CHANGES IN SOIL pH AND CROP GROWTH FOLLOWING THE APPLICATION OF LIME-AMENDED BIOSOLIDS

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ABSTRACT

Approximately half of all the agricultural soils in Australia are affected by soil acidity. Ground limestone is a product used by farmers to better manage and neutralise soil acidity and to improve plant productivity. The effect of lime-amended biosolids (LAB) as an alternative product for neutralising soil acidity was applied at four rates (0, 5, 10 and 15 t DS/ha) and compared with equivalent rates of lime (0, 2.3, 4.6 and 6.7 t/ha) and one rate of dewatered biosolids cake (DBC) (7 t DS/ha) in a wheat/canola cropping rotation on an acidic red/brown sandy loam in the wheatbelt of Western Australia. Soil pH ($CaCl_2$) in the surface soil (0-10 cm) increased significantly with increasing rates of either LAB or lime at the end of the first year, increasing from 4.4 to 7.2, with similar values recorded between equivalent values of lime product. The DBC treatment did not change soil pH. No further changes in soil pH had occurred by the end of the second year. The increased yield of wheat with increasing rates of LAB in the first season was attributed to improved nutrition rather than to the overall reduction in soil acidity. The experiment is ongoing and has been sown to wheat in 2007 to further monitor the effects of LAB over time.

KEY WORDS

Canola, dewatered biosolids cake, lime, lime-amended biosolids, soil acidity, wheat

INTRODUCTION

Approximately 50% of agricultural land in Australia (50 million ha) have surface soil values of less than 5.5 ($CaCl_2$), resulting in reduced productivity of extremely acid-sensitive plants and are below the optimum to prevent subsurface acidity (Australian Agriculture Assessment 2001). The majority of Western Australian soils may be naturally acidic and are light-textured, with a low buffering capacity to change in soil pH and in severe cases can result in aluminium toxicity in sensitive plant species (particularly in the subsoil), nodulation failure in legumes and a deficiency in some nutrients, such as molybdenum. An estimated 178,000 tonnes (t) of lime was applied to farming properties in Western Australia during 1994/95 as an ameliorant against soil acidity. A typical application rate of lime is around 2 t/ha, with rates determined by the neutralising value and particle size of the lime and the pH buffering capacity (lime requirement) of the soil (Moore *et al.* 1998).

A total of 10,000 t dry solids (t/DS) of lime-amended biosolids (LAB) were produced during 2005/06 from the Subiaco Wastewater Treatment Plant (WWTP) and applied to agricultural soils surrounding Perth. Prior to this study, no research had been conducted in Western Australia to investigate the neutralising value of LAB, monitor the plant response to LAB or to establish the economic value of LAB in agriculture. The production of LAB at Subiaco WWTP involves the addition of quicklime (CaO) as a post-treatment to secondary treated dewatered sludge cake to raise the pH of the mixture and destroy pathogens. Perth's two other major WWTPs produce anerobically digested dewatered biosolids cake (DBC) and have previously been investigated as part of the National Biosolids Research Program (NBRP) (McLaughlin *et al*. 2007). The Water Corporation of Western Australia intends that all biosolids products be beneficially used within a range of markets, particularly within agriculture. Alternatively, if deemed unsuitable for agricultural land application, the potential landfill costs of LAB would escalate to almost $2 m/pa (i.e. 34,000 wet tonne @ $57/t) (Penney 2005).

There is a need to astablish suitable agricultural loading rates for LAB to ensure that plant needs are being met, plant growth is not compromised and to establish the neutralising value of LAB. There is also potential to seek a return on the value of the lime input, estimated at $14,000/pa. If successful, this form of biosolids stabilisation/ production may be considered for future sludge handling for other WWTPs in the Perth region (Penney 2005). This paper investigates the effects of LAB on the growth and yield of wheat and canola to changes in soil pH on an acidic soil in the central wheatbelt in Western Australia between 2005 and 2007.

MATERIALS AND METHODS

An experiment was established at Wongamine, 90 km north-east of Perth, Western Australia in 2005 to study the effect of LAB on plant growth and yield using a wheat (*Triticum aestivum* L. cv. Calingiri) and canola (*Brassica napus* L. Surpass) cropping sequence. The region has a Mediterranean climate with cool, wet winters and hot, dry summers and an average rainfall of 390 mm. The soil was an acidic red/brown loamy sand, or a Red Chromosol as described by the Australian Soil Classification (Isbell 1996). Some properties of the <2 mm fraction in the top 0-10 cm surface are as follows: 90% sand, 5% silt, 5% clay; 4.7 pH ($CaCl_2$) 0.01*M* (1:5); 5.3 mS/m EC (1:5); 0.87% Organic carbon (W/B); 0.071% total N; 243 mg/kg total P; 48 mg/kg bicarbonate extractable P; 4.3 mL/g P Retention Index; 94 mg/kg bicarbonate extractable K; 7.06 cmol(+)/kg total exchangeable cations (Ca, Mg, Na, K and NH_4) (Chemistry Centre WA, Report 05A493/1-3).

The experiment consisted of nine treatments arranged in a completely randomised block design with three replicates. Each plot was 10 m long by 2 m wide. There were combinations of four rates of LAB, four rates of lime and one rate of dewatered biosolids cake (DBC).

The DBC was included in the study as it is the predominant biosolids product produced by Perth WWTPs and thus provides for comparative research in terms of crop yield (Pritchard 2005; Pritchard & Collins 2006). The DBC was sourced from Beenyup WWTP, which has a typical analysis consisting of 20% DS, 50,000 mg/kg total N and 25,000 mg/kg total P and pH 7. The LAB from Subiaco WWTP has a lower nutrient content with a typical analysis consisting of 35% DS, 30,000 mg/kg total N, 10,000 mg/kg total P and pH 13; with an expected neutralising value of 44.9%, reflecting the proportion of lime in the product.

Rates of LAB and DBC were determined by multiples of the nitrogen limited biosolids application rate (NLBAR) using the following DEP *et al.* (2002) formula:

$$NLBAR = Crop\ N\ required\ /\ plant\ available\ N$$

The amount of crop N required is determined as the amount of N removed by a crop in a given year. The plant available N is determined from the proportion of organic N and inorganic N that is expected to be available to plants from the biosolids in the first season using a 20% mineralisation rate of organic N and 50% volatilisation rate of ammonium. Thus 1xNLBAR for the LAB = 10.3 t DS/ha (i.e. 64 kg N/ha / 6,207 mg/kg).

The four rates of LAB were 0, 0.5, 1 and 1.5xNLBAR. The DBC was applied at 1xNLBAR, calculated at 7 t DS/ha, being the standard land application rate used in Western Australia. At present, the standard application rate of LAB being applied to land is 5 t DS/ha, which is lower than DBC as it is calculated on the lime content typically applied by farmers in the region rather than on the N value. Agricultural lime is commonly applied in Western Australia at rates between 1 and 2 t/ha. In this experiment, agricultural lime was applied at 0, 2.3, 4.6 and 6.9 t/ha and was designed to directly compare the four rates of LAB used. Thus at 1xNLBAR, the LAB (10.3 t DS/ha) would be expected to provide the equivalent in neutralising value to the 4.6 t/ha lime treatment. The lime used in the experiment had a neutralising value of 96% and was <0.25 mm in size. All lime treatments were supplied with a basal fertiliser dressing of 100 kg/ha urea (46% N) and 100 kg/ha diammonium phosphate (20% N, 18% P) annually to supply a total of 66 kg N/h and 18 kg P/ha. This rate of inorganic N was selected to be comparable to the N in the 1xNLBAR LAB and 1x NLBAR DBC treatments.

The experiment was sown to wheat in 2005, canola in 2006 and wheat in 2007. Prior to each seeding operation, the site was cultivated with discs and a knockdown herbicide applied (Roundup at 1L/ha). Lime and biosolids products were applied as a once off treatment in 2005 by hand and incorporated during the seeding operation using a 12-row disc combine. The lime treatments received DAP at seeding and were top-dressed with urea 12 weeks after sowing at tillering, annually. The treatments containing biosolids products did not receive additional fertiliser and consequently the residual value of the nutrients could be examined over time compared with the freshly applied inorganic fertiliser treatments. The nil treatment did not receive any fertiliser, so the response to all added nutrients could be established. The seeding dates over the three years were as follows: wheat 4/06/05, canola 07/06/06 and wheat 25/05/07.

For each crop species, plant establishment was measured in each plot over three x 1 m rows (0.54 m^2). The total dry matter (DM) of shoots was measured at 8 weeks after seeding and prior to harvest over 3 x 1 m rows following drying at 70^oC for 24 h. Grain yield was determined using a mechanical plot harvester and sub-samples of grain retained. Shoot and grain material was prepared by grinding (<0.5 mm) and the concentration of N measured by Leco and the concentrations of various other nutrients measured by ICP-AES. All analysis was performed by the Chemistry Centre (WA) East Perth, which is accredited by the National Association of Testing Authorities (NATA) using approved methodologies. Following harvest, composite soil samples were collected from the surface (0-10 cm) of each plot and sieved <2 mm. The soil was analysed for pH ($CaCl_2$ 0.01*M* 1:5) at the end of each year to compare the neutralising effect of LAB to agricultural lime. In addition, composite soil samples from each plot were analysed for organic C (%W/B), total N and bicarbonate available P (0.5*M* $NaHCO_3$ 1:100) in 2006.

Data were analysed for differences between the treatments using an ANOVA model in GENSTAT 5 Release 4.1 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

Soil pH

At the rates of LAB used, soil pH ($CaCl_2$) increased significantly from 4.4 in the nil treatment (0 LAB) to 6.4 at 1xNLBAR and to 7.2 at 1.5xNLBAR as measured in the 0-10 cm depth eight months after application and showed no further change by 20 months ($P<0.05$, Table 1). Increase in soil pH following the use of lime-amended biosolids (N-Viro soil) has also been reported in central New South Wales by Cooper (2005) with a linear relationship observed between the amount of NVS applied and soil pH ($r^2 = 0.0854$, $P<0.001$). The neutralising value of the LAB was comparable to that provided by equivalent rates of agricultural lime and was not unexpected, given that the rates of LAB were chosen to be comparative to agricultural lime in terms of their neutralising content. The increase in soil pH would enable farmers to better manage acidic soils, even at 0.5xNLBAR LAB where the pH had increased to 5.8. This is the typical application rate of LAB currently being applied by farmers in Western Australia. From this preliminary investigation, the neutralising value of the lime in the LAB was similar to the predicted value of 45%. This value is consistent with that reported by Sloan and Basta (1995) for a 1:1 dewatered sewage sludge and cement kiln dust mixture, which is reduced to 28% if less kiln dust is added (Cooper 2005).

The change in soil pH over time appeared slower in treatments containing agricultural lime than LAB, although this needs to be investigated into the third year to be conclusive. In comparison, there was no change in pH following the application of 1x NLBAR DBC. The overall benefit of liming this site would be best studied by growing an acid sensitive plant species or a legume.

Soil pH in the subsoil depth below 10 cm needs to be measured to provide a more comprehensive indication as to overall soil chemical changes.

Table 1: Effect of lime-amended biosolids (LAB), dewatered biosolids cake (DBC) and lime on soil pH in the 0-10 cm depth at 8 and 20 months after application

	pH ($CaCl_2$) 1:5	
Treatment	**8 months**	**20 months**
LAB 0	4.4	5.2
LAB 0.5	5.8	5.6
LAB 1.0	6.4	6.3
LAB 1.5	7.2	7.0
DBC 1.0	4.8	4.9
Basal + Lime 0	4.3	4.7
Basal + Lime 2.3	5.6	6.3
Basal + Lime 4.6	6.5	6.9
Basal + Lime 6.9	6.6	7.0
l.s.d (P = 0.05)	*0.84*	*0.65*

LAB=Lime-amended biosolids, DBC=dewatered biosolids cake, biosolids products expressed as multiples of the nitrogen limiting biosolids application rate (NLBAR), Basal = Urea + DAP, Lime rate as t/ha
Reports# 05A448 & 06A271, Chemistry Centre (WA)

Shoot dry matter

The shoot dry matter of wheat (2005) and canola (2006) measured at 8 weeks in the basal fertiliser treatments were no different to the treatments containing applications of LAB or DBC (P>0.05, Table 2). Shoot dry matter, however, was decreased in the treatment containing no fertiliser (LAB 0) indicating that the site was responsive to N and/or P. In the third year (2007) the shoot dry matter of wheat was decreased in the biosolids treatments compared with freshly applied basal fertiliser treatments (P>0.05, Table 2).

Table 2: Effect of lime-amended biosolids (LAB), dewatered biosolids cake (DBC) and lime on shoot dry matter (DM)/20 plants at 8 weeks after sowing over three years

Treatment	**Dry Matter (g/20 plants)**		
	Wheat 2005	**Canola 2006**	**Wheat 2007**
LAB 0	5.69	2.90	*
LAB 0.5	11.73	5.31	10.19
LAB 1.0	18.61	6.74	10.96
LAB 1.5	17.61	7.80	12.96
DBC 1.0	16.34	7.19	11.47
Basal + Lime 0	14.42	6.44	13.68
Basal + Lime 2.3	13.24	10.21	14.63
Basal + Lime 4.6	15.07	7.33	13.32
Basal + Lime 6.9	14.06	7.98	15.24
l.s.d (P = 0.05)	*4.95*	*3.26*	*2.93*

LAB=Lime-amended biosolids, DBC=dewatered biosolids cake, biosolids products expressed as multiples of the nitrogen limiting biosolids application rate (NLBAR), Basal = Urea + DAP, Lime rate as t/ha
** Freshly applied 1xNLBAR LAB applied as an alternative to the control and yielded 16.32 g/20 plants*

Grain yield

Wheat, the primary export crop in Australia, yields on average 1.62 t/ha (2000-03) (ABARE 2003). The grain yield of wheat at harvest in this experiment measured 2.05 t/ha in the treatment containing the standard basal fertiliser (Table 3). The 0 and 0.5x NLBAR LAB treatments had reduced yields compared to the standard basal fertiliser (P<0.05) suggesting that these plants were nutrient deficient. Therefore, additional inorganic fertiliser would need to be applied to the 0.5x NLBAR LAB to provide adequate crop yield. Overall the grain yield of wheat in the LAB at 1xNLBAR (10.3 t DS/ha) was comparable with that obtained by DBC at 1xNLBAR (7 t DS/ha). Therefore, from this preliminary study, the preferred LAB rate would be to apply at 1xNLBAR, as is currently used for DBC. The highest yield was obtained in the

1.5xNLBAR, although it had a large number of small or pinched grain, suggesting that the potential yield was lower than achieved in the given season. It is uncertain as to what caused this decline, as soil moisture was not limiting at the end of the season. Plant symptoms were similar to that caused by the root disease Take-all (*Gaeumannomyces graminis var. tritici*), which is more severe in soils which have been limed (Loughman *et al.* 2000), and is under further investigation. In addition, freshly applied LAB has been applied in 2007 to enable comparison to be made with freshly applied basal fertiliser and with comparative wheat yields in the first season.

Grain yield of canola in the second season (2006) measured 1.50 t/ha in the freshly applied standard inorganic fertiliser treatment (basal fertiliser + nil lime), which was comparable with treatments containing biosolids thus highlighting their value as a residual source of nutrients (P<0.05, Table 3). As in the previous year (2005), grain yields of canola were significantly lower in the nil fertiliser treatment (LAB 0) and yields in 0.5xNLBAR LAB were reduced compared with the higher rates of LAB (P<0.05, Table 3).

Table 3: Effect of lime-amended biosolids (LAB), dewatered biosolids cake (DBC) and lime on grain yield of wheat and seed weight (2005) and canola (2006)

	2005		2006
Treatment	**Grain yield of wheat (t/ha)**	**Weight of 100 wheat seeds (g)**	**Grain yield of canola (t/ha)**
LAB 0	1.23	43.13	0.90
LAB 0.5	1.66	44.10	1.24
LAB 1.0	2.20	39.37	1.33
LAB 1.5	2.21	32.90	1.65
DBC 1.0	1.97	38.53	1.42
Basal + Lime 0	2.05	41.90	1.50
Basal + Lime 2.3	1.97	41.37	1.40
Basal + Lime 4.6	1.90	40.53	1.15
Basal + Lime 6.9	2.06	42.63	1.36
l.s.d (P = 0.05)	*0.254*	*4.52*	*0.316*

LAB=Lime-amended biosolids, DBC=dewatered biosolids cake, biosolids products expressed as multiples of the nitrogen limiting biosolids application rate (NLBAR), Basal = Urea + DAP, Lime rate as t/ha

Concentrations of nutrients in plant and soil samples

The concentrations of nutrients in shoot and soil samples were examined to ascertain the effect of soil pH and treatment on the uptake of critical nutrients. The concentration of P in the dry matter of shoots at 8 weeks over three years was significantly higher (P<0.05) in the inorganic fertiliser treatments than in the biosolids treatments (Reports 05A222, 06A100 and 07A094: Chemistry Centre of WA, data not presented). Although high loading rates of P were applied in the biosolids treatments, the inorganic P treatments appeared to provide plants with a more readily available early source of P as indicated by 8 week shoot P concentration. The background concentration of available soil P in the nil treatment at 20 months after the start of the experiment was 41 mg P/kg and had increased to 79 mg P/kg at 1xNLBAR LAB and 114 mgP/kg at 1.5xNLBAR LAB (Report 06A271: Chemistry Centre of WA, data not presented). It is unknown why the increased soil concentration of P in the LAB was not reflected by increased P concentrations in shoot or grain samples and needs further examination. The concentration of P in shoots of wheat in the first year at 8 weeks was higher in DBC (0.33%) than LAB (0.23%) at equivalent NLBAR, but would be expected given higher initial P concentrations in DBC.

Concentrations of N in shoot samples at 8 week and grain samples at harvest were similar between the inorganic fertiliser treatments and 1xNLBAR biosolids treatments for wheat in 2005 and canola in 2006. Concentrations of total N in shoots were no different (P>0.05) between the inorganic fertiliser treatments and 1xNLBAR biosolids treatments (LAB and DBC) in the second year, suggesting that the NLBAR was comparable to freshly applied inorganic N. As would be expected, the total concentration of soil N was lower in the 0 (nil fertiliser) and 0.5xNLBAR LAB and higher in the 1.5xNLBAR LAB (P<0.05), reflecting the relative loading rates of N at these applications (data not presented). Although grain yield was maximised at rates higher than 1xNLBAR LAB, the effect of changes to soil N was not monitored and should be investigated further to ensure that the formula on which the NLBAR is based is accurate for these soils and environmental conditions.

Grain yield of wheat and canola were similar in all four rates of lime ($P>0.05$, Table 3), suggesting that soil pH was of marginal influence to grain yield and N and P uptake over the two seasons. Given the rapid increase in soil pH over the duration of the experiment, further monitoring may be necessary to establish any problems to plant growth and the environment. It should be mentioned that increasing rates of either lime or LAB significantly decreased concentrations of manganese (Mn) in the shoots of wheat, although concentrations remained above the critical values reported by Reuter & Robinson (1997). The likely explanation for this trend is related to the solubility of Mn, which declines with increasing pH (Moore *et al.* 1998) and also noted by Christie *et al.* (2001) in barley shoots grown in alkaline-stabilised biosolids produced using cement kiln dust. Of interest was the increase in concentration of sulphur (S) in shoot and grain samples of both wheat and canola as the rate of LAB increased compared with inorganic fertiliser treatments ($P<0.05$), and which may have contributed to higher yields at 1.5xNLBAR LAB. No other nutrient appeared to be affected by any of the treatments.

The cost of lime in the LAB is valued at approximately $1.50/t and therefore if full cost recovery for the lime was implemented, the LAB at 1xNLBAR would cost the farmer $15/ha. However, the main benefit of LAB would appear to be from the nutrient content of the biosolids product rather than the lime content. The currently rate of LAB being applied at present (0.5xNLBAR) is suggested as too low to sustain crop growth without the application of additional inorganic fertiliser. Thus it is recommended that the application rate is increased to that based on the N content rather the lime content given that no adverse effect on plant growth was measured at 1xNLBAR. The longer-term effects on soil pH would need to be monitored prior to an economic value being placed on the LAB. In addition, the use of LAB on non-acidic soil, particularly of low buffering capacity would not be recommended given the large potential increase in soil pH.

CONCLUSIONS

1. The current application rate of LAB at approximately 5 t/ha may be inadequate to satisfy the optimum production of wheat and canola in a typical cropping rotation in Western Australia unless additional inorganic fertiliser is applied.
2. It is suggested that the rate of LAB be based on the N content of the product to be consistent with DBC land application rates and applied at 1xNLBAR, i.e. approximately 10 t/ha. This rate is higher than typically applied in Western Australia at present although the increase in soil pH from the lime contained in the product at 1xNLBAR does not appear to have an adverse effect on soil or plant parameters. Rates of LAB below this would need to be supplemented by additional inorganic fertiliser, whereas rates above this may cause excessive changes in soil pH due to the neutralising value of the lime.
3. Further work needs to be conducted on the mineralisation and volatilisation rates used in the NLBAR calculation to accurately quantify plant available N.
4. The benefit of LAB over the two seasons investigated appeared to be from the nutrient value of the recycled nutrients (typically N and P) as would be obtained from DBC, rather than from the initial reduction in soil acidity. The application of LAB would save the farmer costs in having to purchase and spread lime on acidic paddocks, however to be conclusive this investigation needs to be continued over further years to ensure that LAB does not impact adversely on crop production or cause environment harm, all of which may jeopardise the long-term market.

ACKNOWLEDGEMENTS

The authors would like to thank the Water Corporation of Western Australia and the Chemistry Centre (WA) for providing funding and support for this project.

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Word Count = 4,323

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Basal + Lime 6.9	14.06	7.98	15.24
l.s.d (P = 0.05)	*4.95*	*3.26*	*2.93*