Comparisons between applied biosolids and inorganic fertiliser under canola production in a red Dermosol in northeast Victoria, Australia

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Abstract
Management of biosolids is a major environmental issue for Victoria. In 2003, VicWater (a consortium of water authorities in Victoria) and the Victorian Department of Primary Industries (DPI) established a 4 year trial investigating applications of biosolids at Dookie in northern Victoria, to address the issues of metal contaminants and nutrient bioavailability in soil amended with biosolids. Data from the Dookie site is contributing to the CSIRO coordinated National Biosolids Research Program (NBRP), where similar field experiments are occurring around Australia.

Biosolids are rich in organic matter and essential plant nutrients, and thus are useful amendments in agriculture. However, biosolids can contain significant amounts of pathogenic microorganisms, metals and other chemical residues that can cause toxicity in plants and animals if they are inappropriately processed and recycled back into the environment. State and Federal regulatory agencies have released draft guidelines for sustainable reuse and land application of biosolids; both documents provide biosolids classification and ceiling levels of nutrients and contaminants. One of the aims of the NBRP is to determine if these ceiling levels could be better adapted for local soil environments.

This paper reports the effects of land application of biosolids from two urban water authorities on canola production and soil N and P status in an acid soil in north east Victoria. Canola grown in soils treated with increasing rates of biosolids produced equivalent or better yields than conventional fertiliser. The overall difference between the biosolid treatments and the fertiliser control was significant for two sources of biosolids for canola oil seed yields and soil Colwell P at the end of the first cropping season.

Key Words
Sewage sludge, waste reuse, nitrogen, phosphorus.

Introduction
Biosolids are defined as "organic solids derived from biological wastewater treatment processes that are in a state that can be managed to sustainably utilise their nutrient, soil conditioning, energy, or other value" (EPA Victoria, 2004). The solids that do not meet these criteria are defined as wastewater solids or sewage sludges.
Stockpiles of biosolids pose a major disposal problem for major cities and rural centers throughout Australia. In Victoria, approximately 67, 000 dry tonnes of biosolids are generated every year (DNRE 2002). In addition, over 2 million dry tonnes are currently stored in lagoons and stockpiles. However, only relatively small volumes are currently recovered and beneficially recycled in agriculture.

The nutritive and soil conditioning values of biosolids are well documented in other states (Osborne 1995, Penney *et al.* 2003) and internationally. There has been little reported scientific field research on the application of biosolids in agricultural settings in Victoria. Scientists from 5 states in Australia have combined their biosolids research projects under the National Biosolids Research Program (NBRP) to determine at a national scale, the potential benefits and risks associated with the land application of biosolids in a range of diverse soil and crop environments. Data will be collected from 17 experimental field trials - 5 of which are in Victoria. Recent findings from the NBRP have shown significant crop responses to applications of biosolids compared to chemical fertiliser at most of the 17 sites, both for plant biomass production and grain yield (Barry *et al.* 2004).
The aim of this paper was to investigate the effects of land application of biosolids from two urban water authorities in regional Victoria on canola production and soil N and P status in a red Dermosol.

Materials and methods

Biosolids

The two biosolids used in this trial were sourced locally from the Goulburn Valley Water's (GVW) Shepparton Waste Management Facility and North East Water's (NEW) West Wodonga treatment plant. Goulburn Valley Water uses a lagoon based wastewater treatment process in which the sewage has been anaerobically digesting for more than 30 years. The sludge was removed and stabilised by exposure to UV from the sun and air dried to around 70% dry solids over the summer months. The dried biosolids was then stockpiled for two years prior to use in this trial. By contrast, NEW operates an activated sludge treatment process followed by anaerobic digesters. The sludge from the digesters was belt-pressed to around 14% dry solids and delivered to the trial site.

Both biosolids were analysed for a range of properties according to the Australian Standards for composts, soil conditioners and mulches (Standards Australia 1999). According to EPA guidelines (EPA Victoria 2004), both these biosolids are classified as 'Contaminant Grade 2' and are suitable for restricted agricultural uses such as production for processed food crops and sheep grazing. Some selected properties of biosolids from the GVW source and the NEW source are listed in Table 1.

Table 1. Selected properties of biosolids from GVW and NEW.

Property	**Units**	**Biosolid source**	
		GVW	**NEW**
Moisture (40ºC)	%	13	81
Organic matter	%w/w	13	66
pH		7.5	7.3
EC	dS/m	4.7	4.5
Dry bulk density	kg/L	1.1	0.8
Total Carbon (C)	%	6.7	30
Total Nitrogen (N)	%	0.7	5.3
Total Phosphorus (P)	%	0.3	2.5
Total Potassium (K)	%	0.8	0.8
Total Sulphur (S)	%	0.2	0.7
C:N ratio		9.6	5.7
Arsenic[1]	mg/kg	9.5	4.1
Cadmium	mg/kg	1.4	0.9
Chromium	mg/kg	36	18
Copper	mg/kg	66	100
Lead	mg/kg	32	<10
Mercury[1]	mg/kg	0.7	0.1
Nickel	mg/kg	21	10
Selenium[1]	mg/kg	2.5	2.1
Zinc	mg/kg	180	300
DDT & derivatives[1]	mg/kg	<0.5	<0.5
Organochlorine pesticides[1]	mg/kg	<0.05	<0.05
PCBs[1]	mg/kg	<0.2	0.1

[1] Data supplied by the individual water authority.

Trial Site

The trial site is located on the Dookie farm estate, owned by the University of Melbourne. The surface soil (0-10 cm) has a light clay (very fine sandy) texture and is brown (7.5YR5/6) in colour (Munsell 1973). The soil pH and EC is 5.2 and 0.3 dS/m in water (1:5 soil:water), respectively, and contains 3.8% (w/w) organic matter. The soil is classed as a red Dermosol (Isbell 1996) and is prone to structural decline if over cultivated. The mean annual rainfall in Dookie is 520 mm. The site was fallow in 2002, with previous history of pasture, cereal and oilseed crop rotations dating back to 1940.

Treatments and experimental design

The experiment was designed to compare crop and soil responses from biosolid treatments with a conventionally fertilised and an unfertilised control. Table 2 lists the treatments (T1-T8) including the rates of biosolids applied and the quantities of N and P applied. Broadcast application of superphosphate (100 kg/ha) was applied to the entire paddock containing the experimental site prior to setting up the trial.

Treatment 1 (T1) received neither biosolids nor fertiliser (unfertilised control) and T8 (fertiliser control) received the recommended fertiliser rate of 70 kg/ha Diammonium phosphate (DAP). Treated plots (T2-T7) received increasing rates of biosolids, calculated as multiples of the Nitrogen Limiting Application Rate (NLAR). Calculation of the NLAR is based on crop requirements for N and selected biosolid properties (mainly total and available forms of nitrogen, bulk density, and moisture). For this trial, estimation of the NLAR for each biosolid was calculated prior to trial establishment based on the data supplied by the relevant water authorities. However, subsequent analysis of the biosolids sampled on the day of application (at the trial site) resulted in different values. For this reason, no consideration is given to NLAR's in this paper.

The experiment was laid out as a randomised complete block design with 8 treatments; 6 rates of biosolids application, 2 controls – one receiving zero rate of biosolids and no fertiliser (T1), and another control receiving zero rate of biosolids but with fertiliser (T8), 2 sources of biosolids (GVW and NEW) replicated 3 times. Each plot was 5 x 10 m, with a total number of 48 (8 x 2 x 3) plots over a trial area of 30 x 80 m.

Table 2. Treatments, rates of biosolids (dry t/ha) and N and P loadings applied (kg/ha).

Treatments	**Rate of GVW biosolid (dry t/ha)**	**Rate of NEW biosolid**	**N and P loadings GVW biosolid**		**NEW biosolid**	
			N kg/ha	P kg/ha	N kg/ha	P kg/ha
T1	Unfertilised control		0	0	0	0
T2	13	2.3	91	39	122	58
T3	26	4.6	182	78	244	115
T4	39	6.9	273	117	366	173
T5	78	14	546	234	742	350
T6	117	21	819	351	1113	525
T7[1]	Annual application					
T8	Fertilised control		12.6	14	12.6	14

[1]Results from the annual application of biosolids (T7) are not reported in this paper.

Biosolids application and crop establishment

Biosolids were applied to 36 plots (6 biosolid treatments x 2 sources x 3 replicates) over 2 days (10-11 April 2003) using a cattle scale and tractor bucket for weighing. All biosolid treatments were once off applications, except for T7 which received an annual application. Biosolids were spread manually to ensure an even coverage over each plot, before incorporating into the soil by rotating discs to a depth of 10 cm. Canola *(Brassica napus* cv. Beckon) was sown (29 April 2003) at the rate of 4 kg/ha using a shearer combine seeder. Germination was generally poor due to slight undulation on the soil's surface caused by the discs.

Soil and harvest measurements

Soil and plant sampling was restricted to an area of 4 x 9 m in each plot, leaving buffers of 1 m between adjacent plots. Soil samples (0-10 cm) were collected twice during the growing season to determine soil nutrient (N and P) status, immediately after the biosolids and fertilisers were incorporated, and then at harvest (11 Nov 2003). A composite sample of 30 core samples was collected from each plot on each occasion.

Plant dry matter and N and P content in the plant matter were measured after harvest. Two half-meter strips were manually removed from each plot, dried, and the seed and plant matter were separated and weighed to determine yields. The plant dry matter (minus the seed) was analysed for N and P.

Statistical analysis

Analysis of variance (ANOVA) was performed on the means of the response variables to compare the treatments in Table 2. Individual treatment means were compared using Fisher's unprotected least significant difference (LSD) test, at the 5% significance level.

In addition, two comparison contrasts and an orthogonal polynomial contrast to examine the linear and quadratic effects of the biosolid rates were performed in the ANOVA for all the response variables.

Contrast is defined as comparisons between the treatment factor that needs to be assessed (Genstat 2000) and the contrast value is the difference between the mean value of the response variables.

Contrast 1 – The mean of T1 and the mean of T8 were compared to determine whether the site was responsive to fertiliser addition.
Contrast 2 - The mean of biosolid treatments (T2-T6) and the mean of the fertiliser control treatment (T8) were compared to assess the overall value of biosolids as a fertiliser replacement.

In the ANOVA, both controls' (T1 and T8) results for GVW and NEW were treated as the same because they did not receive biosolids treatments (see Tables 3-6). In this paper, orthogonal polynomial contrast is not presented.

Results

The results are presented as (i) individual treatment means for the response variables, (ii) contrast between T1 and T8, and (iii) Contrast between biosolids treatments (T2-T6) and T8.

Individual treatment means for plant dry matter

The application of biosolids generally increased the dry matter production (12.4-23.1 t/ha), compared to both the unfertilised control (7.4 t/ha) and the fertiliser control (11.8 t/ha) (Table 3). Plant dry matters increased significantly for GVW biosolids at the highest application rate (T6) compared to the fertilised control (T8). When compared to the unfertilised control (T1), the plant dry matter recorded for plots treated with GVW biosolids (T3-T6) were significantly greater.

NEW biosolids showed significant increases in plant dry matter for all biosolid treatments, except T4 compared to the unfertilised control (T1), but showed no significant differences compared to the fertilised control (T8).

Individual treatment means for seed yields

The application of biosolids generally increased the seed yields (2.5-3.4 t/ha), compared to both the unfertilised control (1.4 t/ha) and the fertiliser control (1.7 t/ha) (Table 3). Seed yields of T3, T5 and T6 for the GVW biosolid and T5 for the NEW biosolid were significantly higher compared to the fertilised control (T8). GVW biosolids did show significant increases in seed yields for T3 to T6 compared to the unfertilised control (T1); and for NEW biosolids, T3 and T5 gave a greater yield compared to the unfertilised control (T1).

Table 3. Mean plant dry matter (t/ha) and seed yield (t/ha) at harvest.

Treatment	**Plant dry matter (t/ha)**		**Seed yield (t/ha)**	
	GVW	**NEW**	**GVW**	**NEW**
T1	7.42		1.37	
T2	12.41	16.06	2.52	2.67
T3	14.11	15.75	3.37	2.71
T4	13.58	12.56	2.80	2.56
T5	17.80	16.78	3.05	3.23
T6	23.07	15.25	3.35	2.51
T8	11.85		1.74	
LSD (5%)	6.16	6.86	1.29	1.32

Individual treatment means for N and P in the plant matter

The application of biosolids generally did not result in increased N and P concentrations in the plant matter (Table 4). Plant N for the highest application rate treatment (T6) was significantly greater when compared to N concentration for T1, T2 and T3 for both the biosolid sources.

Table 4. N and P concentrations in the dry plant matter (%w/w) at harvest.

Treatment	GVW		NEW	
	N	P	N	P
T1	1.6	0.17	1.6	0.17
T2	1.6	0.19	1.8	0.22
T3	1.5	0.18	1.8	0.22
T4	1.4	0.19	2.0	0.22
T5	1.9	0.21	2.1	0.22
T6	2.1	0.23	2.3	0.25
T8	1.8	0.21	1.8	0.21
LSD (5%)	0.4	0.06	0.3	0.04

Individual treatment means for soil N and P levels after application of treatments

Generally, increasing rates of biosolids increased the concentration of NH_4-N and Colwell P in the soil immediately after incorporation (Table 5). Significant increases in soil ammonium (NH_4^+) concentration compared to the fertiliser control (T8) were observed for T3 to T6 for GVW biosolids, however changes in soil nitrate (NO_3^-) concentrations were not significant for the same rates.

Colwell P increased significantly for T5 and T6 in the case of GVW biosolids and increased only for T6 in the case of NEW biosolids.

The concentrations of both forms of N were highly variable within treatments.

Table 5. Soil (0-10 cm depth) N and P levels (mg/kg) immediately after application of treatments.

Treatment	GVW			NEW		
	NO_3-N	**NH_4-N**	**Colwell P**	**NO_3-N**	**NH_4-N**	**Colwell P**
T1	44	7	80	44	7	80
T2	49	22	97	71	42	101
T3	49	66	99	51	20	101
T4	68	64	94	60	28	92
T5	45	101	123	52	55	129
T6	45	125	120	23	115	153
T8	56	6	81	56	6	81
LSD (5%)	23	50	30	30	76	49

Individual treatment means for soil N and P levels at harvest

Soil NO_3^- and NH_4^+ concentrations at harvest (Table 6) were much lower when compared to concentrations just after soil incorporation of biosolids, which was expected since crops remove much of the N in the soil. Only at the highest rate for NEW biosolids (T5 and T6) were NO_3^- and NH_4^+ concentrations significantly greater.

At the end of the experiment, Colwell P levels were significantly higher for both biosolids at higher application rates (T5 and T6 for GVW and T3-T6 for NEW), compared to the fertiliser control (T8). Further, soil Colwell P levels of T5 and T6 for NEW biosolids were generally higher, when compared to the corresponding values for GVW biosolids.

Contrast between T1 and T8 (Contrast 1)

The contrast between the unfertilised control (T1) and fertiliser control (T8) means showed no significant differences (Table 7) for all the response variables considered, the only exception being plant P for the NEW biosolids.

Table 6. Soil (0-10 cm depth) N and P levels (mg/kg) after harvest.

Treatment	GVW			NEW		
	NO_3-N	**NH_4-N**	**Colwell P**	**NO_3-N**	**NH_4-N**	**Colwell P**
T1	3.2	3.9	70	3.2	3.9	70
T2	2.8	5.7	79	4.5	6.7	94
T3	4.5	4.7	94	6.2	9.2	140
T4	3.9	8.0	90	9.2	9.2	130
T5	6.0	7.1	150	12.7	12.4	193
T6	7.3	6.6	163	38.0	18.7	237
T8	1.6	4.4	60	1.6	4.4	60
LSD (5%)	4.4	3.1	54	11.7	7.3	44

Table 7. Contrasts and corresponding P-values for the response variables based on contrast between unfertilised control (T1) and fertiliser control (T8) means.

Response variable	GVW		NEW	
	Contrast value	**P value[1]**	**Contrast value**	**P value[1]**
Plant dry matter	-4.4	0.143	-4.4	0.183
Seed yields	-0.37	0.544	-0.37	0.551
Plant N	-0.2	0.266	-0.2	0.108
Plant P	-0.04	0.153	-0.04	0.031
Soil N and P after treatment application				
NO_3-N	-12	0.270	-12	0.387
NH_4-N	0	0.987	0	0.992
Colwell P	-1	0.962	-1	0.977
Soil N and P after harvest				
NO_3-N	1.5	0.462	1.5	0.780
NH_4-N	-0.5	0.732	-0.5	0.885
Colwell P	9	0.712	9	0.653

[1]If the P-value is < 0.05, the contrast value between T1 and T8 means is significant.

Table 8. Contrasts and corresponding P-values for the response variables based on contrast between biosolid treatments mean (T2-T6) and fertiliser control (T8) mean.

Response variable	GVW		NEW	
	Contrast value	**P-value[1]**	**Contrast value**	**P-value[1]**
Plant dry matter	4.3	0.071	3.4	0.185
Seed yields	1.28	0.016	1	0.054
Plant N	-0.09	0.526	0192	0.053
Plant P	-0.007	0.724	0.018	0.174
Soil N and P after treatment application				
NO_3-N	-4.7	0.583	-5	0.669
NH_4-N	70	0.002	46	0.115
Colwell P	26	0.030	34	0.071
Soil N and P after harvest				
NO_3-N	3.2	0.059	12.5	0.011
NH_4-N	2	0.097	6.8	0.023
Colwell P	55	0.014	98	<0.001

[1]If the P-value is < 0.05, the contrast value between T2-T6 and T8 means is significant.

Contrast between biosolids treatments (T2-T6) and T8 (Contrast 2)

The contrast between the biosolids treatments (T2-T6) and fertiliser control (T8) means (Table 7) showed significant differences for the following response variables. For GVW biosolids - seed yields, soil NH_4-N and Colwell P soon after application of treatments, and soil Colwell P after harvest. For NEW biosolids - seed yields, plant N, and soil NO_3-N, NH_4-N and Colwell P after harvest.

Discussion

Canola plant dry matter and oil seed yields for T1 (unfertilized control) and T8 (fertilized control) did not differ significantly from each other (Tables 3 and 7). This implies that the standard fertiliser (70 kg DAP/ha) application at this site had no impact on plant dry matter and seed yield. This could partly be due to background superphosphate (100 kg/ha) that was applied to the site prior to trial set up, influencing plant dry matter and seed yield, which may have confounded the results.

When comparing seed yields between biosolids and fertiliser treatments (Contrast 2), the result for GVW biosolids showed a significant difference ($P<0.05$). The contrast value (1.28 in Table 8) indicated that biosolids on average performed better than fertiliser treatment. In the case of NEW, there appears to be differences between biosolids and fertiliser ($P=0.054$) for seed yields. Although this is not statistically significant at the 5% level, but it is very close. Given the variability between the treatments was high due to low number of replicates, a similar reasoning could also be true for plant dry matter.

The overall difference between the biosolid treatments (T2-T6) and the fertiliser control was significant for both sources of biosolids for selected response variables (Table 8). Visual crop responses throughout the growing season were evident, particularly at an early stage (4-5 leaf stage) of growth. This could be explained partly due to high N and P quantities applied through biosolids, reflective in the available soil P and N (NH_4-N) concentrations immediately after incorporation of biosolids (Table 5).

At harvest, GVW biosolids showed a significant increase in plant dry matter for the highest rate (T6) compared to fertiliser control (T8) (Table 3). Soil NH_4^+ and Colwell P concentrations for T6 were generally greater than for T8 at both stages of soil sampling, suggesting the conventional fertiliser could be deficient in the supply and uptake of N and P for optimal crop growth (Tables 5 and 6). However, canola production was generally not significantly different for NEW biosolid treatments compared to fertiliser control (T8), despite differences in soil NO_3^- and Colwell P. The fact that, in most cases (Table 3), both sources of biosolids showed no significant differences in crop production compared to fertiliser control (T8), underpins the fertiliser value of the biosolids used in this study. This is further demonstrated when comparing plant N and P content of biosolid treated plots with that of fertiliser control.

Generally soil N results were highly variable across the plots. At higher rates of GVW biosolids, soil NH_4-N was significantly greater than the controls (T1 and T8) after incorporation of biosolids. As expected, concentrations of NH_4^+ declined after harvest as a result of crop uptake and N transformation during crop growth. Soil Colwell P levels were significantly greater as a result of biosolid application at the end of the experiment. Although not evident from this work, the release of nutrients from biosolids may be slower compared to that from traditional fertilisers. This can be beneficial for the following crops as well as for the soils that are prone to nutrient losses through leaching.

As a source of nutrients and organic matter, biosolids have an attraction for farmers, though there is still some reticence about the potential risk of pathogens, heavy metals or other contaminants which limit their utility. The relatively low nutrient concentration of biosolids (compared to fertilisers and manures) provides a further impediment to its use. Farmers who also assess the cost-effectiveness of the biosolids when compared with fertilisers or manures as nutrient sources investigate this prospect. Unfortunately, their assessment usually doesn’t focus on all of the characteristics of these sources of nutrients, so they generally determine that the application rate of biosolids will be much greater than that of fertilisers or manure for a specific crop on the basis of desirable macronutrient loading. There can be inherent environmental risks associated with the application of fertilisers, manures, soil ameliorants and biosolids, particularly if loading rates are high and receiving soils are either free draining or hydrophobic.

Conclusion

Canola grown in soils treated with increasing rates of biosolids produced equivalent or better yields than conventional fertiliser. The major advantage of using biosolids over conventional fertilisers is that they are cheap, they contain essential trace elements and organic matter to improve soil structure and water holding capacity. For canola production in northern Victoria, the data presented here suggests that canola will respond to biosolids application as a once-off fertiliser; however, uptake of metals and appropriate nutrient loadings will have strong implications on the management of broadacre production and therefore will require future research. Future outcomes of the NBRP will help establish the benchmarks for different metals and nutrients in cereal and oil seed crops across different soil types in Victoria and Australia.

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References

Barry G, Stokes J, Bell M, Pritchard P and Pu G (2004) Crop responses from biosolids applications across States. In 'Proceedings of the AWA Biosolids Speciality II Conference, 2-3 June, Sydney', Australian Water Association Publishing.

DNRE (2002) Market Assessment for Biosolids Application in Victoria, Confidential Report.

EPA Victoria (2004) Guidelines for Environmental Management: Biosolids Land Application, Publication 943.

Isbell RF (1996) The Australian Soil Classification System, CSIRO Publishing, Melbourne.

Munsell (1973) Soil Colour Charts Collection, MacBeth Division of Kollmorgen Corporation, US.

Osborne GJ (1995) Fertilizer value of biosolids – a review. *In:* Biosolid Research in NSW. Organic Waste Recycling Unit, Richmond, NSW.

Penney N, Dumbrell I and Pritchard D (2003) Biosolids in Western Australia - Wanted not wasted. In 'Proceedings of the Fourth International conference of ORBIT Association on Biological Processing of Organics: Advances for a Sustainable Society, 30 April-2 May 2003, Perth', 184-192.

Standards Australia (1999) Australian Standards (4454:1999) Composts, soil conditioners and mulches, Standard Association of Australia, NSW.