with alum to reduce P concentration in the effluent. This is a required for wastewater treatment plants that discharge to inland water bodies to reduce the possibility of environmental problems such as eutrophication. Alum sludge is currently landfilled in Western Australia and research is required into the suitability of alum sludge for land application, so that that the nutrient value of this waste product can be used beneficially. In addition, specific research is required in soils that are naturally acidic, typical throughout many agricultural regions, where the potential problems of Al toxicity are increased (Tang et al., 2001). The solubility of Al in soil solution is dependent on soil pH; free Al^{3+} is the principal form at pH 4-5, and is considered to be the main toxic form (Klöppel et al., 1997). This paper discusses the findings of a two year field investigation to investigate the suitability of alum sludge for crop production. The aims of the investigation were:

i) to investigate changes to available soil Al following alum sludge application and subsequent effects on crop growth over two years;

ii) to investigate the availability of P, and other nutrients, for crop growth in soil treated with alum sludge over two years.

MATERIALS AND METHODS

Study site

The field experiment was established on an acidic sand in the central wheatbelt region of Western Australia at Ucarty (S31°18.597', E116°57.277'), 130 km north-east of Perth. The region has a dry temperate climate with cool, wet winters and hot, dry summers, and typical rainfall of 301 mm over the growing season (April to October) (Figure 1). The total rainfall over the growing season (April-October 2008) was 292 mm, although rainfall for the month of August (4.5 mm) was well below the 1902-2009 average of 49 mm (Australian Government BOM, 2009). Total rainfall for the 2009 growing season was 259 mm, lower than the average; however, rainfall was more evenly distributed over the growing season.

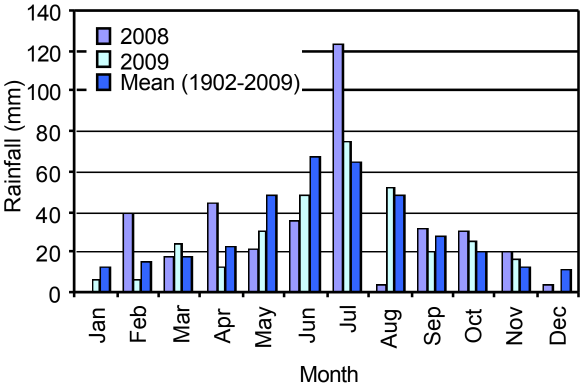

Figure 1: Rainfall during 2008-2009, in comparison to main rainfall for the period 1902-2009 (Australian Government BOM, 2010)

Properties of the <2 mm fraction in the surface soil (0-10 cm) were as follows: 95.5% sand, 2.0% silt, 2.5% clay; pH 5.0 (0.01M calcium chloride ($CaCl_2$);1:5); 6 mS m^{-1} EC (1:5); 0.74% organic carbon (W/B); 0.065% total N; 74 mg kg^{-1} total P; 7 mg kg^{-1} bicarbonate (HCO_3)-extractable P; 0.2 mL g^{-1} P Retention Index; 45 mg kg^{-1} bicarbonate extractable K; 3.79 cmol(+) kg^{-1} total exchangeable cations (Ca, Mg, Na, K); 0.03 cmol(+) kg^{-1} exchangeable Al and <1 mg kg^{-1} $CaCl_2$-extractable Al. (Chemistry Centre of Western Australia; accredited by the National Association of Testing Authorities-NATA).

Alum sludge

Alum sludge from Kemerton Wastewater Treatment Plant (WWTP) was used in the experiment as it has a median Al concentration (8.0±1.4)%, amongst the Western Australian regional treatment plants, which range from 1 to 15% Al. Kemerton WWTP uses a Sequence Batch Reactor (SBR) and sand filtration, with alum dosing for P removal and a belt press for dewatering. The alum sludge was stockpiled in the field the week prior to application. A composite grab sample measured: 14.9% DS; pH 7.2 (H_2O; 1:5); 5% total Kjeldahl N; <5 mg kg^{-1} NO_3-N; 2599 mg kg^{-1} NH_4-N; 3.7% total P; 7.5% total Al (SGS Australia Pty. Ltd., Perth).

Experimental design

The experiment was arranged as a complete randomised block design in triplicate. The treatments included a gradient of application of alum sludge determined by multiples of the Nitrogen Limited Biosolids Application Rate (NLBAR) (DEP et al., 2002)[†], applied at 0.5, 1, 1.5, 2 and 3 NLBAR. The design also included a nil fertiliser control and an inorganic fertiliser treatment, which received 100 kg ha^{-1} diammonium phosphate (DAP: 18% N; 20% P) broadcast at seeding and 118.0 kg ha^{-1} urea (46% N) top-dressed at 4 weeks after sowing. Therefore, the inorganic fertiliser treatment received a total of 72 kg N ha^{-1}, which was equivalent to the plant available N supplied in the 1.0 NLBAR alum sludge treatment. The biosolids were applied during 19-21 June, prior to seeding. Loading rates of dry solids (DS) (t ha^{-1}), N, P and Al (kg ha^{-1}) from each of the treatments are presented in Table 1. The experiment was sown to wheat (*Triticum aestivum* L. cv. Wilgoyne) by hand at a rate of 70 kg ha^{-1} on 21 June 2008. Muriate of potash was applied to supply potassium (K) across the site at a rate of 120 g ha^{-1}. The seed and fertilisers were incorporated using a 12-row disc combine.

In year two the inorganic fertiliser treatment received 142 kg ha^{-1} Agstar (14.3% N; 14.0% P) at seeding (4 June 2009), and 112.5 kg ha^{-1} urea (46% N) four weeks after crop establishment. However, the treatments containing alum sludges received no further applications of sludge to enable the residual value of the nutrients in the sludge to be examined. To ensure that trace elements were not limiting in the second year, basal dressings of Zn, Cu, S, and Mo were applied across the site as follows: 3.0 kg ha^{-1} Zn as $ZnSO_4.7H_2O$, 1.7 kg ha^{-1} Cu as $CuSO_4$ and CuO, 1.5 kg ha^{-1} S as gypsum and 70 g ha^{-1} Mo as $Na_2MoO_4.2H_2O$. Each 20 m^2 plot was split into two 10 m^2 plots and half the trial received 38 kg ha^{-1} urea at seeding and 118.5 kg ha^{-1} urea after crop establishment. Therefore, the residual value of the P in the sludge could be examined in plants grown in adequate N. The experiment was sown with Baudin Barley (*Hordeum vulgare* L. cv. Baudin) on 9 June 2009 at a rate of 60 kg ha^{-1} with a 12-row disc combine; 8 rows were sown at intervals of 0.2 m in each 2 m diameter plot.

Sampling, yield measurements and harvest components

Plant establishment counts were made in each plot over a 1 m^2 area at approximately 20 days after sowing (DAS). Plant samples were collected 8 weeks after emergence and at final harvest over a 1 m^2 area (4x0.25 m^2 quadrats) in each 20m^2 plot in 2008 and over a 0.5m^2 area (4x0.5 m rows) in each 10 m^2 plot in 2009. The total dry matter (DM) of shoots was measured at 8 weeks after emergence, and total DM and grain yield were measured at final harvest following drying at 70°C for 48 h in a forced draught oven. The final harvest dates were 19 November 2008 (151 DAS) and 9 November 2009 (155 DAS).

Treatment	DS (t ha^{-1})	Total Al (kg ha^{-1})	Total N (kg ha^{-1})	Total P (kg ha^{-1})
Control	0	0	0	0
Inorganic fertiliser	N/a	0	72	20
0.5 NLBAR	3.4	252	168	124
1 NLBAR	6.7	503	335	248
1.5 NLBAR	10.1	755	503	372
2 NLBAR	13.4	1006	670	496
3 NLBAR	20.1	1509	1005	744

[†] NLBAR (Mg DS ha^{-1}) = Crop N required (kg ha^{-1})/plant available N (kg Mg^{-1})

where,

1) Crop N required is determined as the amount of N removed by a crop in a given year;

2) Plant available N is determined as the proportion of organic N and inorganic N that is expected to be available to plants from the sludge in the first season. This is determined using an estimated 20% mineralisation rate of organic N and 50% volatilisation rate of NH_4-N.

Table 1: Rates of application of Dry Solids (DS), total Al, total N and total P from each treatment in the field investigation

N/a = not applicable

The number of ears per plot was counted, weighed, the ears threshed, grain yield was weighed and 100 grain weights were recorded for each treatment. The number of grains per ear was calculated by dividing the ear number by the weight of the grain. The Harvest Index (HI) was determined by dividing grain yield by total above ground DM. Following treatment application, 8 week DM harvest and final harvest, composite soil samples were collected from the surface (0-10 cm) of each plot.

Chemical analysis

Plant tissue (8 week DM samples) was prepared by milling (<0.5 mm). The concentration of N was measured using a Leco N analyser and the concentrations of various other nutrients (B, Ca, Cu, Fe, K, Mg, Mn, Mo, Na, P, S and Zn) was measured by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). Soil samples were air-dried and sieved to <2 mm. Sludge particles were screened from the soil sample by the 2 mm sieve, consistent with the method of Pritchard (2005); the particles were removed by hand from the >2 mm fraction, crushed to pass 2 mm and returned to the sample. Samples of soil were measured for pH (0.01M $CaCl_2$; 1:5), bicarbonate ($NaHCO_3$)-extractable P and $CaCl_2$-extractable Al. Soil samples collected in 2008 were also analysed for $CaCl_2$-extractable P.

Statistical analysis

Data were analysed for differences between the treatments using an analysis of variance (ANOVA) model in GENSTAT (Release 9.1) program (Lawes Agricultural Trust, Rothamsted Experimental Station, UK). A single least significant difference (l.s.d.) value of *P* at the 5% level of significance was used to compare different treatment means.

RESULTS AND DISCUSSION

Crop establishment

There was no significant difference in wheat or barley establishment in alum sludge treatments in comparison to the control (nil fertiliser) and inorganic fertiliser treatment ($P>0.05$), which averaged 77 plants m^{-2} in 2008 and 243 plants m^{-2} in 2009. The establishment rate of 77 plants m^{-2} for the wheat crop was considerably lower than expected despite sowing at a high rate of 70 kg ha^{-1}, and is likely to be due to the dry start to the growing season. A density of approximately 150 plants m^{-2} would be typical for this sowing rate (Anderson and Garlinge, 2000).

Early yield measurements

Wheat and barley DM yields at 8 weeks after emergence (g m^{-2}) are shown in Figure 2. Only the barley plots that received no additional inorganic N are presented in Figure 2, as it was demonstrated that N was not limiting in the residual alum sludge treatments. There was a significant difference in DM production ($P<0.001$) between treatments over both years. In both years, there was no significant difference between 0.5 NLBAR, 1 NLBAR and the inorganic fertiliser treatment, and there was a general increase in DM production with increasing rate of alum sludge. The roots of the wheat in the alum sludge treatments appeared normal and did not exhibit any signs of Al toxicity.

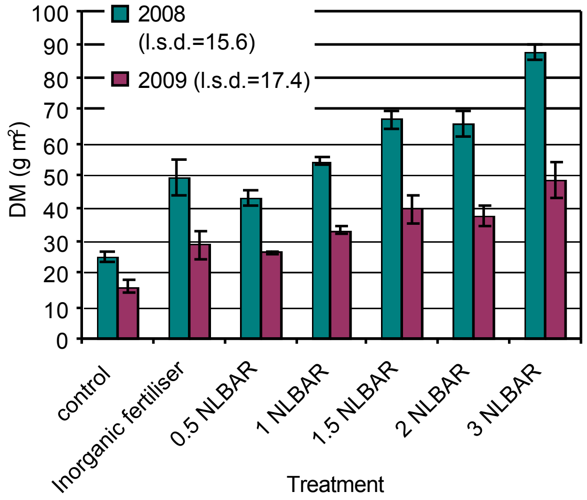

Figure 2 Dry matter (DM) measurements (g m^{-2}) for wheat (2008) and barley (2009) at 8 weeks after emergence in control; inorganic fertiliser treatment and alum biosolids treatments at rates of 0.5 NLBAR, 1 NLBAR, 1 .5NLBAR, 2 NLBAR and 3 NLBAR.

Final grain yield

Grain yield at final harvest is shown in Figure 3, and is expressed as a percentage of the yield in the inorganic fertiliser treatment. There was little relationship between the growth of plants at 8 weeks and final grain yield in both 2008 and 2009. Overall, in 2008, the potential wheat yield was depressed as a consequence of the low establishment rate due to the dry start to the growing season, and the low rainfall in August (Figure 1). The highest grain yield was measured in the inorganic fertiliser treatment (557 kg ha^{-1}), which was well below the Australian average of 1.5 t ha^{-1} (ABARE, 2007). The inorganic fertiliser treatment yielded 44% higher than the control treatment at final grain harvest, demonstrating the requirement for N and P on this site for crop production. The yield of wheat in the alum sludge treatments was generally low, and similar to the control, despite the addition of nutrients contained in the sludge. The exception was the 2 NLBAR treatment, which yielded 492 kg ha^{-1}, and was comparable with the inorganic fertiliser treatment.

In 2009, grain yield in the inorganic fertiliser treatment (1.2 t ha^{-1}) was significantly greater than the unamended control (0.5 t ha^{-1}); a difference of 58%. The grain yield in the 1 NLBAR and 1.5 NLBAR alum sludge treatments were 69% and 67% of the yield achieved in the inorganic fertiliser treatment, although the difference was not statistically significant. The yield in the 2 NLBAR and 3 NLBAR treatments were significantly lower than the yield in the inorganic fertiliser treatment at 66% and 62%, respectively. The lower grain yield in the alum sludge treatments was consistent with the lower yield observed in the first year of the investigation.

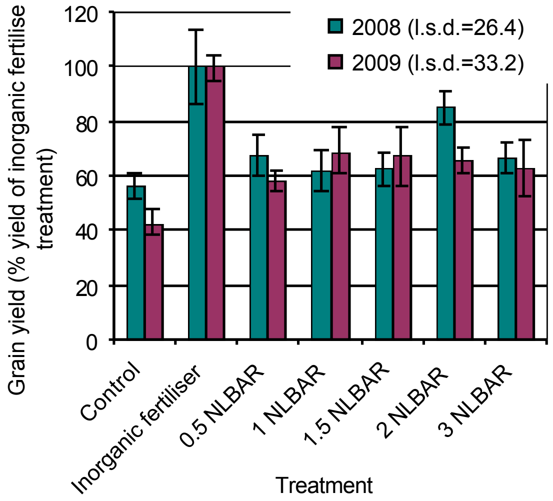

Figure 3: Grain yield (% grain yield of inorganic fertiliser treatment) in control; inorganic fertiliser treatment and alum biosolids at rates of 0.5 NLBAR, 1 NLBAR, 1.5 NLBAR, 2 NLBAR and 3 NLBAR. Error bars represent standard error of the mean.

Yield components

In 2008, there was no significant difference (*P*>0.05) between treatments for total above ground DM; ear number or mass of ears. However, in addition to a significant difference in grain yield (*P*<0.05) there was a significant difference (*P*<0.002) in number of grains per ear and harvest index (HI) (*P*<0.01) between treatments. The number of grains per ear was 11.0 for the inorganic fertiliser treatment, this was significantly greater than all the alum sludge treatments with the exception of the 1.5 NLBAR treatment, which was 9.9 grains per ear. Number of grains per ear for all the other alum sludge treatments, with the exception of the 3 NLBAR treatment, were no different to the control treatment (7.4 grains per ear). However, in the 3 NLBAR treatment a mean value of 2.9 grains per ear was calculated, which may indicate that plants were stressed well before grain ripening. The HI for the inorganic fertiliser treatment, 0.36, was significantly greater than the control, 0.32 and the sludge treatments which were between 0.30 and 0.32. In 2009, above ground DM yield was greater in the inorganic fertiliser treatment in comparison to the control (*P*=0.02) demonstrating the requirement for N and P at this site. Above ground DM yield in the inorganic fertiliser treatment was significantly greater than the 0.5 NLBAR alum sludge treatment, but there was no significant difference between the inorganic fertiliser treatment and alum sludge treatments applied at rates of 1-3 NLBAR. There was no significant difference in ear number, mass of ears or mass of ears. There was a significant difference in harvest index, demonstrating that increasing rates of sludge resulted in lower grain production in comparison to total DM production.

Concentrations of nutrients and Al in plant samples

The concentration of P in wheat and barley tissue at 8 weeks is presented in Figure 4. There was a significant difference in tissue P concentration between treatments (*P*<0.001) with less P available in the alum sludge treatments in comparison to the inorganic fertiliser treatment in both years, with the exception of the 3 NLBAR treatment in 2008. The critical P concentration for wheat at the corresponding growth stage (61 DAS) is 0.44±0.05%, and for barley it is 0.40% (Reuter and Robinson, 1997). Therefore, although no characteristics of P deficiency were observed, tissue P analysis demonstrated that P was deficient in all alum sludge treatments, whereas the inorganic fertiliser treatment (and 3 NLBAR in 2008) had an adequate P concentration. Unless P deficiency is severe wheat may not show symptoms, Elliott et al. (1997) found that yields can fall 40% below maximum owing to P deficiency without exhibiting symptoms. The results indicated that, despite additions of between 124-496 kg P ha^{-1} in the 0.5 NLBAR-2 NLBAR treatments compared to 20 kg ha^{-1} applied as DAP in the inorganic fertiliser treatment, the majority of P added in the sludge was not available for crop uptake in the first two years following application. This is in contrast to findings for dewatered sludge cake (DBC), which have demonstrated that the initial bioavailability for sludge P is approximately 68% as available as inorganic fertiliser P (Pritchard, 2005). In a three year field experiment by Pritchard et al. (unpublished data) to investigate the effects of lime-amended biosolids on crop growth, plant tissue analysis in the first year demonstrated no significant difference between tissue P concentration in DBC treatments and fertiliser treatments, but a significantly lower tissue P content in lime-amended biosolids (LAB). This was expected given the lower total P content of the lime-amended biosolids in comparison to DBC, 1% total P in comparison to 2.5% total P. However, alum sludge has a greater total P content than both DBC and LAB at 3.7%, therefore the findings indicate low bioavailability of P in this sludge type. This is consistent with previous research for alum WTR and alum sludge from wastewater treatment (Heil and Barbarick, 1989; Kuile et al., 1983; Stevens et al. 2003). The tissue P analysis at 8 weeks after establishment may explain the low grain yield in alum sludge treatments in comparison to the inorganic fertiliser treatment, despite the early growth increase in alum sludge treatments, and indicated that P was deficient in alum sludge treated soils. This site had a very low available P concentration of 7 mg kg^{-1} and solubility and plant uptake would have been exacerbated by low end of season soil moisture in 2008.

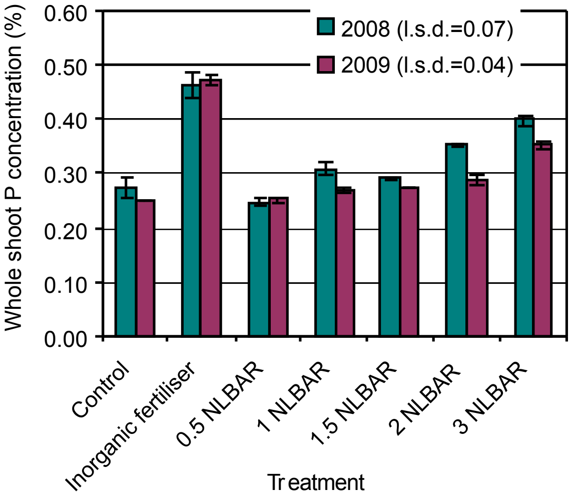

Figure 4 Tissue P (%) at 8 weeks after establishment for wheat in 2008 and barley in 2009, in control; inorganic fertiliser and alum sludge at rates of 0.5 NLBAR, 1.0 NLBAR, 1.5 NLBAR, 2 NLBAR and 3 NLBAR. Error bars represent standard error of the mean.

There was no significant difference in plant tissue N content between any of the treatments and, with the exception of the control and the 0.5 NLBAR treatment, N was adequate for wheat in 2008. In general, there was an increase in N with increasing rate of alum sludge application. There was no significant difference between tissue N in the 1 NLBAR alum sludge treatment and the inorganic fertiliser treatment, which demonstrated that there was sufficient residual N in the alum sludge treatment applied at the standard rate of application for crop growth in the second year. However, due to the overall low yields in year one, the crop would have removed less N than during a typical year, therefore residual N in the second year may be higher than during an average rotation. In 2009, there was a significant difference in tissue N concentration between treatments.

There was no significant difference in plant tissue Al content in either year, which indicated that there was no plant uptake of Al from alum sludge. There was a significant decrease in Mn concentration in alum sludge treatments, however

Mn remained within the adequate range. This may be related to the increase in pH observed in alum sludge treated soils (data not presented), as the solubility of Mn declines with increasing soil pH (Moore et al., 1998). Aluminium toxicity may impair Ca, Mg, K and Fe uptake (Foy et al., 1978; Kabata-Pendias, 2001), but this was not observed in wheat uptake of nutrients at 8 weeks.

Extractable soil P

2008 Season: Bicarbonate-extractable soil P is shown in Figure 5; there was a significant effect of treatment ($P<0.001$) and sampling date ($P=0.03$) on extractable soil P and an interacting effect between treatment and sampling date ($P=0.05$). At 25 DAS the extractable soil P concentration was similar in the inorganic fertiliser treatment, 0.5 NLBAR treatment and 1 NLBAR treatment at approximately 20 mg kg^{-1}.

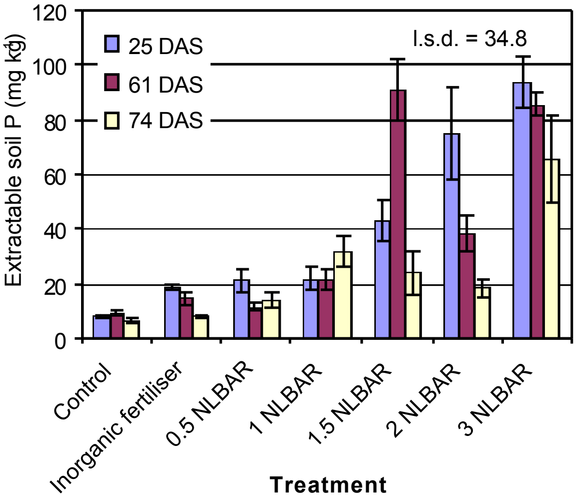

Figure 5. Bicarbonate extractable soil P (mg kg^{-1}) in control, inorganic fertiliser treatment and alum sludge at rates of 0.5 NLBAR, 1.0 NLBAR, 1.5 NLBAR, 2 NLBAR and 3 NLBAR. Error bars represent standard error of the mean; l.s.d value is from two-way ANOVA to investigate the effects of time and treatment on extractable soil P

Extractable P concentration increased with increasing rate of alum sludge application and was 94 mg kg^{-1} in the 3 NLBAR treatment. Extractable P concentration in the inorganic fertiliser treatment decreased from approximately 19 mg kg^{-1} to 8 mg kg^{-1} from 25 DAS-167 DAS, indicating that it had been taken up by the crop, sorbed onto reactive soil sites or moved through the soil profile, this is a possibility given the low P sorbing characteristics of the soil (PRI -0.2 mL g^{-1}). In general, in the alum sludge treatments there was also a net decrease to concentrations of 24, 19 and 56 mg kg^{-1} on 167 DAS for 1.5 NLBAR, 2 NLBAR and 3 NLBAR, respectively. The variability in the alum sludge treatments may be sampling variability due to clumps of sludge that were not evenly distributed through the soil.

Plant tissue analysis at 8 weeks after establishment indicated that P was deficient in the alum sludge treatments. However, this was not evident in soil measurements on HCO$_3$-extractable soil P in alum sludge treatments (0.5 NLBAR-3 NLBAR). It is possible that the bicarbonate-extractable P procedure provided an over-estimate of available P by extracting P adsorbed to the surface of Al-oxides in the alum sludge, and not readily available to the crop (Allen, 2009, pers. comm.). This was investigated further by using a less rigorous extraction procedure for available P (Figure 6). At 25 DAS the concentration of CaCl$_2$-extractable P was significantly greater in the inorganic fertiliser treatment in comparison to the alum sludge treatments, 7.5 mg kg^{-1} in the inorganic fertiliser treatment in comparison to 2.5 mg kg^{-1} in the 1 NLBAR treatment. At 25-167 DAS the CaCl$_2$-extractable P concentration was similar in the 1 NLBAR treatment and the inorganic fertiliser treatment. It is suggested that the concentration of P in the inorganic fertiliser treatment decreased between days 25-74 due to crop uptake, and there was no net release of P from the alum sludge treatments.

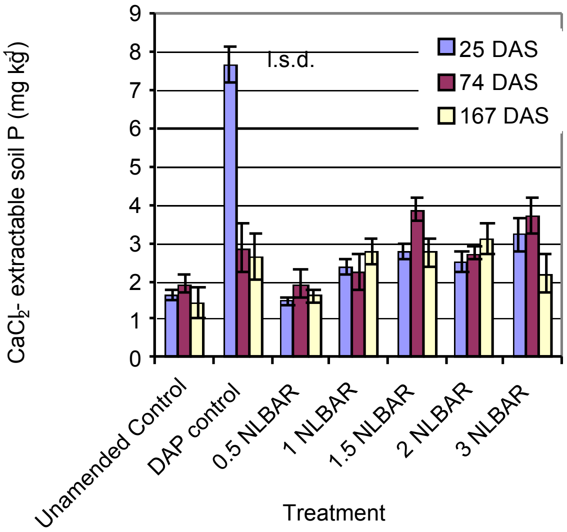

Figure 6 CaCl$_2$- extractable soil P (mg kg^{-1}) in control, inorganic fertiliser treatment and alum sludge at rates of 0.5 NLBAR, 1.0 NLBAR, 1.5 NLBAR, 2 NLBAR and 3 NLBAR. Error bars represent standard error of the mean; l.s.d value is from two-way ANOVA to investigate the effects of time and treatment on extractable soil P

The relationship between CaCl$_2$-extractable P and HCO$_3$-extractable P is shown in Figure 7. The slope of the regression line for soils without alum sludge (y=0.27x-0.13; $P<0.0001$) is greater than that for soils treated with alum sludge (y=0.13x+2.05; $P=0.02$), demonstrating that for HCO_3-extractable P there is more $CaCl_2$-extractable P in soils that did not received alum sludge in comparison to those that did.

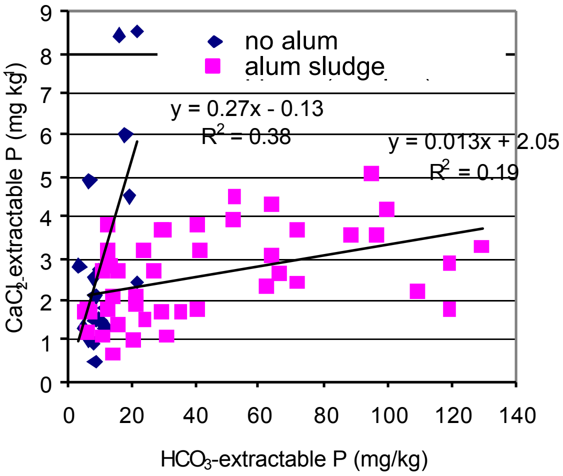

Figure 7: Relationship between $CaCl_2$- extractable soil P (mg kg^{-1}) and HCO_3-extractable soil P (mg kg^{-1}) in control soils and soils treated with alum sludge

This is similar to the findings of Moore and Edwards (2007) who compared water soluble P to Mehlich III P in soils treated with poultry litter compared to soils treated with alum-treated poultry litter. Mehlich III extractable P is comparable to HCO_3-extractable P (Bolland et al. 2003), and as a less rigorous extraction method, $CaCl_2$-extractable P is comparable to water soluble P. They found that a greater proportion of Mehlich III-extractable P was water extractable P in soils fertilised with normal poultry litter in comparison to alum-amended poultry litter. This indicated that the alum sludge treatments had less immediately available P than the inorganic fertiliser treatments; alum sludge-amended soil may therefore contain a greater proportion of P which is chemically bound, to Al compounds for example, and unavailable for crop uptake. In previous experiments with dewatered biosolids cake (DBC) a rate of 1 NLBAR has supplied the crop with adequate P, indicating that there was sufficient dispersion of available P in the root zone for crop uptake (Pritchard, 2005). The results of this experiment would indicate lower bioavailability of P in alum sludge treatments in comparison to DBC; this requires further investigation. Soil analysis indicated that alum sludge amendment increased the P concentration in this P deficient soil; although it was not readily available for crop uptake it may become slowly available. However, crop uptake of P in the second year indicated that there was little change to P availability over time.

2008 Season: Bicarbonate-extractable soil P was similar in the inorganic fertiliser treatment, 0.5 NLBAR, 1 NLBAR and 2 NLBAR treatments and greater in the 1.5 and 3 NLBAR treatments. However, from the findings of the repeated analysis of soil samples from year 1 of the field investigation using a $CaCl_2$ extraction method, bicarbonate extractable P may not accurately reflect the amount of P available for crop uptake in alum sludge amended soil.

Extractable soil Al

There was no $CaCl_2$-extractable Al detected in the control, inorganic fertiliser treatment or any of the alum sludge treatments in 2008-2009. The $CaCl_2$-extractable Al concentrations demonstrated that Al in alum sludge is not present in readily available, toxic forms in this soil type (pH 5.0; $CaCl_2$). The addition of organic matter in alum sludge may act to reduce Al solubility, as binding of Al to organic substances reduces toxicity (Kabata-Pendias, 2001; Klöppel et al., 1997).

Soil pH

The initial soil pH in the control (pH 5.2) did not change over the course of the experiment (data not shown). However, the pH increased from 5.6 in the 0.5 NLBAR alum sludge treatment to 6.3 in the 3 NLBAR treatment ($P<0.001$). The pH of the alum sludge was 7.2, which explains the increase in pH of the topsoil. By 174 days the pH of the alum sludge treatments had decreased, and was no different to the control ($P<0.001$). In 2009, there was a significant difference in pH at 29 DAS. There was an increase in pH with increasing rate of alum sludge application. The soil pH was lower in the inorganic fertiliser treatment (pH 4.9) in comparison to the control (pH 5.1). This may be due to the acidifying effect of ammonium containing fertiliser applied in 2008 and 2009 to the inorganic fertiliser treaments.

Recommendations

Typically when application rates of organic wastes are based on the plant available N content, P is applied in excess of crop requirements (Pierzynski et al. 1994). However, alum sludge did not provide sufficient P for crop growth in P deficient soil over two years. Therefore it may be a suitable organic amendment to in certain soil types where there is sufficient P for crop growth or where soils have a poor P sorbing capacity, to prevent over applications of P resulting in losses by leaching or erosion. Blending alum with poultry litter (Moore et al. 1998; Moore and Edwards, 2005; Moore and Edwards, 2007) and co-applying alum WTR with biosolids (Agin-Birikorang et al., 2008; Ippolito et al., 2002; Ippolito et al., 2003; Ippolito et al., 2006; Wagner et al., 2008) has been investigated to prevent leaching of excess P and has generally indicated a reduction in P availability in treated soils.

Conclusions

Wheat and barley yield was increased in inorganic fertiliser treatments in comparison to the control in both years demonstrating the requirement for N and P at this site. Wheat grain yield in the 1 NLBAR alum sludge treatment was 62% of the grain yield in the inorganic fertiliser treatment in year 1 and was similar to the yield in the control. In year 2, barley yield in the 1 NLBAR treatment was 69% of the grain yield in the inorganic fertiliser treatment. Whole shoot tissue P deficiency was observed at 8 weeks after establishment at the tillering stage of development in both years in the alum sludge treatments, this explains the low grain yield in comparison to the inorganic fertiliser treatment. This is consistent with previous findings, and demonstrated that alum sludge was not an adequate source of P for crop growth and not suitable for application to soils with a low P status without additional inorganic P. Nitrogen concentration was adequate in alum sludge treatments in year 1 and from the residual alum sludge treatments at rates between 0.5-3 NLBAR in year 2. Soil analysis indicated that alum sludge amendment increased extractable P in this P deficient soil. However, $CaCl_2$-extractable P analysis of soil samples demonstrated that in alum sludge treatments, HCO_3-extractable P concentration was not a true representation of the amount of P available for crop uptake. There was no increase in $CaCl_2$-extractable Al in either year in any of the alum sludge treatments, this indicated that Al was not present in available, toxic forms.

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