Effects of applied biosolids on forage sorghum production and soil major nutrient status in an alluvial clay loam soil in southeast Queensland, Australia.

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Abstract
This paper reports the effects of land application of one aerobically (AE) and one anaerobically (AN) digested biosolids on forage sorghum production and major nutrient status in an alluvial clay loam soil in southeast Queensland, Australia. The application rates were 7, 14, 42 and 63 t/ha for the AE and 10, 20, 60 and 90 t/ha for the AN biosolids. Forage sorghum planted in late October 2002 was harvested 4 times from December 2002 to May 2003. The total dry mass of sorghum was found to be significantly higher for the biosolids treated plots (20.7-26.8 t/ha) compared to the untreated plots (16.3 t/ha). Plant materials removed more nitrogen (N), potassium (K), phosphorous (P), cadmium (Cd), copper (Cu) and zinc (Zn) from the biosolids treated plots (369-724 kg N/ha, 753-1012 kg K/ha, 72-122 kg P/ha, 2.3-4.0 g Cd/ha, 134-188 g Cu/ha and 563-858 g Zn/ha) compared to the untreated plots (229 kg N/ha, 604 kg K/ha, 71kg P/ha, 1.6 g Cd/ha, 103 g Cu/ha and 556 g Zn/ha). Application of both biosolids increased levels of soil nitrate and total P, but not soil total carbon (C), even for the highest application rates measured at the end of the experiment. Biosolids application at 7 t/ha for the AE and 10 t/ha for the AN biosolids supplied forage sorghum enough nutrients without artificial fertiliser. Excessive application rates did not show further increases in dry mass of forage sorghum production and resulted in significant increases in soil residue nitrate and P, which in the cases of heavy rainfall or irrigation could result in losses through leaching and runoff.

Key Words
Nitrogen, phosphorus, carbon, metals, leaching and runoff

Introduction
Intensive agriculture could lead to declined soil fertility, especially reduction in soil organic carbon (C) and soil nitrogen (N) (Dalal and Probert, 1997; Dalal et al., 2003; Haynes *et al.*, 2003). Land application of biosolids could help to replenish soil organic matter levels, supply nutrients, such as N, P and K, and other essential micronutrients to plants improve soil structure and water holding capacity, and have beneficial effects on microbial biomass and activity (Barry et al., 2004; Bell et al., 2004; Eriksen et al., 1999; Leifield et al., 2002). The agricultural land where biosolids are applied to and the amounts of biosolids used in crop production have been increasing significantly over the last two decades due to both the recognition of the nutrient value of biosolids and the environmental concerns of other traditional disposal methods. However, the land application of biosolids, , may have problems of soil contamination by heavy metals, organic chemicals and pathogens, as well as nutrient leaching and runoff s (Epstein, 2003).

Quantification of nutrient transformation supplied by biosolids for affective plant growth, like mineral and organic N, is required for better nutrient management strategies in soil-plant ecosystems. However, the transformations of the applied nutrients are complicated and largely depend on the composition of biosolids, soil types and climate conditions, , as well as agricultural production systems. For example, the release of N from biosolids relies on the mineralisation of the biosolids organic N and a wide range of N mineralisation rates from 15 to 55 % within one year after biosolids application have been reported (Binder et al., 2002; Robinson et al., 2002). There is little information about the effects of biosolids land application on N transformations and plant growth in subtropical areas in Australia, as most of the research work has been conducted in areas of temperate climate and in the northern hemisphere.

The aims of this experiment were to investigate plant dry matter yields from different rates of two different biosolids, to estimate the plant removal of major applied nutrients (N, K and P) and selected metals (Cd, Cu and Zn), and to assess the soil nutrient statues after the final harvest.

Materials and methods

Experimental site and biosolids

The experimental site was located at a private farm, near Lowood (27°27'S, 152°34'E), southeast Queensland, Australia, and had been under grass pasture for grazing. The soil is an alluvial clay loam with 55% clay, 23% silt and 21% sand. The area is in subtropical Australia and has a history of long and hot summers and mild winters. From 2000 to 2003, the experimental area experienced a severe drought. During the experimental period from October 2002 to May 2003, the average maximum and minimum temperatures were 29.3 ^{o}C and 15.7 ^{o}C respectively, with a low rainfall of 440 mm.

The two biosolids used in this study were produced at two sewage treatment plants in southeast Queensland, Australia: one aerobically digested biosolids (AE) and one anaerobically digested biosolids (AN). The solid content was 12% for AE and 20% for AN biosolids. The total C levels were34% for AE and 33% for AN biosolids. Some of the selected soil and biosolids properties are listed in Table 1.

Table 1. Selected soil (0-10 cm) and biosolids properties.

	pH	EC	Total N	NH_4-N	NO_3-N	Total P	Total K	Cd	Cu	Zn
	1:5 water	mS/cm	%	mg/kg		%	%	mg/kg	mg/kg	mg/kg
Soil	7.0	0.22	0.4	low	low	0.34	0.15	0.08	34	88
Aerobic	6.5	199	6.0	2800	low	4.3	1.0	2.0	292	455
Anaerobic	7.6	681	5.4	12000	low	3.5	0.3	3.8	707	1874

Values for biosolids based on dry matter.

Experimental details

The experiment consisted of 10 treatments: unfertilised control, fertilised control (65 kg N, 17 kg P and 2 kg S/ha), AE biosolids at application rates of 7(AE0.5), 14 (AE1.0), 52 (AE3.0) and 63 (AE4.5) dry t/ha, and AN biosolids at application rates of 10 (AN0.5), 20 (AN1.0), 60 (AN3.0) and 90 (AN4.5) dry t/ha. Each treatment was replicated 3 times. Each of the experimental plots were 14 x 5.4 m, with 2 m buffers between plots.

In mid October 2002, the two biosolids were applied and incorporated to a soil depth of 10-15 cm. Forage sorghum (variety *Nectar*) was planted two weeks after application and was harvested four times during the experimental period at 7, 12, 21 and 28 weeks post-application. Before the last harvesting, the area experienced frost conditions effecting the plants . The harvested forage sorghum was oven-dried at 60 ^{o}C and the dry mass was recorded for the calculation of the forage sorghum production. The dried plant materials were then mulched and a sub-sample was ground to pass a 2 mm sieve before chemical analysis. The total dry matter of forage sorghum production was compared between the plots treated with biosolids and the plots of the two different controls (fertilised control and unfertilised control).

Soil samples were collected (from all treated plots?) before biosolids application for initial soil characterisation at 0-10, 10-20, 20-30 and 30-50 cm depth. After the last harvest, soil samples were collected at increments of 0-10, 10-20, 20-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm from selected treatments: unfertilised and fertilised controls, AE1.0 (14 t/ha), AE4.5 (63 t/ha), AN1.0 (20 t/ha) and AN4.5 (90 t/ha). Soil samples were air-dried in a glasshouse and ground to pass a 2 mm sieve before chemical analysis.

Chemical analysis

Chemical analysis on dried and ground soil and plant samples was performed to determine metal and nutrient levels using the routine methods including pH: aqueous, 1:5 soil:water, electrode; EC: aqueous, electrode; Nitrate, aqueous as NO_3-N, colorimetry; Total K, P, Cd, Cu and Zn: block digestion, ICP-AES and GFAAS; Total C: Loco, combustion; Total N, Kjeldahl digestion. A reference to each of these methods should be supplied.

Statistics analysis

The differences between treatment means reported here were tested for statistical significance using the least significant difference procedure in Genstat® (6th Version). Figures were produced using the Microsoft® Excel 2000 with standard deviation error bars derived from the 3 replicants.

Results and discussion

Forage sorghum production

The application of biosolids generally increased the forage sorghum production (20.7-26.8 t/ha), compared to both the unfertilised control (16.3 t/ha) and the fertilised control (17.6 t/ha) (Figure 1). The dry plant mass was significantly increased with the increased biosolids application rates for the AE biosolids. However, higher rates (60 and 90 t/ha) did not have the effect on the forage sorghum production for the plots treated with the AN biosolids. The results have shown that the application of biosolids at the rates of 7 t/ha for the AE and 10t/ha for the AN biosolids applied plants with enough nutrients that no artificial fertiliser was needed. It should be noted that the water stress during most of the experimental period, and the frost experienced by the plants before the last harvest limited the potential growth of the forage sorghum and may have masked some growth responses for forage sorghum production.

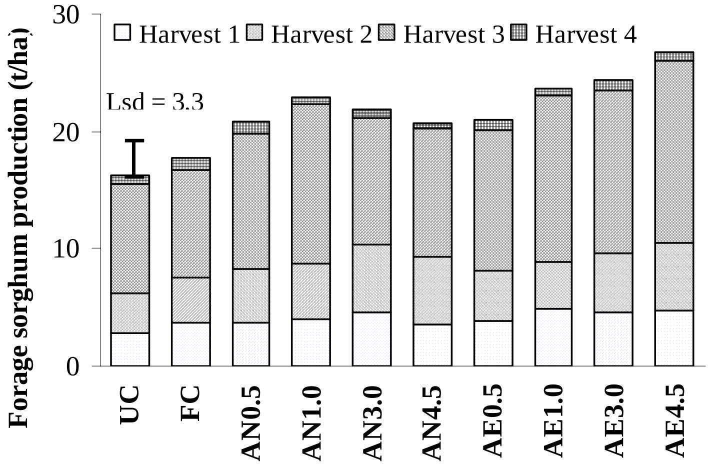

Figure 1. Forage sorghum production as affected by the application of different biosolids at different rates to an alluvial clay loam soil in subtropical Australia. UC: unfertilised control; FC: fertilised control; AE0.5-AE4.5: aerobically digested biosolids applied at 7, 14, 52 and 63 dry t/ha; AN0.5-4.5: anaerobically digested biosolids applied at 10, 20, 60 and 90 dry t/ha.

Nutrient and metal removal by plant materials

Application of both biosolids generally increased the amounts of major nutrients and metals removed by plant materials (369-724 kg N/ha, 753-1012 kg K/ha, 72-122 kg P/ha, 2.3-4.0 g Cd/ha, 134-188 g Cu/ha and 563-858 g Zn/ha), compared to those from the unfertilised plots (229 kg N/ha, 604 kg K/ha, 71 kg P/ha, 1.6g Cd/ha, 103 g Cu/ha and 556 g Zn/ha) and the fertilised plots (336 kg N/ha, 712 kg K/ha, 79 kg P/ha, 2.1 g Cd/ha, 132 g Cu/ha and 664 g Zn/ha) (Figure 2). The increased removal of the major nutrients and metals were mainly attributed to the increased overall forage sorghum biomass production, as the concentrations of the major nutrients and metals in plant materials were similar for plots treated with and without biosolids (actual data not presented). Most of the metals (Cd, Cu and Zn) sourced from biosolids remained in the soil as plants removed only small proportions of the total applied metals. For example, at the application rates of 14 t/ha for the AE and 20 t/ha for the AN biosolids, the plant removed only 5% and 2% of the added Cd respectively.

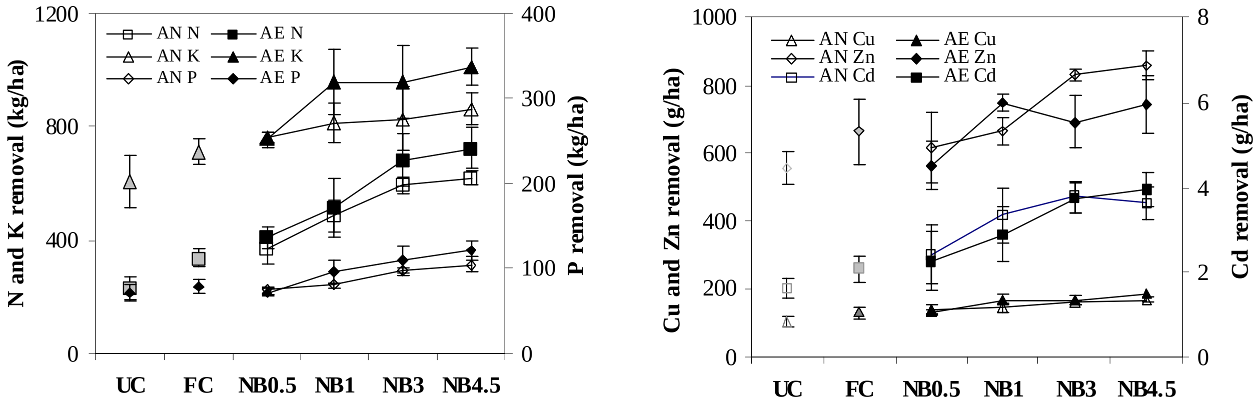

Figure 2. Removal of nutrients N, K and P and metals Cd, Cu and Zn by forage sorghum as affected by different biosolids applied at different rates. NB0.5-NB4.5: corresponding to the rates of AE0.5-AE4.5 and AN0.5-AN4.5 respectively.

Soil nutrient status

At the end of the experiment, soil nitrate and soil total P levels were significantly higher from the selected biosolids treated plots (145-788 kg N/ha and 687-1260 kg P/ha) than from both unfertilised (48 kg N/ha and 466 kg P/ha) and fertilised (34 kg N/ha and 409 kg P/ha) plots, except for the total P in the AN1.0 plots (568 kg P/ha) (Figure 3).

There was no evidence of nitrate leaching d even in the plots treated with highest biosolids rates (63t /ha for the AE and 90 t/ha for the AN biosolids). Nearly all the nitrate remained in the top 90 cm soil, due mainly to the lack of rainfall events throughout the experimental period. Such large amounts of soil residue nitrate in the soil profile would subject to potential losses through leaching in cases of heavy rainfall events or excessive irrigation. For the plots that received the highest rates of both biosolids, more than half the residue nitrate remained in the top 30 cm of soil and nearly all the residue P was in the top 10 cm soil, indicating the high risk of residue N and P losses through runoff.

Results obtained from this experiment show that biosolids had little impact on soil total C pool, due to the already very high total C level in the top soil. For example, the added C from biosolids applied at 90 t/ha (AN biosolids) accounted for <2% of the total soil C pool. The true estimation would be smaller considering that some of the added C would have been lost through what mechanism? Mineralisation/volatilisation?

The application of biosolids at the rates of 14 t/ha for the AE and 20 t/ha for the AN biosolids did not significantly increase soil total N at the end of the experiment, but at higher application rates of 63 t/ha and 90 t/ha respectively, soil total N was increased significantly. No significant differences were observed between the two biosolids and the final nutrient levels in the soil profiles of corresponding plots.

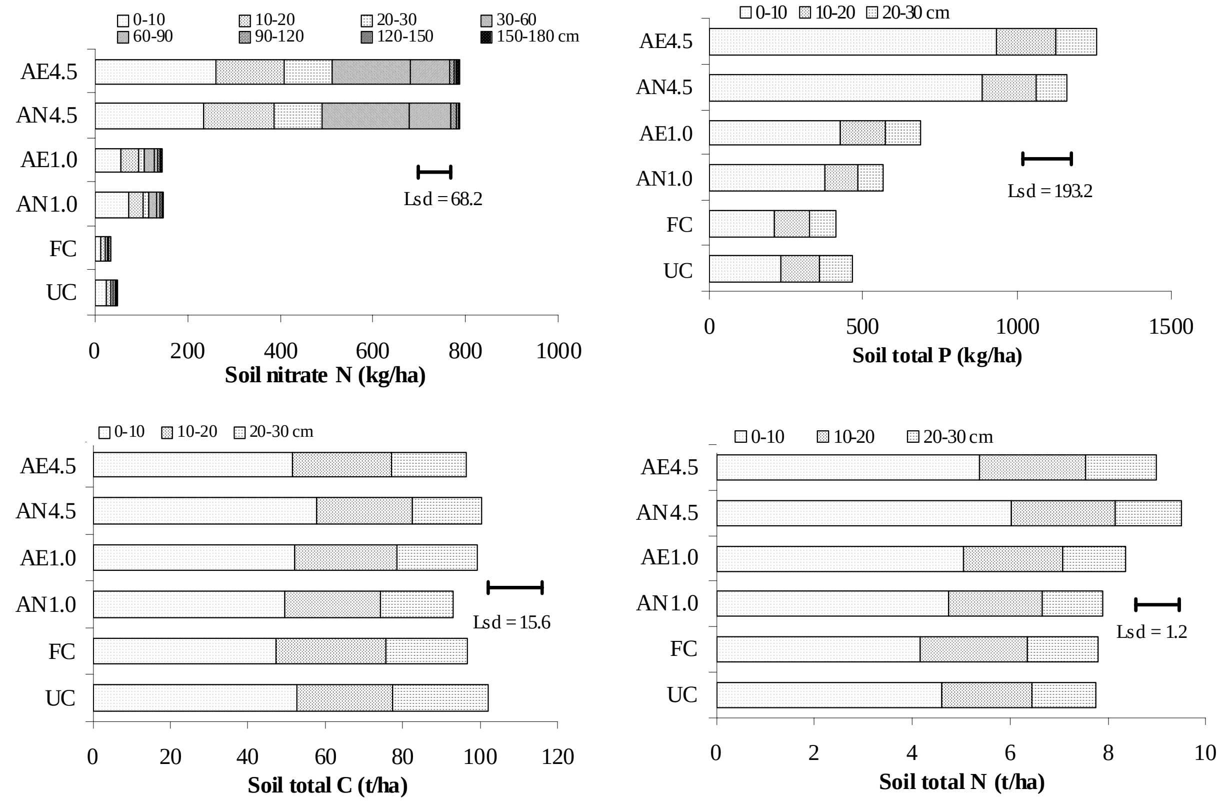

Figure 3. Soil nitrate N, total P, total C, and total N in the soil profile after the last harvesting. The LSD values given are the sums of individual LSDs for each nutrient in all soil layers.

Conclusions

Both of the aerobically and anaerobically digested biosolids are valued resources of major plant nutrients, such as N, P and K. The land application of biosolids at 7 dry t/ha for AE and 10 dry t/ha for AN biosolids supplied enough nutrients for the forage sorghum production without artificial fertiliser. Most of the added P and metals Cd, Cu and Zn remained in the soil. Biosolids application had little impact on total soil C pool. Excessive application rates did not show further increases in the forage sorghum production and resulted in significant increases in soil residue nitrate and residue P in the soil profile, which has greater environmental implications for nutrient runoff and leaching.

Work is underway to investigate the adverse effects of biosolids application on plant production and soil fertility, and to address the residual effects of heavy metals, and the leaching and runoff of nutrients in 4 major farming systems and a forest production system in southeast Queensland.

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