REGIONAL BIOSOLIDS STRATEGY

LOWER NORTH ISLAND

Report 10: Biosolids Processing Trials;

Biosolids Field Trial Final Report

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Ministry for the Environment

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1 EXECUTIVE SUMMARY

Background

The MfE Waste Minimisation funded project "Collective Biosolids Strategy – Lower North Island" is taking a collaborative approach to the issue of sludge management. Together with the Project Team ((Lowe Environmental Impact (LEI), Massey University and Institute of Environmental Science and Research Ltd (ESR)) a collective of ten New Zealand territorial authorities are working in partnership to develop a regional biosolids strategy with a focus on beneficial end-use.

Biosolids (and sludges) are rich in carbon, nitrogen, phosphorous and essential micronutrients (e.g. zinc) and therefore have the potential to improve crop/pasture performance. This report describes the setup and results of a field trial to explore the use of municipal wastewater sludge (sludge) as a soil conditioner for application to crops not intended for direct human consumption.

Aims

This trial aims to explore the potential use of sludge as a soil conditioner by assessing the growth response of three grazing crops: Oats, Italian Ryegrass and existing pasture grown in municipal wastewater treatment sludge amended soil.

Trial

The trial was located at Massey University's Sheep, Beef and Deer Research Unit, where thirty-six plots of 1 m² each were established containing three forage crops grown in four treatments:

- Control (C) – no treatment applied;
- Fresh digested sludge (B);
- Pond sludge (P); and
- Diammonium phosphate fertiliser (F).

The trial was regularly maintained and monitored and ran for 5 months. At the end of the experiment soil and herbage was analysed for a variety of chemical and biochemical parameters and biomass production of each crop was quantified.

Results

The results indicated that the application of Fresh Sludge or Pond Sludge increased the growth of pasture and ryegrass compared with inorganic fertiliser, particularly toward the end of the trial. This is likely attributed to the increased supply of slow release nitrogen and phosphorous in sludge products.

Although trace elements were present in both crops (Zn and Mo), and soils (Cr, Zn, and Pb), the resulting concentrations were within the normal range, and do not present a risk for cattle, sheep or ecological parameters of the soil.

The numbers of *E. coli* in the soil after the 6-month period of the experiment were below 100 MPN/g DW and therefore within the limit (< 100 MPN/g) considered to be safe for public.

2 INTRODUCTION

2.1 Background

More than 320,000 tonnes of wastewater treatment plant solids are produced every year in New Zealand. Most of this sludge ends up in landfills, not considered a long-term management option due to increased levies, space requirements and transportation distances. In addition, Government policy and community expectations now focus on the development of sustainable use options.

The MfE Waste Minimisation funded project "Collective Biosolids Strategy – Lower North Island" is taking a collaborative approach to the issue of sludge management. Together with the Project Team ((Lowe Environmental Impact (LEI), Massey University and Institute of Environmental Science and Research Ltd (ESR)), a collective of nine New Zealand territorial authorities are working in partnership to develop a regional biosolids strategy with a focus on beneficial end-use. The project focus is on smaller councils that may otherwise be unable to fund such investigations and/or solutions individually.

An initial stock-take and gaps analysis determined the scale of the current sludge problem for each district; this information has been used to determine potential collective solutions including processing, end-uses, consenting and stakeholder engagement processes. The outcome of the project aims to provide a 'tool box' of different scenarios in the form of a model of operation that can be applied in other regions around New Zealand.

The Project Team have organised the work into project Activities and Tasks. One of which is Activity 1: Biosolids Processing Trials; testing the feasibility of a selection of potential use option through on ground application (research trials) and desktop feasibility/cost analysis. The three research trials include:

- A large-scale sludge composting trial;
- In laboratory testing of the feasibility for using biosolids/sludges in seedling growth media; and
- A grazing crop field trial using oats, Italian ryegrass and pasture.

These trials may serve to confirm the practical and/or technical viability of some scenarios being considered prior to the completion of the final Strategy document. This report outlines the set up and results of the grazing crop field trial.

The quality of wastewater solids (sewage sludge) is highly variable, ranging from raw sludge to more processed sludges which are often termed 'biosolids'. The broad term ww solids refers to the solid waste produced as a by-product of municipal wastewater treatment (sewage sludge). The 'Guidelines for the Safe Application of Biosolids to Land' define Biosolids as sewage sludges (or sewage sludges mixed with other materials) that have been treated and/or stabilised to the extent that they are able to be safely and beneficially applied to land (NZWWWA, 2003). This determination is based on criteria outlined within the guidelines. The terminology used in this report defines biosolids and sludges according to these criteria.

2.2 Scope

As part of the strategy development Council Partners expressed interest in better understanding the potential end-use options for sludges and biosolids in their region. There are several options for reuse of sludges and biosolids within the lower North Island and many promote sustainable waste management and support Government strategies. These options include:

- Forestry (natives and exotics);
- Drystock (sheep and beef) Farms;
- Improving non-productive land;
- Arboriculturists (tree and shrub nurseries)
- Municipal Landscaping; and
- Road Corridors.

Previous work by the project team has highlighted the complex nature of sludge and biosolids re-use options both from a cultural and consenting perspective. Previous research and surveys indicate that application of sludges and biosolids to land that will be used to produce food crops such as fruit and vegetables, is not supported by local communities or iwi.

As such, this trial aims to explore the use of sludges as a soil conditioner, for application to grazed crops not intended for direct human consumption such as ryegrass, oats and pasture. Sludges are rich in carbon, nitrogen, phosphorous and essential micronutrients (e.g. zinc) and therefore have the potential to improve crop/pasture performance.

The trial design is based around two potential biosolids re-use scenarios:

1. Drystock Farms

Low intensity farming operations occurring on marginal land could benefit from sludge and biosolids application. Typically, this land is used for extensive beef and sheep (drystock) farming. The inclusion of recalcitrant organic matter from sludges and biosolids can increase the resilience of this land, and the nutrients supplied can improve pasture performance.

2. Maize silage or green feed crops

Maize silage is commonly used as a supplement to pasture in situations where cows would otherwise be underfed if grazing pasture alone. The application of sludge nitrogen can increase crop yields. Alternatively, oats could be grown, potentially as a winter greenfeed crop.

2.3 Objectives

This trial aims to explore the potential use of sludges as a soil conditioner by assessing the growth response of three grazing crops: Oats, Italian Ryegrass and existing pasture grown in sludge amended soil. The main objectives of this trial are to:

1. Assess the impact on soil fertility during the trial period following application of sludge to land;
2. Test the availability of nutrients for stock ingestion from biomass; and
3. Assess the growth response of winter grown crops intended for animal consumption.

3 METHODS

3.1 Experimental Design

The trial was located at Massey University's Sheep, Beef and Deer Research Unit, 4 km south of Palmerston North (-40.39178333, 175.60709722). An area of 81 m^2 of pasture on Tokomaru silt loam was allocated for this trial. This represented thirty-six plots of 1 m^2 each with an allowance of 0.6 m mowed strip between each plot to prevent cross contamination. The whole area was mowed prior to trial establishment but not sprayed.

Three forage groups were used for this trial: Milton Oats (O), Winter Star Italian Ryegrass (IR) and the current Pasture (CP). Four treatments, each with three replicates, were used to assess nutrient content and growth of each forage variety:

1. Control (C) – no treatment applied;
2. Fresh digested sludge (B) – applied to the surface of the current pasture plots and dug into the cultivated plots;
3. Pond sludge (P) - applied to the surface of the current pasture plots and dug into the cultivated plots; and
4. Diammonium phosphate inorganic fertiliser (F) - applied to the surface of the current pasture plots and lightly raked over the cultivated plots.

Plots were then randomly selected for forage and treatment type (Figure 3.1). Each plot was then marked out and the respective O and IR plots were rotary hoed to represent cultivation and allow sowing of seed.

Figure 3.1: Field Trial Layout

3.1.1 Soil and Sludge Testing

Prior to trial establishment a bulk soil sample of the trial location was collected for analysis. A total of 10 soil cores (150 mm x 20 mm corer) were collected along a transect line across the plots, mixed and sent to Hills Laboratory (chemical) and ESR (Kenepuru, biochemical) for analyses.

Based on previous analyses of the digested sludge (B) and pond sludge (PS) (moisture content and total nitrogen values), approximately 80 kg of B were collected from the Palmerston North Refuse Station in 15 L sealable buckets and a further 80 kg of PS were collected in sealable buckets from the Bunnythorpe Wastewater Treatment Plant. This represented an approximate amount required to spread over the respective plots. Samples were then transported to ESR Kenepuru where each sludge type was homogenised, and a sample taken for analyses.

A second PS sample was collected and analysed on the day of the trial establishment as the initial PS volume collected fell short for the amount required for application to the identified plots due to moisture content values being higher than that initially calculated. Variables measured for each sample and the date sampled are shown in Table 3.1.

Table 3.1: Variables sampled at beginning of trial

Sample Type	Variables Sampled	Date Sampled
Sludge (PS and B)	Heavy Metal Screen: As, Cd, Cr, Cu, Ni, Pb, Zn; Organic Matter, Dry Matter, Ash, Volatile Solids; Total Recoverable: Ca, Mg, P, K, Na; pH, Total Nitrogen, Ammonium-N, Nitrite-N, Nitrate-N, Nitrate-N + Nitrite-N, Total Carbon; Dehydrogenase analysis, E. coli	13 May 2019
Soil	Heavy Metal Screen: As, Cd, Cr, Cu, Ni, Pb, Zn; Organic Matter, Dry Matter, Ash, Volatile Solids; Total Recoverable: Ca, Mg, P, K, Na; pH, Total Nitrogen, Ammonium-N, Nitrite-N, Nitrate-N, Nitrate-N + Nitrite-N, Total Carbon; Dehydrogenase analysis, E. coli Basic Soil: pH, Olsen P, K, Ca, Mg, Na, CEC, base saturation	13 May 2019
2nd Sludge Sample (PS)	Heavy Metal Screen: As, Cd, Cr, Cu, Ni, Pb, Zn; Organic Matter, Dry Matter, Ash, Volatile Solids; Total Recoverable: Ca, Mg, P, K, Na; pH, Total Nitrogen, Ammonium-N, Nitrite-N, Nitrate-N, Nitrate-N + Nitrite-N, Total Carbon; Dehydrogenase analysis, E. coli	22 May 2019

3.1.2 Sowing Rates

Oats (O) and Italian Ryegrass (IR) were sown at a rate that is used for conventional cultivation as outlined in Table 3.2. Seed was spread by hand, raked over and then compacted by foot for each plot respectively.

Table 3.2: Sowing rates for Oats and Italian Ryegrass used for the trial

Species	Sow Rate	Total Area	rate/m²	Total Required
Milton Oats	110kg/ha	12m²	11g/m²	132g
Winter Star Italian Ryegrass	25kg/ha	12m²	2.5g/m²	30g

The current pasture (CP) plots were treated as grazed plots. An estimate of dry matter was taken at trial establishment and 'grazing events' (dry matter analyses and clipping grass on plots) were created throughout the trial.

3.1.3 Treatment Application Rates

Application of the two sludge treatments was based on the New Zealand Biosolids Guidelines (NZWWA, 2003) that states a rate of 200 kg N/ha application could be applied. Table 3.3 outlines the rate of application on a wet weight basis to achieve a 200 kg N/ha value. Sludge was applied to the respective plots using polypropylene jugs and then raked over. This was to ensure an even application over all plots and to reduce any variability as much as possible.

Diammonium phosphate (DAP) was the inorganic fertiliser used for this trial. This was chosen as it is a typical fertiliser of choice by New Zealand Farmers at crop establishment. Rate of application was based on a typical crop establishment rate that allows for approximately 35 kg plant available N/ha.

Table 3.3: Sludge and fertiliser application rates per 1m² plot based on nitrogen and rate applied based on wet weight in kg for sludge and g/m² for fertiliser

Sludge	Application rate	TN	DM	Total Area	Amount Applied/m²	Amount Applied/m²	Total Required
Pond Sludge (PS)	200 kg N/ha	2.3	7.2	9m²	869.57 g dw	12.077 kg ww	108.69 kg ww
Digested Biosolids (B)	200 kg N/ha	3.6	15	9m²	555.56 g dw	3.703 kg ww	33.327 kg ww
DAP Fertiliser N – 17.6 P – 20 K – 0	200 kg DAP /ha	n/a	n/a	9m²	n/a	20 g DAP / m²	180 g

3.2 Trial Monitoring and Maintenance

Growth and plant nutrition

Weekly photos were taken to assess growth and changes between plots after trial establishment (see Appendix A). Six weeks post trial establishment dry matter (DM) analyses were completed for the nine (9) CP plots (02/07/2019). Three samples were taken per plot using a quadrat measuring 0.2 x 0.5 m (0.1 m²) and electric clippers to approx. 20 mm height (Figure 3.2.1). The CP plots were then mowed to reflect a 'grazing event'. The remaining clippings were removed from the plots and disposed. Samples were transported to ESR Kenepuru where they were analysed for DM.

Figure 3.2.1. Quadrat sampling of pasture plots. Phots taken on 2 July 2019 during 6 week simulated grazing event.

Weeding

Removal of weeds was by hand and spot spray using 'Kiwicare Weed Weapon' (7.2 g/L Glyphosate and 0.07 g/L Saflufenacil). Initial weeding took place on 15 July (2019) and was undertaken to minimise contamination of the O and IR plots.

3.3 Trial Harvest

The final sampling of soil and herbage occurred on 14 October, marking 21 weeks since establishment.

Figure 3.3.1. Overview of the field trial (left) and team collecting grass samples during the last harvest (right). Pictures taken on 14 Oct 2019 after 21 weeks of growth.

3.3.1 Sample Collection

Samples of soils and herbage were collected from the field site on 21 weeks since establishment (14/10/2019). Only Italian Ryegrass and Pasture plots were sampled on that day. In total, 12 plots planted with Pasture and 11 plots planted with Italian Ryegrass were sampled. From each plot (1 x 1 m), 10-12 soil cores were collected using a 100 mm soil core sampler (35 mm width) from areas representative of the whole plot. A depth of 100 mm was chosen to reflect the depth to which sludge was initially dug into the soil. Samples were transported the same day of sampling in labelled zip-lock bags in a chilly bin to ESR laboratory.

Plant material was collected from the Pasture and Italian ryegrass plots using electric clippers at 20 mm from the ground, using a quadrat frame 0.2 x 0.5 m (0.1 m^2). Two to three quadrants per plot were collected depending on growth, and all plant material were transported in zip-lock bags to ESR laboratory on the same day of collection.

3.3.2 Sample Processing

Soils samples were stored at 4 °C until processing. Soil was homogenized by kneading each sample thoroughly. Unwanted loose grass and earthworms were removed. Aseptic conditions were maintained during the process by using ethanol sterilized trays and new gloves for each sample.

Herbage samples were placed in a drying oven at 60 °C and dried until there was no noticeable change in weight. A representative aliquot of each soil sample was sent to Hills Laboratory within 24hrs of collection, while herbage samples were submitted to Hills Laboratory when drying was complete.

3.3.3 *Escherichia coli* most probable number

The number of *E. coli* in the soils was enumerated using a standard 5-tube MPN analysis (APHA, 1998). The results were calculated in MPN per gram of 104 °C dry soil.

3.3.4 Dehydrogenase Activity and Moisture Content

Within 48 hrs of sample collection, samples were analysed for moisture content and dehydrogenase activity (DHA). Moisture was determined by loss of weight of the homogenised fresh sample after drying at 104 °C for 24 hrs or when the weight of the soil has stabilised.

Dehydrogenase activity was determined by the reduction of 2,3,5 – triphenyltetrazolium chloride (TTC) to triphenylformazan (TPF) as described in Wong and Fang, 2000 and Barrena et al. 2008. Results were expressed in DHA (mg TPF kg^{-1} hr^{-1}) on a dry weight basis.

3.3.5 Data analysis

2-way ANOVA followed by Tukey HSD test was performed for herbage dry weight, DHA values and chemical analyses results for soil and herbage samples. Tests were conducted in R using agricolae package.

4 RESULTS AND DISCUSSION

4.1 Baseline sampling

Baseline data for the sludge samples can be seen in table 4.1.

Table 4.1: Sludge and soil sample baseline results

Paramater	Unit	Pond Sludge	Digested Sludge	Soil
Organic Matter	g/100g dry wt	36.5	64	6.9
Dry Matter	g/100g as rcvd	8.15	15	75
Volatile Solids	g/100g dry wt	36.5	64	6.9
Ash	g/100g dry wt	63.5	36	93
Total Calcium	mg/kg dry wt	10750	15100	2500
Total Magnesium	mg/kg dry wt	2550	1720	830
Total Phosphorus	mg/kg dry wt	4650	16300	750
Total Potassium	mg/kg dry wt	1385	1200	540
Total Sodium	mg/kg dry wt	900	620	126
pH	pH Units	6.925	7.32	5.8
Total Nitrogen	g/100g dry wt	2.3	3.6	0.27
Ammonium-N	mg/kg dry wt	1260	6300	< 5
Nitrite-N	mg/kg dry wt	<7	< 4	< 1.0
Nitrate-N	mg/kg dry wt	<9.6	< 4.6	1.6
Nitrate-N + Nitrite-N	mg/kg dry wt	<7	< 4	1.6
Total Carbon	g/100g dry wt	19.4	29	3
Olsen P	mg/L	-	-	27
Exchangeable K	me/100g	-	-	0.32
Exchangeable Ca	me/100g	-	-	7
Exchangeable Mg	me/100g	-	-	0.89
Exchangeable Na	me/100g	-	-	0.14
CEC	me/100g	-	-	13
Total Arsenic	mg/kg dry wt	13.5	4	< 2
Total Cadmium	mg/kg dry wt	*1.895	0.73	0.16
Total Chromium	mg/kg dry wt	26.5	29	9
Total Copper	mg/kg dry wt	*220	164	4
Total Lead	mg/kg dry wt	68.5	33	7.2
Total Nickel	mg/kg dry wt	16	13	3
Total Zinc	mg/kg dry wt	*1035	680	27
Dehydrogenase enzyme	mg TPF kg^{-1} hr^{-1}	177.08	28.3	4.44
E. coli	MPN/g DW	*4.39×10^4	*1.76×10^7	*5.41×10^4

* exceeds limits for Grade A biosolid

** exceeds limits for Grade B biosolids

The data can be summarised as follows:

- Organic matter is above levels set for compost in New Zealand and indicates both sludges would be adequate for a source of OM (>25%, New Zealand Standard for Composts, Soil Conditioners and Mulches, 2005) for crop growth;
- Total N is considered to be within the normal range for biosolids (1 - 6 %)
- Ammonium-N levels are considered to be high for a mature compost (200 – 500 mg/kg). This could be advantageous for plant growth, however if concentrations exceed the plant requirements there is a risk of conversion of N to more labile forms and subsequent leaching to groundwater or runoff;
- Both nitrite and nitrate levels are considered low, presenting low risk for runoff or leaching of N;
- Levels of total metals in the digested sludge are all within acceptable levels and do not pose a risk with regards to human health. However, both cadmium and zinc in PS are above guideline limits for a grade A biosolid (Guidelines for the Safe Application of Biosolids to Land in New Zealand, NZWWA, 2003);
- Dehydrogenase activity shows greater microbial activity in the digested sludge compared to the pond sludge, whilst both are greater than the existing soil; and
- *E. coli* is above guideline levels for grade A biosolids in both cases so would be classed as grade B;

Due to the classification as Grade B for both the digested and pond sludges used for the experiment, application to land in a regular farm setting will require resource consent which may place restrictions on use such as storage and access restrictions. Based on nutrient content and organic matter both sludges would also be suitable amendments for improving soil fertility.

4.2 Crop growth

Pasture harvested after 6 weeks showed variable growth in control plots (C), however the biomass was significantly higher under fertiliser (F) compared to those amended with sludge (B) or pond sludge (PS) (Figure 4.2.1). In contrast, by the end of the trial (21 weeks after set-up) the pasture and ryegrass production in biosolids treated plots was much higher than in all other treatments (22.7 ± 2.1 g/m^2 for Pasture and 39.4 ± 11.7 g/m^2 for Italian Ryegrass) (Figure 4.2.2).

It was visually evident that there was a higher growth rate of Pasture and Italian Ryegrass amended with sludges compared with fertiliser and control treatments (Figures 4.2.3 - 4.3.6, Appendix A). In addition, dry weight (DW) of the pasture and Italian ryegrass herbage differed between treatment and crops (Figure 4.2.2). The DW for Italian Ryegrass was approximately 1.4 times higher than for Pasture. There was no significant difference between DW of Control, Fertiliser, and Pond Sludge treated plots, however an increase in both for Pond Sludge is noted (Figure 4.2.2). During the final harvest, only samples from Pasture and Italian Ryegrass plots were collected.

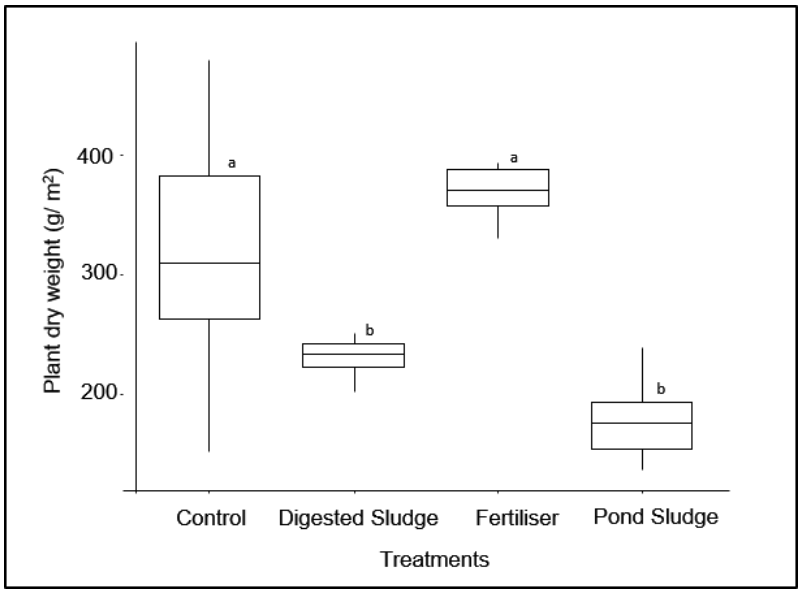


Figure 4.2.1: Dry weight of the harvested herbage of Pasture in Control, Fertiliser, Digested Sludge, and Pond Sludge plots after 6 weeks (July 2019).

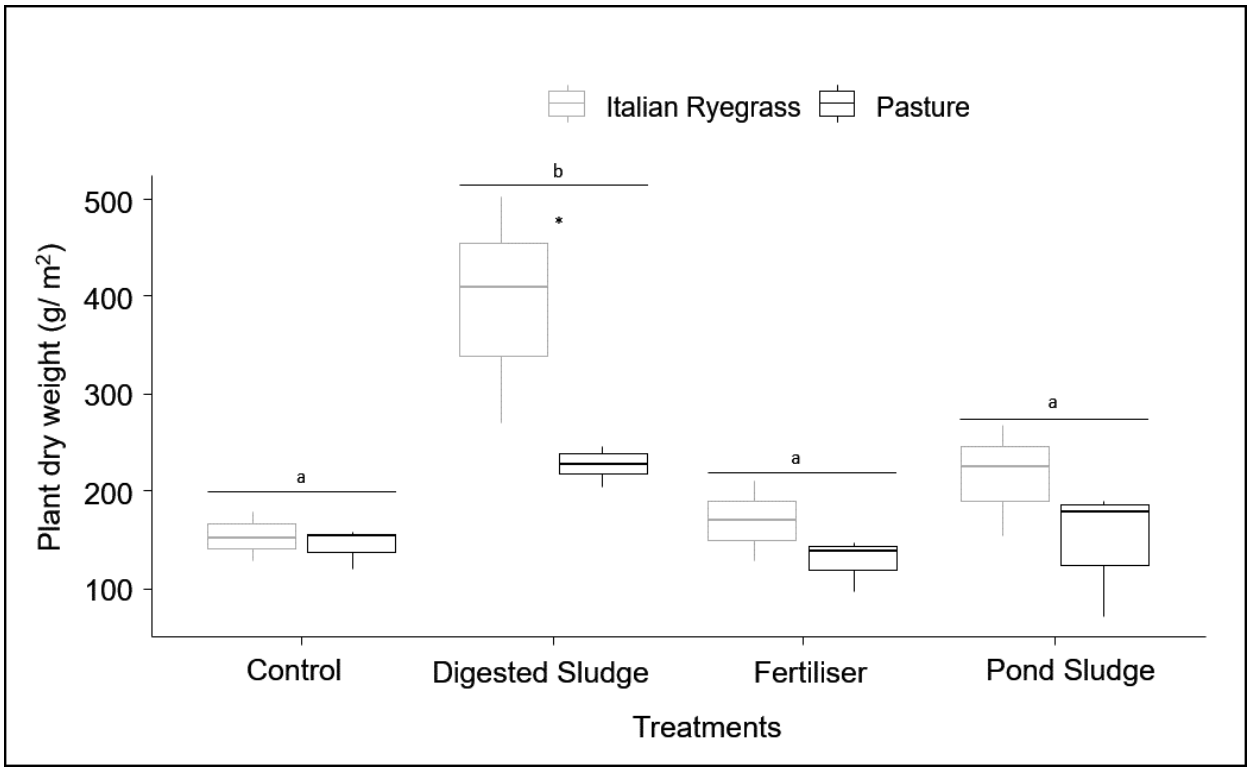


Figure 4.2.2: Dry weight of herbage from Pasture and Italian Ryegrass after 21 weeks. The values plotted are the average of three replicates of each treatment and their standard deviation. Different letters indicate significant differences between treatments ($p < 0.05$). The asterisk (*) indicates significant differences between crops.

Figure 4.2.3: Pasture growth on Digested Sludge compared with DAP fertilizer 21 weeks after amendment (day of final harvest).

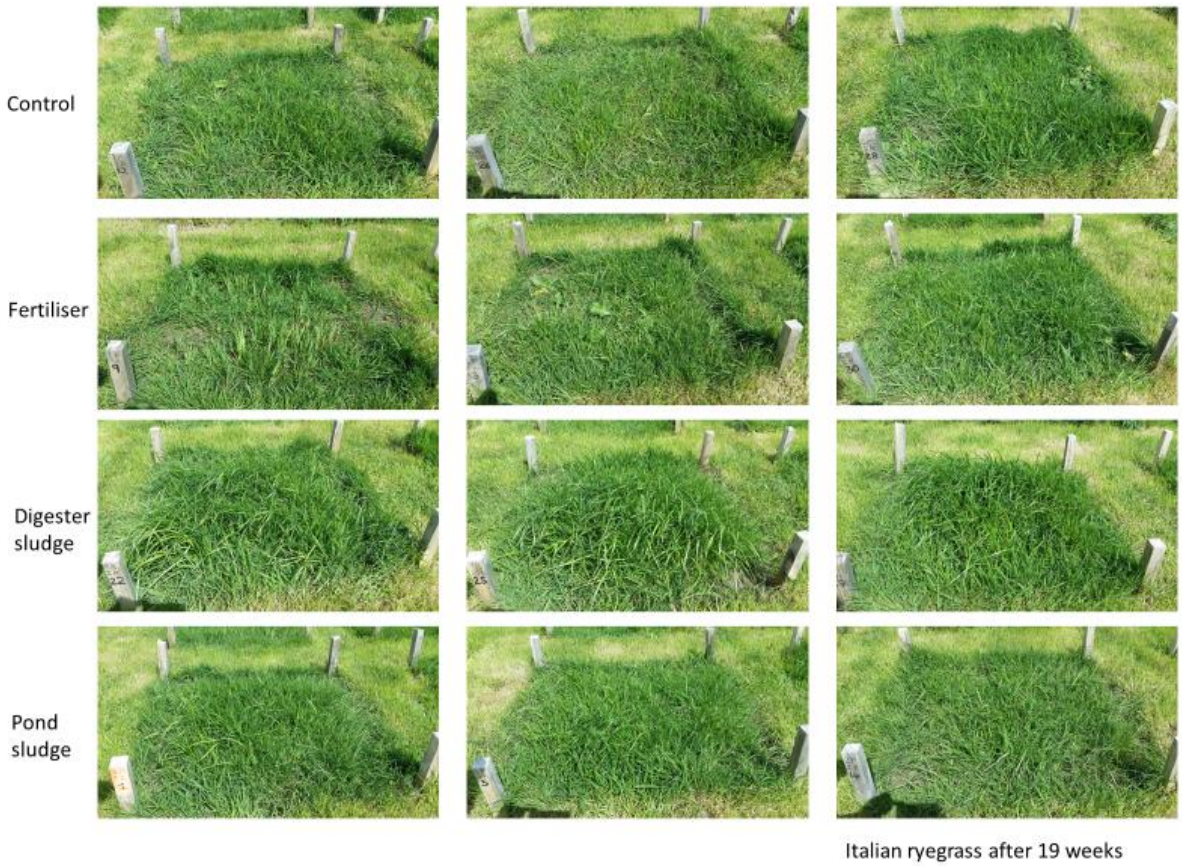


Figure 4.2.4: Italian ryegrass on all treatments after 19 weeks of growth.

Figure 4.2.5: The whole plot after 19 weeks of growth. Markers exhibit Italian ryegrass under Digested Sludge.

4.3 Herbage analysis

For most chemical parameters there was no significant difference between treatment and plant types (Table 4.3.1). The higher input of N and P with Digested Sludge, Pond Sludge and Fertilizer, did not result in an observed elevation of these elements in herbage when compared to controls. This may indicate that these elements are limiting for the growth of pasture and Italian ryegrass, and the uptake is higher due to higher biomass production.

Sulphur (S), calcium (Ca), zinc (Zn) and molybdenum (Mo) values were significantly higher for Digested Sludge and Pond Sludge treated plants compared to Control or Fertiliser. This may suggest these chemicals were more bioavailable in plots amended with Digested Sludge or Pond Sludge, or that these treatments stimulated their uptake (Table 4.4.1). Elevated Zn and Mo in crops growing in Digested Sludge and Pond Sludge amended soil (maximum values, 40 mg Zn/kg, and 2 mg Mo/kg) are within the normal rage for plants (up to 150 mg Zn/kg, up to 3.0 mg Mo/kg, Chaney, 1989), and lower than the maximum levels chronically tolerated by cattle and sheep (300 mg Zn/kg, and 10 mg Mo/kg, Chaney, 1989).

4.4 Soil analysis

4.4.1 Chemical characteristics

The application of Digested Sludge or Pond Sludge did not significantly alter the percentage of carbon, pH or total nitrogen in soil samples. Ammonium levels were higher for soils in plots treated with Biosolid and Pond Sludge and grown with Pasture compared to the control (Table 4.4.1). Total phosphorous and Olsen extractable phosphorous increased in certain treatments with Biosolids, or Fertiliser depending on the crop, with Biosolids producing a significant increase in total P for both pasture and ryegrass (Table 4.4.1).

Soils treated with Biosolids or Pond Sludge exhibited significantly higher concentrations of chromium, copper, lead and zinc compared to Control and Fertiliser (Table 4.4.1). Likely due to the higher concentrations of these contaminants in Biosolids/Sludge than is naturally occurring in the soil. However, the values of these elements in soils are within the lower median range of background concentrations for New Zealand soils[1], and between 2 times lower (for Zn) to 70 times lower (for Pb) than the Eco-SQVs[1] (soil guideline values for the protection of ecological receptors).

[1] Maanaki Whenua. June 2019. UPDATED User Guide: Background soil concentrations and soil guideline values for the protection of ecological receptors (Eco-SGVs) – Consultation draft. Envirolink Grant: C09X1402. http://www.envirolink.govt.nz/assets/R10-4-User-Guide-Background-soil-concentrations-and-soil-guideline-values-for-the-protection-of-ecological-receptors.pdf

Table 4.3.1: Analysis results from herbage samples from Pasture or Italian Ryegrass plots treated with Digested Sludge, Fertiliser or Pond Sludge. Control: no treatment. Average values and standard deviation are presented (n=3). Different letters indicate significant difference ($p < 0.05$) between treatments and/ or herbage type per parameter (see appendix).

Parameter	Unit	Pasture				Italian Ryegrass			
		Control	Digested Sludge	Fertiliser	Pond Sludge	Control	Digested Sludge	Fertiliser	Pond Sludge
Nitrate-N	mg/kg	< 110	< 110	< 110	< 110	< 110	< 110	< 110	< 110
Nitrogen	%	2.27 ± 0.21	2.20 ± 0.00	2.23 ± 0.06	2.23 ± 0.35	2.50 ± 0.10	2.17 ± 0.23	2.10 ± 0.14	2.63 ± 0.25
Phosphorus	%	0.45 ± 0.02	0.47 ± 0.04	0.43 ± 0.03	0.49 ± 0.02	0.43 ± 0.04	0.43 ± 0.02	0.52 ± 0.05	0.43 ± 0.02
Potassium	%	3.53 ± 0.59	3.37 ± 0.86	3.10 ± 0.35	3.83 ± 0.35	3.37 ± 0.12	2.97 ± 0.21	4.05 ± 0.49	3.33 ± 0.32
Sulphur	%	0.25 ± 0.03^{a}	0.26 ± 0.02^{a}	0.23 ± 0.01^{a}	0.41 ± 0.04^{b}	0.25 ± 0.02^{a}	0.23 ± 0.01^{a}	0.26 ± 0.01^{a}	0.35 ± 0.02^{b}
Calcium	%	0.69 ± 0.1^{a}	0.76 ± 0.05^{ab}	0.76 ± 0.02^{ab}	0.80 ± 0.05^{b}	0.70 ± 0.03^{ab}	0.8 ± 0.06^{b}	0.57 ± 0.01^{a}	0.59 ± 0.07^{a}
Magnesium	%	0.22 ± 0.01^{a}	0.24 ± 0.01^{a}	0.21 ± 0.02^{a}	0.23 ± 0.03^{a}	0.19 ± 0.03^{b}	0.21 ± 0.02^{b}	0.20 ± 0.03^{b}	0.18 ± 0.02^{b}
Sodium	%	0.19 ± 0.03	0.20 ± 0.10	0.17 ± 0.06	0.16 ± 0.07	0.10 ± 0.03	0.25 ± 0.05	0.15 ± 0.04	0.14 ± 0.03
Iron	mg/kg	89 ± 12	69.67 ± 3.51	240 ± 263	98 ± 20	80 ± 14	74 ± 21	62 ± 0.7	76 ± 12
Manganese	mg/kg	433 ± 87	333 ± 75	410 ± 70	350 ± 82	277 ± 5.8	290 ± 56	450 ± 268	245 ± 44
Zinc	mg/kg	29 ± 2.1^{a}	34 ±4.36^{ab}	23 ± 0.6^{c}	37 ± 2.1^{b}	26 ± 3.2^{a}	34 ± 3.6^{b}	33 ± 2.8^{b}	37 ± 2.6^{b}
Copper	mg/kg	8.00 ± 1.00	9.00 ± 1.73	7.33 ± 0.58	9.67 ± 1.53	8.33 ± 1.15	8.00 ± 0.00	8.50 ± 0.71	7.67 ± 0.58
Boron	mg/kg	7.00 ± 1.00^{a}	5.67 ± 1.15^{a}	6.00 ± 1.00^{a}	7.33 ± 0.58^{a}	5.00 ± 0.00^{b}	4.67 ± 0.58^{b}	5.50 ± 0.71^{b}	5.00 ± 1.00^{b}
Molybdenum	mg/kg	1.37 ± 0.33^{ab}	1.97 ± 0.23^{c}	1.23 ± 0.07^{ab}	1.42 ± 0.13^{ab}	0.95 ± 0.1^{a}	1.3 ± 0.11^{b}	1.06 ± 0.33^{a}	0.89 ± 0.08^{a}
Cobalt	mg/kg	0.04 ± 0	0.02 ± 0.01	0.07 ± 0.04	0.03 ± 0	0.03 ± 0.01	0.04 ± 0.03	0.02 ± 0.00	0.02 ± 0.01
Selenium	mg/kg	0.02 ± 0.00	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.00	0.02 ± 0.00	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.00

Table 4.4.1: Analysis results from soil samples from Pasture or Italian Ryegrass plots treated with Digested Sludge, Fertiliser or Pond Sludge. Control: no treatment. Average values and standard deviation are presented (n=3). Different letters indicate significant difference ($p < 0.05$) between treatments and/ or herbage type per parameter (see appendix).

Parameter	Unit	Pasture				Italian Ryegrass			
		Control	Digested Sludge	Fertiliser	Pond Sludge	Control	Digested Biosolids	Fertiliser	Pond Sludge
Organic Matter	g/100g dry wt	8.07 ± 0.49[a]	8.33 ± 0.25[a]	8.23 ± 0.23[a]	8.13 ± 0.32[a]	7.63 ± 0.06[b]	8.10 ± 0.26[b]	7.80 ± 0.14[b]	7.90 ± 0.26[b]
Dry Matter	g/100g as rcvd	66 ± 3.8	66 ± 2.00	66 ± 1.15	67 ± 1.53	68 ± 1.15	72 ± 2.3	69 ± 0.0	68 ± 2.0
Ash	g/100g dry wt	92 ± 0.0	92 ± 0.58	92 ± 0.0	92 ± 0.6	92.00 ± 0.00	92.00 ± 0.00	92 ± 0.0	92 ± 0.0
pH	-	5.77 ± 0.06	6.03 ± 0.12	5.87 ± 0.21	5.83 ± 0.12	6.00 ± 0.17	5.83 ± 0.21	5.70 ± 0.14	5.80 ± 0.10
Total C	g/100g dry wt	3.47 ± 0.25	3.60 ± 0.10	3.47 ± 0.12	3.57 ± 0.12	3.17 ± 0.06	3.43 ± 0.21	3.25 ± 0.07	3.43 ± 0.12
Total Mg	mg/kg dry wt	773 ± 31	787 ± 15	750 ± 46	810 ± 78	783 ± 49	793 ± 32	705 ± 7.1	753 ± 31
Total P	mg/kg dry wt	723 ± 23[a]	863 ± 60[b]	777 ± 15[a]	743 ± 21[a]	700 ± 26[a]	830 ± 36[b]	760 ± 14[a]	730 ± 44[a]
Total N	g/100g dry wt	0.29 ± 0.02	0.30 ± 0.01	0.30 ± 0.02	0.30 ± 0.01	0.28 ± 0.01	0.30 ± 0.00	0.29 ± 0.01	0.30 ± 0.01
Ammonium-N	mg/kg dry wt	< 5.00	9.5 ± 0.71	6.67 ± 0.58	7.00 ± 0.00	6.00 ± 0.50	< 5.00	< 5.00	< 5.00
Nitrite-N	mg/kg dry wt	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00
Nitrate-N	mg/kg dry wt	< 1.50	< 1.50	< 1.50	< 1.50	< 1.50	< 1.50	< 1.50	< 1.50
Nitrate-N + Nitrite-N	mg/kg dry wt	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00
Olsen P	mg/L	37 ± 8.5[a]	47 ± 6.6[b]	46 ± 4.7[b]	33 ± 4.4[a]	32 ± 6.0[a]	41 ± 4.7[ab]	47 ± 9.9[b]	35 ± 3.5[a]
Exch. K	me/100g	0.33+0.50	0.33+0.70	0.35+0.95	0.34+0.32	0.31+0.49	0.27+0.97	0.28+0.78	0.32+0.68
Exch. Ca	me/100g	5.63+0.15	6.87+0.05	6.43+0.05	7.13+0.06	6.73+0.05	6.27+0.10	5.75+0.04	6.77+0.03
Exch. Mg	me/100g	1.06+0.02	1.05+0.02	1.03+0.01	1.03+0.01	0.91+0.01	0.86+0.02	0.82+0.00	1.01+0.01
Exch. Na	me/100g	0.11+1.00	0.10+1.00	0.11+0.00	0.10+0.58	0.10+0.58	0.09+0.58	0.07+0.71	0.10+0.58
CEC	me/100g	14.0 ± 1.00	13.0 ± 1.00	14.0 ± 0.00	14.3 ± 0.58	13.7 ± 0.58	13.3 ± 0.58	12.5 ± 0.71	14.3 ± 0.58
Total Base Saturation	%	51.33 ± 2.52	63.00 ± 1.00	56.00 ± 5.57	60.33 ± 4.04	60.00 ± 4.36	56.67 ± 5.86	55.00 ± 2.83	59.00 ± 3.61

Table 4.4.1. continued.

Parameter	Unit	Pasture				Italian Ryegrass			
		Control	Digested Sludge	Fertiliser	Pond Sludge	Control	Digested Sludge	Fertiliser	Pond Sludge
Total As	mg/kg dry wt	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00	< 2.00
Total Cd	mg/kg dry wt	0.15 ± 0.01	0.17 ± 0.01	0.16 ± 0.02	0.16 ± 0.01	0.15 ± 0.01	0.15 ± 0.02	0.15 ± 0.01	0.16 ± 0.03
Total Cr	mg/kg dry wt	8.00 ± 0.00^{a}	8.67 ± 0.58^{b}	8.00 ± 0.00^{a}	8.3 ± 0.58^{ab}	8.0 ± 0.00^{a}	9.0 ± 0.00^{b}	8.0 ± 0.00^{a}	8.3 ± 0.58^{ab}
Total Cu	mg/kg dry wt	4.33 ± 0.58^{a}	6.00 ± 0.00^{b}	4.67 ± 0.58^{a}	6.00 ± 0.00^{b}	4.67 ± 0.58^{a}	6.33 ± 0.58^{b}	4.00 ± 0.00^{a}	6.33 ± 0.58^{b}
Total Pb	mg/kg dry wt	6.7 ± 0.15^{ab}	6.8 ± 0.06^{ab}	6.6 ± 0.25^{a}	7.2 ± 0.29^{c}	6.8 ± 0.06^{ab}	7.1 ± 0.36^{bc}	6.50 ± 0.14^{a}	7.30 ± 0.17^{bc}
Total Ni	mg/kg dry wt	3.0 ± 0.00	3.0 ± 0.00	3.0 ± 0.00	3.0 ± 0.00	3.0 ± 0.00	3.3 ± 0.58	3.0 ± 0.00	3.0 ± 0.00
Total Zn	mg/kg dry wt	30 ± 3.8^{a}	37 ± 3.0^{b}	29 ± 3.8^{a}	37 ± 3.8^{b}	28 ± 1.0^{a}	36 ± 4.0^{b}	26 ± 2.1^{a}	39 ± 2.1^{b}

4.4.2 Dehydrogenase Activity (DHA)

Soil from under Pasture and Italian Ryegrass, treated with Pond Sludge and Digested Sludge exhibited higher DHA levels compared to Control and Fertiliser however this difference was not significant (Figure 4.4.2), however this difference was not significant (see ANOVA results in Appendix).

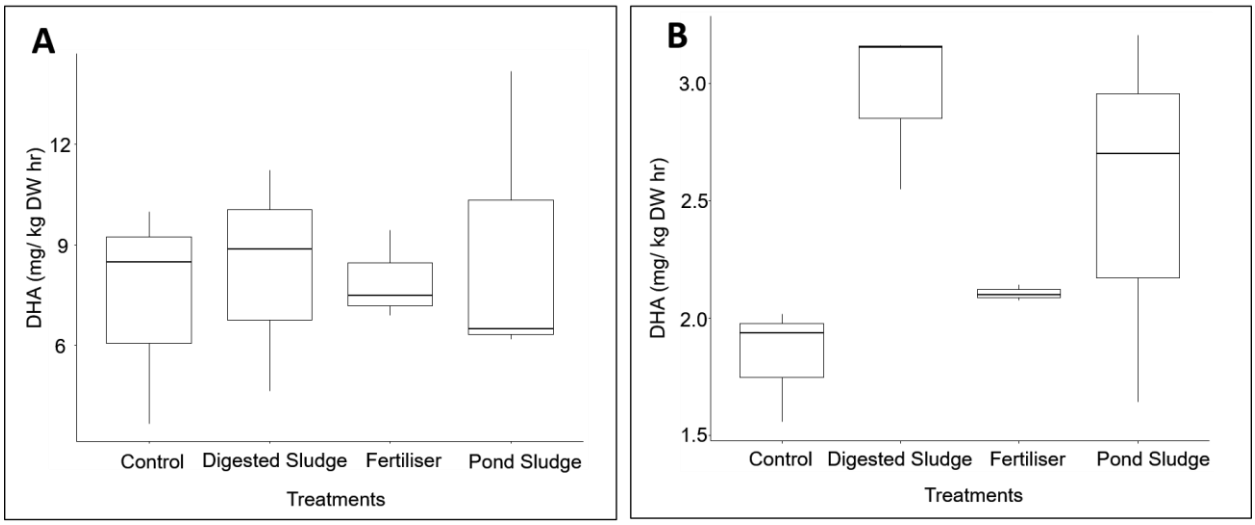


Figure 4.4.2: Dehydrogenase Activity of the soils from Pasture and Italian Ryegrass plots treated with Fertiliser, Digested Sludge or Pond Sludge, and non-treated Control. Average of the three replicates of each treatment and Standard Deviation are presented in the graph (n = 3).

4.4.3 *E. coli* enumeration

Detected *E. coli* numbers between treatments and crops were similar and mostly below values of <30 MPN/ g DW, well within the limit (<100 MPN/g) considered to be safe for public use as stated in the New Zealand Biosolid Guidelines.

4.5 Limitations of results

In spite of efforts to minimise weeds the oats plots suffered significant encroachment from the existing pasture which was not successfully eliminated at the beginning of the trial. Italian ryegrass also had contamination with weeds, however this was considered minimal.

Significant rain events in the week of the 29th July caused ponding on site. In addition, there was a brief grazing event by sheep (26/07/2019) which impacted the consistency of growth on the 12 oats plots. As a result of these events a significant proportion of the oats treatment plots had weak germination/growth and were subsequently contaminated by weed growth and deemed unreliable for analysis (Figure 4.5.1).

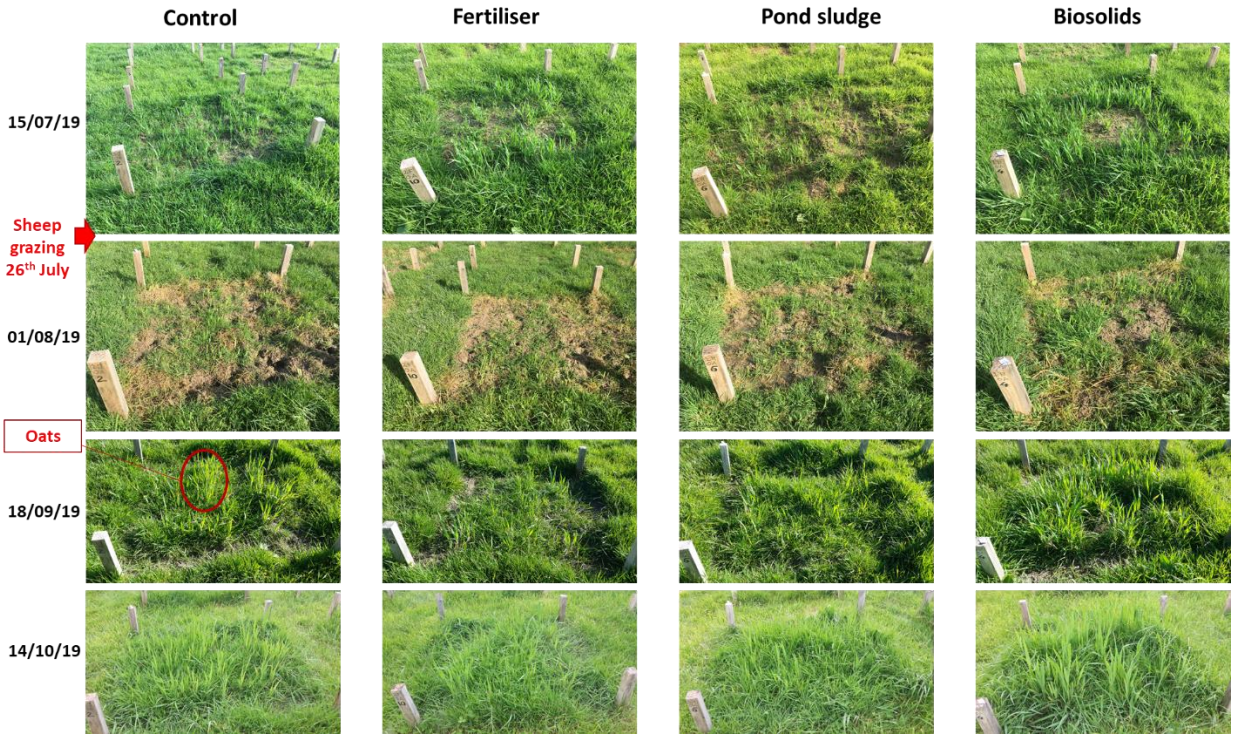


Figure 4.5.1: The progression of oats growth over 5-month under control, fertiliser, pond sludge and digested sludges.

5 CONCLUSIONS

Digested Sludge and Pond Sludge increased the growth of pasture and ryegrass over the 5 month growing period compared with fertiliser, which only produced a better growth response in the first month after application. This is attributed to increased supply of slow release nitrogen and phosphorous contained in the biosolids/sludge, which seemed to be the limiting nutrients for these crops.

Although trace elements are present in both crops (Zn and Mo), and soils (Cr, Zn, and Pb), the resulting concentrations are within the normal values for plants and soils, and do not present a risk for cattle, sheep or ecological parameters of the soil.

The numbers of *E. coli* in the soil after the 5-month period of the experiment were very low, at <100 MPN/g DW.

Results of this experiment indicate that:

1) Soil fertility is improved following the application of sludges by:
   a) Potentially increased microbial activity as exhibited by DHA;
   b) Increased concentrations of Olsen and total P when fresh Digester Sludge is applied, that is equivalent or greater than inorganic DAP fertiliser. This was not observed with aged Pond Sludge; and
   c) Increased concentrations of trace elements, in the case of this experiment concentrations were equivalent to background levels in soils however the source of sludge used would heavily influence this.
2) No significant change is observed to nutrient content of plant biomass, indicating nutrients for stock ingestion are at the same levels as that for crops grown using traditional fertilisers; and
3) The application of both Digested Sludge and Pond Sludge improve crop productivity.
   a) Observed both visually and through DM yields that were greater than that observed under traditional fertiliser and control after five months.

It has been determined that the use of sludge as a soil conditioner, for application to crops not intended for direct human consumption such as ryegrass, oats and pasture is a viable means to increase crop growth.

6 REFERENCES

Barrena R, Vázquez F, Sánchez A. 2008. Dehydrogenase activity as a method for monitoring the composting process. Bioresource Technology, 99: 905-908.

Chaney, R. L. (1989). Toxic element accumulation in soils and crops: protecting soil fertility and agricultural food-chains, in Inorganic Contaminants in the Vadose Zone, eds B. Bar-Yosef, N. J. Barrow, and J. Goldshmid (Berlin: Springer), 140–158.

Wong JWC, Fang M. 2000. Effects of lime addition on sewage sludge composting process. Water Research, 34 (15): 3691-3698.

7 APPENDICES

Appendix A. Photographs of Forage Growth Over Five Month Trial Period
Appendix B. Statistical Analysis Report - R Agricolae Package

APPENDIX B

Photographs of Forage Growth Over Five Month Trial Period

12/06/2019 – 3 weeks post set-up

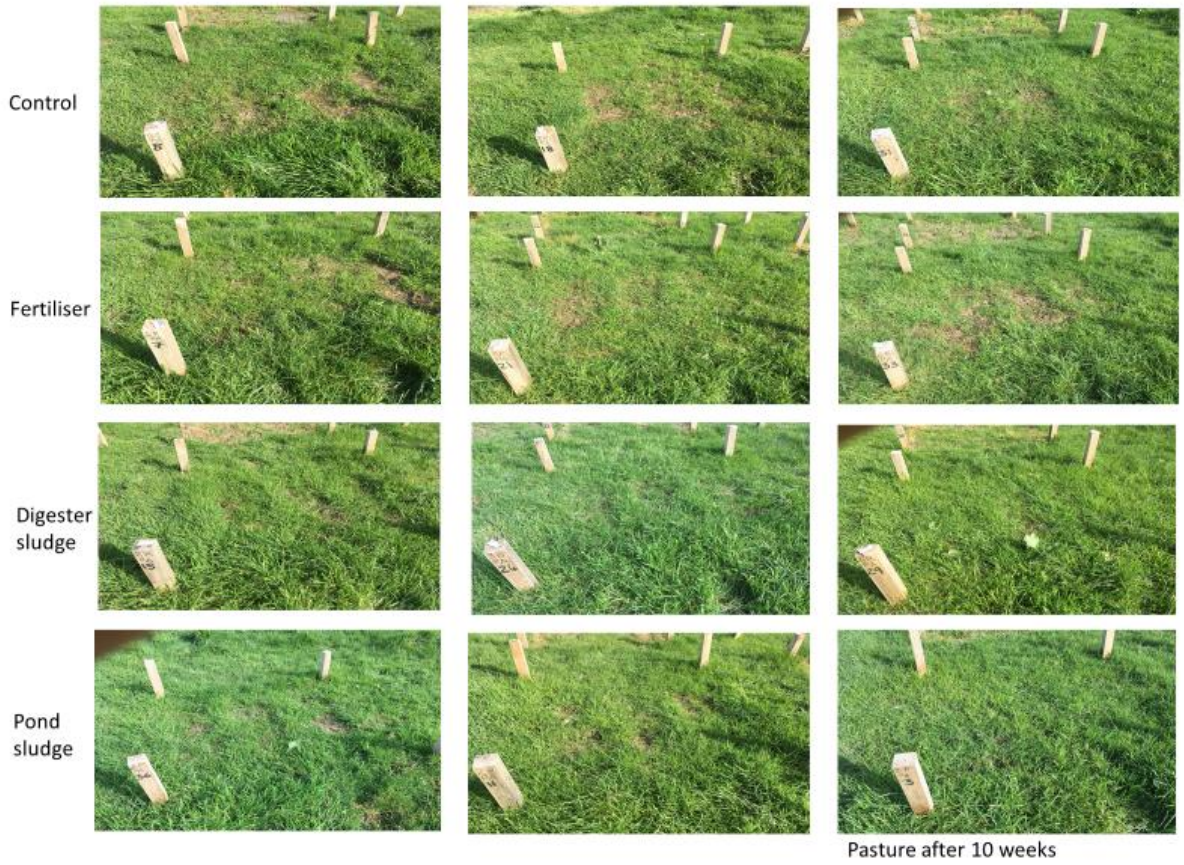
15/07/2019 – 8 weeks post sowing

Italian ryegrass after 8 weeks

Pasture after 8 weeks

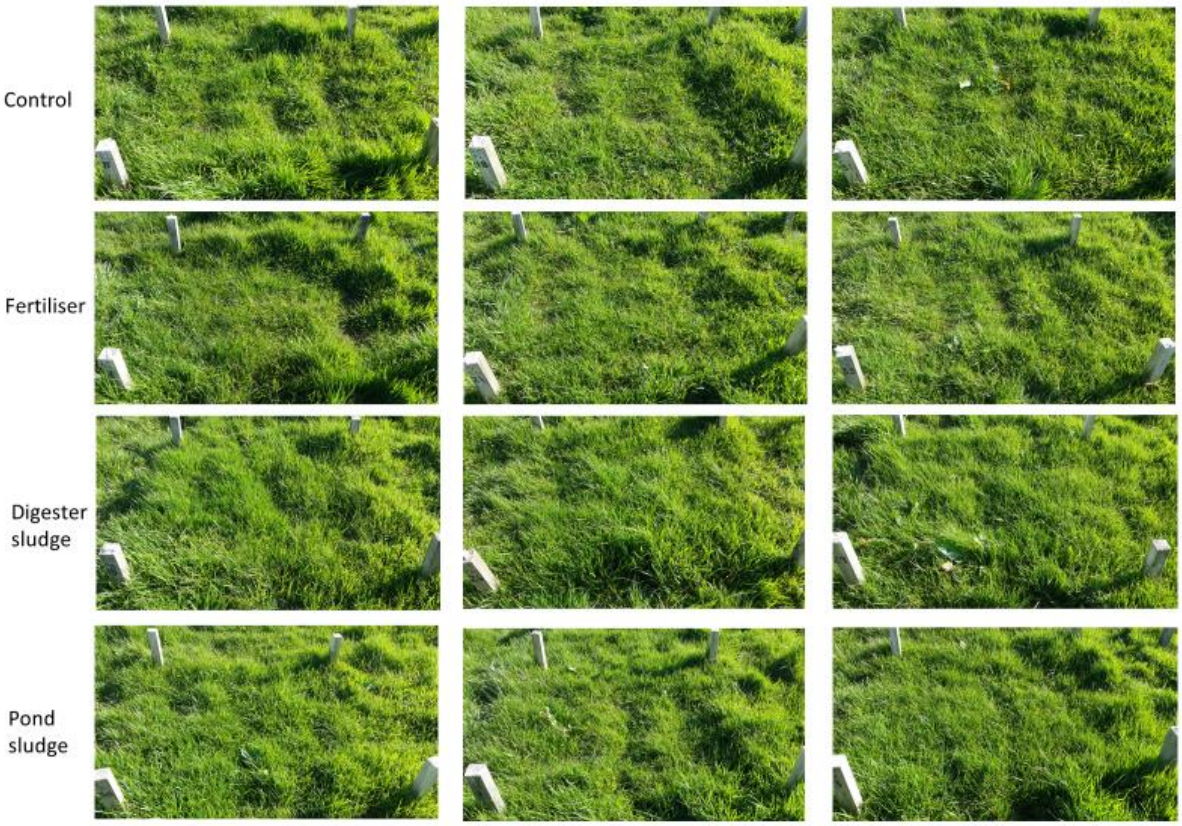
01/08/2019 – 10 weeks post sowing

Italian ryegrass after 10 weeks

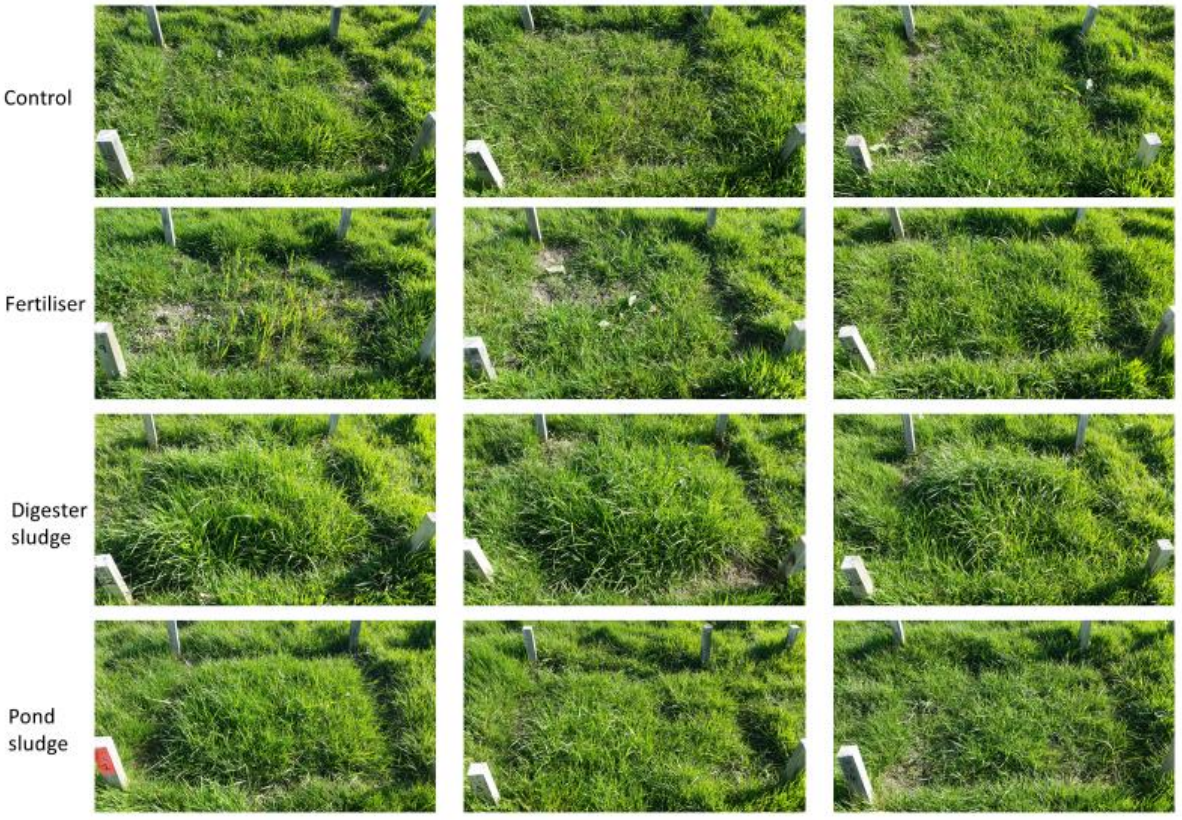


Pasture after 10 weeks

18/09/19 – 17 weeks post sowing

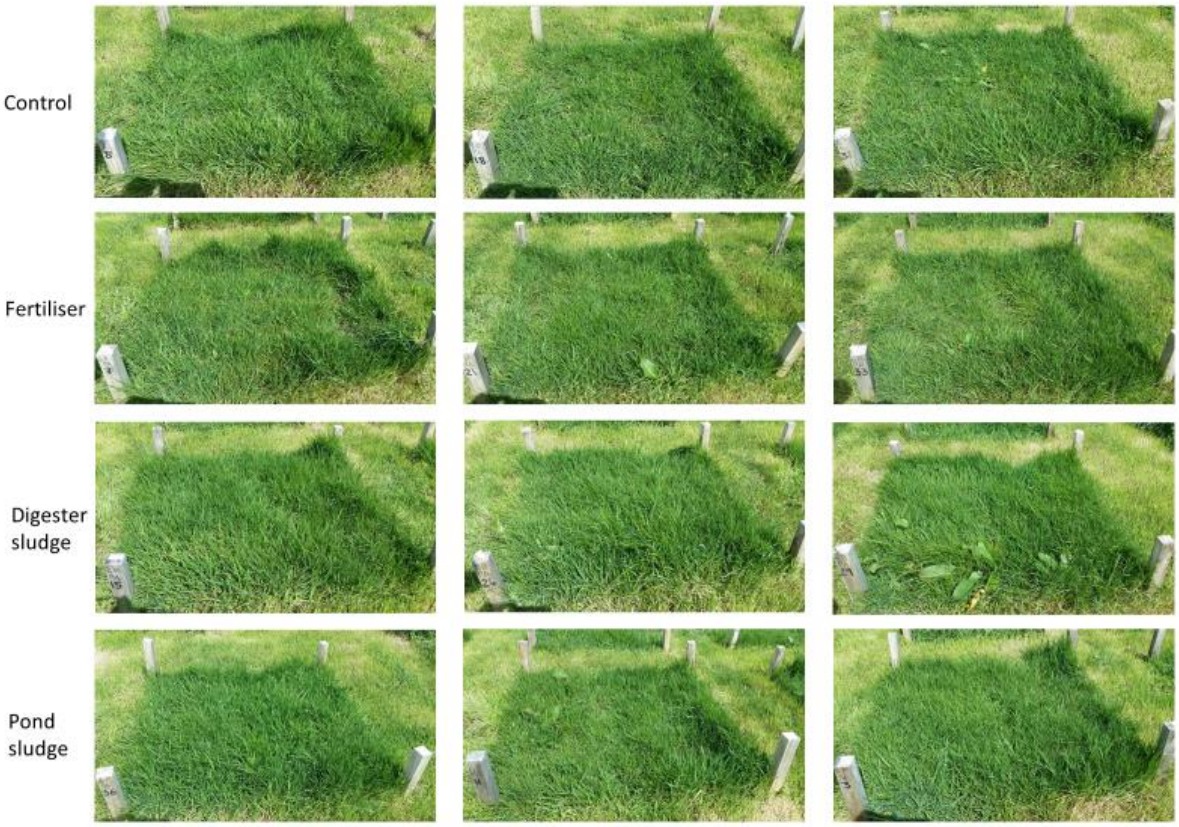


Pasture after 17 weeks

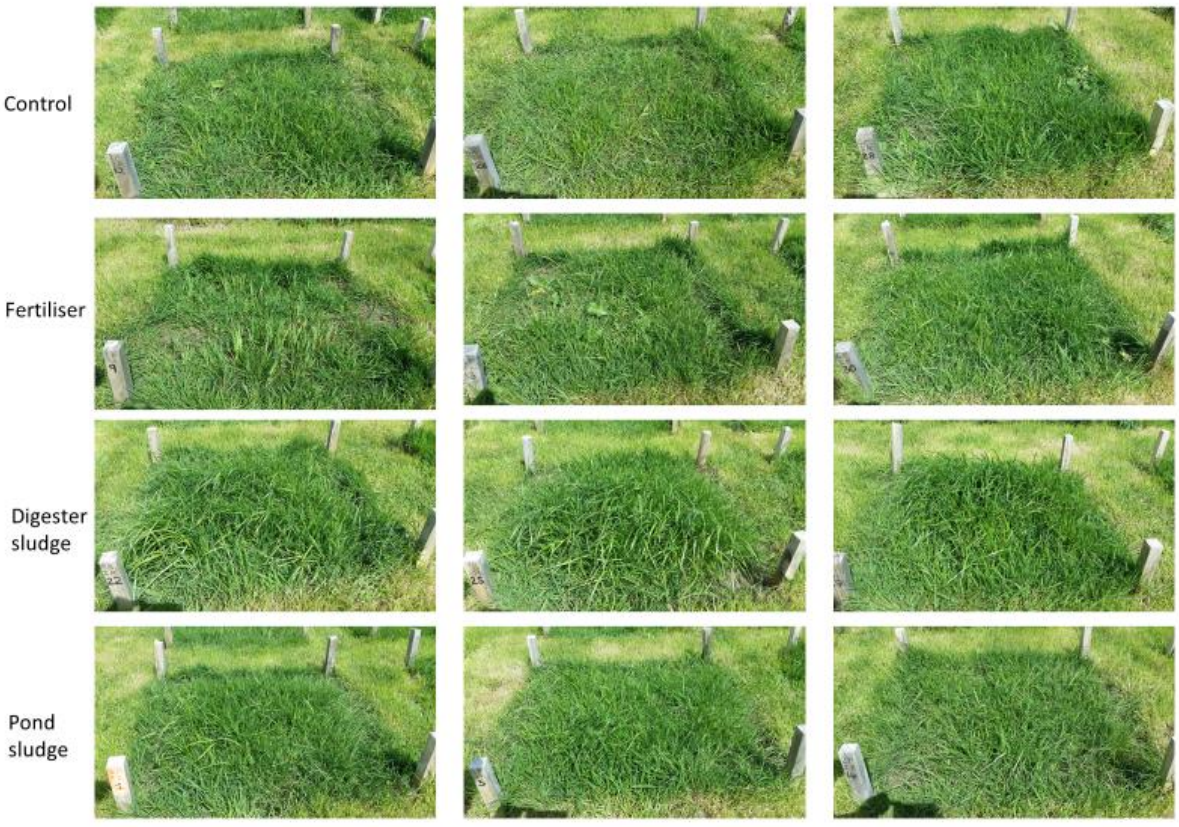


Italian ryegrass after 17 weeks

03/10/2019 – 19 weeks



Pasture after 19 weeks



Italian ryegrass after 19 weeks

APPENDIX B

Statistical Analysis Report - R Agricolae Package

Plant dry weight first harvest

```
          Df Sum Sq Mean Sq F value   Pr(>F)
Treatment    3 170564   56855   15.96 3.05e-06 ***
Residuals   28  99756    3563
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

HSD.test

Study: aov ~ "Treatment"

HSD Test for dry.weight.per.area
Mean Square Error:  3562.699
Treatment,  means

                dry.weight.per.area       std r   Min   Max
Control                   320.3889 103.32464 9 151.9 479.6
Digested Biosolids        231.2000  16.20652 8 201.1 250.7
Fertiliser                369.3429  22.76444 7 330.6 394.1
Pond Sludge               178.5250  36.64469 8 135.4 238.1

Alpha: 0.05 ; DF Error: 28
Critical Value of Studentized Range: 3.861244

Groups according to probability of means differences and alpha level( 0.05 )
Treatments with the same letter are not significantly different.

                dry.weight.per.area groups
Fertiliser                369.3429      a
Control                   320.3889      a
Digested Biosolids        231.2000      b
Pond Sludge               178.5250      b
```

Dry weight of herbage samples

```
Df Sum Sq Mean Sq F value   Pr(>F)
Treatment            3 1063.6   354.5  11.182 0.000333 ***
Plant.type           1  309.5   309.5   9.760 0.006540 **
Treatment:Plant.type  3  207.8    69.3   2.185 0.129553
Residuals           16  507.3    31.7
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Tukey multiple comparisons of means
   95% family-wise confidence level
Fit: aov(formula = ï..Dry.weight ~ Treatment * Plant.type, data = plant.dry)

$Treatment
                                 diff        lwr       upr     p adj
Digested Biosolids-Control     16.16666667   6.865755 25.467578 0.0007192
Fertilizer-Control            0.02833333  -9.272578  9.329245 0.9999998
Pond Sludge-Control             3.29166667  -6.009245 12.592578 0.7445889
Fertilizer-Digested Biosolids  -16.13833333 -25.439245 -6.837422 0.0007318
Pond Sludge-Digested Biosolids -12.87500000 -22.175912 -3.574088 0.0055529
Pond Sludge-Fertilizer          3.26333333  -6.037578 12.564245 0.7494460

$Plant.type
                          diff       lwr       upr   p adj
Pasture-Italian Ryegrass -7.181667 -12.05478 -2.308558 0.00654

$`Treatment:Plant.type`
```

	diff
Digested Biosolids:Italian Ryegrass-Control:Italian Ryegrass	24.0666667
Fertilizer:Italian Ryegrass-Control:Italian Ryegrass	1.7166667
Pond Sludge:Italian Ryegrass-Control:Italian Ryegrass	6.3000000
Control:Pasture-Control:Italian Ryegrass	-0.8833333
Digested Biosolids:Pasture-Control:Italian Ryegrass	7.3833333
Fertilizer:Pasture-Control:Italian Ryegrass	-2.5433333
Pond Sludge:Pasture-Control:Italian Ryegrass	-0.6000000
Fertilizer:Italian Ryegrass-Digested Biosolids:Italian Ryegrass	-22.3500000
Pond Sludge:Italian Ryegrass-Digested Biosolids:Italian Ryegrass	-17.7666667
Control:Pasture-Digested Biosolids:Italian Ryegrass	-24.9500000
Digested Biosolids:Pasture-Digested Biosolids:Italian Ryegrass	-16.6833333
Fertilizer:Pasture-Digested Biosolids:Italian Ryegrass	-26.6100000
Pond Sludge:Pasture-Digested Biosolids:Italian Ryegrass	-24.6666667
Pond Sludge:Italian Ryegrass-Fertilizer:Italian Ryegrass	4.5833333
Control:Pasture-Fertilizer:Italian Ryegrass	-2.6000000
Digested Biosolids:Pasture-Fertilizer:Italian Ryegrass	5.6666667
Fertilizer:Pasture-Fertilizer:Italian Ryegrass	-4.2600000
Pond Sludge:Pasture-Fertilizer:Italian Ryegrass	-2.3166667
Control:Pasture-Pond Sludge:Italian Ryegrass	-7.1833333
Digested Biosolids:Pasture-Pond Sludge:Italian Ryegrass	1.0833333
Fertilizer:Pasture-Pond Sludge:Italian Ryegrass	-8.8433333
Pond Sludge:Pasture-Pond Sludge:Italian Ryegrass	-6.9000000
Digested Biosolids:Pasture-Control:Pasture	8.2666667
Fertilizer:Pasture-Control:Pasture	-1.6600000
Pond Sludge:Pasture-Control:Pasture	0.2833333
Fertilizer:Pasture-Digested Biosolids:Pasture	-9.9266667
Pond Sludge:Pasture-Digested Biosolids:Pasture	-7.9833333
Pond Sludge:Pasture-Fertilizer:Pasture	1.9433333
	lwr
Digested Biosolids:Italian Ryegrass-Control:Italian Ryegrass	8.149505
Fertilizer:Italian Ryegrass-Control:Italian Ryegrass	-14.200495
Pond Sludge:Italian Ryegrass-Control:Italian Ryegrass	-9.617161
Control:Pasture-Control:Italian Ryegrass	-16.800495
Digested Biosolids:Pasture-Control:Italian Ryegrass	-8.533828
Fertilizer:Pasture-Control:Italian Ryegrass	-18.460495
Pond Sludge:Pasture-Control:Italian Ryegrass	-16.517161
Fertilizer:Italian Ryegrass-Digested Biosolids:Italian Ryegrass	-38.267161
Pond Sludge:Italian Ryegrass-Digested Biosolids:Italian Ryegrass	-33.683828
Control:Pasture-Digested Biosolids:Italian Ryegrass	-40.867161
Digested Biosolids:Pasture-Digested Biosolids:Italian Ryegrass	-32.600495
Fertilizer:Pasture-Digested Biosolids:Italian Ryegrass	-42.527161
Pond Sludge:Pasture-Digested Biosolids:Italian Ryegrass	-40.583828
Pond Sludge:Italian Ryegrass-Fertilizer:Italian Ryegrass	-11.333828
Control:Pasture-Fertilizer:Italian Ryegrass	-18.517161
Digested Biosolids:Pasture-Fertilizer:Italian Ryegrass	-10.250495
Fertilizer:Pasture-Fertilizer:Italian Ryegrass	-20.177161
Pond Sludge:Pasture-Fertilizer:Italian Ryegrass	-18.233828
Control:Pasture-Pond Sludge:Italian Ryegrass	-23.100495
Digested Biosolids:Pasture-Pond Sludge:Italian Ryegrass	-14.833828
Fertilizer:Pasture-Pond Sludge:Italian Ryegrass	-24.760495
Pond Sludge:Pasture-Pond Sludge:Italian Ryegrass	-22.817161
Digested Biosolids:Pasture-Control:Pasture	-7.650495
Fertilizer:Pasture-Control:Pasture	-17.577161
Pond Sludge:Pasture-Control:Pasture	-15.633828
Fertilizer:Pasture-Digested Biosolids:Pasture	-25.843828
Pond Sludge:Pasture-Digested Biosolids:Pasture	-23.900495
Pond Sludge:Pasture-Fertilizer:Pasture	-13.973828
	upr
Digested Biosolids:Italian Ryegrass-Control:Italian Ryegrass	39.9838279
Fertilizer:Italian Ryegrass-Control:Italian Ryegrass	17.6338279
Pond Sludge:Italian Ryegrass-Control:Italian Ryegrass	22.2171612
Control:Pasture-Control:Italian Ryegrass	15.0338279
Digested Biosolids:Pasture-Control:Italian Ryegrass	23.3004945
Fertilizer:Pasture-Control:Italian Ryegrass	13.3738279
Pond Sludge:Pasture-Control:Italian Ryegrass	15.3171612
Fertilizer:Italian Ryegrass-Digested Biosolids:Italian Ryegrass	-6.4328388
Pond Sludge:Italian Ryegrass-Digested Biosolids:Italian Ryegrass	-1.8495055
Control:Pasture-Digested Biosolids:Italian Ryegrass	-9.0328388
Digested Biosolids:Pasture-Digested Biosolids:Italian Ryegrass	-0.7661721
Fertilizer:Pasture-Digested Biosolids:Italian Ryegrass	-10.6928388
Pond Sludge:Pasture-Digested Biosolids:Italian Ryegrass	-8.7495055
Pond Sludge:Italian Ryegrass-Fertilizer:Italian Ryegrass	20.5004945

Control:Pasture-Fertilizer:Italian Ryegrass 13.3171612
Digested Biosolids:Pasture-Fertilizer:Italian Ryegrass 21.5838279
Fertilizer:Pasture-Fertilizer:Italian Ryegrass 11.6571612
Pond Sludge:Pasture-Fertilizer:Italian Ryegrass 13.6004945
Control:Pasture-Pond Sludge:Italian Ryegrass 8.7338279
Digested Biosolids:Pasture-Pond Sludge:Italian Ryegrass 17.0004945
Fertilizer:Pasture-Pond Sludge:Italian Ryegrass 7.0738279
Pond Sludge:Pasture-Pond Sludge:Italian Ryegrass 9.0171612
Digested Biosolids:Pasture-Control:Pasture 24.1838279
Fertilizer:Pasture-Control:Pasture 14.2571612
Pond Sludge:Pasture-Control:Pasture 16.2004945
Fertilizer:Pasture-Digested Biosolids:Pasture 5.9904945
Pond Sludge:Pasture-Digested Biosolids:Pasture 7.9338279
Pond Sludge:Pasture-Fertilizer:Pasture 17.8604945

p adj
Digested Biosolids:Italian Ryegrass-Control:Italian Ryegrass 0.0016281
Fertilizer:Italian Ryegrass-Control:Italian Ryegrass 0.9999265
Pond Sludge:Italian Ryegrass-Control:Italian Ryegrass 0.8576990
Control:Pasture-Control:Italian Ryegrass 0.9999992
Digested Biosolids:Pasture-Control:Italian Ryegrass 0.7408325
Fertilizer:Pasture-Control:Italian Ryegrass 0.9990258
Pond Sludge:Pasture-Control:Italian Ryegrass 0.9999999
Fertilizer:Italian Ryegrass-Digested Biosolids:Italian Ryegrass 0.0033430
Pond Sludge:Italian Ryegrass-Digested Biosolids:Italian Ryegrass 0.0232461
Control:Pasture-Digested Biosolids:Italian Ryegrass 0.0011289
Digested Biosolids:Pasture-Digested Biosolids:Italian Ryegrass 0.0365087
Fertilizer:Pasture-Digested Biosolids:Italian Ryegrass 0.0005725
Pond Sludge:Pasture-Digested Biosolids:Italian Ryegrass 0.0012691
Pond Sludge:Italian Ryegrass-Fertilizer:Italian Ryegrass 0.9683203
Control:Pasture-Fertilizer:Italian Ryegrass 0.9988787
Digested Biosolids:Pasture-Fertilizer:Italian Ryegrass 0.9101274
Fertilizer:Pasture-Fertilizer:Italian Ryegrass 0.9785929
Pond Sludge:Pasture-Fertilizer:Italian Ryegrass 0.9994662
Control:Pasture-Pond Sludge:Italian Ryegrass 0.7644799
Digested Biosolids:Pasture-Pond Sludge:Italian Ryegrass 0.9999968
Fertilizer:Pasture-Pond Sludge:Italian Ryegrass 0.5554412
Pond Sludge:Pasture-Pond Sludge:Italian Ryegrass 0.7965626
Digested Biosolids:Pasture-Control:Pasture 0.6298949
Fertilizer:Pasture-Control:Pasture 0.9999413
Pond Sludge:Pasture-Control:Pasture 1.0000000
Fertilizer:Pasture-Digested Biosolids:Pasture 0.4218168
Pond Sludge:Pasture-Digested Biosolids:Pasture 0.6662690
Pond Sludge:Pasture-Fertilizer:Pasture 0.9998317

HSD Test
Mean Square Error: 31.7052
Treatment, means

	ï..Dry.weight	std	r	Min	Max
Control	14.89167	2.110786	6	12.10	17.90
Digested Biosolids	31.05833	11.830318	6	20.55	50.30
Fertilizer	14.92000	3.897255	6	9.67	21.15
Pond Sludge	18.18333	6.731840	6	7.15	26.90

Alpha: 0.05 ; DF Error: 16
Critical Value of Studentized Range: 4.046093
Minimun Significant Difference: 9.300912
Treatments with the same letter are not significantly different.

	ï..Dry.weight	groups
Digested Biosolids	31.05833	a
Pond Sludge	18.18333	b
Fertilizer	14.92000	b
Control	14.89167	b

Chemical parameters of herbage samples

Nitrogen

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	0.3020	0.10067	2.462	0.103
Plant.Type	1	0.0961	0.09607	2.350	0.146
Treatment:Plant.Type	3	0.2486	0.08287	2.027	0.153
Residuals	15	0.6133	0.04089		

Phosphorus

```
                  Df   Sum Sq  Mean Sq F value  Pr(>F)
Treatment          3 0.001385 0.000462   0.542 0.66105
Plant.Type         1 0.000696 0.000696   0.817 0.38033
Treatment:Plant.Type  3 0.015057 0.005019   5.889 0.00728 **
Residuals         15 0.012783 0.000852
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Potassium

```
                  Df Sum Sq Mean Sq F value Pr(>F)
Treatment          3  0.568  0.1895   0.881 0.4730
Plant.Type         1  0.037  0.0371   0.173 0.6836
Treatment:Plant.Type  3  1.703  0.5675   2.640 0.0874 .
Residuals         15  3.225  0.2150
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Sulphur

```
                  Df  Sum Sq  Mean Sq F value   Pr(>F)
Treatment          3 0.07623 0.025411  54.582 2.65e-08 ***
Plant.Type         1 0.00253 0.002526   5.426   0.0342 *
Treatment:Plant.Type  3 0.00566 0.001886   4.050   0.0271 *
Residuals         15 0.00698 0.000466
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = Sulphur ~ Treatment * Plant.Type, data = plant.all)

$Treatment
                                  diff         lwr         upr     p adj
Digested Biosolids-Control     -0.006666667 -0.04257056 0.02923722 0.9490886
Fertiliser-Control             -0.011666667 -0.04932298 0.02598965 0.8085922
Pond sludge-Control             0.125000000  0.08909611 0.16090389 0.0000003
Fertiliser-Digested Biosolids  -0.005000000 -0.04265632 0.03265632 0.9802143
Pond sludge-Digested Biosolids  0.131666667  0.09576278 0.16757056 0.0000001
Pond sludge-Fertiliser          0.136666667  0.09901035 0.17432298 0.0000002

$Plant.Type
                      diff         lwr          upr     p adj
Ryegrass-Pasture -0.02090909 -0.04010629 -0.001711897 0.0347467

$`Treatment:Plant.Type`
                                                      diff
Digested Biosolids:Pasture-Control:Pasture             0.010000000
Fertiliser:Pasture-Control:Pasture                    -0.023333333
Pond sludge:Pasture-Control:Pasture                    0.153333333
Control:Ryegrass-Control:Pasture                      -0.003333333
Digested Biosolids:Ryegrass-Control:Pasture           -0.026666667
Fertiliser:Ryegrass-Control:Pasture                    0.001666667
Pond sludge:Ryegrass-Control:Pasture                   0.093333333
Fertiliser:Pasture-Digested Biosolids:Pasture         -0.033333333
Pond sludge:Pasture-Digested Biosolids:Pasture         0.143333333
Control:Ryegrass-Digested Biosolids:Pasture           -0.013333333
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture -0.036666667
Fertiliser:Ryegrass-Digested Biosolids:Pasture        -0.008333333
Pond sludge:Ryegrass-Digested Biosolids:Pasture        0.083333333
Pond sludge:Pasture-Fertiliser:Pasture                 0.176666667
Control:Ryegrass-Fertiliser:Pasture                    0.020000000
Digested Biosolids:Ryegrass-Fertiliser:Pasture        -0.003333333
Fertiliser:Ryegrass-Fertiliser:Pasture                 0.025000000
Pond sludge:Ryegrass-Fertiliser:Pasture                0.116666667
Control:Ryegrass-Pond sludge:Pasture                  -0.156666667
Digested Biosolids:Ryegrass-Pond sludge:Pasture       -0.180000000
Fertiliser:Ryegrass-Pond sludge:Pasture               -0.151666667
Pond sludge:Ryegrass-Pond sludge:Pasture              -0.060000000
Digested Biosolids:Ryegrass-Control:Ryegrass          -0.023333333
Fertiliser:Ryegrass-Control:Ryegrass                   0.005000000
Pond sludge:Ryegrass-Control:Ryegrass                  0.096666667
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass        0.028333333
```

Pond sludge:Ryegrass-Digested Biosolids:Ryegrass 0.120000000
Pond sludge:Ryegrass-Fertiliser:Ryegrass 0.091666667

	lwr	upr	p adj
Digested Biosolids:Pasture-Control:Pasture	-0.05153786	0.071537858	0.9988254
Fertiliser:Pasture-Control:Pasture	-0.08487119	0.038204524	0.8758875
Pond sludge:Pasture-Control:Pasture	0.09179548	0.214871191	0.0000066
Control:Ryegrass-Control:Pasture	-0.06487119	0.058204524	0.9999993
Digested Biosolids:Ryegrass-Control:Pasture	-0.08820452	0.034871191	0.7894996
Fertiliser:Ryegrass-Control:Pasture	-0.06713475	0.070468083	1.0000000
Pond sludge:Ryegrass-Control:Pasture	0.03179548	0.154871191	0.0017394
Fertiliser:Pasture-Digested Biosolids:Pasture	-0.09487119	0.028204524	0.5750725
Pond sludge:Pasture-Digested Biosolids:Pasture	0.08179548	0.204871191	0.0000152
Control:Ryegrass-Digested Biosolids:Pasture	-0.07487119	0.048204524	0.9931179
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture	-0.09820452	0.024871191	0.4664918
Fertiliser:Ryegrass-Digested Biosolids:Pasture	-0.07713475	0.060468083	0.9998263
Pond sludge:Ryegrass-Digested Biosolids:Pasture	0.02179548	0.144871191	0.0049702
Pond sludge:Pasture-Fertiliser:Pasture	0.11512881	0.238204524	0.0000011
Control:Ryegrass-Fertiliser:Pasture	-0.04153786	0.081537858	0.9382994
Digested Biosolids:Ryegrass-Fertiliser:Pasture	-0.06487119	0.058204524	0.9999993
Fertiliser:Ryegrass-Fertiliser:Pasture	-0.04380142	0.093801416	0.8967484
Pond sludge:Ryegrass-Fertiliser:Pasture	0.05512881	0.178204524	0.0001693
Control:Ryegrass-Pond sludge:Pasture	-0.21820452	-0.095128809	0.0000050
Digested Biosolids:Ryegrass-Pond sludge:Pasture	-0.24153786	-0.118462142	0.0000008
Fertiliser:Ryegrass-Pond sludge:Pasture	-0.22046808	-0.082865250	0.0000296
Pond sludge:Ryegrass-Pond sludge:Pasture	-0.12153786	0.001537858	0.0585771
Digested Biosolids:Ryegrass-Control:Ryegrass	-0.08487119	0.038204524	0.8758875
Fertiliser:Ryegrass-Control:Ryegrass	-0.06380142	0.073801416	0.9999945
Pond sludge:Ryegrass-Control:Ryegrass	0.03512881	0.158204524	0.0012329
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass	-0.04046808	0.097134750	0.8263655
Pond sludge:Ryegrass-Digested Biosolids:Ryegrass	0.05846214	0.181537858	0.0001234
Pond sludge:Ryegrass-Fertiliser:Ryegrass	0.02286525	0.160468083	0.0057322

HSD Test for Sulphur
Mean Square Error: 0.0004655556

Treatment, means

	Sulphur	std r	Min	Max
Control	0.2516667	0.02041241	6	0.23 0.28
Digested Biosolids	0.2450000	0.02258318	6	0.22 0.28
Fertiliser	0.2400000	0.01581139	5	0.22 0.26
Pond sludge	0.3766667	0.04366539	6	0.33 0.43

Alpha: 0.05 ; DF Error: 15
Critical Value of Studentized Range: 4.075974

```
Groups according to probability of means differences and alpha level( 0.05 )
Treatments with the same letter are not significantly different.

                   Sulphur groups
Pond sludge        0.3766667      a
Control            0.2516667      b
Digested Biosolids 0.2450000      b
Fertiliser         0.2400000      b
```

Calcium

```
Df  Sum Sq Mean Sq F value  Pr(>F)
Treatment             3 0.03682 0.01227   3.733 0.03473 *
Plant.Type            1 0.03793 0.03793  11.538 0.00398 **
Treatment:Plant.Type  3 0.07250 0.02417   7.350 0.00295 **
Residuals            15 0.04932 0.00329
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = Calcium ~ Treatment * Plant.Type, data = plant.all)

$Treatment
                                    diff         lwr         upr     p adj
Digested Biosolids-Control       0.08500000 -0.01041287  0.18041287 0.0891344
Fertiliser-Control              -0.01666667 -0.11673653  0.08340320 0.9623594
Pond sludge-Control              0.00000000 -0.09541287  0.09541287 1.0000000
Fertiliser-Digested Biosolids   -0.10166667 -0.20173653 -0.00159680 0.0458546
Pond sludge-Digested Biosolids  -0.08500000 -0.18041287  0.01041287 0.0891344
Pond sludge-Fertiliser           0.01666667 -0.08340320  0.11673653 0.9623594

$Plant.Type
                        diff        lwr        upr     p adj
Ryegrass-Pasture -0.08102273 -0.1320384 -0.0300071 0.0040802

$`Treatment:Plant.Type`
                                                        diff
Digested Biosolids:Pasture-Control:Pasture               0.073333333
Fertiliser:Pasture-Control:Pasture                       0.066666667
Pond sludge:Pasture-Control:Pasture                      0.110000000
Control:Ryegrass-Control:Pasture                         0.013333333
Digested Biosolids:Ryegrass-Control:Pasture              0.110000000
Fertiliser:Ryegrass-Control:Pasture                     -0.125000000
Pond sludge:Ryegrass-Control:Pasture                    -0.096666667
Fertiliser:Pasture-Digested Biosolids:Pasture           -0.006666667
Pond sludge:Pasture-Digested Biosolids:Pasture           0.036666667
Control:Ryegrass-Digested Biosolids:Pasture             -0.060000000
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture   0.036666667
Fertiliser:Ryegrass-Digested Biosolids:Pasture          -0.198333333
Pond sludge:Ryegrass-Digested Biosolids:Pasture         -0.170000000
Pond sludge:Pasture-Fertiliser:Pasture                   0.043333333
Control:Ryegrass-Fertiliser:Pasture                     -0.053333333
Digested Biosolids:Ryegrass-Fertiliser:Pasture           0.043333333
Fertiliser:Ryegrass-Fertiliser:Pasture                  -0.191666667
Pond sludge:Ryegrass-Fertiliser:Pasture                 -0.163333333
Control:Ryegrass-Pond sludge:Pasture                    -0.096666667
Digested Biosolids:Ryegrass-Pond sludge:Pasture          0.000000000
Fertiliser:Ryegrass-Pond sludge:Pasture                 -0.235000000
Pond sludge:Ryegrass-Pond sludge:Pasture                -0.206666667
Digested Biosolids:Ryegrass-Control:Ryegrass             0.096666667
Fertiliser:Ryegrass-Control:Ryegrass                    -0.138333333
Pond sludge:Ryegrass-Control:Ryegrass                   -0.110000000
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass         -0.235000000
Pond sludge:Ryegrass-Digested Biosolids:Ryegrass        -0.206666667
Pond sludge:Ryegrass-Fertiliser:Ryegrass                 0.028333333
                                                        lwr
Digested Biosolids:Pasture-Control:Pasture              -0.09020059
Fertiliser:Pasture-Control:Pasture                      -0.09686725
Pond sludge:Pasture-Control:Pasture                     -0.05353392
Control:Ryegrass-Control:Pasture                        -0.15020059
```

Digested Biosolids:Ryegrass-Control:Pasture	-0.05353392
Fertiliser:Ryegrass-Control:Pasture	-0.30783648
Pond sludge:Ryegrass-Control:Pasture	-0.26020059
Fertiliser:Pasture-Digested Biosolids:Pasture	-0.17020059
Pond sludge:Pasture-Digested Biosolids:Pasture	-0.12686725
Control:Ryegrass-Digested Biosolids:Pasture	-0.22353392
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture	-0.12686725
Fertiliser:Ryegrass-Digested Biosolids:Pasture	-0.38116981
Pond sludge:Ryegrass-Digested Biosolids:Pasture	-0.33353392
Pond sludge:Pasture-Fertiliser:Pasture	-0.12020059
Control:Ryegrass-Fertiliser:Pasture	-0.21686725
Digested Biosolids:Ryegrass-Fertiliser:Pasture	-0.12020059
Fertiliser:Ryegrass-Fertiliser:Pasture	-0.37450315
Pond sludge:Ryegrass-Fertiliser:Pasture	-0.32686725
Control:Ryegrass-Pond sludge:Pasture	-0.26020059
Digested Biosolids:Ryegrass-Pond sludge:Pasture	-0.16353392
Fertiliser:Ryegrass-Pond sludge:Pasture	-0.41783648
Pond sludge:Ryegrass-Pond sludge:Pasture	-0.37020059
Digested Biosolids:Ryegrass-Control:Ryegrass	-0.06686725
Fertiliser:Ryegrass-Control:Ryegrass	-0.32116981
Pond sludge:Ryegrass-Control:Ryegrass	-0.27353392
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass	-0.41783648
Pond sludge:Ryegrass-Digested Biosolids:Ryegrass	-0.37020059
Pond sludge:Ryegrass-Fertiliser:Ryegrass	-0.15450315

	upr
Digested Biosolids:Pasture-Control:Pasture	0.2368672519
Fertiliser:Pasture-Control:Pasture	0.2302005852
Pond sludge:Pasture-Control:Pasture	0.2735339186
Control:Ryegrass-Control:Pasture	0.1768672519
Digested Biosolids:Ryegrass-Control:Pasture	0.2735339186
Fertiliser:Ryegrass-Control:Pasture	0.0578364793
Pond sludge:Ryegrass-Control:Pasture	0.0668672519
Fertiliser:Pasture-Digested Biosolids:Pasture	0.1568672519
Pond sludge:Pasture-Digested Biosolids:Pasture	0.2002005852
Control:Ryegrass-Digested Biosolids:Pasture	0.1035339186
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture	0.2002005852
Fertiliser:Ryegrass-Digested Biosolids:Pasture	-0.0154968541
Pond sludge:Ryegrass-Digested Biosolids:Pasture	-0.0064660814
Pond sludge:Pasture-Fertiliser:Pasture	0.2068672519
Control:Ryegrass-Fertiliser:Pasture	0.1102005852
Digested Biosolids:Ryegrass-Fertiliser:Pasture	0.2068672519
Fertiliser:Ryegrass-Fertiliser:Pasture	-0.0088301874
Pond sludge:Ryegrass-Fertiliser:Pasture	0.0002005852
Control:Ryegrass-Pond sludge:Pasture	0.0668672519
Digested Biosolids:Ryegrass-Pond sludge:Pasture	0.1635339186
Fertiliser:Ryegrass-Pond sludge:Pasture	-0.0521635207
Pond sludge:Ryegrass-Pond sludge:Pasture	-0.0431327481
Digested Biosolids:Ryegrass-Control:Ryegrass	0.2602005852
Fertiliser:Ryegrass-Control:Ryegrass	0.0445031459
Pond sludge:Ryegrass-Control:Ryegrass	0.0535339186
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass	-0.0521635207
Pond sludge:Ryegrass-Digested Biosolids:Ryegrass	-0.0431327481
Pond sludge:Ryegrass-Fertiliser:Ryegrass	0.2111698126

	p adj
Digested Biosolids:Pasture-Control:Pasture	0.7619812
Fertiliser:Pasture-Control:Pasture	0.8331128
Pond sludge:Pasture-Control:Pasture	0.3300712
Control:Ryegrass-Control:Pasture	0.9999880
Digested Biosolids:Ryegrass-Control:Pasture	0.3300712
Fertiliser:Ryegrass-Control:Pasture	0.3127711
Pond sludge:Ryegrass-Control:Pasture	0.4756723
Fertiliser:Pasture-Digested Biosolids:Pasture	0.9999999
Pond sludge:Pasture-Digested Biosolids:Pasture	0.9915868
Control:Ryegrass-Digested Biosolids:Pasture	0.8922728
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture	0.9915868
Fertiliser:Ryegrass-Digested Biosolids:Pasture	0.0289866
Pond sludge:Ryegrass-Digested Biosolids:Pasture	0.0388248
Pond sludge:Pasture-Fertiliser:Pasture	0.9784006
Control:Ryegrass-Fertiliser:Pasture	0.9372636
Digested Biosolids:Ryegrass-Fertiliser:Pasture	0.9784006
Fertiliser:Ryegrass-Fertiliser:Pasture	0.0366968
Pond sludge:Ryegrass-Fertiliser:Pasture	0.0503916
Control:Ryegrass-Pond sludge:Pasture	0.4756723

Digested Biosolids:Ryegrass-Pond sludge:Pasture 1.0000000
Fertiliser:Ryegrass-Pond sludge:Pasture 0.0077994
Pond sludge:Ryegrass-Pond sludge:Pasture 0.0089832
Digested Biosolids:Ryegrass-Control:Ryegrass 0.4756723
Fertiliser:Ryegrass-Control:Ryegrass 0.2142510
Pond sludge:Ryegrass-Control:Ryegrass 0.3300712
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass 0.0077994
Pond sludge:Ryegrass-Digested Biosolids:Ryegrass 0.0089832
Pond sludge:Ryegrass-Fertiliser:Ryegrass 0.9991325

HSD Test

Alpha: 0.05 ; DF Error: 15
Critical Value of Studentized Range: 4.075974
Groups according to probability of means differences and alpha level(0.05)
Treatments with the same letter are not significantly different.

	Calcium	groups
Digested Biosolids	0.7816667	a
Control	0.6966667	ab
Pond sludge	0.6966667	ab
Fertiliser	0.6800000	b

Magnesium

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Treatment	3	0.001113	0.000371	0.898	0.46517	
Plant.Type	1	0.005190	0.005190	12.557	0.00295	**
Treatment:Plant.Type	3	0.000896	0.000299	0.723	0.55379	
Residuals	15	0.006200	0.000413			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Sodium

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	0.02349	0.007830	2.340	0.115
Plant.Type	1	0.00196	0.001956	0.585	0.456
Treatment:Plant.Type	3	0.01490	0.004967	1.484	0.259
Residuals	15	0.05020	0.003347		

Iron

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	31125	10375	1.107	0.377
Plant.Type	1	11444	11444	1.221	0.287
Treatment:Plant.Type	3	27418	9139	0.975	0.431
Residuals	15	140596	9373		

Manganese

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Treatment	3	53592	17864	2.028	0.1532	
Plant.Type	1	29419	29419	3.339	0.0876	.
Treatment:Plant.Type	3	28671	9557	1.085	0.3856	
Residuals	15	132150	8810			

Zinc

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Treatment	3	435.2	145.06	17.454	3.72e-05	***
Plant.Type	1	7.6	7.64	0.920	0.3528	
Treatment:Plant.Type	3	118.2	39.39	4.739	0.0161	*
Residuals	15	124.7	8.31			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = Zinc ~ Treatment * Plant.Type, data = plant.all)

$Treatment

	diff	lwr	upr	p adj
Digested Biosolids-Control	6.83333333	2.036161	11.630505	0.0046228
Fertiliser-Control	0.03333333	-4.997983	5.064650	0.9999974
Pond sludge-Control	10.00000000	5.202828	14.797172	0.0001268
Fertiliser-Digested Biosolids	-6.80000000	-11.831316	-1.768684	0.0069914

```
Pond sludge-Digested Biosolids  3.16666667  -1.630505  7.963839 0.2681917
Pond sludge-Fertiliser          9.96666667   4.935350 14.997983 0.0002173

$Plant.Type
                diff       lwr      upr     p adj
Ryegrass-Pasture 1.15 -1.414966 3.714966 0.3544063

$`Treatment:Plant.Type`
                                                    diff
Digested Biosolids:Pasture-Control:Pasture             5.3333333
Fertiliser:Pasture-Control:Pasture                    -5.3333333
Pond sludge:Pasture-Control:Pasture                    8.6666667
Control:Ryegrass-Control:Pasture                      -3.0000000
Digested Biosolids:Ryegrass-Control:Pasture            5.3333333
Fertiliser:Ryegrass-Control:Pasture                    4.3333333
Pond sludge:Ryegrass-Control:Pasture                   8.3333333
Fertiliser:Pasture-Digested Biosolids:Pasture        -10.6666667
Pond sludge:Pasture-Digested Biosolids:Pasture         3.3333333
Control:Ryegrass-Digested Biosolids:Pasture           -8.3333333
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture  0.0000000
Fertiliser:Ryegrass-Digested Biosolids:Pasture        -1.0000000
Pond sludge:Ryegrass-Digested Biosolids:Pasture        3.0000000
Pond sludge:Pasture-Fertiliser:Pasture                14.0000000
Control:Ryegrass-Fertiliser:Pasture                    2.3333333
Digested Biosolids:Ryegrass-Fertiliser:Pasture        10.6666667
Fertiliser:Ryegrass-Fertiliser:Pasture                 9.6666667
Pond sludge:Ryegrass-Fertiliser:Pasture               13.6666667
Control:Ryegrass-Pond sludge:Pasture                 -11.6666667
Digested Biosolids:Ryegrass-Pond sludge:Pasture       -3.3333333
Fertiliser:Ryegrass-Pond sludge:Pasture               -4.3333333
Pond sludge:Ryegrass-Pond sludge:Pasture              -0.3333333
Digested Biosolids:Ryegrass-Control:Ryegrass           8.3333333
Fertiliser:Ryegrass-Control:Ryegrass                   7.3333333
Pond sludge:Ryegrass-Control:Ryegrass                 11.3333333
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass       -1.0000000
Pond sludge:Ryegrass-Digested Biosolids:Ryegrass       3.0000000
Pond sludge:Ryegrass-Fertiliser:Ryegrass               4.0000000
                                                      lwr        upr
Digested Biosolids:Pasture-Control:Pasture          -2.8888311 13.5554978
Fertiliser:Pasture-Control:Pasture                -13.5554978  2.8888311
Pond sludge:Pasture-Control:Pasture                 0.4445022 16.8888311
Control:Ryegrass-Control:Pasture                  -11.2221645  5.2221645
Digested Biosolids:Ryegrass-Control:Pasture         -2.8888311 13.5554978
Fertiliser:Ryegrass-Control:Pasture               -4.8593260 13.5259927
Pond sludge:Ryegrass-Control:Pasture                0.1111689 16.5554978
Fertiliser:Pasture-Digested Biosolids:Pasture     -18.8888311 -2.4445022
Pond sludge:Pasture-Digested Biosolids:Pasture      -4.8888311 11.5554978
Control:Ryegrass-Digested Biosolids:Pasture       -16.5554978 -0.1111689
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture  -8.2221645  8.2221645
Fertiliser:Ryegrass-Digested Biosolids:Pasture    -10.1926593  8.1926593
Pond sludge:Ryegrass-Digested Biosolids:Pasture     -5.2221645 11.2221645
Pond sludge:Pasture-Fertiliser:Pasture              5.7778355 22.2221645
Control:Ryegrass-Fertiliser:Pasture               -5.8888311 10.5554978
Digested Biosolids:Ryegrass-Fertiliser:Pasture      2.4445022 18.8888311
Fertiliser:Ryegrass-Fertiliser:Pasture            0.4740073 18.8593260
Pond sludge:Ryegrass-Fertiliser:Pasture             5.4445022 21.8888311
Control:Ryegrass-Pond sludge:Pasture              -19.8888311 -3.4445022
Digested Biosolids:Ryegrass-Pond sludge:Pasture    -11.5554978  4.8888311
Fertiliser:Ryegrass-Pond sludge:Pasture           -13.5259927  4.8593260
Pond sludge:Ryegrass-Pond sludge:Pasture            -8.5554978  7.8888311
Digested Biosolids:Ryegrass-Control:Ryegrass        0.1111689 16.5554978
Fertiliser:Ryegrass-Control:Ryegrass              -1.8593260 16.5259927
Pond sludge:Ryegrass-Control:Ryegrass               3.1111689 19.5554978
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass   -10.1926593  8.1926593
Pond sludge:Ryegrass-Digested Biosolids:Ryegrass    -5.2221645 11.2221645
Pond sludge:Ryegrass-Fertiliser:Ryegrass          -5.1926593 13.1926593
                                                     p adj
Digested Biosolids:Pasture-Control:Pasture         0.3698134
Fertiliser:Pasture-Control:Pasture                 0.3698134
Pond sludge:Pasture-Control:Pasture                0.0353575
Control:Ryegrass-Control:Pasture                   0.8948572
Digested Biosolids:Ryegrass-Control:Pasture        0.3698134
Fertiliser:Ryegrass-Control:Pasture                0.7179899
```

Pond sludge:Ryegrass-Control:Pasture 0.0458711
Fertiliser:Pasture-Digested Biosolids:Pasture 0.0072093
Pond sludge:Pasture-Digested Biosolids:Pasture 0.8367252
Control:Ryegrass-Digested Biosolids:Pasture 0.0458711
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture 1.0000000
Fertiliser:Ryegrass-Digested Biosolids:Pasture 0.9999151
Pond sludge:Ryegrass-Digested Biosolids:Pasture 0.8948572
Pond sludge:Pasture-Fertiliser:Pasture 0.0005414
Control:Ryegrass-Fertiliser:Pasture 0.9688408
Digested Biosolids:Ryegrass-Fertiliser:Pasture 0.0072093
Fertiliser:Ryegrass-Fertiliser:Pasture 0.0359318
Pond sludge:Ryegrass-Fertiliser:Pasture 0.0006956
Control:Ryegrass-Pond sludge:Pasture 0.0032623
Digested Biosolids:Ryegrass-Pond sludge:Pasture 0.8367252
Fertiliser:Ryegrass-Pond sludge:Pasture 0.7179899
Pond sludge:Ryegrass-Pond sludge:Pasture 0.9999999
Digested Biosolids:Ryegrass-Control:Ryegrass 0.0458711
Fertiliser:Ryegrass-Control:Ryegrass 0.1705228
Pond sludge:Ryegrass-Control:Ryegrass 0.0042448
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass 0.9999151
Pond sludge:Ryegrass-Digested Biosolids:Ryegrass 0.8948572
Pond sludge:Ryegrass-Fertiliser:Ryegrass 0.7862983

HSD Test for Zinc

Mean Square Error: 8.311111

Treatment, means

	Zinc	std	r	Min	Max
Control	27.16667	2.926887	6	22	31
Digested Biosolids	34.00000	3.577709	6	30	39
Fertiliser	27.20000	5.495453	5	23	35
Pond sludge	37.16667	2.136976	6	35	40

Alpha: 0.05 ; DF Error: 15
Critical Value of Studentized Range: 4.075974

Groups according to probability of means differences and alpha level(0.05)

Treatments with the same letter are not significantly different.

	Zinc	groups
Pond sludge	37.16667	a
Digested Biosolids	34.00000	a
Fertiliser	27.20000	b
Control	27.16667	b

Copper

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	2.403	0.801	0.700	0.567
Plant.Type	1	1.186	1.186	1.036	0.325
Treatment:Plant.Type	3	8.114	2.705	2.363	0.112
Residuals	15	17.167	1.144		

Boron

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	3.446	1.149	1.641	0.222088
Plant.Type	1	12.975	12.975	18.536	0.000625 ***
Treatment:Plant.Type	3	2.991	0.997	1.424	0.274794
Residuals	15	10.500	0.700		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Molybdenum

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	1.0228	0.3409	9.673	0.000844 ***
Plant.Type	1	1.2135	1.2135	34.427	3.09e-05 ***
Treatment:Plant.Type	3	0.1717	0.0572	1.624	0.225904
Residuals	15	0.5287	0.0352		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Fit: aov(formula = Molybdenum ~ Treatment * Plant.Type, data = plant.all)

$Treatment

	diff	lwr	upr	p adj
Digested Biosolids-Control	0.478333333	0.1659257	0.7907410	0.0025308
Fertiliser-Control	0.001666667	-0.3259892	0.3293225	0.9999988
Pond sludge-Control	-0.006666667	-0.3190743	0.3057410	0.9999125
Fertiliser-Digested Biosolids	-0.476666667	-0.8043225	-0.1490108	0.0038934
Pond sludge-Digested Biosolids	-0.485000000	-0.7974076	-0.1725924	0.0022448
Pond sludge-Fertiliser	-0.008333333	-0.3359892	0.3193225	0.9998520

$Plant.Type

	diff	lwr	upr	p adj
Ryegrass-Pasture	-0.4582576	-0.6252966	-0.2912186	3.21e-05

$`Treatment:Plant.Type`

	diff	lwr
Digested Biosolids:Pasture-Control:Pasture	0.60333333	0.06787894
Fertiliser:Pasture-Control:Pasture	-0.13666667	-0.67212106
Pond sludge:Pasture-Control:Pasture	0.05000000	-0.48545439
Control:Ryegrass-Control:Pasture	-0.41666667	-0.95212106
Digested Biosolids:Ryegrass-Control:Pasture	-0.06333333	-0.59878773
Fertiliser:Ryegrass-Control:Pasture	-0.31166667	-0.91032288
Pond sludge:Ryegrass-Control:Pasture	-0.48000000	-1.01545439
Fertiliser:Pasture-Digested Biosolids:Pasture	-0.74000000	-1.27545439
Pond sludge:Pasture-Digested Biosolids:Pasture	-0.55333333	-1.08878773
Control:Ryegrass-Digested Biosolids:Pasture	-1.02000000	-1.55545439
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture	-0.66666667	-1.20212106
Fertiliser:Ryegrass-Digested Biosolids:Pasture	-0.91500000	-1.51365621
Pond sludge:Ryegrass-Digested Biosolids:Pasture	-1.08333333	-1.61878773
Pond sludge:Pasture-Fertiliser:Pasture	0.18666667	-0.34878773
Control:Ryegrass-Fertiliser:Pasture	-0.28000000	-0.81545439
Digested Biosolids:Ryegrass-Fertiliser:Pasture	0.07333333	-0.46212106
Fertiliser:Ryegrass-Fertiliser:Pasture	-0.17500000	-0.77365621
Pond sludge:Ryegrass-Fertiliser:Pasture	-0.34333333	-0.87878773
Control:Ryegrass-Pond sludge:Pasture	-0.46666667	-1.00212106
Digested Biosolids:Ryegrass-Pond sludge:Pasture	-0.11333333	-0.64878773
Fertiliser:Ryegrass-Pond sludge:Pasture	-0.36166667	-0.96032288
Pond sludge:Ryegrass-Pond sludge:Pasture	-0.53000000	-1.06545439
Digested Biosolids:Ryegrass-Control:Ryegrass	0.35333333	-0.18212106
Fertiliser:Ryegrass-Control:Ryegrass	0.10500000	-0.49365621
Pond sludge:Ryegrass-Control:Ryegrass	-0.06333333	-0.59878773
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass	-0.24833333	-0.84698954
Pond sludge:Ryegrass-Digested Biosolids:Ryegrass	-0.41666667	-0.95212106
Pond sludge:Ryegrass-Fertiliser:Ryegrass	-0.16833333	

Pond sludge:Ryegrass-Fertiliser:Ryegrass -0.76698954

	upr	p adj
Digested Biosolids:Pasture-Control:Pasture	1.138787727	0.0220499
Fertiliser:Pasture-Control:Pasture	0.398787727	0.9824154
Pond sludge:Pasture-Control:Pasture	0.585454393	0.9999697
Control:Ryegrass-Control:Pasture	0.118787727	0.1903212
Digested Biosolids:Ryegrass-Control:Pasture	0.472121060	0.9998517
Fertiliser:Ryegrass-Control:Pasture	0.286989545	0.6184065
Pond sludge:Ryegrass-Control:Pasture	0.055454393	0.0953715
Fertiliser:Pasture-Digested Biosolids:Pasture	-0.204545607	0.0041461
Pond sludge:Pasture-Digested Biosolids:Pasture	-0.017878940	0.0403898
Control:Ryegrass-Digested Biosolids:Pasture	-0.484545607	0.0001605
Digested Biosolids:Ryegrass-Digested Biosolids:Pasture	-0.131212273	0.0101565
Fertiliser:Ryegrass-Digested Biosolids:Pasture	-0.316343789	0.0016139
Pond sludge:Ryegrass-Digested Biosolids:Pasture	-0.547878940	0.0000810
Pond sludge:Pasture-Fertiliser:Pasture	0.722121060	0.9142628
Control:Ryegrass-Fertiliser:Pasture	0.255454393	0.6136518
Digested Biosolids:Ryegrass-Fertiliser:Pasture	0.608787727	0.9996101
Fertiliser:Ryegrass-Fertiliser:Pasture	0.423656211	0.9636454
Pond sludge:Ryegrass-Fertiliser:Pasture	0.192121060	0.3827269
Control:Ryegrass-Pond sludge:Pasture	0.068787727	0.1108504
Digested Biosolids:Ryegrass-Pond sludge:Pasture	0.422121060	0.9940087
Fertiliser:Ryegrass-Pond sludge:Pasture	0.236989545	0.4505764
Pond sludge:Ryegrass-Pond sludge:Pasture	0.005454393	0.0533417
Digested Biosolids:Ryegrass-Control:Ryegrass	0.888787727	0.3508692
Fertiliser:Ryegrass-Control:Ryegrass	0.703656211	0.9980993
Pond sludge:Ryegrass-Control:Ryegrass	0.472121060	0.9998517
Fertiliser:Ryegrass-Digested Biosolids:Ryegrass	0.350322878	0.8214047
Pond sludge:Ryegrass-Digested Biosolids:Ryegrass	0.118787727	0.1903212
Pond sludge:Ryegrass-Fertiliser:Ryegrass	0.430322878	0.9703139

HSD Test
Alpha: 0.05 ; DF Error: 15
Critical Value of Studentized Range: 4.075974
Groups according to probability of means differences and alpha level(0.05)
Treatments with the same letter are not significantly different.

	Molybdenum groups	
Digested Biosolids	1.636667	a
Fertiliser	1.160000	b
Control	1.158333	b
Pond sludge	1.151667	b

Cobalt

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	0.001401	0.0004671	1.314	0.307
Plant.Type	1	0.000764	0.0007642	2.149	0.163
Treatment:Plant.Type	3	0.002449	0.0008164	2.296	0.119
Residuals	15	0.005333	0.0003556		

Selenium

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	1.435e-04	4.783e-05	2.870	0.07140 .
Plant.Type	1	1.579e-04	1.579e-04	9.474	0.00765 **
Treatment:Plant.Type	3	9.211e-05	3.070e-05	1.842	0.18285
Residuals	15	2.500e-04	1.667e-05		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Chemical parameters of soil samples

pH

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	0.0648	0.02159	0.972	0.4319
Plant.type	1	0.0070	0.00702	0.316	0.5824
Treatment:Plant.type	3	0.1696	0.05655	2.545	0.0952 .
Residuals	15	0.3333	0.02222		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Olsen-P

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	677.9	225.97	6.140	0.00619 **
Plant.type	1	24.8	24.84	0.675	0.42415

```
Treatment:Plant.type  3   76.1   25.37   0.690 0.57241
Residuals            15  552.0   36.80
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

HSD Test

OlsenPhosphorus groups
Fertiliser              46.20000      a
Digested Biosolids      43.83333     ab
Control                 34.33333      b
Pond sludge             34.00000      b

  Tukey multiple comparisons of means
    95% family-wise confidence level
Fit: aov(formula = OlsenPhosphorus ~ Treatment * Plant.type, data = soil.all)

$Treatment
                                  diff        lwr        upr     p adj
Digested Biosolids-Control       9.5000000  -0.5943802 19.5943802 0.0685269
Fertiliser-Control              11.8666667   1.2795914 22.4537420 0.0257171
Pond sludge-Control             -0.3333333 -10.4277136  9.7610469 0.9996765
Fertiliser-Digested Biosolids    2.3666667  -8.2204086 12.9537420 0.9159037
Pond sludge-Digested Biosolids  -9.8333333 -19.9277136  0.2610469 0.0574727
Pond sludge-Fertiliser         -12.2000000 -22.7870753 -1.6129247 0.0215661
```

Potassium (mg/kg)

```
                    Df Sum Sq Mean Sq F value Pr(>F)
Treatment            3    422   140.6   0.268  0.848
Plant.type           1   1431  1431.2   2.726  0.120
Treatment:Plant.type 3    502   167.4   0.319  0.812
Residuals           15   7876   525.1
```

Calcium (mg/kg)

```
                    Df Sum Sq Mean Sq F value Pr(>F)
Treatment            3  96419   32140   1.626  0.225
Plant.type           1   2698    2698   0.136  0.717
Treatment:Plant.type 3 121982   40661   2.057  0.149
Residuals           15 296467   19764
```

Magnesium (mg/kg)

```
Df Sum Sq Mean Sq F value   Pr(>F)
Treatment            3  273.3    91.1   1.002 0.419224
Plant.type           1 1675.4  1675.4  18.419 0.000642 ***
Treatment:Plant.type 3  464.4   154.8   1.702 0.209339
Residuals           15 1364.4    91.0
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Sodium (mg/kg)

```
                    Df Sum Sq Mean Sq F value Pr(>F)
Treatment            3  33.64   11.21   1.490 0.2574
Plant.type           1  38.01   38.01   5.053 0.0401 *
Treatment:Plant.type 3  68.49   22.83   3.035 0.0619 .
Residuals           15 112.85    7.5
```

CEC

```
                    Df Sum Sq Mean Sq F value Pr(>F)
Treatment            3  4.670  1.5565   3.258 0.0513 .
Plant.type           1  0.568  0.5684   1.190 0.2926
Treatment:Plant.type 3  2.465  0.8216   1.720 0.2058
Residuals           15  7.167  0.4778
---
```

Total Base Saturation

```
                    Df Sum Sq Mean Sq F value Pr(>F)
Treatment            3  97.21   32.40   1.944 0.1659
Plant.type           1   0.02    0.02   0.001 0.9759
Treatment:Plant.type 3 176.68   58.89   3.534 0.0408 *
Residuals           15 250.00   16.67
```

Potassium (MAF)

```
                    Df Sum Sq Mean Sq F value Pr(>F)
```

```
Treatment            3  0.952  0.3174   0.162  0.920
Plant.type           1  2.402  2.4018   1.228  0.285
Treatment:Plant.type 3  2.965  0.9883   0.505  0.684
Residuals           15 29.333  1.9556
```

Calcium (MAF)

```
                     Df Sum Sq Mean Sq F value Pr(>F)
Treatment            3  3.104  1.0348   1.826 0.1857
Plant.type           1  0.568  0.5684   1.003 0.3324
Treatment:Plant.type 3  7.132  2.3772   4.195 0.0242 *
Residuals           15  8.500  0.5667
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Magnesium (MAF)

```
                    Df Sum Sq Mean Sq F value Pr(>F)
Treatment           3   2.31   0.771   0.156 0.9241
Plant.type          1  15.83  15.833   3.209 0.0934 .
Treatment:Plant.type 3  37.33  12.444   2.523 0.0971 .
Residuals           15  74.00   4.933
```

Sodium (MAF)

```
                     Df Sum Sq Mean Sq F value Pr(>F)
Treatment            3  0.546  0.1821   0.683  0.576
Plant.type           1  0.086  0.0860   0.322  0.579
Treatment:Plant.type 3  1.281  0.4269   1.601  0.231
Residuals           15  4.000  0.2667
```

Volume Weight (g/ml)

```
                     Df  Sum Sq  Mean Sq F value Pr(>F)
Treatment            3 0.00437 0.001456   0.225  0.878
Plant.type           1 0.01475 0.014754   2.280  0.152
Treatment:Plant.type 3 0.03201 0.010671   1.649  0.220
Residuals           15 0.09707 0.006471
```

Organic Matter

```
                    Df Sum Sq Mean Sq F value Pr(>F)
Treatment           3 0.4085  0.1362   1.656 0.2189
Plant.type          1 0.6135  0.6135   7.461 0.0154 *
Treatment:Plant.type 3 0.0568  0.0189   0.230 0.8737
Residuals           15 1.2333  0.0822
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Dry Matter

```
                    Df Sum Sq Mean Sq F value Pr(>F)
Treatment           3  11.85    3.95   0.907 0.4610
Plant.type          1  54.96   54.96  12.619 0.0029 **
Treatment:Plant.type 3  15.07    5.02   1.153 0.3600
Residuals           15  65.33    4.36
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’
```

Ash

```
  Df Sum Sq Mean Sq F value Pr(>F)
Treatment           3 0.1594 0.05314   0.598  0.626
Plant.type          1 0.1754 0.17544   1.974  0.180
Treatment:Plant.type 3 0.1579 0.05263   0.592  0.630
Residuals           15 1.3333 0.08889
```

Total Recoverable Magnesium

```
                     Df Sum Sq Mean Sq F value Pr(>F)
Treatment            3  10745    3582   1.948  0.165
Plant.type           1   2280    2280   1.240  0.283
Treatment:Plant.type 3   5183    1728   0.940  0.446
Residuals           15  27583    1839
```

Total Recoverable Phosphorous

```
    Df Sum Sq Mean Sq F value   Pr(>F)
Treatment            3  61998   20666  17.547 3.61e-05 ***
Plant.type           1   2741    2741   2.327    0.148
Treatment:Plant.type 3    342     114   0.097    0.961
Residuals           15  17667    1178
```

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

HSD Test for Total.Recoverable.Phosphorus
Mean Square Error: 1177.778
Treatment, means

	Total.Recoverable.Phosphorus	std	r	Min	Max
Control	711.6667	25.62551	6	670	750
Digested Biosolids	846.6667	48.02777	6	800	920
Fertiliser	770.0000	15.81139	5	750	790
Pond sludge	736.6667	31.41125	6	700	780

Alpha: 0.05 ; DF Error: 15
Critical Value of Studentized Range: 4.075974
Groups according to probability of means differences and alpha level(0.05)
Treatments with the same letter are not significantly different.

	Total.Recoverable.Phosphorus	groups
Digested Biosolids	846.6667	a
Fertiliser	770.0000	b
Pond sludge	736.6667	b
Control	711.6667	b

Total Nitrogen

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	0.0010206	0.0003402	2.734	0.0804 .
Plant.type	1	0.0000568	0.0000568	0.457	0.5094
Treatment:Plant.type	3	0.0002298	0.0000766	0.616	0.6155
Residuals	15	0.0018667	0.0001244		

Total Carbon

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	0.1640	0.05468	2.524	0.09700 .
Plant.type	1	0.2361	0.23607	10.896	0.00485 **
Treatment:Plant.type	3	0.0236	0.00787	0.363	0.78064
Residuals	15	0.3250	0.02167		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Total Recoverable Cadmium

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	0.0003206	0.0001069	0.562	0.648
Plant.type	1	0.0001375	0.0001375	0.724	0.408
Treatment:Plant.type	3	0.0004658	0.0001553	0.817	0.504
Residuals	15	0.0028500	0.0001900		

Total Recoverable Chromium

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	2.7029	0.9010	6.757	0.0042 **
Plant.type	1	0.0439	0.0439	0.329	0.5748
Treatment:Plant.type	3	0.1228	0.0409	0.307	0.8199
Residuals	15	2.0000	0.1333		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

HSD Test for Total.Recoverable.Chromium
Mean Square Error: 0.1333333
Treatment, means

	Total.Recoverable.Chromium	std	r	Min	Max
Control	8.000000	0.0000000	6	8	8
Digested Biosolids	8.833333	0.4082483	6	8	9
Fertiliser	8.000000	0.0000000	5	8	8
Pond sludge	8.333333	0.5163978	6	8	9

Alpha: 0.05 ; DF Error: 15
Critical Value of Studentized Range: 4.075974
Groups according to probability of means differences and alpha level(0.05)
Treatments with the same letter are not significantly different.

	Total.Recoverable.Chromium	groups
Digested Biosolids	8.833333	a

```
Pond sludge                 8.333333     ab
Control                     8.000000      b
Fertiliser                  8.000000      b
```

Total Recoverable Copper

```
Df Sum Sq Mean Sq F value   Pr(>F)
Treatment            3 16.851   5.617  25.276 4.08e-06 ***
Plant.type           1  0.086   0.086   0.387    0.543
Treatment:Plant.type  3  0.947   0.316   1.421    0.276
Residuals           15  3.333   0.222
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

HSD Test for Total.Recoverable.Copper

Mean Square Error:  0.2222222
Treatment,  means

                 Total.Recoverable.Copper       std r Min Max
Control                          4.500000 0.5477226 6   4   5
Digested Biosolids               6.166667 0.4082483 6   6   7
Fertiliser                       4.400000 0.5477226 5   4   5
Pond sludge                      6.166667 0.4082483 6   6   7

Alpha: 0.05 ; DF Error: 15
Critical Value of Studentized Range: 4.075974
Groups according to probability of means differences and alpha level( 0.05 )
Treatments with the same letter are not significantly different.

                 Total.Recoverable.Copper groups
Digested Biosolids               6.166667      a
Pond sludge                      6.166667      a
Control                          4.500000      b
Fertiliser                       4.400000      b
```

Total Recoverable Lead

```
                  Df Sum Sq Mean Sq F value   Pr(>F)
Treatment            3 1.4455  0.4818  10.424 0.000587 ***
Plant.type           1 0.1328  0.1328   2.873 0.110738
Treatment:Plant.type  3 0.1075  0.0358   0.776 0.525625
Residuals           15 0.6933  0.0462
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> HSD.test(aov, "Treatment", group = TRUE, console = TRUE)

Study: aov ~ "Treatment"

HSD Test for Total.Recoverable.Lead
Mean Square Error:  0.04622222
Treatment,  means

                 Total.Recoverable.Lead       std r Min Max
Control                        6.750000 0.1378405 6 6.5 6.9
Digested Biosolids             6.933333 0.2943920 6 6.7 7.5
Fertiliser                     6.540000 0.1949359 5 6.3 6.8
Pond sludge                    7.233333 0.2250926 6 7.0 7.5

Alpha: 0.05 ; DF Error: 15
Critical Value of Studentized Range: 4.075974
Groups according to probability of means differences and alpha level( 0.05 )
Treatments with the same letter are not significantly different.

                 Total.Recoverable.Lead groups
Pond sludge                    7.233333      a
Digested Biosolids             6.933333     ab
Control                        6.750000     bc
Fertiliser                     6.540000      c
```

Total Recoverable Nickel

```
Df Sum Sq Mean Sq F value Pr(>F)
Treatment            3 0.1232 0.04106   0.924  0.453
Plant.type           1 0.0439 0.04386   0.987  0.336
Treatment:Plant.type  3 0.1228 0.04094   0.921  0.454
```

Residuals 15 0.6667 0.04444

Total Recoverable Zinc

```
                  Df Sum Sq Mean Sq F value   Pr(>F)
Treatment          3  482.3  160.75  15.881 6.36e-05 ***
Plant.type         1    7.0    6.96   0.688    0.420
Treatment:Plant.type  3   21.9    7.30   0.721    0.555
Residuals         15  151.8   10.12
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

HSD Test for Total.Recoverable.Zinc
Mean Square Error:  10.12222
Treatment,  means

                  Total.Recoverable.Zinc      std r Min Max
Control                         29.16667 2.786874 6  26  33
Digested Biosolids              36.33333 3.265986 6  31  40
Fertiliser                      27.40000 3.361547 5  24  33
Pond sludge                     38.33333 2.943920 6  33  41

Alpha: 0.05 ; DF Error: 15
Critical Value of Studentized Range: 4.075974
Groups according to probability of means differences and alpha level( 0.05 )
Treatments with the same letter are not significantly different.

                  Total.Recoverable.Zinc groups
Pond sludge                       38.33333      a
Digested Biosolids                36.33333      a
Control                           29.16667      b
Fertiliser                        27.40000      b
```

Overall comparison across all parameter

```
                    Df Sum Sq Mean Sq F value Pr(>F)
Treatment           3 131683   43894   1.192  0.346
Plant.Type          1  42173   42173   1.145  0.302
Treatment:Plant.Type  3 102549   34183   0.928  0.451
Residuals           15 552540   36836
```

ANOVA results of the DHA levels of soils from Pasture and Italian Ryegrass plots

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	4.970191	3	1.65673	0.293525	0.829483	3.238872
Columns (crops)	199.7404	1	199.7404	35.38828	2.04E-05	4.493998
Interaction	1.078503	3	0.359501	0.063693	0.978276	3.238872
Within	90.30805	16	5.644253			
Total	296.0971	23				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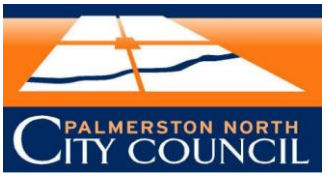
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