FROM WASTE TO SOIL TO PLANT TO FEED – THE FATE OF BIOSOLIDS NUTRIENTS AND CONTAMINANTS IN A REAL FARM SITUATION

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ABSTRACT

This paper examines the outcomes of a study which tracked the impact of biosolids application on soil, plant and feed (silage/hay/grain). Whilst such studies have been mainly limited to experimental plots in the past, an attempt was made to undertake the study under a "real farm management regime".

Biosolids were applied at the rate of 98 dry tonees/ha to cover around 7.9 ha of farm land. A 5 m buffer was observed which was used as a "control study" area. Triticale was planted in both biosolids treated and control areas. Soil, herbage and grain samples were analysed and results from the analyses suggest that:

- Contaminant build up in the soil due to biosolids application was negligible;
- Nutrient (P and K) build up in the soil due to biosolids application was significant;
- Nutrient (N, P, K and S) build up in the herbage due to biosolids application was significant;
- Concentrations of most metals in the herbage in the biosolids treated areas appeared to be considerably lower than that grown in the "control study" area.

The results provide increased confidence to the end–user of the benefits of biosolids application.

INTRODUCTION

Western Water's Gisborne Recycled Water Plant (Gisborne RWP) is a tertiary treatment plant that collects and treats around 1 ML per day of sewage from the township of Gisborne. The tertiary treatment process consists of an activated sludge process with chemical precipitation of phosphorus. Waste Activated Sludge (WAS) is collected in a sludge lagoon and the lagoon is de-sludged every six to eight months. The sludge is then dried on a sludge drying bed and transported to another Western Waters recycled water plant facility located at Romsey. At the Romsey facility (near the Macedon Ranges), the sludge is generally turned mechanically until a solid content of 70% is achieved. At this stage the product is referred to as biosolids.

Western Water has been applying biosolids generated from its Gisborne RWP on two farms (known as "Trethellen" and "Red Hill of Macedon") comprising in total around 125 ha area, located at Woodend in Victoria (Figure 1). The farms consist of a number of individual paddocks defined by fencing. The biosolids application is undertaken under an Environment Improvement Plan (EIP) approved by the Victorian Environment Protection Authority (EPA).

In order to get an understanding of the benefits and potential adverse impacts of the biosolids, it was decided to undertake an analysis of soil and crop (herbage, silage, grain and straw) subsequent to the application of biosolids.

The purpose of the study is to assess the positive impacts of the ongoing farm application of biosolids generated from Western Water's Recycled Water Plants in order to build confidence among the farming community. Whilst there are numerous studies of this nature worldwide including Australia (eg. DPI 2007, McLaughlin *et al.* 2008), such studies under real farming situations (paddock scale) are limited.

BIOSOLIDS QUALITY

The Gisborne RWP biosolids are C2, due to elevated copper and zinc concentrations. C2 biosolids are suitable for a range of beneficial uses, including agricultural use.

The Gisborne biosolids used in this study have been digested in sludge lagoons and discharged to drying beds. Subsequently they are then stockpiled for two years. The treatment process does not meet recognised T1 or T2 treatment processes, therefore a T3 grading was targeted. Testing for E.*coli* showed that the biosolids readily meet T3 microbiological criteria specified in the Victorian EPA guidelines.

As a C2/T3 product, the Gisborne biosolids are suitable for land application for agriculture including sheep grazing or human food crops that are processed or cooked before consumption (e.g. cereal crops, oil seeds). Risk management practices include 30 day post-application withholding period for grazing and crop harvesting and preferably incorporation of the biosolids (e.g. by ploughing).

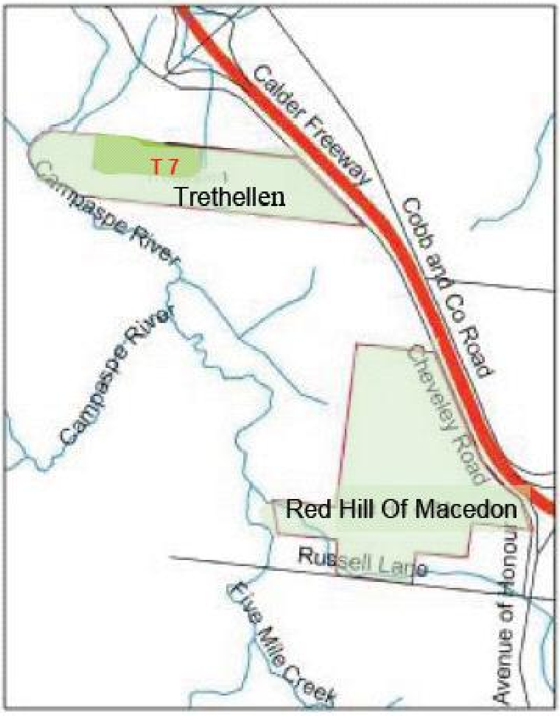

Fig 1: Map of the Study Site

BIOSOLIDS APPLICATION

"T7" paddock at the Trethellen farm (Figure 1) was chosen for application of biosolids in 2009. Biosolids samples and soil samples from "T7" paddock were analysed and an application rate was calculated as per the nutrient loading application rate (NLAR), a contaminant limiting application rate (CLAR) and cadmium loading rate. NLAR is the site-specific rate at which biosolids can be applied to land without exceeding the annual crop/pasture nutrient requirement.

Contaminant and nutrient concentrations of biosolids applied to paddock "T7" is provided in Table 1. As per EPA Guidelines it was determined as a C2 quality. As discussed previously the biosolids had a treatment grade of T3.

The CLAR was calculated for each contaminant in the biosolids. This determined the rate at which biosolids application will achieve the Receiving Soil Contaminant Limit (RSCL) set by the Victorian EPA to protect human health, the environment and food safety. To ensure that biosolids application does not result in significant accumulation of cadmium in the soil, the biosolids guidelines impose a maximum cadmium loading limit of 150 g/ha/5 years.

Table 1: Properties of biosolids used in paddock "T7"

Analyte	Units	Mean Concentration
Arsenic (As)	mg/kg	2.5
Cadmium (Cd)	mg/kg	0.6
Chromium (Cr)	mg/kg	30
Copper (Cu)	mg/kg	124
Lead (Pb)	mg/kg	18
Mercury (Hg)	mg/kg	0.7
Nickel (Ni)	mg/kg	19
Selenium (Se)	mg/kg	2.5
Zinc (Zn)	mg/kg	265
Aldrin	µg/kg	<0.5
4.4`-DDD	µg/kg	<0.9
4.4`-DDE	µg/kg	<0.10
4.4`-DDT	µg/kg	<0.11
Dieldrin	µg/kg	<0.12
Heptachlor	µg/kg	<0.19
Heptachlor epoxide	µg/kg	<0.20
Hexachlorobenzene (HCB)	µg/kg	<0.21
Total Polychlorinated biphenyls	µg/kg	<0.26
pH		4.9
Total Nitrogen as N	mg/kg	5186
Total Phosphorus as P	mg/kg	5765

Relevant soil data prior to biosolids application is shown in Table 2.

On 23 April 2009, the biosolids from Gisborne RWP were applied to the "T7" paddock. A 5 m wide buffer was observed around the paddock as per the Victorian EPA Guidelines. Triticale (rust resistant Yakuri variety) was used as the test crop. Triticale is a cross variety between wheat (*Triticum* species) and rye (*Secale* species) and is used in livestock diets as an energy source. Its major strength is its versatility for use as silage, hay, grain and straw. The crop was planted on 14 May 2009 in both biosolids treated and on the buffer (control) area.

Biosolids were spread using a mechanical spreader. The biosolids were applied at a rate of 97.7 dry tonnes per hectare (123 product tonnes/ha) based on NLAR. After application to the surface of the soil, the biosolids were incorporated into the soil.

Table 2: Soil tests prior to the application of biosolids

Soil test	Units	Paddock "T7"	
		0-10 cm depth	10-45 cm depth
Salinity			
$EC_{1:5}$	dS/m	0.28	0.07
pH			
pH($CaCl_2$)		4.6	5.2
Sodicity			
ESP	%	2	2
Nutrients			
Bray P	mg/kg	15	
P sorption	mg/kg	386	
P sorption index		2.9	
Exchangeable K	me/100g	0.6	
Organic matter			
Organic carbon	%	3.2	
Heavy metals			
Arsenic (As)	mg/kg	1.1	
Cadmium (Cd)	mg/kg	<0.5	
Chromium (Cr)	mg/kg	110	
Copper (Cu)	mg/kg	15	
Lead (Pb)	mg/kg	15	
Mercury (Hg)	mg/kg	<0.2	
Nickel (Ni)	mg/kg	25	
Selenium (Se)	mg/kg	<0.5	
Zinc (Zn)	mg/kg	32	

$EC_{1:5}$=Electrical conductivity in 1:5 soil:water extract, ESP=Exchangeable Sodium percentage

SAMPLING PROGRAM

A sampling program (Table 3) was undertaken in close consultation with the property owner.

Table 3: Sampling program undertaken at Paddock "T7"

Sample type	Cut date	Sampling date	Control Area		Biosolids Treated Area			
			Site 1	Site 2	Site 1	Site 2	Site 3	Site 4
Soil - 110 days after application	-	10-Aug-09	■	■	■	■	■	■
Soil - 9 months after application	-	20-Jan-10	■	■	■	■	■	■
Herbage - 90 days after sowing	-	10-Aug-09	■	■	■	■	■	■
Silage	5-Nov-09	20-Jan-10	■					
Hay	11-Nov-09	20-Jan-10			■			
Grain	15-Jan-09	15-Jan-10		■		■	■	■
Straw	15-Jan-09	20-Jan-10		■		■	■	■

■ Indicates sampling locations

Two sample points were selected at the buffer strip located in the north and west of "T7" designated as the "control study" area.

Four sample points were selected from the biosolids applied area designated the "treated study" area. The points were recorded with GPS for future sampling. For consistency, the same locations were used for soil and herbage sampling. Soil samples were collected at both topsoil (0-10 cm) and subsoil (10-45 cm) depths.

Soil and herbage samples were collected on 10 August 2009 from the control study area and the biosolids treated area. In total 12 soil and 6 herbage samples were collected.

On 5 November 2009, part of the crop at one of the sampling points in the designated as control study area was harvested for producing silage (see Table 3). On 11 November 2009, part of the crop at one of the sampling points in the designated biosolids treated area (Site 1) was harvested for hay. The rest of the crop was left to produce grain (see Table 3).

Silage samples were collected on 20 January 2010. Grain samples were collected by the property owner on 15 January 2010 at the time of harvest.

Straw and soil samples were also collected on 20 January 2010 following grain harvest. For consistency, it was ensured that hay, silage and grain samples were collected from areas previously designated as sampling points. One sample of silage from the control area (Site 1) and one hay sample from the treated area (Site 1) were collected. Four composite samples of grain - consisting one sample from the control area (Site 2) and samples from three of the designated sampling points in the treated area (Sites 2-4) were collected.

Sample numbers were limited due to time and cost constraints. However, the number of samples has been assumed to be reasonable as the soil type and the topography of the area is considered fairly uniform in the paddock "T7".

Table 4 lists the laboratories used for the analysis of biosolids, soil, silage, hay, grain and straw.

Table 4: Laboratories used for analysis

Sample type	Laboratory
Biosolids – pre application	ALS Laboratory Services
Soil – pre application	National Measurement Institute & Department of Lands Scone Research Centre
Soil – 90 days after application	DPI Werribee[1]
Herbage – 90 days after application	DPI Werribee
Silage	Weston Technologies[2]
Hay	Weston Technologies
Grain	Weston Technologies & DPI Werribee
Straw	Weston Technologies
Soil – Post grain harvest	DPI Werribee

[1]Victorian Department of Primary Industries, Werribee
[2]Weston Food Laboratories operated by George Weston Foods Pty Ltd, Enfield, New South Wales

STUDY

The main purposes of the study were to:

- Assess whether the application of biosolids had increased the unwanted contaminants in the soil;
- Determine whether the application of biosolids resulted in the uptake of any unwanted contaminants in the plants grown in the biosolids treated area including during both the growing and harvesting period;
- Assess whether there was any build up of contaminants in the grain;
- Assess the potential agronomic benefits of biosolids as a soil additive.
- Determine whether application of biosolids improved feed value and nutrient composition.

Based on the above aims, analysis of samples was carried out using:

- A suite of chemical measurements for determining the build up of contaminants in the soil, herbage, hay, straw and grain;

- Soil chemistry from an agricultural point of view;

- Nutrient value of hay and grain as stock feed material.

RESULTS & DISCUSSION

Nutrients and Contaminants in Soil

The soil prior to application of biosolids in Paddock "T7" was non-saline, non-sodic and moderately acidic (Table 2). Both available P and potassium levels appear low. Organic carbon is considered high given the soil used for cropping is located in a low rainfall area of Victoria (Peverill *et al*. 1991). All contaminants concentrations were below the receiving soil contaminant limits (RSCLs) for biosolids.

Similar results were observed 110 days after biosolids application, with the notable exception of nutrients (Table 5). Phosphorus (total and available forms) and available potassium (Skene K) levels in the treated areas for both top and subsoil depths increased substantially compared to the control area.

Table 5: Soil tests 110 days after biosolids application

Soil test	Units	0-10 cm depth		10-45 cm depth	
		Control Area (n=2)	Treated Area (n=4)	Control Area (n=2)	Treated Area (n=4)
Salinity					
$EC_{1:5}$	dS/m	0.09	0.09	0.07	0.11
pH					
pH(water)		5.1	4.9	5.3	4.9
pH($CaCl_2$)		4.3	4.3	4.6	4.3
Sodicity					
ESP	%	<1	<1	<1	<1
$SAR_{1:5}$		<1	<1	<1	<1
Nutrients					
Total P	mg/kg	570	1298	550	615
Bray-1 P	mg/kg	10	74	4	10
Olsen P	mg/kg	13	43	6	9
Skene K	mg/kg	115	230	73	129
Organic matter					
Total carbon	%	3.6	3.5	2.2	1.4
Heavy metals					
Arsenic	mg/kg	1	2	1	2
Cadmium	mg/kg	<0.3	<0.3	<0.3	<0.3
Chromium	mg/kg	44	68	76	104
Copper	mg/kg	6	13	9	9
Lead	mg/kg	8	10	9	11
Mercury	mg/kg	0.0	0.0	0.1	0.0
Nickel	mg/kg	10	12	21	19
Selenium	mg/kg	0.08	0.13	0.13	0.15
Zinc	mg/kg	13	26	16	15

$SAR_{1:5}$= Sodium Adsorption Ratio in 1:5 soil:water extract

Even nine months after the application of biosolids, available P and K remained notably higher in the treated area (Table 6). The crop to be planted following the Triticale crop at paddock

"T7" is expected to benefit as a result of build up from the biosolids application.

Table 6: Soil tests 9 months after biosolids application (post grain harvest)

Soil test	Units	0-10 cm depth		10-45 cm depth	
		Control Area (n=2)	Treated Area (n=4)	Control Area (n=2)	Treated Area (n=4)
Salinity					
$EC_{1:5}$	dS/m	0.07	0.18	0.05	0.11
pH					
pH(water)		4.9	5.2	5.5	5.3
pH($CaCl_2$)		4.3	4.9	4.7	4.9
Sodicity					
ESP	%	<1	<1	<1	<1
Nutrients					
Bray-1 P	mg/kg	9	57	3	10
Olsen P	mg/kg	11	35	5	8
Skene K	mg/kg	84	156	69	127

Contaminant data for the post harvest soils was not availabe when this paper was prepared. However, it is not expected that contaminants will increase in the treated area.

Nutrients and Contaminants in Herbage, Grain and Straw

An increase in nutrient concentration in the **herbage** (3 months growth crop) grown in the biosolids treated area was noted particularly for N, P, K and S (Table 7). Interestingly, herbage Fe and Al concentrations decreased eight fold in the treated area in comparison with the control area. It is possible that in the biosolids treated area in this acidic soil, the additional P is enabling formation of Fe and Al precipitates, rendering less Fe and Al available to plants. There is no clear evidence of contaminants accumulation in the herbage in the treated area (Table 7).

As in the case of herbage, nutrients (N, P, K and S) in the Triticale **grain** appeared to be higher in the biosolids treated area compared to the control area (Table 8). Again no discernable differences were observed in contaminants concentration in the grain with and without biosolids application (Table 9), except Zinc.

Table 7: Herbage Analysis – mineral nutrients and contaminants

Parameter	Units	Control Area	Treated Area Mean
Nitrogen	%	4.3	5.1
Phosphorus	%	0.31	0.49
Potassium	%	2.6	4.1
Calcium	%	0.28	0.26
Magnesium	%	0.18	0.14
Sodium	%	0.06	0.02
Sulfur	%	0.33	0.52
Cobalt	mg/kg	1.3	0.3
Boron	mg/kg	4.5	4.3
Molybdenum	mg/kg	0.13	0.14
Manganese	mg/kg	235	198
Iron	mg/kg	3050	378
Aluminium	mg/kg	2100	255
Arsenic	µg/kg	179	34
Cadmium	mg/kg	0.13	0.06
Chromium	mg/kg	6	1
Copper	mg/kg	7	7
Lead	mg/kg	0.95	0.15
Nickel	mg/kg	2.3	0.8
Selenium	µg/kg	28	15
Zinc	mg/kg	24	39

Table 8: Mineral nutrients in Triticale Grain (dry matter basis)

Mineral Nutrients	Units	Control Area	Treated Area Mean
Nitrogen	%	2.2	2.7
Phosphorus	mg/kg	2870	4393
Potassium	mg/kg	5100	5877
Calcium	mg/kg	408	417
Magnesium	mg/kg	1130	1297
Sulfur	mg/kg	1550	1790
Manganese	mg/kg	56	84
Iron	mg/kg	45	63
Cobalt	mg/kg	0.1	0.1
Molybdenum	mg/kg	0.12	0.2
Chloride	mg/kg	733	663

Table 9: Heavy metals in Triticale Grain (dry matter basis)

Heavy metals	Units	Control Area	Treated Area Mean
Arsenic	mg/kg	<10	<10
Cadmium	mg/kg	<0.03	0.04
Chromium	mg/kg	0.3	0.6
Copper	mg/kg	5	5
Lead	mg/kg	<0.01	<0.1
Nickel	mg/kg	0.75	1
Selenium	mg/kg	15	23
Zinc	mg/kg	22	44

Cadmium is one of the few elements in biosolids that can concentrate in cereal crops and reach levels that render the grain unfit for human consumption. To protect human health, a limit of 0.1 mg/kg has been set in Australia as the maximum limit (ML) for wheat grains in foodstuffs (FSANZ, 2005). Cadmium concentration in the grain is shown in Table 9. The results indicate that the human health limit level is not exceeded.

Potassium, Sulphur and Zinc are observed to be higher in the **Straw** grown in biosolids treated area (Table 10).

Table 10: Mineral nutrient in the Triticale Straw (As Feed)

Mineral Nutrients	Units	Control Area	Treated Area Mean
Nitrogen	mg/kg	0.4	0.4
Phosphorus	mg/kg	505	431
Potassium	mg/kg	6730	12457
Calcium	mg/kg	1520	1270
Magnesium	mg/kg	682	487
Sulfur	mg/kg	603	740
Manganese	mg/kg	83	89
Iron	mg/kg	56	47
Zinc	mg/kg	8	25
Chloride	mg/kg	1183	1474

Feed Quality – Hay, Silage, Grain and Straw

Inadvertently, the crop in the control area was packed for silage prior to the collection of hay sample. The hay harvested from treated area were not provided for silage. Therefore there was no hay sample available from the control area and no silage sample was available from the treated area for a comparitive assessment .

However, feed tests and mineral content data for **silage** (Table 11) and **hay** (Table 12) are still considered useful for future comparison with silage and hay produced from the biosolids treated crops.

Feed quality data for the grain is shown in Table 13. An increase in crude protein and a decrease in starch was noted in the **grain** harvested from the biosolids treated area (Table 13).

Average grain crude protein (% as Feed) for four Triticale varieties (Abacus, Madonna, Tahara and Credit) in Australia is reported to be 11.1 % (van Barrneveld, 2001).

Furthermore, King (2010) reported that the average crude protein (% as Feed) of Triticale grain (12.9%) is higher when compared to that of other major cereal grains used in livestock feeding in Australia. In this study, 2% more protein was observed due to biosolids application compared to the control (Table 13). This should be of notable interest to livestock nutritionists.

It is considered that lower starch content in the grain from biosolids treated area is advantageous for ruminants. Starch from cereal grain is hydrolysed rapidly in the rumen, which may adversely affect rumen function and cause subacute ruminal acidosis (King, 2010).

Table 11: Feed value attributes and mineral nutrients in the Triticale Silage (As Feed) in the Control Area (Site 1)

Parameter	Units	Control Area
Dry matter	%	32
Metabolizable Energy (ME)	MJ/kg	3
Relative Feed Value (RFV)		88
Neutral Detergent Fibre (NDF)	%	20
Acid Detergent Fibre (ADF)	%	12
Crude protein	%	3.5
Starch	%	0.7
Ammonia % Crude protein	%	1
Ammonia % Total nitrogen	%	6.4
Nitrogen	%	1.7
Phosphorus	mg/kg	3150
Potassium	mg/kg	20200
Calcium	mg/kg	3340
Magnesium	mg/kg	2140
Sulfur	mg/kg	2670
Manganese	mg/kg	252
Iron	mg/kg	170
Zinc	mg/kg	22
Chloride	mg/kg	7302

Feed value attributes for the Triticale stalk did not vary between the biosolids treated and the control areas (Table 14).

Table 12: Feed value attributes and mineral nutrients in the Triticale Hay (As Feed) in the biosolids Treated Area (Site 1)

Parameter	Units	Treated Area
Dry matter	%	87
Metabolizable Energy	MJ/kg	7
Relative Feed Value		90
Neutral Detergent Fibre	%	53
Acid Detergent Fibre	%	34
Crude protein	%	3.5
Starch	%	1
Nitrogen	mg/kg	1.8
Phosphorus	mg/kg	3280
Potassium	mg/kg	18200
Calcium	mg/kg	3200
Magnesium	mg/kg	2130
Sulphur	mg/kg	2900
Manganese	mg/kg	202
Iron	mg/kg	93
Zinc	mg/kg	32
Chloride	mg/kg	6272

Table 13: Feed value attributes of Triticale Grain (As Feed)

Feed Value Attribute	Units	Control Area	Treated Area Mean
Metabolizable Energy (ME)	MJ/kg	11.2	11.3
Neutral Detergent Fibre (NDF)	%	18.7	17.0
Acid Detergent Fibre (ADF)	%	3.6	3.1
Crude protein	%	9.7	11.7
Starch	%	53.2	48.2
Lysine	%	0.4	0.4
Methionine	%	0.2	0.2

Table 14: Feed value attributes of Triticale Straw (As Feed)

Feed Value Attributes	Units	Control Area	Treated Area Mean
Dry matter	%	91	93
Metabolizable Energy (ME)	MJ/kg	4.8	4.6
Relative Feed Value (RFV)		44	40
Neutral Detergent Fibre (NDF)	%	81	81
Acid Detergent Fibre (ADF)	%	55	61
Crude protein	%	3	3

CONCLUSIONS

Biosolids application increased nutrient concentration in the soil. The concentrations of contaminants in the biosolids applied soil were below the Receiving Soil Contaminant Limits. Nutrients in herbage and grain under biosolids treatment increased in comparison with the control. Overall biosolids improved feed grain quality.

There appears to be a number of benefits of biosolids application on soil, plant and feed. Further studies are needed in order to assess other possible positive impacts of biosolids under "real farming conditions" to establish a solid biosolids market for future.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance provided by the following personnel in the preparation of this manuscript:

George Croatta and Ron Walsh, both from Department of Primary Industries (DPI Werribee);

Nicole Cooper from Western Water;

Dominic Flanagan from L.V. Rawlinson & Associates, Transpacific Industries Group Ltd.

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