# Final report

Carbon & Energy Management
ALBERTA RESEARCH COUNCIL
250 KARL CLARK ROAD
EDMONTON, ALBERTA T6N 1E4

Development of a preliminary database of digestate chemistry, heavy metal and pathogen content to assist in Alberta regulation compliance

**Part A**
Prepared by
Ruth Eckford

**Part B**
Prepared by Tiejun TJ Gao
and
edited by Ruth Eckford

**for**

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**ABSTRACT**

This study was used to report salt concentrations, heavy metal concentrations, fecal coliform and *Salmonella* sp. in pre-digested biowaste substrates and post-digested products. Heavy metal and salt concentrations were followed for digestate separated liquid and solid fractions. Batch anaerobic cultures were used for 25 manure and non-manure substrates and two substrates were chosen to be used in a continuously stirred tank reactor Pilot Plant digestion system. The results showed that manures contained the highest concentrations for heavy metals and that the manure substrates exceeded the Canadian Council of Ministers of the Environment (CCME) guidelines for soil application. Some non-manure substrates including grocery waste, poultry slaughterhouse waste and thermally hydrolyzed waste exceeded the heavy metal soil guideline concentrations from the CCME. Manure and non-manure substrates showed heavy metal concentrations that exceeded the CCME water guidelines for agricultural use. Salt concentrations were highest in manure substrates and the non-manure substrates that contained high salt concentrations were poultry slaughterhouse waste, hog slaughterhouse peptone waste, potato process waste and potato plant vines. Heavy metal and salt concentrations were increased with digestion and the separated liquid fractions contained higher concentrations than the separated solid fractions. Results showed that heavy metals may be retained in large digester systems due to incomplete purging of substrates and precipitation. Levels above the US Environmental Protection Agency (USEPA) Class A and Class B biosolids and CCME compost guidelines for fecal coliform were found in freshly collected dairy and chicken manures. *Salmonella* sp. above the accepted USEPA for Class A biosolids was found in one freshly collected dairy manure. Fecal coliform numbers were decreased on storage of dairy manure. Anaerobic digestion at 55° and 14-day hydraulic retention time using a continuously stirred tank reactor system reduced fecal coliform and *Salmonella* sp.

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# PART A: DATA BASE OF DIGESTATE CHEMISTRY

## 1.0 Introduction

For Alberta, there is an ongoing investigation into the possibility of designing biogas facilities that will use various biowaste feedstocks or substrates. Currently, digestate from biowaste substrates other than manure is regulated under sewage sludge. When digestate slurry and separated liquid and solid fractions from anaerobic digesters are designated as sewage sludge, there is an automatic assumption as to the characteristics, and these assumptions may not be accurate. This designation could present economical challenges to an emerging anaerobic digestion industry.

Work that was previously done by the Alberta Research Council showed that elevated heavy metal content is found mostly in manure and slaughterhouse waste and not in general biowaste. However, the limited data from Alberta Research Council does not give Alberta Environment enough information to set guidelines for handling the digestate generated from biogas plants using various biowastes. There is a need to determine the levels of heavy metals, salts, as well as nitrogen, phosphorous and potassium in feedstock biowastes used for anaerobic digestion and the post-digestion digestates, separated liquids and solids. As well, there is a need to determine levels and destruction of pathogens in biowaste during anaerobic digestion. The combined information will provide data for Alberta Environment to develop guidelines for the biogas industry.

Two objectives were used for this study:

- to determine the chemical characteristics, including nutrient, heavy metal and salt content of various biowaste feedstocks or substrates and the chemical characteristics of their digestates and digestates separated into liquids and solids,
- to perform a preliminary assessment of pathogen content and destruction through anaerobic digestion.

## 2.0 Methods

### *2.1 Methane potential using batch culture*

Methane potential or productivity measurements are used to indicate the yield of methane per unit of a variable. For this trial, the methane potential was performed using batch cultures with chosen substrates and a methanogenic inoculum. The batch culture method was used to determine whether stable methanogenic conditions were obtained for each substrate during anaerobic digestion.

In order to maintain consistent results for this study, the total amount of inoculum required for batch cultures using all substrates was collected in pails from a large digestion system operating under stable conditions. There were no adequate resources available to remix the collected inoculum. However, since the inoculum was obtained from one collection period, it was assumed that the inoculum in each pail did not differ to a large degree. The inoculum was immediately transferred to Alberta Research Council, Biowaste Resource Recovery Laboratory in Vegreville and frozen at -20°C. When a substrate was ready to be tested during the study, the appropriate amount of inoculum was gently thawed, ground, mixed and incubated for 7 days at 55°C to determine its viability, stimulate activity and remove as much excess carbon as possible. Ten sets of substrates with 2 or 3 substrates per test set were used for this study. For each test set, triplicate cultures with only inoculum were set up. At the same time, the quality of the inoculum was evaluated with cellulose (Alfa Aesar, Ward Hill, MA) using triplicate 5% total solids (TS), 300-ml cultures in 1-L Corning™ bottles with black butyl stoppers (Fisher Scientific, Canada).

Methane potential for a chosen substrate was obtained at a predetermined substrate/inoculum VS ratio, temperature and incubation period. Pretesting of substrate was done using 250-ml Wheaton™ culture bottles with cut-out top and butyl inserts (Fisher Scientific, Canada) containing 8% TS, the same TS that was used for the substrates in this study. Various mixtures of substrate and inoculum were evaluated in order to determine the VS ratio that would be used for each substrate.

The method used for methane potential is consistent with the standard methods ISO 11734 and DIN 38414 Part 8. The production of biogas components such as methane, carbon dioxide and hydrogen sulfide were measured. Briefly, substrate was added to inoculum and the mixture was incubated at 55°C in sealed glass culture bottles for 30 or 45 days. The cultures are considered finished when the daily biogas production was approximately 1% of the total biogas production. The extended incubation period was needed in some cases in order to meet that requirement. During incubation, biogas volume was calculated from pressure readings and biogas components such as methane, carbon dioxide and hydrogen sulfide were determined using gas chromatography (GC). The results for the aforementioned biogases that were produced in cultures containing only inoculum were subtracted from the same biogas results for cultures with substrate plus inoculum. The biogas volume results were normalized to standard conditions.

Over the incubation period, all bottles for each substrate were monitored for pressure. Due to time restraints, gases, including hydrogen, oxygen, nitrogen, methane, carbon dioxide and hydrogen sulfide, were monitored by GC on 5 bottles for each substrate. The methods for batch culture anaerobic digestion are described in the Biowaste Resource Recovery Laboratory manual (1).

After the digestion period, digestate from each culture mixture was separated into liquid and solid fractions. In order to obtain sufficient separated solids from the digestate after incubation, several 2-L Corning™ bottles with black butyl stoppers (Fisher Scientific, Canada) containing 8% TS and 800 ml of culture were used. For the methane potential of the first four test sets of substrates using cattle feedlot bed pack manure, dairy manure (2 types), potato tuber waste, broiler chicken manure, laying hen manure, hog slaughterhouse waste (sludge and peptone), unstripped glycerine, potato process waste and potato vine, 10 to 12 bottles were used. For the remaining test sets of substrates including cattle carcass, poultry slaughterhouse, sugar beet waste, thermally hydrolyzed biowaste (2 types), grocery waste, thin stillage, wet distillers grains, cheese whey, sewage sludge, beef slaughterhouse waste and solid hog manure, it was found that nine bottles produced an adequate amount of separated solids. For the liquid hog and liquid sewage substrates, the TS results were low, and 14 bottles with 5% TS were needed.

The cultures were incubated in New Brunswick Scientific Classic Incubator Shakers (Edison, NJ), C-24 for small culture bottles and E-25R for large bottles. The bottles in the incubators were covered with an insulation jacket to prevent heat loss during pressure and GC analyses. The gas chromatographic instrument was a Varian

CP-4900 Micro-GC (Walnut Creek, CA) equipped with a Molsieve 5Å PLOT (10 m) for analyzing hydrogen, oxygen, nitrogen, and methane and a Poraplot U (10 m) for carbon dioxide and hydrogen sulfide. Pressure readings were done using a SRP PT420 transducer (SRP Control Systems, Mississauga, Ont.) with a 0-25 psig range and readout pressure meter.

### *2.2 Post-digestion separation of digestate into liquid and solid fractions*

The overall plan for large-scale anaerobic digestion facilities must include the handling of the post-digestion product or digestate from digesters. Often, the digestate is separated into liquid and solid fractions. There is a need to evaluate digestate and the separated fractions in order to make environmentally safe decisions as to how they will be used.

Laboratory equipment was designed to simulate large-scale anaerobic digestion separators. The equipment was used to separate digestate from batch cultures into liquid and solid fractions after anaerobic digestion for 30 or 45 days. The sieve assembly consisted of three pieces, a nylon bottom fluted piece, a sieve (USA Standard Test Sieve, ASTM E11 specification, 500 μm, #35) to fit over the raised part of the bottom and a nylon top piece to fit inside the sieve. The separation process was done after digestate was scraped from batch culture bottles and mixed. Once the sieve was assembled, the digestate was slowly poured through the sieve and then pressure was applied using a hydraulic press. Liquid was extruded from the solids until the consistency was similar to separated solids from large-scale facilities.

### *2.3 Chemical analyses*

Chemical parameters are important indicators for anaerobic digestion processes. They are used to determine the suitability of substrates for digestion, potential toxic conditions that may arise during digestion and what nutrient resources remain after digestion. Optimum conditions for ultimate methane yield may not be achieved because of inhibitory factors contained in certain substrates. Therefore, it is beneficial to test new substrates for factors that may inhibit methanogenic activity.

Each biowaste substrate was collected at the place of origin by non-ARC staff into containers supplied by the company or into new clean containers supplied by ARC. The samples were immediately shipped to ARC by courier or other means. Upon arrival at ARC, the substrates were carefully mixed and ground. They were then proportioned into new clean small containers and analyzed immediately or frozen at -20°C and analyzed as soon as possible. The methods used for handling substrates after arrival and preparation for analyses are described in the Biowaste Resource Recovery Laboratory Manual (1).

Due to time and economic restraints, the inoculum was completely analyzed for chemical parameters and heavy metals only at the beginning of the study. The results were used to determine the amount of heavy metals that the inoculum would contribute to a digestion mixture. After the inoculum was incubated, complete results for chemical parameters and heavy metals for final cultures and separated fractions were obtained for the inoculum for 30-day and 45-day incubation periods. The 45-day results were obtained at the beginning of the study and the 30-day results were obtained near the end of the study. During the course of the study, when each of the substrate test sets was done, the inoculum was analyzed for TS, total carbon (Total C) and total nitrogen (Total N). These results were used to determine the consistency of the inoculum that was collected for the study.

Table 2.1 gives the list of chemical parameters and a brief explanation of the method used for each parameter. All samples were prepared at the Biowaste Resource Recovery Laboratory at Alberta Research Council in Vegreville, Alberta. Most analyses were done at the Biowaste Resource Recovery Laboratory at Alberta Research Council in Vegreville, Alberta. The ICP-MS analyses for heavy metals and phosphorous were done at the Analytical Chemistry Laboratory, Environmental Management Group at Alberta Research Council in Vegreville, Alberta. The available nitrogen colorimetry and potassium atomic absorption were done at the Natural Resources Analytical Laboratory at the University of Alberta, Edmonton and the Karl Fisher moisture content was done at the Advanced Materials Unit, Alberta Research Council, Devon, Alberta. All samples were analyzed within a very short period of time after they were prepared. If analyses were not done quickly, the samples were frozen at -20°C. Generally, triplicate analyses were done for each parameter except for Total N, Total C and total sulphur. These were done on 10 replicates for Total N and Total C and 5 replicates for sulphur.

Samples for heavy metal analysis of substrate, initial culture, final culture, liquid and solid were dried at 70°C for 48 h and one mixed sample was sent for analysis. Samples for available heavy metals, nitrogen, phosphorous and potassium analyses were done in triplicate, diluted in distilled water if needed and sent for analysis. There was no need for dilution of the two thermally hydrolyzed biowaste substrates, cheese whey, liquid hog, liquid sewage and two ARC Pilot Plant substrates.

The heavy metals were analyzed as samples were prepared. The available heavy metals were done shortly after the substrates arrived at the laboratory. The heavy metals for the initial culture mixtures were done as soon as the batch cultures were set up and the final digestate and separated liquid and solid samples were sent for analysis at the same time after the incubation period.

Electrical conductivity (EC) and pH were performed on substrates and samples diluted with distilled water to give 2 g TS slurry in 100 ml. The EC results were used to give an indication of the salt content for a substrate and resulting digestate as well as separated liquid and solid fractions. If the TS of the substrate or sample was <2%, no dilution was done. Due to convenience, EC and pH were performed on the same slurry sample. Initial investigation of the EC method showed that there was no linear relationship for EC results when various dilutions were compared for one substrate. Since the substrates had diverse matrices and many substrates required dilution to obtain a slurry for the probe measurement, a consistent dilution of 2 g TS in 100 ml solution was chosen. This allowed comparison of EC results for the substrates used in this study.

Biowaste substrates are not always homogeneous even after rigorous mixing. Therefore, results were difficult to obtain in some cases and more samples were analyzed in order to get a range of results, especially when wet samples were used. These samples are noted in the tables of results. Unless otherwise indicated, results were within 15% of the mean as recommended in the Recommended Methods of Manure Analysis (2).

Table 2. 1: Explanation of chemical parameters analyzed for this study

| Parameter | Explanation |
|---|---|
| Total solids (TS) | Forced-air oven-drying method at 70°C for 48 h; assumed only water removed (3) |
| Volatile solids (VS) | Muffle furnace at 550°C for 2.5 h giving an indication of organic content (3) |
| Total nitrogen ( Total N) | Leco TruSpec CN method on wet sample |
| Total carbon (Total C) | Leco TruSpec CN method on wet sample |
| Total potassium (Total K)[a] | Acid digestion and ICP-MS analysis on dried sample |
| Total phosphorus (Total P)[a] | Acid digestion and ICP-MS analysis on dried sample |
| Total sulphur (Total S) | Leco TruSpec S method on dried sample |
| Available nitrogen (Available $NH_4^+$-N) | Water extracted ammonium-N ($NH_4^+$-N) on wet sample and measured by colorimetry (3) |
| Available potassium (Available K) | Water extracted potassium on wet sample and measured by atomic absorption spectroscopy |
| Available phosphorus (Available P) | Water extracted phosphorus on wet sample and measured by ICP-MS[b] |
| Electrical conductivity (EC)[c] | Probe was used; gives an indication of dissolved salts and ions |
| pH[c] | Probe was used; determines acid or basic characteristic |
| Heavy metal analyses[d] measured by ICP-MS[a] | Water extracted available heavy metals on wet sample and acid digested extractable heavy metals on dried sample |

[a] The biowaste material was oven dried at 70°C for 48 hours. Samples were acid digested using an EPA method (4). Elemental analysis was done using a Perkin Elmer Elan DRC-II Inductively Coupled Plasma Mass Spectrometer (ICP-MS) following an EPA method (5).

[b] ICP-MS was done using a Perkin Elmer Elan DRC-II Inductively Coupled Plasma Mass Spectrometer (ICP-MS) following an EPA method (5)

[c] Performed on samples diluted with distilled water to give 2 g TS slurry in 100 ml. EC was done using a YSI Model 32 conductance meter and probe (Yellow Springs Inst. Co. Inc., Yellow Springs, OH). The pH was done using probe Model IQ 150, Spectrum Technologies Inc. (Plainfield, IL). EC and pH were performed on the same slurry.

[d] For aqueous sample, water extractable dissolved heavy metals were analyzed with no digestion of the wet samples. For dried sample, the sample was dried at 70°C for 48 hours and digested with nitric acid before heavy metals were analyzed.

The names and symbols for the heavy metals analyzed in this study are: Ag-Silver; Al-Aluminum; As-Arsenic; B-Boron; Ba-Barium; Be-Beryllium; Bi-Bismuth; Ca-Calcium; Cd-Cadmium; Cl-Chloride; Co-Cobalt; Cr-Chromium; Cu-Copper; Fe-Iron; Hg-Mercury; Li-Lithium; Mg-Magnesium; Mn-Manganese; Mo-Molybdenum; Na-Sodium; Ni-Nickel; Pb-Lead; Sb-Antimony; Se-Selenium; Sn-Tin; Sr-Strontium; Th-Thorium; Ti-Titanium; TI-Thallium; U-Uranium; V-Vanadium; Zn-Zinc.

Two sets of biowaste substrates were chosen to be evaluated using the fully automated ARC Pilot Plant system in Vegreville, Alberta (referred to as ARC Pilot Plant from this point). The system includes 80-L continuous stirred tank reactor digesters. This part of the study was important in order to simulate the digestion process that occurs in large-scale systems. The first ARC Pilot Plant test used a dairy manure (labeled #1 in Section 3.0) plus glycerine and the second ARC Pilot Plant test used the wet distillers grain. For the ARC Pilot Plant substrates, the initial digestion mixture, digestate and separated liquid and solid fractions were analyzed, and the results are in the Pilot Plant section of this report. The substrates were also used in the batch cultures, and the chemical parameter and heavy metal results for these substrates are included with the batch culture results.

For batch cultures in our laboratory, substrate is added to inoculum, placed in an anaerobic environment and monitored for an incubation period. The mixture is not disturbed during the incubation period other than a swirling mix when gases are released and monitored. In the continuous stirred tank reactor digesters at the ARC Pilot Plant, substrate is fed, mixed and digestate removed at predetermined intervals over a 14-day hydraulic retention time. The biogas is continuously monitored using an automatic system. The continuous stirred tank reactor system cannot handle a large number of different substrates over a short period of time. The batch culture, on the other hand, is valuable for obtaining methane potential of a substrate, is less expensive for studies that include a large number of different substrates and can evaluate several substrates at one time. We have found in our work at ARC that these two systems work very well together for the evaluation of substrates.

### *2.4 CCME soil and water quality guidelines*

Excerpts from the Canadian Council of Ministers of the Environment (CCME) guidelines that pertain to heavy metal concentrations in soil from agriculture, parks, residential, commercial and industrial sites and in irrigation and livestock water used for agriculture are presented in Tables 2.2 and 2.3. For each substrate, water extracted available heavy metals on wet substrate and acid digested extractable heavy metals on dried substrate, initial culture mixture, final culture mixture and separated liquid and solid from digestate were compared to the concentrations in the guidelines.

Due to time and financial restraints, only the heavy metals from Table 1 in the Canadian Soil Quality Guidelines for the Protection of Environmental and Human

Health, update 7.0, September 2007 and the footnotes that accompany the heavy metals in the guidelines were used in this study. They are presented in Table 2.2. The conductivity guideline shown in Table 2.2 is from Table 2 in the Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health, update 7.0, September 2007. Conductivity is used to evaluate salt content.

The water quality guidelines for heavy metals are from the Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses, Summary Table, update October 2005. The water quality guidelines use total dissolved solids for salt guidelines. This parameter was not measured in our study.

The reader is encouraged to visit the CCME website to obtain more information about the guidelines and guidelines for other heavy metals from the Canadian Soil Quality Guidelines Table 2 that were released in 1991. The website location is http://www.ccme.ca.

Table 2. 2: CCME soil quality guidelines

| CCME soil quality guidelines for the protection of environmental and human health (heavy metals given in μg/g and conductivity or salts given in dS/m) for application to soils from CCME Table 1, update 7.0, September 2007 for metals and Table 2 for Conductivity (6) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Heavy metal values, footnote references from CCME document and year guideline set | | | | | | | | | |
| Parameter | Agriculture | | Parks/Residential | | Commercial | | Industrial | | Year guideline set |
| As | 12 | b | 12 | b | 12 | b | 12 | b | 1997 |
| Ba | 750 | c | 500 | c | 2000 | c | 2000 | c | 1999 |
| Cd | 1.4 | b | 10 | g | 22 | b | 22 | b | 1999 |
| Cr (total) | 64 | b | 64 | b | 87 | b | 87 | b | 1997/99 |
| Cu | 63 | b | 63 | b | 91 | b | 91 | b | 1999 |
| Hg | 6.6 | b | 6.6 | b | 24 | b | 50 | b | 1999 |
| Ni | 50 | l | 50 | l | 50 | l | 50 | l | 1999 |
| Pb | 70 | b | 140 | b | 260 | b | 600 | b | 1999 |
| Se | 1 | b | 1 | b | 2.9 | b | 2.9 | b | 2007 |
| TI | 1 | n | 1 | o | 1 | o | 1 | o | 1999 |
| U | 23 | t | 23 | t | 33 | t | 300 | t | 2007 |
| V | 130 | l | 130 | l | 130 | i | 130 | i | 1997 |
| Zn | 200 | l | 200 | l | 360 | l | 360 | l | 1999 |
| Conductivity | 2 | | 2 | | 4 | | 4 | | 1991 |

* For guidelines derived prior to 2004, differentiation between soil texture (coarse/fine) is not applicable.

b Data are sufficient and adequate to calculate an SQGHH and an SQGE. Therefore the soil quality guideline is the lower of the two and represents a fully integrated *de novo* guideline for this land use, derived in accordance with the soil protocol (CCME 1996; 2006). The corresponding interim soil quality criterion (CCME 1991) is superseded by the soil quality guideline.

c Data are insufficient/inadequate to calculate an SQGHH, a provisional SQGHH, an SQGE , or a provisional SQGE. Therefore the interim soil quality criterion (CCME 1991) is retained as the soil quality guideline for this land use .

g The soil–plant–human pathway was not considered in the guideline derivation. If produce gardens are present or planned, a site-specific objective must be derived to take into account the bioaccumulation potential (e.g., adopt the agricultural guideline as objective). The off-site migration check should be recalculated accordingly.

i Data are sufficient and adequate to calculate only an SQGE. An interim soil quality criterion (CCME 1991) was not established for this land use, therefore the SQGE becomes the soil quality guideline.

l Data are sufficient and adequate to calculate only an SQGE, which is less than the interim soil quality criterion (CCME 1991) for this land use. Therefore the SQGE becomes the soil quality guideline, which supersedes the interim soil quality criterion for this land use.

n Data are sufficient and adequate to calculate a provisional SQGHH and an SQGE . The provisional SQGHH is equal to the SQGE and to the existing interim soil quality criterion (CCME 1991) and thus becomes the soil quality guideline, which supersedes the interim soil quality criterion for this land use.

o Data are sufficient and adequate to calculate a provisional SQGHH and an SQGE . The provisional SQGHH is less than the SQGE and thus becomes the soil quality guideline for this land use.

t Data are sufficient and adequate to calculate an SQGHH and an SQGE. Therefore the soil quality guideline is the lower of the two and represents a fully integrated *de novo* guideline for this land use.

u Author's note: Data for conductivity is given in μS/cm in Tables related to substrates used in this study. The conversion factor is μS/cm ÷ 1000 = dS/m.

Table 2. 3: CCME water quality guidelines

| CCME water guidelines for the protection of agricultural water uses, Summary table, updated October 2005, in µg/L for agricultural applications (7) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Heavy metal values, footnote references from CCME document and year guideline set | | | | | | | |
| Metal | | Irrigation | | Year | Livestock | | Year |
| Al | d | 5000 | | 1987 | 5000 | | 1987 |
| As | e | 100 | f | 1997 | 25 | f | 1997 |
| B | d | 500-6000 | h | 1987 | 5000 | | 1987 |
| Be | d | 100 | | 1987 | 100 | f | 1987 |
| Ca | d | | | | 1 000 000 | | 1987 |
| Cd | | 5.1 | i,j | 1996 | 80 | | 1996 |
| Cl | d | 100 000-700 000 | k | 1987 | | | |
| Co | d | 50 | | | 1000 | | 1987 |
| Cu | d | 200-1000 | o | 1987 | 500-5000 | p | 1987 |
| Fe | d | 5000 | | 1987 | | | |
| Hg | d | | | | 3 | | 1987 |
| Li | d | 2500 | | 1987 | | | |
| Mn | d | 200 | | 1987 | | | |
| Mo | d | 10-50 | r | 1987 | 500 | | 1987 |
| Ni | d | 200 | | 1987 | 1000 | | 1987 |
| Pb | d | 200 | | 1987 | 100 | | 1987 |
| Se | d | 20-50 | s | 1987 | 50 | | 1987 |
| U | d | 10 | f | 1987 | 200 | | 1987 |
| V | d | 100 | | 1987 | 100 | | 1987 |
| Zn | d | 1000-5000 | u | 1987 | 50 000 | | 1987 |

d No fact sheet created.
e The technical document for the guideline is available from the Ontario Ministry of the Environment.
f Interim guideline.
h Boron guideline =500 µg·L-1 for blackberries =500–1000 µg·L-1 for peaches, cherries, plums, grapes, cowpeas, onions, garlic, sweet potatoes, wheat, barley, sunflowers, mung beans, sesame, lupins, strawberries, Jerusalem artichokes, kidney beans, and lima beans = 1000–2000 µg·L-1 for red peppers, peas, carrots, radishes, potatoes, and cucumbers = 2000–4000 µg·L-1 for lettuce, cabbage, celery, turnips, Kentucky bluegrass, oats, corn, artichokes, tobacco, mustard, clover, squash, and muskmelons = 4000–6000 µg·L-1 for sorghum, tomatoes, alfalfa, purple vetch, parsley, red beets, and sugar beets = 6000 µg·L-1 for asparagus
i Guideline value slightly modified from CCREM 1987 + Appendixes due to re-evaluation of the significant figures.
j Guideline is crop-specific (see fact sheet).
k Chloride guideline Foliar damage = 100–178 mg·L-1 for almond apricots and plums = 178–355 mg·L-1 for grapes, peppers, potatoes, and tomatoes = 355–710 mg·L-1 for alfalfa, barley, corn, and cucumbers >710 mg·L-1 for cauliflower, cotton, safflower, sesame, sorghum, sugar beets, and sunflowers Rootstocks =180–600 mg·L-1 for stone fruit (peaches, plums, etc.) =710–900 mg·L-1 for grapes Cultivars = 110–180 mg·L-1 for strawberries = 230–460 mg·L-1 for grapes = 250 mg·L-1 for boysenberries, blackberries, and raspberries
o Copper guideline = 200 µg·L-1 for cereals = 1000 µg·L-1 for tolerant crops
p Copper guideline = 500 µg·L-1 for sheep, 1000 µg·L-1 for cattle, 5000 µg·L-1 for swine and poultry.
r Molybdenum guideline = 50 µg·L-1 for short-term use on acidic soils
s Selenium guideline = 20 µg·L-1 for continuous use = 50 µg·L-1 for intermittent use
u Zinc guideline = 1000 µg·L-1 when soil pH < 6.5 = 5000 µg·L-1 when soil pH > 6.5

## 3.0 Biowaste Substrates

The following gives the list of substrates used for this project. The sewage sludge and liquid sewage wastewater were included for heavy metal comparisons. The samples were collected from various producers throughout central and southern Alberta.

1. Cattle feedlot bed pack manure
2. Dairy manure #1
3. Chicken laying hen manure
4. Chicken broiler manure
5. Potato tuber waste
6. Dairy manure #2
7. Potato process waste
8. Potato plant vines
9. Poultry slaughter waste
10. Cattle carcass
11. Sugar beet tailings
12. Grocery waste
13. Thermally hydrolyzed biowaste (#1)
14. Thermally hydrolyzed biowaste (#2)
15. Thin stillage (ethanol production from wheat)
16. Glycerine with methanol
17. Hog slaughterhouse waste; peptone
18. Hog slaughterhouse waste; sludge (DAF)
19. Wet distillers grains (ethanol production from wheat)
20. Cheese whey
21. Beef slaughterhouse waste (paunch)
22. Solid hog manure (manure with bed pack)
23. Liquid hog manure
24. Sewage sludge
25. Liquid sewage wastewater
26. Sample 1 from the ARC Pilot Plant (Dairy #1 and glycerine)
27. Sample 2 from the ARC Pilot Plant (Wet distillers grain)

## 4.0 Results

### *4.1 Methane potential using batch culture*

In order to determine whether stable methanogenic conditions were reached in the batch cultures, methane potential was monitored for each substrate. Methane potential for manures depends on animal species, feed ration, manure age, manure collection methods, manure storage, foreign material incorporated in the manure and chemicals in the manure (8,9). The same conditions likely apply to other biowaste substrates. Although the biogas and methane potential results were monitored, the results are not given in this report.

The inoculum that was used for each test set was evaluated with cellulose and in each case, met the cellulose conversion requirement to methane and carbon dioxide in 7 days. The biogas and methane results showed that all the biowaste substrates in the batch cultures obtained stable methane production conditions except for the hog slaughterhouse sludge and peptone substrates.

The hog slaughterhouse substrates were tested at several VS ratios. In each case, stable methanogenic conditions were not observed. It was thought that something in the substrates was producing toxic conditions for the batch cultures. The peptone culture produced high concentrations of hydrogen sulfide gas early in the incubation period and the cultures became unstable with very little biogas production. Previous results from the ARC Pilot Plant showed that sulfide in digestion liquid can produce toxic conditions that result in decreased methane production. Sulfide toxicity is substrate, pH and temperature dependent and is related to the partitioning of hydrogen sulfide gas in the headspace to total soluble sulfide (TSS) in the liquid (personal communication with Earl Jenson, Pilot Plant operational manager). Given that the total sulphur for hog slaughterhouse peptone sample was 3% (Table 4.26), it is likely that there was a high concentration of TSS for the culture, although no measurement was taken. Dilution of the peptone substrate with inoculum did not result in stable methane production in batch culture. Information from the substrate supplier revealed that a polymer was added during the production of the hog slaughterhouse sludge and peptone, and this addition could have been toxic for methanogenic activity. No further investigation was made to reveal the exact cause for the low biogas production results.

### 4.2 *Chemical characteristics for biowaste substrates and batch cultures*

Because of sample matrix problems, the method for analyzing available phosphorous was changed after the start of this study and could only be done on a few select substrates. The substrates were dairy manure, chicken broiler manure, thermally hydrolyzed biowaste, wet distillers grain and inoculum.

In order to follow changes in chemical parameters and heavy metals during anaerobic digestion, each substrate for batch culture tests was analyzed as:

- Liquid substrate, diluted or undiluted depending on TS (for available heavy metals and shown in heavy metal tables as Aqueous Substrate),
- Substrate (shown in tables as Substrate or Dried Substrate)
- Initial batch culture mixture with substrate and inoculum, before incubation (shown in tables as Culture, initial),
- Final batch culture mixture with substrate and inoculum, after incubation (shown in tables as Culture, final),
- Post-digestion batch culture mixture separated into liquid and solid fractions (shown in tables as Post-digestion separation fractions, liquid or solid)

For the ARC Pilot Plant substrates, each was analyzed as:

- Initial liquid substrate mixture (for available heavy metals and shown in heavy metal tables as Aqueous mixture)
- Initial substrate mixture before digestion (shown in tables as Culture, initial)
- Final substrate after digestion (shown in table as Culture, final)
- Post-digestion mixture separated into liquid and solid fractions (shown in tables as Post-digestion separation fractions, liquid or solid)

For the ten substrate test sets used in this study, the inoculum was evaluated for quality and consistency. For each set, the analyses were done on the inoculum used for the initial culture mixture and after incubation. For all the test sets, the inoculum converted 70% or more of the cellulose within 7 days of incubation, showing good quality.

An average was taken for the Total N, Total C and TS results and the individual values for each test set parameter were compared to the average value of that test set. For the 10 inoculum samples that were used in the initial culture mixture (not incubated), the

TS results were 5% or less, the Total N results were 10% or less and the Total C results were 5% or less compared to the average result. For the inoculum that was incubated for 45 days (2 samples), the TS and Total C results were 2% and the Total N results were 6% from the average result. For the inoculum that was incubated for 30 days (8 samples), the TS results were 1% or less, the Total N results were 11% or less and the Total C results were 6% or less than the average result. The chemical parameters for the 45-day incubation final inoculum culture were obtained at the beginning of the study and the parameters for the 30-day incubation final inoculum culture were obtained close to the end of the study. The results were fairly similar except for the available $NH_4^+$ -N (Table 4.28). It was concluded that available $NH_4^+$ -N was lost on storage over a 9-month period. The loss was about 0.1%. The results from this evaluation of the inoculum showed that throughout the testing period, the inoculum was of good quality and was sufficiently consistent between collection pails.

In this report, Sections 4.2 to 4.7 and Tables 4.1 to 4.81 give results for chemical parameter and heavy metal results for substrates used in this study. Please refer to the table of contents for locations of specific results. Abbreviations that have been used in the tables are as follows: ww – wet weight; dw – dry weight; St dev – Standard deviation; BD- Below Detection for the instrument. Where no standard deviation is given for a result, there was one value reported, the other replicates were BD.

Generally, the manure substrates contained sufficient amounts of carbon, nitrogen, phosphorous and potassium for anaerobic digestion, with these nutrients remaining in the post-digestion substrates. Of course, high values of nitrogen could mean toxicity in anaerobic digestion systems, as seen for thermally hydrolyzed biowaste substrates (Tables 4.13 and 4.14), and low VS values, as seen with the laying hen chicken manure (Table 4.5), could indicate that a substrate has low organic carbon concentrations. Most non-manure substrates had good amounts of carbon, nitrogen, phosphorous and potassium. However, some non-manure substrates such as glycerine (Table 4.16) and hog slaughterhouse sludge (DAF; Table 4.24) were deficient or low in these parameters. As well, hog slaughterhouse peptone (Table 4.24) and thin stillage substrate (Table 4.15) had total sulfur values that were 1% and above, indicating that high hydrogen sulfide gas concentrations will occur during digestion. These observations show that care must be taken when using substrates in large-scale anaerobic digestion systems.

Increased salts in soils can adversely affect the growth of many plants (10). “Soil salinity refers to the presence of the major dissolved inorganic solutes in the aqueous phase consisting of soluble and readily dissolvable salts in soil, including charged species like $Na^{+}$, $K^{+}$, $Mg^{2+}$, $Ca^{2+}$, $Cl^{-}$, $HCO_3^{-}$ , $NO_3^{-}$-, $SO_4^{2-}$, $CO_3^{2-}$, nonionic solutes, and ions that combine to form ion pairs. Soil salinity is quantified in terms of the total concentration of the soluble salts as measured by the EC of a solution” and is traditionally measured using the saturation paste method. Another variant of this method is EC measurement on solution extracted from a 1:2 soil-water mixture (11). Using the traditional soil methods for measuring EC, an EC value of 2.0 dS/m may be considered high for salt-sensitive fruit and vegetable crops and values <4.0 dS/m are given for normal soils with pH <8.5 (10). The CCME guidelines (Table 2.2) state that soil for agricultural, parks and recreational use should have conductivity values no higher than 2 dS/m and soils for commercial and industrial use, no higher than 4 dS/m.

For the substrates used in this study, the manures generally had the highest EC results. However, the poultry slaughterhouse waste had a higher EC result than most of the manures and some non-manure vegetable/grain substrates and other non-manure substrates had surprisingly high results (See following tables). Comparatively, the vegetable/grain substrates had the lowest EC results.

The EC analysis was performed on a 2% TS slurry. This method was followed in order to be able to compare the EC results for the biowaste substrates and digestate samples used in this study. Comparison of EC results using various dilutions of one substrate cannot be done since there is no linear relationship among the dilutions. As mentioned above, the classical method for soil EC analysis uses the saturated paste method. Therefore, direct comparison of the EC results from this study to soil EC results cannot be done. The CCME soil guideline tables (6) do not mention which method was used for conductivity. One can only assume that a result for 2% TS would be lower than a result for saturated paste. We performed this comparison on a soil sample and discovered this to be true.

Given the fact that direct comparisons cannot be done, our results showed that there were high EC or salt concentrations associated with substrates used in this study, and caution must be exercised when using post-digestion products from these substrates. There are many environmental conditions that affect the concentration of salt in soils including the type of application and rate of application for organic fertilizers, soil location and topography, climate, soil type and irrigation. If a post-digestion product is applied to land without proper monitoring, salts could accumulate (11).

The EC ranges for substrates that produced methane in this study were from 1.0 dS/m for cattle carcass (Table 4.10) to 12.0 dS/m for liquid hog manure (Table 4.22). The sewage sludge substrate fell in this range at 1.3 dS/m (Table 4.21). The range for the digestates was 4.3 dS/m for cattle feedlot bed pack manure (Table 4.1) to 7.6 dS/m for chicken broiler manure (Table 4.4). For the separated fractions, the liquid ranged from 7.0 dS/m for thermally hydrolyzed biowaste #2 and glycerine (Tables 4.14 and 4.16) to 11.0 dS/m for chicken laying hen manure (Table 4.5). The solid fraction ranged from 0.6 dS/m for chicken laying hen manure (Table 4.5) to 1.7 dS/m for thermally hydrolyzed biowaste #1 (Table 4.13).

Of course, the digestate results for the substrates used in batch cultures would be affected by the inoculum EC results. For this study, the inoculum incubated for 30 days had EC values of approximately 6.1 dS/m after incubation, 8.3 dS/m for the separated liquid and 1.5 dS/m for the separated solid. The inoculum incubated for 45 days had EC values of 6.6 dS/m after incubation, 9.2 dS/m for the separated liquid and 1.0 dS/m for the separated solid (Table 4.26). The inoculum results show that salt concentrations increase as incubation times increase.

There was no attempt made to subtract the inoculum EC results from the inoculum plus substrate EC results for the biowaste batch cultures. The results from all the batch culture digestions and the Pilot Plant samples showed an increase in salt concentration after incubation. Comparison of results for the liquid and solid samples clearly showed that the salts are more concentrated in the liquid fraction of the separated digestate and that salts stay with the liquid fraction during separation.

Work at ARC has shown that salt concentrations for the separated liquid fraction can be reduced to approximately 0.2 dS/m using wastewater treatment processes. Given that salts may accumulate with unmonitored application of biosolids to land, more work is recommended concerning different Alberta soil types and climates after repeated application of biowaste solids. It may be necessary to reduce salt concentrations in solids before land application.

Table 4. 1: Cattle feedlot bed pack manure

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | | Culture | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Initial | | | Final | | | Liquid | | | Solid | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| TS (% ww) | 29 | ± | 0.1 | 8 | ± | 0.01 | 6 | ± | 0.1 | 4 | ± | 0.004 | 22 | ± | 0.2 |
| VS (% dw) | 78 | ± | 0.4 | 73 | ± | 0.7 | 64 | ± | 0.1 | 56 | ± | 0.2 | 75 | ± | 0.5 |
| Total C (% dw) | 40 | ± | 1 | 36 | ± | 2 | 34 | ± | 2 | 34 | ± | 1 | 40 | ± | 1 |
| Total N (% dw) | 3.0 | ± | 0.1 | 3.8 | ± | 0.2 | 4.8 | ± | 0.2 | 6.7 | ± | 0.3 | 1.9 | ± | 0.1 |
| Total K (% dw) | 2.1 | ± | 0.1 | 2.7 | ± | 0.1 | 3.8 | ± | 0.1 | 5.5 | ± | 0.2 | 1.1 | ± | 0.03 |
| Total P (% dw) | 0.9 | ± | 0.01 | 0.9 | ± | 0.02 | 1.1 | ± | 0.03 | 1.3 | ± | 0.04 | 0.7 | ± | 0.02 |
| Total S (% dw) | 0.5 | ± | 0.004 | 0.5 | ± | 0.01 | 0.6 | ± | 0.02 | 0.6 | ± | 0.03 | 0.5 | ± | 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 9 | ± | 0.1 | 16 | ± | 0.4 | 34 | ± | 1 | 50 | ± | 3 | 7 | ± | 0.1 |
| Available K (mg/g dw) | 19 | ± | 0.3 | 26 | ± | 1 | 38 | ± | 0.4 | 56 | ± | 6 | 8 | ± | 0.2 |
| Available P (mg/g dw) | Not done | | | | | | | | | | | | | | |
| EC (dS/m) | 3.0 | ± | 0.1 | 3.7 | ± | 0.4 | 4.3[a] | ± | | 9.5 | ± | 0.1 | 1.2 | ± | 0.5 |
| pH | 7.6 | ± | 0.1 | 8.2 | ± | 0.01 | 8.7[a] | ± | | 8.0 | ± | 0.01 | 8.9 | ± | 0.02 |

[a] Only one analysis done

Table 4. 2: Dairy manure #1

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 16 | ± 0.1 | 8 | ± 0.2 | 7 | ± 0.3 | 4 | ± 0.004 | 23 | ± 0.1 |
| VS (% dw) | 85 | ± 0.2 | 74 | ± 0.6 | 69 | ± 1 | 57 | ± 0.2 | 84 | ± 0.2 |
| Total C (% dw) | 45 | ± 1 | 36 | ± 2 | 36 | ± 5 | 37 | ± 2 | 43 | ± 2 |
| Total N (% dw) | 3.7 | ± 0.1 | 4.3 | ± 0.1 | 4.9 | ± 0.1 | 7.2 | ± 0.3 | 2 | ± 0.1 |
| Total K (% dw) | 2.3 | ± 0.1 | 2.8 | ± 0.3 | 3.7 | ± 0.1 | 6.0 | ± 0.4 | 1.2 | ± 0.04 |
| Total P (% dw) | 0.6 | ± 0.02 | 0.9 | ± 0.1 | 0.9 | ± 0.04 | 1.4 | ± 0.1 | 0.5 | ± 0.003 |
| Total S (% dw) | 0.5 | ± 0.02 | 0.5 | ± 0.01 | 0.6 | ± 0.004 | 0.7 | ± 0.01 | 0.5 | ± 0.02 |
| Available $NH_4^+$-N (mg/g dw) | 21 | ± 2 | 23 | ± 0.2 | 35 | ± 0.3 | 55 | ± 0.3 | 8 | ± 0.1 |
| Available K (mg/g dw) | 25 | ± 0.3 | 34 | ± 2 | 38 | ± 0.8 | 60 | ± 0.8 | 8 | ± 0.03 |
| Available P (mg/g dw) | 0.2 | ± 0.03 | 0.3 | ± 0.01 | 0.4 | ± 0 | 0.8 | ± 0.01 | 0.6 | ± 0.003 |
| EC (dS/m) | 3.6 | ± 0.1 | 4.2 | ± 0.4 | 5.8 | ± 0.4 | 9.7 | ± 0.1 | 1.2 | ± 0.02 |
| pH | 7.9 | ± 0.02 | 8.4 | ± 0 | 8.2 | ± 0.01 | 8.2 | ± 0.01 | 8.9 | ± 0.03 |

Table 4. 3: Potato tuber waste

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 21 | ± 0.1 | 8 | ± 0.03 | 6 | ± 0.01 | 4 | ± 0.002 | 19 | ± 0.1 |
| VS (% dw) | 94 | ± 0.1 | 73 | ± 0.04 | 63 | ± 0.3 | 57 | ± 0.2 | 76 | ± 0.2 |
| Total C (% dw) | 40 | ± 0.9 | 38 | ± 0.7 | 35 | ± 1 | 33 | ± 1 | 41 | ± 1 |
| Total N (% dw) | 2.0 | ± 0.04 | 3.9 | ± 0.1 | 5.2 | ± 0.1 | 6.7 | ± 0.2 | 2.0 | ± 0.1 |
| Total K (% dw) | 2.2 | ± 0.03 | 3.4 | ± 0.03 | 4.8 | ± 0.1 | 6.0 | ± 0.1 | 1.3 | ± 0.03 |
| Total P (% dw) | 0.2 | ± 0.01 | 0.8 | ± 0.005 | 1.1 | ± 0.02 | 1.3 | ± 0.02 | 1.2 | ± 0.02 |
| Total S (% dw) | 0.2 | ± 0.005 | 0.5 | ± 0.03 | 0.6 | ± 0.01 | 0.7 | ± 0.01 | 0.4 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 3 | ± 0.1 | 23 | ± 0.3 | 19 | ± 1 | 29 | ± 3 | 5 | ± 0.2 |
| Available K (mg/g dw) | 23 | ± 0.6 | 31 | ± 0.3 | 42 | ± 0.5 | 56 | ± 0.7 | 11 | ± 0.1 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 1.5 | ± 0.04 | 3.8 | ± 0.2 | 6.8 | ± 0.2 | 9.1 | ± 0.1 | 1.3 | ± 0.04 |
| pH | 5.7 | ± 0.04 | 8.5 | ± 0.01 | 8.1 | ± 0.01 | 8.1 | ± 0.01 | 9.0 | ± 0.01 |

Table 4. 4: Chicken broiler manure

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 77 | ± 0.03 | 7 | ± 0.05 | 6 | ± 0.01 | 4 | ± 0.004 | 24 | ± 0.2 |
| VS (% dw) | 83 | ± 0.09 | 71 | ± 0.3 | 62 | ± 0.08 | 56 | ± 0.1 | 73 | ± 0.5 |
| Total C (% dw) | 40 | ± 0.3 | 38 | ± 2 | 36 | ± 0.9 | 34 | ± 0.6 | 39 | ± 0.7 |
| Total N (% dw) | 5.0 | ± 0.09 | 4.8 | ± 0.1 | 5.9 | ± 0.3 | 8.0 | ± 0.2 | 2.3 | ± 0.1 |
| Total K (% dw) | 1.6 | ± 0.04 | 3.3 | ± 0.04 | 4.2 | ± 0.07 | 5.0 | ± 0.04 | 1.0 | ± 0.01 |
| Total P (% dw) | 2.1 | ± 0.02 | 1.3 | ± 0.01 | 2.0 | ± 0.02 | 2.0 | ± 0.03 | 2.3 | ± 0.03 |
| Total S (% dw) | 0.6 | ± 0.01 | 0.6 | ± 0.02 | 0.6 | ± 0.02 | 0.7 | ± 0.01 | 0.5 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 6 | ± 0.1 | 22 | ± 0.4 | 26 | ± 0.6 | 36 | ± 3 | 5 | ± 0.2 |
| Available K (mg/g dw) | 12 | ± 0.1 | 26 | ± 0.3 | 38 | ± 0.8 | 50 | ± 0.9 | 7 | ± 0.1 |
| Available P (mg/g dw) | 0.6 | ± 0.2 | 0.5 | ± 0.003 | 1 | ± 0.06 | 2 | ± 0.07 | 0.8 | ± 0.03 |
| EC (dS/m) | 1.9 | ± 0.01 | 4.0 | ± 0.01 | 7.6 | ± 0.1 | 10.1 | ± 0.1 | 1.0 | ± 0.03 |
| pH | 7.6 | ± 0.01 | 8.3 | ± 0 | 8.1 | ± 0.01 | 8.0 | ± 0.01 | 9.0 | ± 0.06 |

Table 4. 5: Chicken laying hen manure

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 35 | ± 0.5 | 7 | ± 0.2 | 6 | ± 0.2 | 4 | ± 0.02 | 37 | ± 0.2 |
| VS (% dw) | 38 | ± 0.7 | 57 | ± 1 | 49 | ± 2 | 53 | ± 0.5 | 33 | ± 0.6 |
| Total C (% dw) | 25 | ± 0.4 | 31 | ± 2 | 30 | ± 2 | 32 | ± 1 | 23 | ± 1 |
| Total N (% dw) | 4.1 | ± 0.2 | 4.5 | ± 0.2 | 5.4 | ± 0.2 | 8.6 | ± 0.2 | 1.1 | ± 0.07 |
| Total K (% dw) | 1.4 | ± 0.04 | 3.0 | ± 0.04 | 3.4 | ± 0.07 | 4.9 | ± 0.08 | 0.4 | ± 0.01 |
| Total P (% dw) | 2.6 | ± 0.02 | 1.9 | ± 0.01 | 2.7 | ± 0.05 | 2.7 | ± 0.04 | 1.8 | ± 0.02 |
| Total S (% dw) | 0.4 | ± 0.01 | 0.4 | ± 0.02 | 0.6 | ± 0.06 | 0.7 | ± 0.01 | 0.3[a] | ± 0.04 |
| Available $NH_4^+$-N (mg/g dw) | 27 | ± 0.1 | 29 | ± 0.3 | 25 | ± 0.3 | 41 | ± 3 | 2 | ± 0.1 |
| Available K (mg/g dw) | 16 | ± 0.5 | 25 | ± 0.3 | 33 | ± 0.5 | 53 | ± 0.7 | 4 | ± 0.2 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 2.8 | ± 0.1 | 5.2 | ± 0.3 | 6.9 | ± 0.1 | 11.0 | ± 0.1 | 0.6 | ± 0.01 |
| pH | 8.0 | ± 0.01 | 8.3 | ± 0.01 | 8.2 | ± 0.01 | 8.1 | ± 0.01 | 8.9 | ± 0.03 |

[a] Five replicate results were within  20% of the mean

Table 4. 6: Dairy manure #2

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 9 | ± 0.01 | 8 | ± 0.02 | 7 | ± 0.03 | 4 | ± 0.01 | 27 | ± 0.3 |
| VS (% dw) | 85 | ± 0.1 | 74 | ± 0.1 | 70 | ± 0.1 | 58 | ± 0.2 | 84 | ± 0.01 |
| Total C (% dw) | 45 | ± 1 | 39 | ± 0.8 | 38 | ± 2 | 34 | ± 0.5 | 43 | ± 2 |
| Total N (% dw) | 2.9 | ± 0.1 | 4.0 | ± 0.3 | 4.6 | ± 0.5 | 7.1 | ± 0.5 | 1.4 | ± 0.1 |
| Total K (% dw) | 2.3 | ± 0.03 | 3.4 | ± 0.04 | 4.1 | ± 0.1 | 6.3 | ± 0.1 | 1.1 | ± 0.02 |
| Total P (% dw) | 0.6 | ± 0.01 | 0.7 | ± 0.01 | 0.9 | ± 0.005 | 1.2 | ± 0.002 | 0.4 | ± 0.002 |
| Total S (% dw) | 0.4 | ± 0.02 | 0.5 | ± 0.01 | 0.5 | ± 0.01 | 0.6 | ± 0.01 | 0.4 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 14 | ± 0.04 | 20 | ± 0.2 | 25 | ± 0.5 | 40 | ± 0.1 | 5 | ± 0.2 |
| Available K (mg/g dw) | 22 | ± 2 | 27 | ± 2 | 34 | ± 0.5 | 54 | ± 0.4 | 7 | ± 0.3 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 4.6 | ± 0.1 | 4.9 | ± 0.1 | 6.4 | ± 0.1 | 9.6 | ± 0.1 | 1.0 | ± 0.03 |
| pH | 7.3 | ± 0.02 | 8.1 | ± 0.01 | 8.2 | ± 0.02 | 8.1 | ± 0.02 | 9.0 | ± 0.02 |

Table 4. 7: Potato process waste

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 52 | ± 1 | 8 | ± 0.04 | 6 | ± 0.1 | 4 | ± 0.004 | 23 | ± 0.3 |
| VS (% dw) | 91 | ± 0.3 | 73 | ± 0.1 | 62 | ± 0.2 | 55 | ± 0.03 | 77 | ± 0.2 |
| Total C (% dw) | 51 | ± 0.5 | 41 | ± 0.8 | 35 | ± 2 | 31 | ± 0.6 | 39 | ± 1 |
| Total N (% dw) | 0.8 | ± 0.04 | 3.6 | ± 0.1 | 5.0 | ± 0.2 | 5.7 | ± 0.4 | 1.7 | ± 0.1 |
| Total K (% dw) | 1.0 | ± 0.02 | 3.6 | ± 0.1 | 4.4 | ± 0.1 | 6.3 | ± 0.03 | 1.2 | ± 0.01 |
| Total P (% dw) | 0.1 | ± 0.001 | 0.9 | ± 0.01 | 1.0 | ± 0.01 | 1.1 | ± 0.01 | 1.2 | ± 0.01 |
| Total S (% dw) | 0.1 | ± 0.002 | 0.6 | ± 0.04 | 0.6 | ± 0.002 | 0.6 | ± 0.02 | 0.4 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 0.6 | ± 0.01 | 16 | ± 0.2 | 22 | ± 0.2 | 28 | ± 0.7 | 5 | ± 0.2 |
| Available K (mg/g dw) | 10 | ± 0.2 | 27 | ± 0.1 | 41 | ± 3 | 55 | ± 1 | 8 | ± 0.1 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 3.1 | ± 0.3 | 5.1 | ± 0.1 | 7.4 | ± 0.1 | 10.3 | ± 0.1 | 1.5 | ± 0.01 |
| pH | 5.6 | ± 0.2 | 8.3 | ± 0.02 | 8.1 | ± 0.03 | 8.2 | ± 0.01 | 8.9 | ± 0.04 |

Table 4. 8: Potato stems and leaves

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 12 | ± 0.02 | 8 | ± 0.01 | 7 | ± 0.02 | 5 | ± 0.001 | 28 | ± 0.1 |
| VS (% dw) | 58 | ± 0.1 | 63 | ± 0.1 | 57 | ± 0.1 | 50 | ± 0.2 | 72 | ± 0.2 |
| Total C (% dw) | 32 | ± 1 | 33 | ± 0.8 | 31 | ± 1 | 32 | ± 2 | 39 | ± 1 |
| Total N (% dw) | 2.4 | ± 0.1 | 3.7 | ± 0.1 | 4.3 | ± 0.2 | 5.6 | ± 0.2 | 1.4 | ± 0.1 |
| Total K (% dw) | 4.3 | ± 0.1 | 4.3 | ± 0.1 | 4.5 | ± 0.03 | 6.3 | ± 0.1 | 1.3 | ± 0.01 |
| Total P (% dw) | 0.1 | ± 0.001 | 0.7 | ± 0.01 | 0.8 | ± 0.01 | 1.0 | ± 0.01 | 0.5 | ± 0.01 |
| Total S (% dw) | 0.2 | ± 0.002 | 0.6 | ± 0.1 | 0.5 | ± 0.02 | 0.6 | ± 0.003 | 0.4 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 4 | ± 0.1 | 15 | ± 0.2 | 19 | ± 0.7 | 25 | ± 1 | 4 | ± 0.04 |
| Available K (mg/g dw) | 36 | ± 0.4 | 35 | ± 0.5 | 46 | ± 2 | 49 | ± 5 | 8 | ± 0.2 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 3.2 | ± 0.5 | 4.1 | ± 0.5 | 6.3 | ± 0.1 | 8.3 | ± 0.1 | 1.1 | ± 0.01 |
| pH | 6.9 | ± 0.05 | 8.2 | ± 0.01 | 8.2 | ± 0.01 | 8.2 | ± 0.01 | 9.0 | ± 0.04 |

Table 4. 9: Poultry slaughter waste

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 47 | ± 1 | 8 | ± 0.02 | 7 | ± 0.01 | 5 | ± 0.02 | 23 | ± 0.2 |
| VS (% dw) | 95 | ± 0.1 | 68 | ± 0.1 | 63 | ± 0.2 | 56 | ± 0.1 | 77 | ± 0.03 |
| Total C (% dw) | 57 | ± 1 | 36 | ± 0.7 | 36 | ± 1 | 35 | ± 0.4 | 42 | ± 1 |
| Total N (% dw) | 4.3 | ± 0.1 | 4.6 | ± 0.1 | 5.0 | ± 0.1 | 6.7 | ± 0.2 | 1.9 | ± 0.1 |
| Total K (% dw) | 0.6 | ± 0.01 | 3.7 | ± 0.1 | 4.2 | ± 0.1 | 5.7 | ± 0.1 | 1.3 | ± 0.02 |
| Total P (% dw) | 0.3 | ± 0.01 | 1.0 | ± 0.01 | 1.2 | ± 0.01 | 1.6 | ± 0.01 | 0.7 | ± 0.003 |
| Total S (% dw) | 0.4 | ± 0.01 | 0.6 | ± 0.003 | 0.7 | ± 0.01 | 0.7 | ± 0.01 | 0.5 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 3[a] | ± 0.4 | 18 | ± 0.2 | 23 | ± 0.6 | 28 | ± 3 | 6 | ± 0.1 |
| Available K (mg/g dw) | 4 | ± 0.5 | 36 | ± 2 | 38 | ± 0.7 | 52 | ± 0.6 | 8 | ± 0.02 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 6.5 | ± 0.5 | 4.7 | ± 0.2 | 6.5 | ± 0.1 | 8.6 | ± 0.2 | 1.4 | ± 0.04 |
| pH | 6.1 | ± 0.05 | 8.3 | ± 0.02 | 8.2 | ± 0.01 | 8.2 | ± 0.01 | 8.8 | ± 0.01 |

[a] Triplicate results were within 20% of the mean

Table 4. 10: Cattle carcass

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 34 | ± 0.6 | 8 | ± 0.04 | 6 | ± 0.02 | 5 | ± 0.001 | 24 | ± 0.1 |
| VS (% dw) | 94 | ± 0.2 | 70 | ± 0.3 | 63 | ± 0.1 | 56 | ± 0.1 | 76 | ± 0.4 |
| Total C (% dw) | 59 | ± 4 | 39 | ± 0.7 | 38 | ± 0.9 | 36 | ± 0.7 | 42 | ± 0.9 |
| Total N (% dw) | 8.5 | ± 0.2 | 5.2 | ± 0.1 | 5.9 | ± 0.2 | 8.3 | ± 0.3 | 1.9 | ± 0.1 |
| Total K (% dw) | 1.1 | ± 0.02 | 3.4 | ± 0.03 | 4.2 | ± 0.1 | 6.0 | ± 0.1 | 1.2 | ± 0.03 |
| Total P (% dw) | 0.5 | ± 0.01 | 1.0 | ± 0.01 | 1.2 | ± 0.01 | 1.7 | ± 0.03 | 0.7 | ± 0.01 |
| Total S (% dw) | 0.4 | ± 0.04 | 0.6 | ± 0.004 | 0.7 | ± 0.01 | 0.7 | ± 0.01 | 0.5 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 1 | ± 0.1 | 15 | ± 0.3 | 32 | ± 0.3 | 46 | ± 7 | 8 | ± 0.1 |
| Available K (mg/g dw) | 5 | ± 0.7 | 32 | ± 0.4 | 40 | ± 0.8 | 55 | ± 2 | 8 | ± 0.3 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 1.0 | ± 0.1 | 4.6 | ± 0.1 | 7.4 | ± 0.1 | 10.1 | ± 0.2 | 1.4 | ± 0.02 |
| pH | 6.1 | ± 0.03 | 8.4 | ± 0.03 | 8.2 | ± 0.01 | 8.2 | ± 0.01 | 8.7 | ± 0 |

Table 4. 11: Sugar beet tailings

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 16 | ± 0.01 | 8 | ± 0.04 | 6 | ± 0.02 | 5 | ± 0.01 | 23 | ± 0.02 |
| VS (% dw) | 82 | ± 0.03 | 69 | ± 0.1 | 62 | ± 0.2 | 55 | ± 0.1 | 75 | ± 0.2 |
| Total C (% dw) | 40 | ± 0.5 | 37 | ± 0.3 | 36 | ± 0.8 | 35 | ± 0.5 | 41 | ± 1 |
| Total N (% dw) | 1.7 | ± 0.1 | 4.3 | ± 0.1 | 5.0 | ± 0.2 | 6.9 | ± 0.3 | 1.8 | ± 0.1 |
| Total K (% dw) | 1.3 | ± 0.03 | 3.7 | ± 0.03 | 4.8 | ± 0.1 | 5.9 | ± 0.1 | 1.2 | ± 0.02 |
| Total P (% dw) | 0.2 | ± 0.002 | 1.0 | ± 0.01 | 1.2 | ± 0.01 | 1.5 | ± 0.02 | 0.8 | ± 0.01 |
| Total S (% dw) | 0.1 | ± 0.004 | 0.6 | ± 0.001 | 0.6 | ± 0.004 | 0.7 | ± 0.02 | 0.5 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 0.2 | ± 0.01 | 16 | ± 0.4 | 21 | ± 0.4 | 26 | ± 0.5 | 6 | ± 0.1 |
| Available K (mg/g dw) | 10 | ± 1 | 32 | ± 0.7 | 39 | ± 0.3 | 55 | ± 0.2 | 7 | ± 0.1 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 1.2 | ± 0.03 | 6.2 | ± 0.7 | 5.5 | ± 0.1 | 8.6 | ± 0.2 | 1.2 | ± 0.01 |
| pH | 4.7 | ± 0.02 | 8.2 | ± 0.01 | 8.1 | ± 0.01 | 8.2 | ± 0.01 | 8.4 | ± 0.6 |

Table 4. 12: Grocery waste

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 16 | ± 0.04 | 8 | ± 0.04 | 6 | ± 0.02 | 5 | ± 0.01 | 22 | ± 0.1 |
| VS (% dw) | 95 | ± 0.3 | 70 | ± 0.2 | 63 | ± 0.1 | 56 | ± 0.1 | 76 | ± 0.06 |
| Total C (% dw) | 43 | ± 0.7 | 37 | ± 2 | 34 | ± 0.8 | 34 | ± 0.2 | 40 | ± 0.9 |
| Total N (% dw) | 1.0 | ± 0.04 | 3.9 | ± 0.2 | 5.0 | ± 0.1 | 6.5 | ± 0.2 | 1.9 | ± 0.08 |
| Total K (% dw) | 1.8 | ± 0.01 | 3.8 | ± 0.06 | 4.9 | ± 0.04 | 6.9 | ± 0.1 | 1.5 | ± 0.02 |
| Total P (% dw) | 0.2 | ± 0.001 | 1.0 | ± 0.01 | 1.1 | ± 0.009 | 1.5 | ± 0.02 | 0.9 | ± 0.009 |
| Total S (% dw) | 0.1 | ± 0.01 | 0.6 | ± 0.01 | 0.7 | ± 0.004 | 0.7 | ± 0.01 | 0.5 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 0.03 | ± 0.01 | 6 | ± 0.9 | 20 | ± 0.1 | 28 | ± 0.6 | 5 | ± 0.1 |
| Available K (mg/g dw) | 17 | ± 0.2 | 33 | ± 1 | 40 | ± 0.1 | 56 | ± 0.3 | 9 | ± 0.02 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 1.1 | ± 0.03 | 5.0 | ± 0.5 | 6.2 | ± 1.0 | 8.2 | ± 0.4 | 1.2 | ± 0.01 |
| pH | 3.9 | ± 0.02 | 8.2 | ± 0.06 | 8.1 | ± 0.01 | 8.3 | ± 0.02 | 8.8 | ± 0.03 |

Table 4. 13: Thermally hydrolyzed biowaste #1

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 20 | ± 0.06 | 8 | ± 0.01 | 7 | ± 0.01 | 5 | ± 0.01 | 22 | ± 0.04 |
| VS (% dw) | 82 | ± 0.08 | 68 | ± 0.1 | 63 | ± 0.05 | 56 | ± 0.1 | 75 | ± 0.2 |
| Total C (% dw) | 42 | ± 3 | 38 | ± 2 | 34 | ± 1 | 34 | ± 0.4 | 40 | ± 0.7 |
| Total N (% dw) | 7.2 | ± 0.6 | 4.9 | ± 0.2 | 5.7 | ± 0.2 | 7.4 | ± 0.4 | 2.1 | ± 0.07 |
| Total K (% dw) | 0.4 | ± 0.003 | 3.7 | ± 0.06 | 4.5 | ± 0.04 | 6.1 | ± 0.09 | 1.3 | ± 0.01 |
| Total P (% dw) | 2.7 | ± 0.01 | 1.3 | ± 0.02 | 1.3 | ± 0.01 | 1.8 | ± 0.01 | 1.0 | ± 0.007 |
| Total S (% dw) | 0.4 | ± 0.01 | 0.6 | ± 0.004 | 0.7 | ± 0.01 | 0.8 | ± 0.01 | 0.5 | ± 0.005 |
| Available $NH_4^+$-N (mg/g dw) | 5 | ± 0.03 | 9 | ± 0.6 | 28 | ± 0.1 | 36 | ± 0.5 | 7 | ± 0.1 |
| Available K (mg/g dw) | 5[a] | ± 1 | 33 | ± 0.3 | 38 | ± 0.2 | 51 | ± 2 | 9 | ± 0.5 |
| Available P (mg/g dw) | 0.6 | ± 0.01 | 1 | ± 0.05 | 1 | ± 0.02 | 2 | ± 0.03 | 0.7 | ± 0.01 |
| EC (dS/m) | 1.3 | ± 0.03 | 4.7 | ± 0.05 | 6.7 | ± 0.1 | 8.7 | ± 1.1 | 1.7 | ± 0.5 |
| pH | 5.8 | ± 0.03 | 8.3 | ± 0.02 | 8.2 | ± 0.01 | 7.9 | ± 0.6 | 7.8 | ± 0.01 |

[a] Triplicate results were within 25% of the mean

Table 4. 14: Thermally hydrolyzed biowaste #2

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 29 | ± 0.06 | 8 | ± 0.01 | 7 | ± 0.01 | 5 | ± 0.003 | 21 | ± 0.06 |
| VS (% dw) | 79 | ± 1 | 67 | ± 0.08 | 62 | ± 0.2 | 56 | ± 0.2 | 77 | ± 0.1 |
| Total C (% dw) | 40 | ± 1 | 37 | ± 0.8 | 35 | ± 0.9 | 33 | ± 0.4 | 40 | ± 0.7 |
| Total N (% dw) | 9.4 | ± 0.3 | 4.9 | ± 0.1 | 5.7 | ± 0.2 | 7.3 | ± 0.3 | 2.2 | ± 0.07 |
| Total K (% dw) | 0.4 | ± 0.002 | 4.0 | ± 0.08 | 4.4 | ± 0.05 | 6.0 | ± 0.08 | 1.5 | ± 0.03 |
| Total P (% dw) | 2.9 | ± 0.02 | 1.3 | ± 0.02 | 1.3 | ± 0.02 | 1.9 | ± 0.01 | 0.8 | ± 0.01 |
| Total S (% dw) | 0.4 | ± 0.03 | 0.6 | ± 0.006 | 0.7 | ± 0.008 | 0.8 | ± 0.01 | 0.5 | ± 0.02 |
| Available $NH_4^+$-N (mg/g dw) | 17 | ± 0.1 | 19 | ± 0.3 | 26 | ± 0.1 | 31 | ± 2 | 7 | ± 0.1 |
| Available K (mg/g dw) | 5 | ± 0.5 | 32 | ± 0.5 | 38 | ± 0.5 | 49 | ± 2 | 10 | ± 0.1 |
| Available P (mg/g dw) | 0.6 | ± 0.03 | 1.2 | ± 0.03 | 1.2 | ± 0.01 | 1.7 | ± 0.02 | 0.8 | ± 0.02 |
| EC (dS/m) | 3.3 | ± 0.5 | 5.1 | ± 0.04 | 6.7 | ± 0.3 | 7.0 | ± 0.03 | 1.6 | ± 0.06 |
| pH | 6.9 | ± 0.01 | 8.3 | ± 0.01 | 8.2 | ± 0.01 | 8.3 | ± 0 | 8.8 | ± 0.02 |

Table 4. 15: Thin stillage

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 9 | ± 0.03 | 8 | ± 0.05 | 7 | ± 0.02 | 5 | ± 0 | 22 | ± 0.2 |
| VS (% dw) | 93 | ± 0.6 | 68 | ± 0.2 | 63 | ± 0.1 | 56 | ± 0.2 | 78 | ± 0.07 |
| Total C (% dw) | 46 | ± 0.3 | 36 | ± 0.7 | 34 | ± 1 | 33 | ± 0.4 | 39 | ± 0.7 |
| Total N (% dw) | 7.5 | ± 0.1 | 4.8 | ± 0.3 | 5.2 | ± 0.1 | 6.4 | ± 0.1 | 2.1 | ± 0.09 |
| Total K (% dw) | 1.4 | ± 0.02 | 4.1 | ± 0.08 | 3.9 | ± 0.2 | 5.1 | ± 0.2 | 1.2 | ± 0.04 |
| Total P (% dw) | 0.9 | ± 0.02 | 1.2 | ± 0.01 | 1.3 | ± 0.05 | 1.5 | ± 0.1 | 0.8 | ± 0.02 |
| Total S (% dw) | 1.1 | ± 0.03 | 0.7 | ± 0.004 | 0.6 | ± 0.01 | 0.7 | ± 0.03 | 0.5 | ± 0.002 |
| Available $NH_4^+$-N (mg/g dw) | 0.2 | ± 0.0003 | 15 | ± 0.3 | 20 | ± 0.5 | 25 | ± 1 | 6 | ± 0.1 |
| Available K (mg/g dw) | 13 | ± 0.1 | 34 | ± 0.1 | 38 | ± 0.4 | 51 | ± 0.3 | 9 | ± 0.2 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 1.7 | ± 0.01 | 4.9 | ± 0.04 | 6.6 | ± 0.1 | 8.5 | ± 0.1 | 1.6 | ± 0.02 |
| pH | 4.1 | ± 0.03 | 8.4 | ± 0.01 | 8.2 | ± 0.01 | 8.2 | ± 0.02 | 8.6 | ± 0.01 |

Table 4. 16: Glycerine with methanol

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 80 | ± 0.1 | 8 | ± 0.01 | 7 | ± 0.005 | 5 | ± 0.01 | 22 | ± 0.04 |
| VS (% dw) | 91 | ± 0.1 | 70 | ± 0.08 | 62 | ± 0.08 | 55 | ± 0.1 | 78 | ± 0.08 |
| Total C (% dw) | 56 | ± 2 | 39 | ± 0.8 | 35 | ± 0.6 | 34 | ± 0.4 | 42 | ± 0.7 |
| Total N (% dw) | BD (<0.008) | | 4.3 | ± 0.2 | 4.7 | ± 0.2 | 6.8 | ± 0.4 | 2.1 | ± 0.08 |
| Total K (% dw) | 4 | ± 0.04 | 4.8 | ± 0.09 | 5.0 | ± 0.04 | 6.5 | ± 0.03 | 1.6 | ± 0.02 |
| Total P (% dw) | 0.04 | ± 0.0006 | 0.9 | ± 0.01 | 1.2 | ± 0.005 | 1.4 | ± 0.01 | 0.7 | ± 0.008 |
| Total S (% dw) | 0.1 - 0.2[a] | ± | 0.6 | ± 0.01 | 0.7 | ± 0.01 | 0.8 | ± 0.01 | 0.5 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | BD (<0.001) | | 17 | ± 0.2 | 24 | ± 0.3 | 31 | ± 0.1 | 6 | ± 0.2 |
| Available K (mg/g dw) | 33 | ± 0.4 | 36 | ± 0.6 | 47 | ± 0.7 | 65 | ± 5 | 11 | ± 0.02 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 0.8 | ± 0.04 | 5.1 | ± 0.04 | 6.2 | ± 0.7 | 7.0 | ± 0.09 | 1.3 | ± 0.003 |
| pH | 10.2 | ± 0.03 | 8.5 | ± 0.01 | 8.3 | ± 0.02 | 8.3 | ± 0.01 | 9.0 | ± 0.01 |

[a] Sulphur result reported as a range because 5 replicates showed variability of 50% from the mean

Table 4. 17: Cheese whey

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 6 | ± 0.02 | 7 | ± 0.02 | 5 | ± 0.003 | 4 | ± 0.001 | 23 | ± 0.02 |
| VS (% dw) | 92 | ± 0.1 | 73 | ± 0.1 | 62 | ± 0.04 | 55 | ± 0.06 | 76 | ± 0.04 |
| Total C (% dw) | 40 | ± 0.5 | 35 | ± 1 | 34 | ± 0.9 | 31 | ± 0.2 | 11 | ± 0.3 |
| Total N (% dw) | 2.5[a] | ± 0.4 | 3.6 | ± 0.1 | 5.4 | ± 0.2 | 6.9 | ± 0.5 | 0.6 | ± 0.03 |
| Total K (% dw) | 2.6 | ± 0.04 | 2.9 | ± 0.07 | 4.8 | ± 0.1 | 6.1 | ± 0.1 | 1.1 | ± 0.03 |
| Total P (% dw) | 0.7 | ± 0.01 | 1.0 | ± 0.02 | 1.5 | ± 0.03 | 1.4 | ± 0.01 | 1.2 | ± 0.03 |
| Total S (% dw) | 0.2 | ± 0.004 | 0.5 | ± 0.008 | 0.6 | ± 0.01 | 0.7 | ± 0.01 | 0.5 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 2 | ± 0.03 | 16 | ± 0.06 | 25 | ± 1 | 34 | ± 0.6 | 5 | ± 0.3 |
| Available K (mg/g dw) | 23 | ± 0.5 | 30 | ± 0.4 | 46 | ± 2 | 66 | ± 2 | 8 | ± 0.07 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 2.5 | ± 0.01 | 4.6 | ± 0.1 | 6.6 | ± 0.3 | 9.7 | ± 0.1 | 1.3 | ± 0.06 |
| pH | 4.9 | ± 0.02 | 8.1 | ± 0 | 8.1 | ± 0.01 | 8.2 | ± 0.01 | 8.7 | ± 0.03 |

[a] Triplicate results were within 25% of the mean

Table 4. 18: Wet distillers grains

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (%ww) | 23 | ± 0.5 | 7 | ± 0.08 | 5 | ± 0.01 | 4 | ± 0.004 | 21 | ± 0.2 |
| VS (% dw) | 97 | ± 0.1 | 76 | ± 0.1 | 67 | ± 0.08 | 58 | ± 0.1 | 81 | ± 0.1 |
| Total C (% dw) | 50 | ± 3 | 38 | ± 1 | 36 | ± 0.6 | 33 | ± 1 | 11 | ± 0.1 |
| Total N (% dw) | 4.0 | ± 0.3 | 4.2 | ± 0.2 | 5.9 | ± 0.2 | 7.8 | ± 0.3 | 0.6 | ± 0.02 |
| Total K (% dw) | 0.4 | ± 0.004 | 2.9 | ± 0.07 | 3.8 | ± 0.1 | 5.2 | ± 0.1 | 1.0 | ± 0.03 |
| Total P (% dw) | 0.5 | ± 0.004 | 1.0 | ± 0.02 | 1.3 | ± 0.03 | 1.6 | ± 0.02 | 0.8 | ± 0.008 |
| Total S (% dw) | 0.9 | ± 0.06 | 0.6 | ± 0.01 | 0.7 | ± 0.007 | 0.8 | ± 0.02 | 0.5 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 0.2 | ± 0.002 | 14 | ± 0.3 | 29 | ± 1 | 40 | ± 0.8 | 6 | ± 0.2 |
| Available K (mg/g dw) | 5 | ± 0.1 | 23 | ± 0.07 | 37 | ± 1 | 51 | ± 0.9 | 7 | ± 0.2 |
| Available P (mg/g dw) | 3 | ± 0.2 | 1 | ± 0.01 | 2 | ± 0.01 | 2 | ± 0.04 | 0.8 | ± 0.02 |
| EC (dS/m) | 0.7 | ± 0.002 | 3.9 | ± 0.006 | 7.2 | ± 0.05 | 9.7 | ± 0.04 | 1.4 | ± 0.06 |
| pH | 4.0 | ± 0.03 | 8.0 | ± 0.01 | 8.2 | ± 0.02 | 8.3 | ± 0.01 | 8.6 | ± 0.02 |

Table 4. 19: Cattle slaughterhouse waste - paunch

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 15 | ± 0.1 | 7 | ± 0.004 | 6 | ± 0.04 | 5 | ± 0.002 | 24 | ± 0.01 |
| VS (% dw) | 90 | ± 0.1 | 68 | ± 0.05 | 65 | ± 0.2 | 56 | ± 0.08 | 80 | ± 0.04 |
| Total C (% dw) | 46 | ± 1 | 35 | ± 0.8 | 35 | ± 1 | 32 | ± 0.5 | 39 | ± 0.5 |
| Total N (% dw) | 1.8 | ± 0.06 | 4.2 | ± 0.1 | 5.1 | ± 0.1 | 6.7 | ± 0.1 | 1.8 | ± 0.04 |
| Total K (% dw) | 0.7 | ± 0.03 | 4.1 | ± 0.1 | 3.2 | ± 0.1 | 5.0 | ± 0.2 | 1.1 | ± 0.02 |
| Total P (% dw) | 0.6 | ± 0.02 | 1.0 | ± 0.02 | 1.1 | ± 0.01 | 1.5 | ± 0.03 | 0.7 | ± 0.01 |
| Total S (% dw) | 0.2 | ± 0.02 | 0.6 | ± 0.02 | 0.6 | ± 0.01 | 0.7 | ± 0.01 | 0.5 | ± 0.02 |
| Available $NH_4^+$-N (mg/g dw) | 1 | ± 0.03 | 15 | ± 0.5 | 24 | ± 0.3 | 34 | ± 0.3 | 5 | ± 0.2 |
| Available K (mg/g dw) | 6 | ± 0.3 | 33 | ± 0.7 | 36 | ± 0.3 | 50 | ± 0.7 | 8 | ± 0.8 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 1.7 | ± 0.02 | 4.5 | ± 0.2 | 5.8 | ± 0.04 | 7.5 | ± 0.09 | 1.3 | ± 0.02 |
| pH | 7.2 | ± 0.02 | 8.4 | ± 0.01 | 8.2 | ± 0.01 | 8.2 | ± 0 | 8.9 | ± 0.01 |

Table 4. 20: Solid hog manure

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 29 | ± 0.2 | 8 | ± 0.05 | 6 | ± 0.05 | 4 | ± 0 | 24 | ± 0.06 |
| VS (% dw) | 84 | ± 0.1 | 73 | ± 0.3 | 67 | ± 0.01 | 58 | ± 0.01 | 82 | ± 0.03 |
| Total C (% dw) | 44 | ± 1 | 33 | ± 1 | 34 | ± 2 | 33 | ± 0.4 | 41 | ± 0.6 |
| Total N (% dw) | 3.5 | ± 0.09 | 4.0 | ± 0.06 | 5.2 | ± 0.2 | 7.2 | ± 0.3 | 1.9 | ± 0.05 |
| Total K (% dw) | 2.0 | ± 0.02 | 3.5 | ± 0.1 | 3.4 | ± 0.1 | 5.3 | ± 0.1 | 0.9 | ± 0.03 |
| Total P (% dw) | 1.0 | ± 0.01 | 1.5 | ± 0.03 | 1.4 | ± 0.01 | 1.9 | ± 0.03 | 0.6 | ± 0.01 |
| Total S (% dw) | 0.8 | ± 0.03 | 0.6 | ± 0.03 | 0.7 | ± 0.02 | 0.8 | ± 0.01 | 0.6 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 6 | ± 0.4 | 15 | ± 2 | 23 | ± 0.4 | 34 | ± 0.04 | 5 | ± 0.08 |
| Available K (mg/g dw) | 16 | ± 1 | 28 | ± 0.3 | 34 | ± 0.6 | 51 | ± 2 | 7 | ± 0.4 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 2.5 | ± 0.1 | 3.9 | ± 0.3 | 5.2 | ± 0.2 | 7.4 | ± 0.2 | 1.1 | ± 0.05 |
| pH | 8.4 | ± 0.05 | 8.3 | ± 0.02 | 8.2 | ± 0 | 8.3 | ± 0.01 | 9.0 | ± 0.03 |

Table 4. 21: Sewage sludge

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 8 | ± 0.2 | 7 | ± 0.02 | 6 | ± 0.02 | 5 | ± 0.01 | 27 | ± 0.02 |
| VS (% dw) | 72 | ± 0.3 | 69 | ± 0.2 | 61 | ± 0.1 | 55 | ± 0.01 | 78 | ± 0.06 |
| Total C (% dw) | 41[a] | ± 3 | 35 | ± 1 | 32 | ± 0.6 | 31 | ± 0.5 | 38 | ± 0.4 |
| Total N (% dw) | 3.4 | ± 0.3 | 4.1 | ± 0.09 | 5.3 | ± 0.2 | 6.6 | ± 0.2 | 1.7 | ± 0.04 |
| Total K (% dw) | 0.3 | ± 0.01 | 3.3 | ± 0.07 | 3.1 | ± 0.1 | 3.6 | ± 0.1 | 0.8 | ± 0.03 |
| Total P (% dw) | 1.5 | ± 0.02 | 1.1 | ± 0.02 | 1.5 | ± 0.02 | 1.8 | ± 0.03 | 0.9 | ± 0.02 |
| Total S (% dw) | 0.7 | ± 0.03 | 0.6 | ± 0.02 | 0.7 | ± 0.01 | 0.8 | ± 0.02 | 0.5 | ± 0.02 |
| Available $NH_4^+$-N (mg/g dw) | 5 | ± 0.3 | 14 | ± 0.5 | 25 | ± 0.4 | 34 | ± 0.2 | 4 | ± 0.2 |
| Available K (mg/g dw) | 1 | ± 0.02 | 24 | ± 0.6 | 29 | ± 0.4 | 40 | ± 1 | 5[a] | ± 0.9 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 1.3 | ± 0.02 | 3.7 | ± 0.2 | 5.3 | ± 0.04 | 6.7 | ± 0.06 | 0.9 | ± 0.004 |
| pH | 5.6 | ± 0.01 | 7.9 | ± 0.02 | 8.2 | ± 0.01 | 8.2 | ± 0.01 | 8.8 | ± 0.01 |

[a] The triplicate values were within 20% of the mean

Table 4. 22: Liquid hog

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 2 | ± 0.01 | 5 | ± 0.003 | 5 | ± 0.01 | 4 | ± 0.004 | 24 | ± 0.1 |
| VS (% dw) | 73 | ± 0.2 | 68 | ± 0.1 | 63 | ± 0.1 | 56 | ± 0.02 | 79 | ± 0.1 |
| Total C (% dw) | 46 | ± 3 | 37 | ± 1 | 34 | ± 0.8 | 32 | ± 0.5 | 39 | ± 0.5 |
| Total N (% dw) | 12.1 | ± 0.5 | 5.1 | ± 0.2 | 6.4 | ± 0.2 | 7.9 | ± 0.2 | 1.8 | ± 0.1 |
| Total K (% dw) | 4.7 | ± 0.1 | 3.7 | ± 0.1 | 4.2 | ± 0.1 | 5.8 | ± 0.2 | 0.9 | ± 0.02 |
| Total P (% dw) | 2.5 | ± 0.1 | 1.2 | ± 0.02 | 1.4 | ± 0.02 | 1.8 | ± 0.04 | 0.8 | ± 0.01 |
| Total S (% dw) | 0.8 | ± 0.02 | 0.6 | ± 0.01 | 0.7 | ± 0.02 | 0.8 | ± 0.02 | 0.5 | ± 0.03 |
| Available $NH_4^+$-N (mg/g dw) | 54 | ± 2 | 28 | ± 0.4 | 34 | ± 0.9 | 46 | ± 0.7 | 5 | ± 0.7 |
| Available K (mg/g dw) | 45 | ± 0.7 | 36 | ± 0.6 | 43 | ± 2 | 55 | ± 0.2 | 6 | ± 0.4 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 12.0[a] | ± 0.3 | 5.6 | ± 0.03 | 7.4 | ± 0.2 | 9.3 | ± 0.5 | 1.2 | ± 0.003 |
| pH | 7.8[a] | ± 0.02 | 8.4 | ± 0.02 | 8.1 | ± 0 | 8.3 | ± 0 | 8.8 | ± 0.01 |

[a] Performed on undiluted substrate

Table 4. 23: Liquid sewage

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 0.1[a] | ± 0 | 5 | ± 0.02 | 4 | ± 0.01 | 3 | ± 0.01 | 23 | ± 0.04 |
| VS (% dw) | 45 | ± 2 | 67 | ± 0.1 | 63 | ± 0.05 | 56 | ± 0.1 | 79 | ± 0.1 |
| Total C (% dw) | BD(<0.005) | ± | 33 | ± 1 | 33 | ± 1 | 30 | ± 0.6 | 38 | ± 0.5 |
| Total N (% dw) | 0-20[b] | ± | 4.2 | ± 0.2 | 5.2 | ± 0.2 | 6.5 | ± 0.4 | 1.4 | ± 0.05 |
| Total K (% dw) | 0.9 | ± 0.03 | 3.8 | ± 0.07 | 3.7 | ± 0.1 | 5.7 | ± 0.2 | 0.9 | ± 0.02 |
| Total P (% dw) | 0.7 | ± 0.01 | 1.1 | ± 0.02 | 1.2 | ± 0.02 | 1.6 | ± 0.02 | 0.6 | ± 0.01 |
| Total S (% dw) | 3.3 | ± 0.1 | 0.6 | ± 0.02 | 0.7 | ± 0.02 | 0.8 | ± 0.01 | 0.5 | ± 0.03 |
| Available $NH_4^+$-N (mg/g dw) | 35 | ± 0.7 | 22 | ± 0.4 | 26 | ± 0.6 | 36 | ± 0.7 | 4 | ± 0.3 |
| Available K (mg/g dw) | 11 | ± 0.4 | 35 | ± 1 | 39 | ± 0.7 | 55 | ± 0.9 | 6 | ± 0.1 |
| Available P (mg/g dw) | Not done | | | | | | | | | |
| EC (dS/m) | 1.3[c] | ± 0.03 | 4.8 | ± 0.06 | 5.9 | ± 0.2 | 8.4 | ± 0.03 | 1.0 | ± 0.006 |
| pH | 7.0[c] | ± 0.03 | 8.4 | ± 0.02 | 8.0 | ± 0.01 | 8.1 | ± 0 | 8.8 | ± 0.02 |

[a] This results would be more accurate if measured using the COD method. This was not done for this study [b] The substrate was analyzed 20 times for TN. Only a range could be obtained. [c] Performed on undiluted substrate

Table 4. 24: Hog slaughterhouse waste

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Substrate only, no culture mixtures analyzed | | | |
|---|---|---|---|---|
| | Hog slaughterhouse peptone | | Hog slaughterhouse sludge (DAF) | |
| | Mean | Std dev | Mean | Std dev |
| TS (% ww) | 18 | ± 0.3 | 20 | ± 0.04 |
| VS (% dw) | 80 | ± 2 | 90 | ± 0.7 |
| Total C (% dw) | 44 | ± 0.2 | 60 | ± 1 |
| Total N (% dw) | 9.0 | ± 0.05 | 6.8 | ± 0.06 |
| Total K (% dw) | 1.4 | ± 0.03 | 0.03 | ± 0.0004 |
| Total P (% dw) | 1.0 | ± 0.007 | 0.3 | ± 0.002 |
| Total S (% dw) | 3.0 | ± 0.03 | 0.7 | ± 0.02 |
| Available $NH_4^+$-N (mg/g dw) | 2 | ± 0.2 | 2 | ± 0.01 |
| Available K (mg/g dw) | 11 | ± 0.2 | 0.2 | ± 0.0006 |
| Available P (mg/g dw) | Not done | | | |
| EC (dS/m) | 3.7 | ± 0.04 | 0.6 | ± 0.01 |
| pH | 8.1 | ± 0.01 | 4.8 | ± 0.06 |

## *4.3 Chemical characteristics for substrates used in the ARC Pilot Plant*

Table 4. 25: ARC Pilot Plant substrates

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | Culture | | | | | | | | | | | | Post culture separation | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial | | | Final | | | Liquid | | | Solid | | |
| ARC Pilot Plant (1) mixture | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| TS (% ww) | 14 | ± | 0.05 | 12 | ± | 0.08 | 4 | ± | 0.01 | 29 | ± | 0.2 |
| VS (% dw) | 88 | ± | 1 | 83 | ± | 0.3 | 62 | ± | 0.4 | 90 | ± | 0.2 |
| Total C (% dw) | 52 | ± | 0.9 | 47 | ± | 4 | 38 | ± | 2 | 49 | ± | 1 |
| Total N (% dw) | 1.6 | ± | 0.07 | 2.5 | ± | 0.2 | 5.5 | ± | 0.4 | 1.0[a] | ± | 0.2 |
| Total K (% dw) | 3.2 | ± | 0.05 | 4.5 | ± | 0.1 | 12 | ± | 0.2 | 1.6 | ± | 0.04 |
| Total P (% dw) | 0.3 | ± | 0.003 | 0.5 | ± | 0.003 | 0.9 | ± | 0.01 | 0.3 | ± | 0.004 |
| Total S (% dw) | 0.2 | ± | 0.01 | 0.3 | ± | 0.01 | 0.6 | ± | 0.003 | 0.2 | ± | 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 6 | ± | 0.2 | 5 | ± | 0.01 | 2 | ± | 0.08 | 2 | ± | 0.07 |
| Available K (mg/g dw) | 31 | ± | 0.2 | 41 | ± | 1 | 15 | ± | 0.4 | 13 | ± | 0.3 |
| Available P (mg/g dw) | Not done | | | | | | | | | | | |
| EC (μS/cm) | 2.7 | ± | 0.08 | 3.0 | ± | 0.06 | 8.2 | ± | 0.05 | 1.0 | ± | 0.05 |
| pH | 8.0 | ± | 0.05 | 8.6 | ± | 0.02 | 8.3 | ± | 0.01 | 9.4 | ± | 0.02 |
| ARC Pilot Plant (2) mixture | | | | | | | | | | | | |
| TS (% ww) | 6 | ± | 0.03 | 6 | ± | 0.2 | 1 | ± | 0.01 | 26 | ± | 0.2 |
| VS (% dw) | 96 | ± | 0.01 | 89 | ± | 0.2 | 76 | ± | 0.2 | 91 | ± | 0.3 |
| Total C (% dw) | 50 | ± | 2 | 36 | ± | 5 | 49 | ± | 0.9 | 47 | ± | 1 |
| Total N (% dw) | 3.9 | ± | 0.2 | 4.3 | ± | 0.1 | 16.7 | ± | 0.8 | 1.7 | ± | 0.06 |
| Total K (% dw) | 0.7 | ± | 0.01 | 0.9 | ± | 0.01 | 4.0 | ± | 0.03 | 0.2 | ± | 0.002 |
| Total P (% dw) | 0.5 | ± | 0.004 | 1.0 | ± | 0.007 | 1.4 | ± | 0.009 | 0.9 | ± | 0.007 |
| Total S (% dw) | 0.7 | ± | 0.06 | 0.6 | ± | 0.04 | 1.0 | ± | 0.03 | 0.4 | ± | 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 0.1 | ± | 0.007 | 21 | ± | 0.3 | 88 | ± | 17 | 4 | ± | 0.2 |
| Available K (mg/g dw) | 6 | ± | 0.2 | 8 | ± | 0.2 | 36 | ± | 1 | 1 | ± | 0.01 |
| Available P (mg/g dw) | Not done | | | | | | | | | | | |
| EC (μS/cm) | 0.9 | ± | 0.01 | 4.0 | ± | 0.3 | 12.0[b] | ± | 0.03 | 0.7 | ± | 0.04 |
| pH | 3.7 | ± | 0.02 | 7.9 | ± | 0.02 | 8.0[b] | ± | 0.02 | 8.4 | ± | 0.03 |

[a] Triplicate results were within 30% of the mean. [b] Performed on undiluted substrate

*4.4 Chemical characteristics for inoculum used in this study*

Table 4. 26: Inoculum

| Parameters, refer to Table 2.1 and Section 4.2 for explanations | After collection and before incubation | | Culture | | | | Post-digestion separation fractions | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial (after 7 d incubation)[a] | | Final | | Liquid | | Solid | |
| | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev | Mean | Std dev |
| Held for 44 days | | | | | | | | | | |
| TS (% ww) | 8 | ± 0.01 | 7 | ± 0.02 | 6 | ± 0.05 | 5 | ± 0.03 | 23 | ± 0.3 |
| VS (% dw) | 69 | ± 0.01 | 67 | ± 0.3 | 62 | ± 0.5 | 56 | ± 0.5 | 76 | ± 0.1 |
| Total C (% dw) | 36 | ± 0.4 | 36 | ± 0.9 | 37 | ± 1 | 33 | ± 0.6 | 40 | ± 1.1 |
| Total N (% dw) | 4.5 | ± 0.1 | 4.8 | ± 0.2 | 5.0 | ± 0.2 | 6.9 | ± 0.4 | 1.9 | ± 0.07 |
| Total K (% dw) | 3.4 | ± 0.1 | 3.6 | ± 0.1 | 4.6 | ± 0.08 | 6.6 | ± 0.07 | 1.5 | ± 0.02 |
| Total P (% dw) | 1.1 | ± 0.02 | 1.3 | ± 0.02 | 1.1 | ± 0.02 | 1.4 | ± 0.01 | 0.7 | ± 0.01 |
| Total S (% dw) | 0.6 | ± 0.01 | 0.6 | ± 0.01 | 0.6 | ± 0.04 | 0.7 | ± 0.01 | 0.5 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | 26 | ± 3 | 24 | ± 0.9 | 35 | ± 0.4 | 49 | ± 0.8 | 8 | ± 0.05 |
| Available K (mg/g dw) | 33 | ± 0.8 | 39 | ± 4 | 41 | ± 0.2 | 56 | ± 0.5 | 9 | ± 0.2 |
| Available P (mg/g dw) | 1 | ± 0.1 | 1 | ± 0.01 | 1 | ± | 1 | ± 0.04 | 0.7 | ± 0.01 |
| EC (μS/cm) | 5.7 | ± 0.03 | 4.2 | ± 0.4 | 6.6 | ± 0.06 | 9.2 | ± 0.06 | 1.0 | ± 0.01 |
| pH | 8.0 | ± 0.03 | 8.5 | ± 0.02 | 8.5 | ± 0.01 | 8.2 | ± 0.01 | 8.9 | ± 0.03 |
| Held for 30 days | | | | | | | | | | |
| TS (% ww) | | | | | 7 | ± 0.01 | 5 | ± 0.01 | 24 | ± 0.1 |
| VS (% dw) | | | | | 63 | ± 0.08 | 55 | ± 0.07 | 76 | ± 0.1 |
| Total C (% dw) | | | | | 35 | ± 0.9 | 32 | ± 0.5 | 39 | ± 1.0 |
| Total N (% dw) | | | | | 5.0 | ± 0.2 | 5.8 | ± 0.1 | 1.9 | ± 0.1 |
| Total K (% dw) | | | | | 4.8 | ± 0.04 | 5.8 | ± 0.1 | 1.5 | ± 0.02 |
| Total P (% dw) | Not done | | | | 1.1 | ± 0.01 | 1.5 | ± 0.01 | 0.7 | ± 0.01 |
| Total S (% dw) | | | | | 0.7 | ± 0.01 | 0.7 | ± 0.01 | 0.5 | ± 0.01 |
| Available $NH_4^+$-N (mg/g dw) | | | | | 17[b] | ± 0.7 | 20 | ± 1 | 4 | ± 0.1 |
| Available K (mg/g dw) | | | | | 42 | ± 0.7 | 55 | ± 1 | 9 | ± 0.2 |
| Available P (mg/g dw) | | | | | 1 | ± 0.1 | 2 | ± 0.03 | 1 | ± 0.03 |
| EC (μS/cm) | | | | | 6.1 | ± 0.06 | 8.3 | ± 0.02 | 1.5 | ± 0.02 |
| pH | | | | | 8.3 | ± 0.01 | 8.3 | ± 0 | 8.9 | ± 0.02 |

[a] The 7 day incubation was done before the inoculum was used for the culture mixture [b] There appeared to be a loss of available $NH_4$-N with storage

*4.5* *Heavy metals for biowaste substrates and batch cultures*, please refer to Section 4.2 for explanations

Table 4. 27: Heavy metals for cattle feedlot bed pack manure

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | BD | ± | | 0.0193 | ± | 0.00081 |
| Al | 13.7 | ± | 0.50 | 2290 | ± | 36 |
| As | 0.230 | ± | 0.012 | 0.623 | ± | 0.019 |
| B | 6.09 | ± | 0.37 | 17.5 | ± | 0.63 |
| Ba | 1.11 | ± | 0.019 | 56.2 | ± | 1.7 |
| Be | BD | ± | | 0.0787 | ± | 0.0084 |
| Bi | 0.00218 | ± | 0.00040 | 0.0253 | ± | 0.00040 |
| Ca | 1090 | ± | 27 | 19600 | ± | 420 |
| Cd | 0.00463 | ± | 0.00019 | 0.0858 | ± | 0.0044 |
| Cl | 9050 | ± | 400 | 21800 | ± | 690 |
| Co | 0.754 | ± | 0.026 | 2.93 | ± | 0.065 |
| Cr | 0.497 | ± | 0.012 | 28.5 | ± | 0.45 |
| Cu | 1.32 | ± | 0.047 | 26.9 | ± | 0.82 |
| Fe | 93.3 | ± | 1.7 | 2650 | ± | 76 |
| Hg | 0.0121 | ± | | 0.163 | ± | 0.0074 |
| Li | 1.34 | ± | 0.054 | 2.43 | ± | 0.078 |
| Mg | 483 | ± | 35 | 5740 | ± | 140 |
| Mn | 3.47 | ± | 0.15 | 153 | ± | 2.5 |
| Mo | 0.548 | ± | 0.046 | 4.67 | ± | 0.17 |
| Na | 4390 | ± | 200 | 5420 | ± | 170 |
| Ni | 1.18 | ± | 0.028 | 28.1 | ± | 0.79 |
| Pb | 0.032 | ± | 0.0020 | 0.932 | ± | 0.018 |
| Sb | 0.0127 | ± | 0.00099 | 0.0191 | ± | 0.00083 |
| Se | 0.111 | ± | 0.0063 | 0.178 | ± | 0.048 |
| Sn | BD | ± | | 0.0318 | ± | 0.0012 |
| Sr | 3.40 | ± | 0.14 | 32.8 | ± | 1.4 |
| Th | 0.00492 | ± | 0.00072 | 0.334 | ± | 0.010 |
| Ti | 6.27 | ± | 0.042 | 71.0 | ± | 2.4 |
| TI | BD | ± | | 0.0439 | ± | 0.0011 |
| U | 0.00560 | ± | 0.00025 | 0.214 | ± | 0.0052 |
| V | 0.252 | ± | 0.0038 | 5.38 | ± | 0.13 |
| Zn | 7.10 | ± | 0.31 | 177 | ± | 3.8 |

Table 4. 28: Heavy metals for cattle feedlot bed pack manure culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, μg/g dw | | | Final, μg/g dw | | | Liquid, μg/g dw | | | Solid, μg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0656 | ± | 0.0028 | 0.111 | ± | 0.0021 | 0.115 | ± | 0.0025 | 0.0460 | ± | 0.0014 |
| Al | 2560 | ± | 15 | 6530 | ± | 22 | 8970 | ± | 120 | 3690 | ± | 14 |
| As | 1.03 | ± | 0.0091 | 1.79 | ± | 0.011 | 2.22 | ± | 0.035 | 0.865 | ± | 0.0064 |
| B | 21.3 | ± | 0.46 | 31.2 | ± | 0.39 | 35.1 | ± | 0.92 | 14.4 | ± | 0.28 |
| Ba | 71.3 | ± | 0.98 | 96.9 | ± | 1.2 | 125 | ± | 1.6 | 52.4 | ± | 0.67 |
| Be | 0.129 | ± | 0.0078 | 0.145 | ± | 0.0093 | 0.162 | ± | 0.0095 | 0.0786 | ± | 0.0067 |
| Bi | 0.0463 | ± | 0.0017 | 0.0308 | ± | 0.00076 | 0.0373 | ± | 0.0010 | 0.0169 | ± | 0.00023 |
| Ca | 21100 | ± | 590 | 27200 | ± | 430 | 36500 | ± | 630 | 18900 | ± | 220 |
| Cd | 0.0969 | ± | 0.0028 | 0.156 | ± | 0.0031 | 0.193 | ± | 0.0031 | 0.0877 | ± | 0.0019 |
| Cl | 27800 | ± | 930 | 14200 | ± | 240 | 33000 | ± | 1100 | 11800 | ± | 200 |
| Co | 3.60 | ± | 0.050 | 5.17 | ± | 0.035 | 5.78 | ± | 0.049 | 2.40 | ± | 0.020 |
| Cr | 14.5 | ± | 0.24 | 35.7 | ± | 0.27 | 52.0 | ± | 0.28 | 29.4 | ± | 0.20 |
| Cu | 32.3 | ± | 0.79 | 53.3 | ± | 0.44 | 63.7 | ± | 0.63 | 28.2 | ± | 0.31 |
| Fe | 2900 | ± | 100 | 4850 | ± | 32 | 6250 | ± | 25 | 3390 | ± | 21 |
| Hg | 0.109 | ± | 0.0020 | 0.0704 | ± | 0.0023 | 0.0818 | ± | 0.0023 | 0.0617 | ± | 0.0017 |
| Li | 3.29 | ± | 0.078 | 6.12 | ± | 0.064 | 7.72 | ± | 0.10 | 2.60 | ± | 0.031 |
| Mg | 6870 | ± | 75 | 7480 | ± | 49 | 10000 | ± | 74 | 5690 | ± | 47 |
| Mn | 179 | ± | 3.0 | 253 | ± | 1.2 | 332 | ± | 1.6 | 139 | ± | 0.87 |
| Mo | 3.19 | ± | 0.050 | 6.87 | ± | 0.076 | 8.96 | ± | 0.082 | 4.62 | ± | 0.050 |
| Na | 7840 | ± | 120 | 11300 | ± | 83 | 14400 | ± | 140 | 2360 | ± | 25 |
| Ni | 17.8 | ± | 0.38 | 28.0 | ± | 0.25 | 38.1 | ± | 0.29 | 20.6 | ± | 0.19 |
| Pb | 1.69 | ± | 0.0095 | 1.99 | ± | 0.0097 | 2.70 | ± | 0.016 | 1.21 | ± | 0.0071 |
| Sb | 0.0368 | ± | 0.0019 | 0.0548 | ± | 0.00041 | 0.0494 | ± | 0.00061 | 0.0282 | ± | 0.0015 |
| Se | 0.272 | ± | 0.082 | 1.33 | ± | 0.052 | 1.55 | ± | 0.099 | 0.823 | ± | 0.067 |
| Sn | 0.0668 | ± | 0.0035 | 0.393 | ± | 0.0041 | 0.282 | ± | 0.0020 | 0.0631 | ± | 0.0014 |
| Sr | 84.7 | ± | 2.6 | 136 | ± | 1.8 | 172 | ± | 3.4 | 69.2 | ± | 0.65 |
| Th | 0.309 | ± | 0.0090 | 0.923 | ± | 0.0092 | 1.08 | ± | 0.012 | 0.434 | ± | 0.0042 |
| Ti | 129 | ± | 14 | 223 | ± | 3.1 | 284 | ± | 5.9 | 136 | ± | 3.1 |
| TI | 0.0709 | ± | 0.0016 | 0.0694 | ± | 0.0010 | 0.0947 | ± | 0.0010 | 0.0389 | ± | 0.00059 |
| U | 0.349 | ± | 0.0037 | 0.284 | ± | 0.0033 | 0.369 | ± | 0.0042 | 0.157 | ± | 0.0020 |
| V | 5.47 | ± | 0.070 | 13.8 | ± | 0.13 | 17.6 | ± | 0.14 | 7.26 | ± | 0.077 |
| Zn | 180 | ± | 5.1 | 306 | ± | 2.0 | 389 | ± | 7.6 | 174 | ± | 2.1 |

Table 4. 29: Heavy metals for dairy manure #1

| Heavy metal | Results given as μg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | BD | ± | | 0.0179 | ± | 0.00064 |
| Al | 15.7 | ± | 0.48 | 962 | ± | 15 |
| As | BD | ± | | 0.244 | ± | 0.0062 |
| B | 15.0 | ± | 0.51 | 34.5 | ± | 1.0 |
| Ba | 2.07 | ± | 0.0084 | 50.0 | ± | 0.88 |
| Be | 0.00158 | ± | | 0.0539 | ± | 0.0070 |
| Bi | 0.00887 | ± | 0.0066 | 0.0300 | ± | 0.0032 |
| Ca | 2820 | ± | 16 | 20400 | ± | 760 |
| Cd | 0.00749 | ± | 0.00098 | 0.139 | ± | 0.0044 |
| Cl | 6160 | ± | 46 | 12200 | ± | 780 |
| Co | 0.993 | ± | 0.011 | 2.76 | ± | 0.047 |
| Cr | 0.486 | ± | 0.0020 | 2.83 | ± | 0.58 |
| Cu | 3.12 | ± | 0.080 | 58.7 | ± | 1.8 |
| Fe | 99.3 | ± | 1.5 | 1190 | ± | 47 |
| Hg | BD | ± | | 0.0110 | ± | 0.00083 |
| Li | 2.12 | ± | 0.11 | 2.46 | ± | 0.065 |
| Mg | 1310 | ± | 16 | 6150 | ± | 87 |
| Mn | 8.86 | ± | 0.19 | 222 | ± | 2.5 |
| Mo | 0.498 | ± | 0.013 | 1.77 | ± | 0.043 |
| Na | 3470 | ± | 35 | 4050 | ± | 42 |
| Ni | 1.25 | ± | 0.026 | 3.54 | ± | 0.11 |
| Pb | 0.0241 | ± | 0.0015 | 0.498 | ± | 0.014 |
| Sb | 0.0131 | ± | 0.0018 | 0.0492 | ± | 0.0016 |
| Se | BD | ± | | 0.500 | ± | 0.060 |
| Sn | BD | ± | | 0.0942 | ± | 0.00057 |
| Sr | 17.5 | ± | 0.18 | 75.0 | ± | 2.6 |
| Th | 0.0140 | ± | 0.0091 | 0.194 | ± | 0.0037 |
| Ti | 2.82 | ± | 0.065 | 41.0 | ± | 1.6 |
| TI | 0.00410 | ± | 0.0013 | 0.111 | ± | 0.0039 |
| U | 0.785 | ± | 0.0078 | 3.21 | ± | 0.91 |
| V | 0.566 | ± | 0.0069 | 3.43 | ± | 0.075 |
| Zn | 11.5 | ± | 0.54 | 265 | ± | 8.7 |

Table 4. 30: Heavy metals for dairy manure #1 culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0875 | ± | 0.0020 | 0.0754 | ± | 0.0016 | 0.133 | ± | 0.0023 | 0.0580 | ± | 0.00093 |
| Al | 3450 | ± | 53 | 4270 | ± | 15 | 8420 | ± | 65 | 2500 | ± | 11 |
| As | 1.07 | ± | 0.029 | 1.35 | ± | 0.015 | 2.09 | ± | 0.023 | 0.726 | ± | 0.0061 |
| B | 30.7 | ± | 1.1 | 31.4 | ± | 0.57 | 42.6 | ± | 0.82 | 18.1 | ± | 0.56 |
| Ba | 77.6 | ± | 1.9 | 70.3 | ± | 0.72 | 124 | ± | 1.4 | 39.5 | ± | 0.52 |
| Be | 0.114 | ± | 0.010 | 0.108 | ± | 0.0081 | 0.180 | ± | 0.014 | 0.0607 | ± | 0.0034 |
| Bi | 0.0406 | ± | 0.0019 | 0.0276 | ± | 0.00075 | 0.0383 | ± | 0.00090 | 0.0131 | ± | 0.00049 |
| Ca | 23600 | ± | 710 | 22600 | ± | 250 | 40100 | ± | 260 | 13900 | ± | 140 |
| Cd | 0.145 | ± | 0.0031 | 0.159 | ± | 0.0036 | 0.229 | ± | 0.0029 | 0.0909 | ± | 0.0018 |
| Cl | 34500 | ± | 1100 | 18100 | ± | 520 | 25800 | ± | 480 | 5240 | ± | 300 |
| Co | 4.31 | ± | 0.092 | 4.03 | ± | 0.048 | 5.73 | ± | 0.061 | 2.26 | ± | 0.018 |
| Cr | 5.74 | ± | 0.092 | 7.17 | ± | 0.044 | 13.9 | ± | 0.053 | 5.04 | ± | 0.014 |
| Cu | 54.1 | ± | 1.3 | 60.5 | ± | 0.66 | 93.4 | ± | 0.66 | 35.5 | ± | 0.31 |
| Fe | 2970 | ± | 65 | 3180 | ± | 25 | 5650 | ± | 51 | 1950 | ± | 11 |
| Hg | 0.0192 | ± | 0.0012 | 0.169 | ± | 0.00095 | 0.0274 | ± | 0.0014 | 0.0129 | ± | 0.0014 |
| Li | 4.10 | ± | 0.079 | 4.86 | ± | 0.096 | 8.05 | ± | 0.10 | 2.06 | ± | 0.030 |
| Mg | 7870 | ± | 84 | 6850 | ± | 26 | 11800 | ± | 83 | 3950 | ± | 21 |
| Mn | 232 | ± | 2.1 | 230 | ± | 0.83 | 389 | ± | 2.7 | 130 | ± | 0.77 |
| Mo | 2.21 | ± | 0.048 | 2.72 | ± | 0.038 | 4.24 | ± | 0.037 | 1.44 | ± | 0.017 |
| Na | 7600 | ± | 102 | 8380 | ± | 51 | 14000 | ± | 67 | 2260 | ± | 20 |
| Ni | 10.1 | ± | 0.25 | 8.57 | ± | 0.13 | 13.3 | ± | 0.14 | 4.21 | ± | 0.056 |
| Pb | 1.98 | ± | 0.0095 | 1.65 | ± | 0.0067 | 2.87 | ± | 0.010 | 0.925 | ± | 0.0051 |
| Sb | 0.0280 | ± | 0.0017 | 0.433 | ± | 0.0010 | 0.0532 | ± | 0.0012 | 0.0324 | ± | 0.0013 |
| Se | 0.461 | ± | 0.076 | 1.19 | ± | 0.048 | 1.65 | ± | 0.030 | 0.770 | ± | 0.039 |
| Sn | 0.0705 | ± | 0.0027 | 0.0826 | ± | 0.0019 | 0.305 | ± | 0.0037 | 0.320 | ± | 0.0039 |
| Sr | 128 | ± | 3.3 | 136 | ± | 1.7 | 227 | ± | 3.1 | 73.0 | ± | 0.88 |
| Th | 0.575 | ± | 0.011 | 0.530 | ± | 0.0064 | 1.08 | ± | 0.0091 | 0.367 | ± | 0.0041 |
| Ti | 145 | ± | 7.4 | 162 | ± | 2.6 | 301 | ± | 3.4 | 116 | ± | 1.9 |
| TI | 0.129 | ± | 0.0038 | 0.0760 | ± | 0.0012 | 0.136 | ± | 0.0018 | 0.0474 | ± | 0.00091 |
| U | 2.25 | ± | 0.051 | 1.29 | ± | 0.020 | 2.05 | ± | 0.026 | 0.713 | ± | 0.0083 |
| V | 7.91 | ± | 0.17 | 9.67 | ± | 0.083 | 16.5 | ± | 0.13 | 5.48 | ± | 0.043 |
| Zn | 240 | ± | 6.5 | 274 | ± | 2.8 | 453 | ± | 6.3 | 173 | ± | 1.7 |

Table 4. 31: Heavy metals for potato tuber waste

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | BD | ± | | 0.0103 | ± | 0.00026 |
| Al | 0.838 | ± | 0.079 | 117 | ± | 2.7 |
| As | BD | ± | | 0.0247 | ± | 0.0041 |
| B | 3.52 | ± | 0.17 | 7.05 | ± | 0.16 |
| Ba | 0.448 | ± | 0.035 | 2.66 | ± | 0.047 |
| Be | BD | ± | | 0.00750 | ± | 0.0037 |
| Bi | 0.000560 | ± | 0.00035 | 0.00371 | ± | 0.00031 |
| Ca | 69.4 | ± | 0.83 | 363 | ± | 10 |
| Cd | 0.164 | ± | 0.0025 | 0.452 | ± | 0.015 |
| Cl | 2490 | ± | 100 | 11700 | ± | 290 |
| Co | 0.0650 | ± | 0.0048 | 0.180 | ± | 0.0069 |
| Cr | 0.0701 | ± | 0.022 | 0.501 | ± | 0.040 |
| Cu | 1.27 | ± | 0.079 | 2.66 | ± | 0.068 |
| Fe | 5.80 | ± | 0.57 | 173 | ± | 1.1 |
| Hg | 0.00345 | ± | | 0.00386 | ± | 0.00079 |
| Li | 0.190 | ± | 0.042 | 0.124 | ± | 0.0044 |
| Mg | 634 | ± | 7.9 | 1340 | ± | 21 |
| Mn | 3.26 | ± | 0.055 | 10.1 | ± | 0.070 |
| Mo | 0.0594 | ± | 0.0017 | 0.177 | ± | 0.0070 |
| Na | 37.0 | ± | 64 | 214 | ± | 4.6 |
| Ni | 0.343 | ± | 0.011 | 0.854 | ± | 0.028 |
| Pb | 0.0490 | ± | | 0.0505 | ± | 0.0012 |
| Sb | 0.00126 | ± | 0.00059 | 0.00458 | ± | 0.00070 |
| Se | BD | ± | | BD | ± | |
| Sn | BD | ± | | 0.00458 | ± | 0.00081 |
| Sr | 0.275 | ± | 0.0059 | 1.16 | ± | 0.043 |
| Th | 0.0297 | ± | 0.0083 | 0.0276 | ± | 0.00077 |
| Ti | 3.26 | ± | 0.20 | 10.9 | ± | 0.64 |
| TI | 0.0212 | ± | 0.00072 | 0.00920 | ± | 0.00065 |
| U | 0.000887 | ± | 0.000090 | 0.0149 | ± | 0.00071 |
| V | 0.0197 | ± | 0.0070 | 0.287 | ± | 0.012 |
| Zn | 6.97 | ± | 0.22 | 11.0 | ± | 0.29 |

Table 4. 32: Heavy metals for potato tuber waste culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0647 | ± | 0.0011 | 0.105 | ± | 0.00094 | 0.153 | ± | 0.0032 | 0.0527 | ± | 0.0012 |
| Al | 5960 | ± | 28 | 5960 | ± | 103 | 8280 | ± | 160 | 3030 | ± | 50 |
| As | 1.28 | ± | 0.025 | 1.80 | ± | 0.022 | 2.08 | ± | 0.033 | 0.834 | ± | 0.0085 |
| B | 18.6 | ± | 0.30 | 24.8 | ± | 0.61 | 28.5 | ± | 1.3 | 11.9 | ± | 0.37 |
| Ba | 71.9 | ± | 0.63 | 97.7 | ± | 0.98 | 129 | ± | 2.8 | 48.4 | ± | 0.60 |
| Be | 0.102 | ± | 0.0083 | 0.113 | ± | 0.0041 | 0.147 | ± | 0.0054 | 0.0574 | ± | 0.0046 |
| Bi | 0.0253 | ± | 0.00045 | 0.0406 | ± | 0.00043 | 0.0650 | ± | 0.0018 | 0.0182 | ± | 0.00035 |
| Ca | 19700 | ± | 190 | 25300 | ± | 750 | 31200 | ± | 610 | 13500 | ± | 350 |
| Cd | 0.222 | ± | 0.0039 | 0.331 | ± | 0.0046 | 0.389 | ± | 0.0072 | 0.157 | ± | 0.0018 |
| Cl | 15500 | ± | 380 | 23400 | ± | 380 | 21900 | ± | 930 | 19000 | ± | 290 |
| Co | 2.94 | ± | 0.014 | 3.79 | ± | 0.025 | 4.27 | ± | 0.069 | 2.16 | ± | 0.031 |
| Cr | 7.77 | ± | 0.11 | 7.80 | ± | 0.12 | 11.2 | ± | 0.21 | 4.82 | ± | 0.065 |
| Cu | 32.9 | ± | 0.24 | 39.9 | ± | 0.54 | 47.0 | ± | 1.1 | 20.8 | ± | 0.47 |
| Fe | 3940 | ± | 12 | 4700 | ± | 56 | 6340 | ± | 85 | 2770 | ± | 31 |
| Hg | 0.158 | ± | 0.00086 | 0.0238 | ± | 0.00070 | 0.0350 | ± | 0.0017 | 0.0119 | ± | 0.00094 |
| Li | 4.46 | ± | 0.049 | 5.11 | ± | 0.067 | 6.72 | ± | 0.18 | 2.12 | ± | 0.032 |
| Mg | 5940 | ± | 44 | 4510 | ± | 72 | 5850 | ± | 190 | 6080 | ± | 41 |
| Mn | 199 | ± | 1.1 | 257 | ± | 3.6 | 318 | ± | 5.7 | 118 | ± | 0.92 |
| Mo | 1.99 | ± | 0.015 | 2.98 | ± | 0.049 | 3.24 | ± | 0.073 | 1.42 | ± | 0.022 |
| Na | 6350 | ± | 63 | 9360 | ± | 190 | 11800 | ± | 220 | 2280 | ± | 46 |
| Ni | 7.75 | ± | 0.074 | 9.87 | ± | 0.061 | 12.0 | ± | 0.23 | 4.78 | ± | 0.063 |
| Pb | 1.87 | ± | 0.012 | 2.51 | ± | 0.0073 | 3.42 | ± | 0.085 | 1.30 | ± | 0.0063 |
| Sb | 0.0306 | ± | 0.0011 | 0.0439 | ± | 0.00071 | 0.0478 | ± | 0.0020 | 0.0252 | ± | 0.00075 |
| Se | 0.841 | ± | 0.045 | 0.919 | ± | 0.061 | 1.26 | ± | 0.036 | 0.586 | ± | 0.026 |
| Sn | 0.0894 | ± | 0.0019 | 0.0814 | ± | 0.0017 | 0.190 | ± | 0.0030 | BD | ± | |
| Sr | 130 | ± | 1.2 | 170 | ± | 1.7 | 200 | ± | 4.9 | 87.9 | ± | 1.9 |
| Th | 0.717 | ± | 0.0048 | 0.776 | ± | 0.0042 | 1.34 | ± | 0.039 | 0.210 | ± | 0.0018 |
| Ti | 214 | ± | 1.9 | 230 | ± | 4.7 | 330 | ± | 4.1 | 135 | ± | 3.5 |
| TI | 0.0651 | ± | 0.0015 | 0.0809 | ± | 0.0012 | 0.113 | ± | 0.0036 | 0.0441 | ± | 0.00059 |
| U | 0.263 | ± | 0.0029 | 0.310 | ± | 0.0025 | 0.433 | ± | 0.013 | 0.154 | ± | 0.0020 |
| V | 10.0 | ± | 0.086 | 10.9 | ± | 0.19 | 14.5 | ± | 0.35 | 5.76 | ± | 0.11 |
| Zn | 167 | ± | 1.5 | 265 | ± | 6.0 | 322 | ± | 2.8 | 114 | ± | 2.3 |

Table 4. 33: Heavy metals for chicken broiler manure

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | BD | ± | | 0.00747 | ± | 0.00063 |
| Al | 0.358 | ± | 0.032 | 197 | ± | 2.1 |
| As | BD | ± | | 0.0468 | ± | 0.012 |
| B | 8.72 | ± | 0.28 | 27.5 | ± | 0.93 |
| Ba | 0.299 | ± | 0.017 | 44.9 | ± | 1.2 |
| Be | BD | ± | | 0.0101 | ± | 0.0028 |
| Bi | BD | ± | | 0.00405 | ± | 0.00046 |
| Ca | 892 | ± | 49 | 34000 | ± | 960 |
| Cd | 0.0130 | ± | 0.00095 | 0.107 | ± | 0.0040 |
| Cl | 8940 | ± | 300 | 22500 | ± | 700 |
| Co | 0.129 | ± | 0.0051 | 0.492 | ± | 0.011 |
| Cr | 0.147 | ± | | 10.9 | ± | 1.2 |
| Cu | 127 | ± | 5.4 | 322 | ± | 9.3 |
| Fe | 29.5 | ± | 1.8 | 579 | ± | 20 |
| Hg | BD | ± | | 0.0617 | ± | 0.0051 |
| Li | 0.789 | ± | 0.030 | 1.02 | ± | 0.030 |
| Mg | 762 | ± | 62 | 5850 | ± | 130 |
| Mn | 3.48 | ± | 0.33 | 366 | ± | 1.8 |
| Mo | 0.480 | ± | 0.051 | 4.21 | ± | 0.089 |
| Na | 3500 | ± | 110 | 4410 | ± | 110 |
| Ni | 2.76 | ± | 0.070 | 14.7 | ± | 0.39 |
| Pb | 0.00341 | ± | 0.0050 | 0.184 | ± | 0.0035 |
| Sb | 0.00572 | ± | 0.0015 | 0.121 | ± | 0.0028 |
| Se | 0.660 | ± | 0.021 | 1.20 | ± | 0.14 |
| Sn | BD | ± | | 0.0304 | ± | 0.0010 |
| Sr | 1.26 | ± | 0.059 | 38.7 | ± | 0.92 |
| Th | BD | ± | | 0.0532 | ± | 0.0014 |
| Ti | 2.70 | ± | 0.27 | 68.4 | ± | 3.1 |
| TI | 0.00808 | ± | 0.00048 | 0.122 | ± | 0.0069 |
| U | 0.000230 | ± | 0.000096 | 0.0591 | ± | 0.0013 |
| V | 0.0120 | ± | 0.0020 | 0.729 | ± | 0.025 |
| Zn | 23.5 | ± | 0.77 | 397 | ± | 11 |

Table 4. 34: Heavy metals for chicken broiler manure culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, μg/g dw | | | Final, μg/g dw | | | Liquid, μg/g dw | | | Solid, μg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0743 | ± | 0.0017 | 0.0665 | ± | 0.0016 | 0.0724 | ± | 0.0025 | 0.0381 | ± | 0.0014 |
| Al | 5030 | ± | 23 | 5450 | ± | 110 | 5740 | ± | 88 | 2640 | ± | 34 |
| As | 1.20 | ± | 0.012 | 1.45 | ± | 0.019 | 1.82 | ± | 0.021 | 0.734 | ± | 0.016 |
| B | 25.0 | ± | 0.53 | 25.4 | ± | 0.87 | 27.9 | ± | 0.81 | 17.9 | ± | 0.34 |
| Ba | 75.6 | ± | 0.82 | 96.9 | ± | 1.3 | 113 | ± | 1.1 | 62.7 | ± | 0.59 |
| Be | 0.0902 | ± | 0.0041 | 0.0927 | ± | 0.0034 | 0.0985 | ± | 0.0060 | 0.0496 | ± | 0.0037 |
| Bi | 0.0220 | ± | 0.00060 | 0.0331 | ± | 0.00081 | 0.0367 | ± | 0.0032 | 0.0179 | ± | 0.00033 |
| Ca | 27900 | ± | 200 | 37500 | ± | 720 | 38400 | ± | 700 | 37900 | ± | 680 |
| Cd | 0.136 | ± | 0.0027 | 0.170 | ± | 0.0017 | 0.217 | ± | 0.0033 | 0.0953 | ± | 0.0030 |
| Cl | 6410 | ± | 210 | 32600 | ± | 690 | 41900 | ± | 1300 | 22000 | ± | 260 |
| Co | 2.87 | ± | 0.023 | 2.94 | ± | 0.020 | 3.52 | ± | 0.031 | 2.12 | ± | 0.024 |
| Cr | 18.6 | ± | 0.062 | 16.1 | ± | 0.19 | 17.1 | ± | 0.19 | 9.84 | ± | 0.11 |
| Cu | 139 | ± | 1.2 | 141 | ± | 2.0 | 162 | ± | 1.6 | 103 | ± | 1.2 |
| Fe | 3470 | ± | 14 | 4380 | ± | 33 | 3800 | ± | 50 | 2400 | ± | 20 |
| Hg | 0.0236 | ± | 0.00091 | 0.0367 | ± | 0.0019 | 0.0344 | ± | 0.0017 | 0.0218 | ± | 0.00046 |
| Li | 4.11 | ± | 0.041 | 4.91 | ± | 0.088 | 4.99 | ± | 0.092 | 2.18 | ± | 0.043 |
| Mg | 6990 | ± | 24 | 6550 | ± | 120 | 7010 | ± | 120 | 6070 | ± | 88 |
| Mn | 293 | ± | 1.4 | 422 | ± | 2.0 | 440 | ± | 3.3 | 246 | ± | 1.3 |
| Mo | 4.35 | ± | 0.042 | 4.77 | ± | 0.073 | 4.84 | ± | 0.061 | 2.80 | ± | 0.028 |
| Na | 7670 | ± | 64 | 9810 | ± | 250 | 12300 | ± | 300 | 2540 | ± | 43 |
| Ni | 16.7 | ± | 0.16 | 15.1 | ± | 0.16 | 16.7 | ± | 0.20 | 9.31 | ± | 0.14 |
| Pb | 1.64 | ± | 0.0064 | 2.19 | ± | 0.018 | 2.55 | ± | 0.015 | 1.21 | ± | 0.0056 |
| Sb | 0.0603 | ± | 0.0010 | 0.0503 | ± | 0.00051 | 0.0517 | ± | 0.0013 | 0.0341 | ± | 0.0010 |
| Se | 1.24 | ± | 0.089 | 1.46 | ± | 0.060 | 1.83 | ± | 0.052 | 1.46 | ± | 0.026 |
| Sn | 0.267 | ± | 0.0021 | BD | ± | | BD | ± | | BD | ± | |
| Sr | 126 | ± | 1.5 | 155 | ± | 2.9 | 184 | ± | 2.6 | 99.4 | ± | 0.96 |
| Th | 0.758 | ± | 0.0083 | 0.108 | ± | 0.0016 | 0.0373 | ± | 0.00070 | 0.0156 | ± | 0.00038 |
| Ti | 220 | ± | 1.9 | 133 | ± | 2.7 | 83.7 | ± | 1.3 | 90.9 | ± | 1.9 |
| TI | 0.0854 | ± | 0.0018 | 0.107 | ± | 0.0013 | 0.107 | ± | 0.0021 | 0.0923 | ± | 0.0013 |
| U | 0.226 | ± | 0.0013 | 0.262 | ± | 0.0034 | 0.296 | ± | 0.0017 | 0.135 | ± | 0.0021 |
| V | 9.04 | ± | 0.059 | 9.25 | ± | 0.13 | 10.1 | ± | 0.15 | 5.08 | ± | 0.052 |
| Zn | 289 | ± | 2.4 | 404 | ± | 10 | 488 | ± | 8.8 | 181 | ± | 1.9 |

Table 4. 35: Heavy metals for chicken laying hen manure

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | BD | ± | | 0.0190 | ± | 0.0010 |
| Al | 1.82 | ± | 0.60 | 323 | ± | 19 |
| As | 0.0146 | ± | | 0.331 | ± | 0.020 |
| B | 13.3 | ± | 0.91 | 28.6 | ± | 0.51 |
| Ba | 0.527 | ± | 0.096 | 30.2 | ± | 0.39 |
| Be | BD | ± | | 0.0643 | ± | 0.012 |
| Bi | 0.00242 | ± | 0.00079 | 0.00731 | ± | 0.00088 |
| Ca | 245 | ± | 42 | 230000 | ± | 5500 |
| Cd | 0.0197 | ± | 0.012 | 0.251 | ± | 0.0069 |
| Cl | 4060 | ± | 200 | 15100 | ± | 160 |
| Co | 0.380 | ± | 0.031 | 1.65 | ± | 0.046 |
| Cr | 0.386 | ± | 0.067 | 6.60 | ± | 0.13 |
| Cu | 4.14 | ± | 0.37 | 43.8 | ± | 0.67 |
| Fe | 85.9 | ± | 11 | 1110 | ± | 98 |
| Hg | 0.00641 | ± | | 0.00662 | ± | 0.00091 |
| Li | 0.508 | ± | 0.060 | 0.807 | ± | 0.014 |
| Mg | 24.7 | ± | 5.5 | 7640 | ± | 130 |
| Mn | 2.08 | ± | 0.38 | 481 | ± | 7.9 |
| Mo | 0.846 | ± | 0.048 | 3.14 | ± | 0.070 |
| Na | BD | ± | | 2080 | ± | 30 |
| Ni | 2.34 | ± | 0.30 | 11.9 | ± | 0.38 |
| Pb | 0.0634 | ± | 0.043 | 0.633 | ± | 0.016 |
| Sb | 0.0109 | ± | 0.0022 | 0.123 | ± | 0.0034 |
| Se | 0.560 | ± | 0.11 | 2.10 | ± | 0.16 |
| Sn | BD | ± | | 0.0799 | ± | 0.0024 |
| Sr | 0.881 | ± | 0.18 | 132 | ± | 3.5 |
| Th | 0.00241 | ± | 0.0012 | 0.193 | ± | 0.0071 |
| Ti | 12.9 | ± | 0.80 | 71.7 | ± | 3.3 |
| TI | 0.00333 | ± | 0.00022 | 0.0559 | ± | 0.0011 |
| U | 0.0200 | ± | 0.0012 | 0.376 | ± | 0.017 |
| V | 0.0762 | ± | 0.0084 | 2.04 | ± | 0.031 |
| Zn | 35.7 | ± | 5.5 | 485 | ± | 12 |

Table 4. 36: Heavy metals for chicken laying hen manure culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0481 | ± | 0.00057 | 0.0626 | ± | 0.00055 | 0.0774 | ± | 0.0026 | 0.0184 | ± | 0.00041 |
| Al | 3640 | ± | 26 | 3960 | ± | 88 | 3850 | ± | 62 | 886 | ± | 16 |
| As | 1.05 | ± | 0.012 | 1.24 | ± | 0.018 | 1.57 | ± | 0.028 | 0.390 | ± | 0.033 |
| B | 27.5 | ± | 0.55 | 28.3 | ± | 0.30 | 33.9 | ± | 0.91 | 8.43 | ± | 0.22 |
| Ba | 63.3 | ± | 0.57 | 81.4 | ± | 0.90 | 94.5 | ± | 0.74 | 39.4 | ± | 0.36 |
| Be | 0.0732 | ± | 0.0057 | 0.0780 | ± | 0.0053 | 0.0967 | ± | 0.0073 | 0.0486 | ± | 0.0041 |
| Bi | 0.0198 | ± | 0.00062 | 0.0271 | ± | 0.00014 | 0.0361 | ± | 0.00082 | 0.00828 | ± | 0.00034 |
| Ca | 83700 | ± | 1300 | 75900 | ± | 870 | 55800 | ± | 760 | 281000 | ± | 4800 |
| Cd | 0.178 | ± | 0.0040 | 0.250 | ± | 0.0030 | 0.293 | ± | 0.0050 | 0.143 | ± | 0.0017 |
| Cl | 10600 | ± | 130 | 36400 | ± | 520 | 70400 | ± | 2100 | 14500 | ± | 330 |
| Co | 2.81 | ± | 0.016 | 2.95 | ± | 0.041 | 3.65 | ± | 0.034 | 0.830 | ± | 0.019 |
| Cr | 6.80 | ± | 0.017 | 7.13 | ± | 0.043 | 7.74 | ± | 0.10 | 3.71 | ± | 0.077 |
| Cu | 50.4 | ± | 0.32 | 57.6 | ± | 0.71 | 73.2 | ± | 0.74 | 10.7 | ± | 0.18 |
| Fe | 2730 | ± | 9.2 | 3450 | ± | 48 | 3570 | ± | 60 | 1430 | ± | 48 |
| Hg | 0.0129 | ± | 0.00088 | 0.0171 | ± | 0.00053 | 0.0249 | ± | 0.0021 | 0.00964 | ± | 0.00049 |
| Li | 3.24 | ± | 0.020 | 4.04 | ± | 0.059 | 4.05 | ± | 0.048 | 1.03 | ± | 0.019 |
| Mg | 6670 | ± | 24 | 6850 | ± | 73 | 7800 | ± | 94 | 4410 | ± | 110 |
| Mn | 382 | ± | 1.3 | 513 | ± | 5.1 | 578 | ± | 4.6 | 303 | ± | 2.9 |
| Mo | 3.46 | ± | 0.029 | 4.14 | ± | 0.042 | 5.03 | ± | 0.052 | 0.923 | ± | 0.012 |
| Na | 6070 | ± | 44 | 6240 | ± | 120 | 9310 | ± | 150 | 986 | ± | 23 |
| Ni | 7.50 | ± | 0.072 | 8.18 | ± | 0.15 | 11.0 | ± | 0.17 | 3.34 | ± | 0.43 |
| Pb | 1.54 | ± | 0.0031 | 2.00 | ± | 0.0050 | 2.59 | ± | 0.010 | 0.968 | ± | 0.018 |
| Sb | 0.0623 | ± | 0.0010 | 0.0652 | ± | 0.0010 | 0.0700 | ± | 0.00082 | 0.0492 | ± | 0.0015 |
| Se | 1.82 | ± | 0.061 | 2.14 | ± | 0.046 | 2.47 | ± | 0.033 | 1.40 | ± | 0.065 |
| Sn | 0.0789 | ± | 0.0011 | BD | ± | | BD | ± | | BD | ± | |
| Sr | 126 | ± | 1.2 | 149 | ± | 1.8 | 158 | ± | 1.7 | 144 | ± | 0.86 |
| Th | 0.443 | ± | 0.0037 | 0.0836 | ± | 0.0010 | 0.0437 | ± | 0.0011 | 0.0379 | ± | 0.0014 |
| Ti | 181 | ± | 1.1 | 128 | ± | 1.8 | 114 | ± | 2.5 | 70.9 | ± | 2.1 |
| TI | 0.0694 | ± | 0.00073 | 0.0911 | ± | 0.00075 | 0.104 | ± | 0.0016 | 0.0357 | ± | 0.00080 |
| U | 0.352 | ± | 0.0024 | 0.374 | ± | 0.0058 | 0.435 | ± | 0.0024 | 0.488 | ± | 0.0070 |
| V | 7.28 | ± | 0.039 | 7.49 | ± | 0.069 | 7.56 | ± | 0.14 | 2.66 | ± | 0.042 |
| Zn | 354 | ± | 1.9 | 576 | ± | 7.3 | 694 | ± | 11 | 94.1 | ± | 0.78 |

Table 4. 37: Heavy metals for dairy manure #2

| Heavy metal | Results given as μg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000911 | ± | 0.00035 | 0.0307 | ± | 0.0013 |
| Al | 6.90 | ± | 0.17 | 394 | ± | 8.0 |
| As | 0.0911 | ± | 0.0090 | 0.246 | ± | 0.0067 |
| B | 9.10 | ± | 0.32 | 18.4 | ± | 0.72 |
| Ba | 5.75 | ± | 0.059 | 56.1 | ± | 0.44 |
| Be | 0.000959 | ± | 0.000018 | 0.0425 | ± | 0.0042 |
| Bi | 0.000792 | ± | 0.0064 | 0.0102 | ± | 0.00024 |
| Ca | 2940 | ± | 1.4 | 18000 | ± | 300 |
| Cd | 0.0109 | ± | 0.00055 | 0.293 | ± | 0.0038 |
| Cl | 10400 | ± | 190 | 22800 | ± | 570 |
| Co | 0.410 | ± | 0.00019 | 1.23 | ± | 0.013 |
| Cr | 0.666 | ± | 0.024 | 6.83 | ± | 0.088 |
| Cu | 3.01 | ± | 0.055 | 87.4 | ± | 1.3 |
| Fe | 30.2 | ± | 0.55 | 923 | ± | 28 |
| Hg | 0.0109 | ± | 0.000037 | 0.0224 | ± | 0.00091 |
| Li | 0.738 | ± | 0.075 | 1.07 | ± | 0.020 |
| Mg | 3210 | ± | 69 | 5220 | ± | 90 |
| Mn | 6.56 | ± | 0.011 | 144 | ± | 1.2 |
| Mo | 0.182 | ± | 0.0012 | 1.82 | ± | 0.023 |
| Na | 8910 | ± | 200 | 9370 | ± | 240 |
| Ni | 0.884 | ± | 0.0018 | 4.15 | ± | 0.039 |
| Pb | 0.0136 | ± | 0.0023 | 0.285 | ± | 0.0011 |
| Sb | 0.00590 | ± | 0.00032 | 0.0337 | ± | 0.0010 |
| Se | 0.168 | ± | 0.0026 | 0.614 | ± | 0.020 |
| Sn | 0.00558 | ± | 0.0038 | 0.0329 | ± | 0.0011 |
| Sr | 19.8 | ± | 0.22 | 56.5 | ± | 0.63 |
| Th | 0.00212 | ± | 0.00036 | 0.0756 | ± | 0.00068 |
| Ti | 2.51 | ± | 0.044 | 25.6 | ± | 0.40 |
| TI | 0.00233 | ± | 0.00047 | 0.0390 | ± | 0.0012 |
| U | 0.216 | ± | 0.0086 | 0.778 | ± | 0.0072 |
| V | 0.273 | ± | 0.0084 | 1.81 | ± | 0.028 |
| Zn | 5.93 | ± | 0.11 | 121 | ± | 1.8 |

Table 4. 38: Heavy metals for dairy manure #2 culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, μg/g dw | | | Final, μg/g dw | | | Liquid, μg/g dw | | | Solid, μg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0483 | ± | 0.00079 | 0.142 | ± | 0.0027 | 0.197 | ± | 0.0046 | 0.0767 | ± | 0.0030 |
| Al | 3780 | ± | 29 | 6560 | ± | 81 | 8970 | ± | 100 | 3600 | ± | 55 |
| As | 1.20 | ± | 0.019 | 1.37 | ± | 0.030 | 1.88 | ± | 0.020 | 0.647 | ± | 0.0072 |
| B | 19.8 | ± | 0.59 | 26.3 | ± | 0.59 | 31.5 | ± | 0.54 | 14.4 | ± | 0.24 |
| Ba | 75.4 | ± | 1.2 | 114 | ± | 1.1 | 157 | ± | 1.6 | 62.8 | ± | 0.90 |
| Be | 0.0779 | ± | 0.012 | 0.110 | ± | 0.0057 | 0.140 | ± | 0.010 | 0.0669 | ± | 0.011 |
| Bi | 0.0364 | ± | 0.0012 | 0.0291 | ± | 0.00093 | 0.0383 | ± | 0.0011 | 0.155 | ± | 0.00024 |
| Ca | 23100 | ± | 230 | 20000 | ± | 260 | 26700 | ± | 320 | 11100 | ± | 140 |
| Cd | 0.199 | ± | 0.0035 | 0.245 | ± | 0.0053 | 0.307 | ± | 0.0030 | 0.121 | ± | 0.0047 |
| Cl | 22100 | ± | 700 | 29300 | ± | 550 | 36000 | ± | 550 | 20800 | ± | 87 |
| Co | 2.90 | ± | 0.030 | 3.26 | ± | 0.022 | 3.99 | ± | 0.027 | 1.79 | ± | 0.019 |
| Cr | 8.27 | ± | 0.066 | 10.8 | ± | 0.097 | 15.4 | ± | 0.14 | 5.87 | ± | 0.046 |
| Cu | 63.2 | ± | 0.60 | 78.4 | ± | 0.82 | 90.7 | ± | 0.90 | 36.6 | ± | 0.46 |
| Fe | 3100 | ± | 25 | 3560 | ± | 49 | 4720 | ± | 73 | 2150 | ± | 21 |
| Hg | 0.0223 | ± | 0.0016 | 0.0239 | ± | 0.0020 | 0.0329 | ± | 0.0025 | 0.0125 | ± | 0.0012 |
| Li | 3.48 | ± | 0.067 | 3.80 | ± | 0.032 | 5.38 | ± | 0.095 | 1.53 | ± | 0.045 |
| Mg | 8000 | ± | 93 | 7670 | ± | 92 | 10400 | ± | 140 | 4090 | ± | 45 |
| Mn | 213 | ± | 1.6 | 222 | ± | 0.92 | 333 | ± | 1.6 | 115 | ± | 0.50 |
| Mo | 2.39 | ± | 0.028 | 2.95 | ± | 0.028 | 3.86 | ± | 0.048 | 1.35 | ± | 0.017 |
| Na | 10700 | ± | 180 | 11900 | ± | 190 | 18500 | ± | 250 | 2790 | ± | 41 |
| Ni | 7.87 | ± | 0.14 | 9.36 | ± | 0.097 | 12.6 | ± | 0.14 | 4.20 | ± | 0.044 |
| Pb | 1.65 | ± | 0.012 | 2.17 | ± | 0.0097 | 3.13 | ± | 0.026 | 1.20 | ± | 0.0026 |
| Sb | 0.0282 | ± | 0.00070 | 0.139 | ± | 0.0040 | 0.167 | ± | 0.0013 | 0.0665 | ± | 0.0023 |
| Se | 1.07 | ± | 0.043 | 1.18 | ± | 0.089 | 1.81 | ± | 0.087 | 0.781 | ± | 0.089 |
| Sn | 0.0750 | ± | 0.0067 | 0.373 | ± | 0.0041 | 0.478 | ± | 0.0068 | 0.205 | ± | 0.0033 |
| Sr | 125 | ± | 1.6 | 158 | ± | 1.4 | 219 | ± | 1.5 | 73.6 | ± | 0.66 |
| Th | 0.523 | ± | 0.0056 | 0.981 | ± | 0.0051 | 1.31 | ± | 0.018 | 0.483 | ± | 0.0065 |
| Ti | 165 | ± | 1.6 | 317 | ± | 3.4 | 422 | ± | 3.8 | 190 | ± | 2.8 |
| TI | 0.0670 | ± | 0.00024 | 0.0915 | ± | 0.0018 | 0.118 | ± | 0.0025 | 0.0498 | ± | 0.0014 |
| U | 0.652 | ± | 0.0096 | 0.718 | ± | 0.0092 | 0.960 | ± | 0.019 | 0.365 | ± | 0.0038 |
| V | 7.85 | ± | 0.062 | 9.71 | ± | 0.082 | 12.9 | ± | 0.15 | 5.20 | ± | 0.021 |
| Zn | 166 | ± | 1.5 | 187 | ± | 1.3 | 343 | ± | 4.0 | 98.9 | ± | 0.87 |

Table 4. 39: Heavy metals for potato process waste

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000565 | ± | 0.00010 | 0.00378 | ± | 0.00055 |
| Al | 1.55 | ± | 0.16 | 47.6 | ± | 0.49 |
| As | BD | ± | | 0.0605 | ± | 0.024 |
| B | 2.38 | ± | 0.081 | 3.38 | ± | 0.15 |
| Ba | 0.913 | ± | 0.013 | 1.95 | ± | 0.025 |
| Be | BD | ± | | BD | ± | |
| Bi | 0.000578 | ± | 0.00034 | 0.00185 | ± | 0.00019 |
| Ca | 158 | ± | 1.6 | 264 | ± | 2.9 |
| Cd | 0.0479 | ± | 0.0015 | 0.0654 | ± | 0.0035 |
| Cl | 49700 | ± | 760 | 72600 | ± | 1500 |
| Co | 0.0368 | ± | 0.00077 | 0.0408 | ± | 0.0015 |
| Cr | 0.551 | ± | 0.22 | 1.39 | ± | 0.15 |
| Cu | 0.467 | ± | 0.034 | 1.32 | ± | 0.022 |
| Fe | 3.85 | ± | 0.17 | 24.0 | ± | 0.81 |
| Hg | 0.00464 | ± | 0.0014 | 0.0110 | ± | 0.00090 |
| Li | BD | ± | | 0.0654 | ± | 0.0047 |
| Mg | 567 | ± | 6.5 | 612 | ± | 3.9 |
| Mn | 2.98 | ± | 0.13 | 3.10 | ± | 0.016 |
| Mo | 0.0793 | ± | 0.0014 | 0.122 | ± | 0.0066 |
| Na | 27600 | ± | 1800 | 28300 | ± | 310 |
| Ni | 0.0804 | ± | 0.018 | 0.180 | ± | 0.0068 |
| Pb | 0.0533 | ± | 0.083 | 0.0246 | ± | 0.00034 |
| Sb | 0.000446 | ± | 0.000075 | 0.00282 | ± | 0.00067 |
| Se | 0.0274 | ± | 0.014 | 0.238 | ± | 0.12 |
| Sn | 0.00221 | ± | 0.00034 | 0.00767 | ± | 0.00079 |
| Sr | 0.612 | ± | 0.0077 | 1.19 | ± | 0.0097 |
| Th | 0.0134 | ± | 0.0028 | 0.0137 | ± | 0.0021 |
| Ti | 2.74 | ± | 0.31 | 4.57 | ± | 0.065 |
| TI | 0.00115 | ± | 0.000031 | 0.00322 | ± | 0.00041 |
| U | 0.00278 | ± | 0.0020 | 0.00313 | ± | 0.00014 |
| V | 0.113 | ± | 0.062 | 0.364 | ± | 0.036 |
| Zn | 4.52 | ± | 0.062 | 4.91 | ± | 0.034 |

Table 4. 40: Heavy metals for potato process waste culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.151 | ± | 0.0021 | 0.0660 | ± | 0.0016 | 0.113 | ± | 0.0020 | 0.0455 | ± | 0.00061 |
| Al | 7410 | ± | 110 | 5920 | ± | 65 | 9190 | ± | 23 | 4020 | ± | 220 |
| As | 1.48 | ± | 0.018 | 1.85 | ± | 0.029 | 2.39 | ± | 0.0097 | 0.838 | ± | 0.0089 |
| B | 21.1 | ± | 0.44 | 24.6 | ± | 0.25 | 30.6 | ± | 0.33 | 12.2 | ± | 0.22 |
| Ba | 106 | ± | 1.5 | 85.6 | ± | 0.38 | 110 | ± | 0.58 | 56.2 | ± | 0.18 |
| Be | 0.131 | ± | 0.0047 | 0.115 | ± | 0.018 | 0.155 | ± | 0.0092 | 0.0451 | ± | 0.0052 |
| Bi | 0.0329 | ± | 0.00045 | 0.0321 | ± | 0.00029 | 0.0426 | ± | 0.00051 | 0.0181 | ± | 0.00014 |
| Ca | 17500 | ± | 300 | 24600 | ± | 79 | 29500 | ± | 160 | 16700 | ± | 64 |
| Cd | 0.141 | ± | 0.0042 | 0.167 | ± | 0.0017 | 0.210 | ± | 0.0020 | 0.0840 | ± | 0.0025 |
| Cl | 47600 | ± | 1100 | 40400 | ± | 1310 | 24100 | ± | 290 | 12300 | ± | 220 |
| Co | 3.08 | ± | 0.032 | 3.96 | ± | 0.023 | 4.86 | ± | 0.032 | 1.93 | ± | 0.016 |
| Cr | 11.9 | ± | 0.12 | 12.9 | ± | 0.11 | 14.2 | ± | 0.054 | 4.84 | ± | 0.035 |
| Cu | 33.3 | ± | 0.43 | 41.2 | ± | 0.22 | 49.7 | ± | 0.13 | 21.9 | ± | 0.069 |
| Fe | 3760 | ± | 11 | 4300 | ± | 42 | 5670 | ± | 48 | 2970 | ± | 20 |
| Hg | 0.0210 | ± | 0.00037 | 0.0203 | ± | 0.0013 | 0.0283 | ± | 0.0019 | 0.0120 | ± | 0.0012 |
| Li | 4.43 | ± | 0.084 | 4.95 | ± | 0.039 | 7.01 | ± | 0.077 | 2.36 | ± | 0.020 |
| Mg | 6540 | ± | 85 | 8040 | ± | 55 | 8170 | ± | 29 | 10400 | ± | 22 |
| Mn | 197 | ± | 1.3 | 292 | ± | 1.5 | 357 | ± | 1.6 | 150 | ± | 0.66 |
| Mo | 2.26 | ± | 0.035 | 2.70 | ± | 0.017 | 3.47 | ± | 0.019 | 1.38 | ± | 0.0060 |
| Na | 19300 | ± | 350 | 20700 | ± | 220 | 29500 | ± | 190 | 4610 | ± | 13 |
| Ni | 9.83 | ± | 0.14 | 11.8 | ± | 0.13 | 14.0 | ± | 0.093 | 5.00 | ± | 0.021 |
| Pb | 2.40 | ± | 0.015 | 2.50 | ± | 0.015 | 3.04 | ± | 0.0073 | 1.43 | ± | 0.0039 |
| Sb | 0.119 | ± | 0.0032 | 0.0382 | ± | 0.0014 | 0.0489 | ± | 0.0020 | 0.0277 | ± | 0.00079 |
| Se | 1.08 | ± | 0.040 | 0.826 | ± | 0.057 | 1.23 | ± | 0.040 | 0.582 | ± | 0.068 |
| Sn | 0.376 | ± | 0.0031 | 0.104 | ± | 0.0025 | 0.249 | ± | 0.0035 | 0.0857 | ± | 0.0010 |
| Sr | 151 | ± | 2.0 | 196 | ± | 1.3 | 227 | ± | 0.97 | 150 | ± | 0.35 |
| Th | 1.13 | ± | 0.010 | 0.542 | ± | 0.0051 | 1.22 | ± | 0.0033 | 0.350 | ± | 0.0035 |
| Ti | 359 | ± | 12 | 223 | ± | 0.85 | 347 | ± | 0.87 | 180 | ± | 0.53 |
| TI | 0.0879 | ± | 0.0017 | 0.0726 | ± | 0.00083 | 0.0979 | ± | 0.00086 | 0.0478 | ± | 0.00077 |
| U | 0.359 | ± | 0.0050 | 0.278 | ± | 0.0027 | 0.366 | ± | 0.0045 | 0.156 | ± | 0.0015 |
| V | 11.4 | ± | 0.15 | 10.6 | ± | 0.047 | 15.7 | ± | 0.025 | 6.27 | ± | 0.027 |
| Zn | 169 | ± | 1.7 | 219 | ± | 0.95 | 251 | ± | 1.3 | 119 | ± | 0.29 |

Table 4. 41: Heavy metals for potato stems and leaves

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.00215 | ± | 0.00016 | 0.119 | ± | 0.0037 |
| Al | 7.75 | ± | 0.45 | 14600 | ± | 190 |
| As | 0.349 | ± | 0.0050 | 2.49 | ± | 0.025 |
| B | 10.5 | ± | 0.081 | 35.5 | ± | 0.96 |
| Ba | 20.7 | ± | 0.12 | 315 | ± | 2.5 |
| Be | 0.000797 | ± | 0.00033 | 0.373 | ± | 0.025 |
| Bi | 0.00354 | ± | 0.0015 | 0.0503 | ± | 0.00055 |
| Ca | 1520 | ± | 8.1 | 24300 | ± | 160 |
| Cd | 0.119 | ± | 0.00087 | 1.14 | ± | 0.0097 |
| Cl | 5520 | ± | 31 | 30100 | ± | 120 |
| Co | 0.410 | ± | 0.0060 | 2.95 | ± | 0.0076 |
| Cr | 1.11 | ± | 0.012 | 147 | ± | 0.89 |
| Cu | 1.21 | ± | 0.0090 | 12.6 | ± | 0.082 |
| Fe | 71.2 | ± | 0.20 | 7300 | ± | 73 |
| Hg | 0.0252 | ± | 0.0012 | 1.94 | ± | 0.026 |
| Li | 0.411 | ± | 0.0099 | 7.18 | ± | 0.13 |
| Mg | 6.41 | ± | 0.050 | 13700 | ± | 81 |
| Mn | 11.8 | ± | 0.13 | 199 | ± | 0.72 |
| Mo | 0.231 | ± | 0.0076 | 16.4 | ± | 0.13 |
| Na | 170 | ± | 2.0 | 2650 | ± | 27 |
| Ni | 2.62 | ± | 0.023 | 97.9 | ± | 0.52 |
| Pb | 0.130 | ± | 0.0012 | 4.57 | ± | 0.034 |
| Sb | 0.0251 | ± | 0.00060 | 0.240 | ± | 0.0032 |
| Se | 0.0419 | ± | 0.0042 | 0.567 | ± | 0.053 |
| Sn | 0.00401 | ± | 0.00031 | 0.431 | ± | 0.0030 |
| Sr | 14.0 | ± | 0.076 | 97.2 | ± | 0.64 |
| Th | 0.0668 | ± | 0.024 | 2.14 | ± | 0.042 |
| Ti | 2.17 | ± | 0.083 | 439 | ± | 18 |
| TI | 0.00824 | ± | 0.00028 | 0.183 | ± | 0.0026 |
| U | 0.0390 | ± | 0.00053 | 0.590 | ± | 0.0082 |
| V | 0.321 | ± | 0.0040 | 21.3 | ± | 0.41 |
| Zn | 1.60 | ± | 0.037 | 30.3 | ± | 0.16 |

Table 4. 42: Heavy metals for potato stems and leaves culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.159 | ± | 0.0015 | 0.0753 | ± | 0.0029 | 0.0950 | ± | 0.0023 | 0.0705 | ± | 0.0016 |
| Al | 11800 | ± | 110 | 7580 | ± | 20 | 8750 | ± | 450 | 5620 | ± | 17 |
| As | 2.19 | ± | 0.023 | 2.24 | ± | 0.029 | 2.70 | ± | 0.031 | 1.28 | ± | 0.028 |
| B | 29.9 | ± | 0.63 | 29.2 | ± | 0.31 | 36.7 | ± | 0.61 | 19.8 | ± | 0.63 |
| Ba | 204 | ± | 2.0 | 150 | ± | 0.43 | 180 | ± | 0.72 | 95.2 | ± | 0.56 |
| Be | 0.260 | ± | 0.0090 | 0.176 | ± | 0.015 | 0.201 | ± | 0.014 | 0.114 | ± | 0.0091 |
| Bi | 0.0409 | ± | 0.00082 | 0.0417 | ± | 0.00075 | 0.0481 | ± | 0.00082 | 0.0329 | ± | 0.0016 |
| Ca | 23500 | ± | 300 | 29800 | ± | 37 | 36900 | ± | 260 | 18800 | ± | 54 |
| Cd | 0.535 | ± | 0.0078 | 0.608 | ± | 0.0041 | 0.712 | ± | 0.010 | 0.347 | ± | 0.0056 |
| Cl | 30600 | ± | 1200 | 17500 | ± | 560 | 38200 | ± | 1400 | 2920 | ± | 29 |
| Co | 3.55 | ± | 0.048 | 3.90 | ± | 0.012 | 4.56 | ± | 0.020 | 2.38 | ± | 0.0050 |
| Cr | 59.0 | ± | 0.26 | 61.4 | ± | 0.27 | 49.2 | ± | 0.21 | 32.6 | ± | 0.12 |
| Cu | 30.4 | ± | 0.23 | 34.9 | ± | 0.11 | 42.3 | ± | 0.38 | 20.8 | ± | 0.081 |
| Fe | 5800 | ± | 25 | 5970 | ± | 24 | 6910 | ± | 27 | 4260 | ± | 53 |
| Hg | 0.358 | ± | 0.0061 | 0.211 | ± | 0.0026 | 0.249 | ± | 0.0051 | 0.226 | ± | 0.0051 |
| Li | 5.93 | ± | 0.096 | 5.97 | ± | 0.037 | 7.68 | ± | 0.087 | 3.26 | ± | 0.024 |
| Mg | 10600 | ± | 65 | 12800 | ± | 27 | 17400 | ± | 84 | 7090 | ± | 9.9 |
| Mn | 232 | ± | 1.8 | 324 | ± | 1.2 | 382 | ± | 1.7 | 156 | ± | 0.97 |
| Mo | 7.58 | ± | 0.047 | 5.19 | ± | 0.018 | 5.81 | ± | 0.061 | 4.28 | ± | 0.037 |
| Na | 7580 | ± | 62 | 5690 | ± | 25 | 8650 | ± | 64 | 1360 | ± | 5.3 |
| Ni | 40.3 | ± | 0.41 | 33.9 | ± | 0.15 | 35.5 | ± | 0.17 | 23.3 | ± | 0.17 |
| Pb | 3.45 | ± | 0.038 | 3.08 | ± | 0.0074 | 3.90 | ± | 0.027 | 1.98 | ± | 0.0060 |
| Sb | 0.181 | ± | 0.00083 | 0.0493 | ± | 0.00091 | 0.101 | ± | 0.0011 | 0.0435 | ± | 0.0015 |
| Se | 1.18 | ± | 0.065 | 0.755 | ± | 0.12 | 0.923 | ± | 0.074 | 0.566 | ± | 0.056 |
| Sn | 0.438 | ± | 0.0043 | 0.0536 | ± | 0.0013 | 0.0894 | ± | 0.0020 | 0.127 | ± | 0.0019 |
| Sr | 162 | ± | 1.2 | 181 | ± | 0.65 | 216 | ± | 1.3 | 93.6 | ± | 0.62 |
| Th | 1.49 | ± | 0.028 | 0.643 | ± | 0.0031 | 0.799 | ± | 0.0047 | 0.759 | ± | 0.0049 |
| Ti | 426 | ± | 11 | 198 | ± | 0.59 | 209 | ± | 1.5 | 176 | ± | 0.92 |
| TI | 0.131 | ± | 0.0015 | 0.0994 | ± | 0.0015 | 0.123 | ± | 0.0018 | 0.0686 | ± | 0.00038 |
| U | 0.448 | ± | 0.0073 | 0.296 | ± | 0.0017 | 0.371 | ± | 0.0032 | 0.189 | ± | 0.0014 |
| V | 17.7 | ± | 0.18 | 14.4 | ± | 0.13 | 16.5 | ± | 0.15 | 10.5 | ± | 0.077 |
| Zn | 141 | ± | 0.94 | 158 | ± | 0.49 | 183 | ± | 1.3 | 107 | ± | 0.26 |

Table 4. 43: Heavy metals for poultry slaughter waste

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000684 | ± | 0.00016 | 0.00930 | ± | 0.00040 |
| Al | 0.573 | ± | 0.074 | 175 | ± | 1.7 |
| As | 0.00957 | ± | 0.00026 | 0.0231 | ± | 0.0012 |
| B | 0.321 | ± | 0.058 | 0.900 | ± | 0.051 |
| Ba | 0.0345 | ± | 0.0074 | 1.12 | ± | 0.015 |
| Be | 0.000290 | ± | 0.00050 | 0.00110 | ± | 0.00070 |
| Bi | 0.000498 | ± | 0.00011 | 0.00410 | ± | 0.00030 |
| Ca | 62.8 | ± | 11 | 603 | ± | 7.0 |
| Cd | 0.0233 | ± | 0.0049 | 0.0522 | ± | 0.0014 |
| Cl | 1950 | ± | 198 | 5410 | ± | 180 |
| Co | 0.0316 | ± | 0.0052 | 0.0834 | ± | 0.0012 |
| Cr | 0.102 | ± | 0.0062 | 2.42 | ± | 0.037 |
| Cu | 6.82 | ± | 1.2 | 12.4 | ± | 0.20 |
| Fe | 15.2 | ± | 2.2 | 236 | ± | 8.6 |
| Hg | BD | ± | | 0.00540 | ± | 0.00070 |
| Li | 0.174 | ± | 0.065 | 0.703 | ± | 0.019 |
| Mg | 119 | ± | 21 | 475 | ± | 4.2 |
| Mn | 0.817 | ± | 0.16 | 6.24 | ± | 0.042 |
| Mo | 0.0986 | ± | 0.019 | 0.314 | ± | 0.0059 |
| Na | 1570 | ± | 200 | 2870 | ± | 41 |
| Ni | 0.0560 | ± | 0.017 | 1.11 | ± | 0.012 |
| Pb | 0.00567 | ± | 0.0016 | 0.949 | ± | 0.00090 |
| Sb | 0.000325 | ± | 0.00012 | 0.00220 | ± | 0.00020 |
| Se | 0.456 | ± | 0.076 | 1.11 | ± | 0.032 |
| Sn | 0.00390 | ± | 0.00091 | 0.0185 | ± | 0.00040 |
| Sr | 0.636 | ± | 0.13 | 5.50 | ± | 0.092 |
| Th | 0.0289 | ± | 0.010 | 0.0427 | ± | 0.0015 |
| Ti | 8.27 | ± | 1.3 | 22.9 | ± | 0.50 |
| TI | 0.00910 | ± | 0.0022 | 0.0161 | ± | 0.00040 |
| U | 0.0000619 | ± | 0.000052 | 0.00890 | ± | 0.00020 |
| V | 0.0226 | ± | 0.0024 | 0.159 | ± | 0.0030 |
| Zn | 15.5 | ± | 2.7 | 62.2 | ± | 0.82 |

Table 4. 44: Heavy metals for poultry slaughter waste culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, μg/g dw | | | Final, μg/g dw | | | Liquid, μg/g dw | | | Solid, μg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0901 | ± | 0.0030 | 0.110 | ± | 0.0026 | 0.175 | ± | 0.0019 | 0.0737 | ± | 0.0014 |
| Al | 6520 | ± | 35 | 7070 | ± | 240 | 11800 | ± | 140 | 4330 | ± | 41 |
| As | 1.62 | ± | 0.014 | 1.97 | ± | 0.017 | 2.66 | ± | 0.036 | 0.984 | ± | 0.017 |
| B | 21.1 | ± | 0.61 | 25.6 | ± | 0.63 | 32.2 | ± | 0.57 | 16.4 | ± | 0.32 |
| Ba | 82.1 | ± | 1.0 | 102 | ± | 1.7 | 147 | ± | 1.0 | 56.5 | ± | 0.62 |
| Be | 0.101 | ± | 0.011 | 0.123 | ± | 0.012 | 0.199 | ± | 0.0086 | 0.0875 | ± | 0.0058 |
| Bi | 0.0309 | ± | 0.00040 | 0.0428 | ± | 0.0013 | 0.0638 | ± | 0.00090 | 0.0220 | ± | 0.00030 |
| Ca | 23700 | ± | 350 | 29100 | ± | 360 | 40200 | ± | 680 | 17200 | ± | 370 |
| Cd | 0.134 | ± | 0.0024 | 0.155 | ± | 0.0037 | 0.216 | ± | 0.0032 | 0.0839 | ± | 0.0015 |
| Cl | 15000 | ± | 260 | 21100 | ± | 310 | 17800 | ± | 400 | 2390 | ± | 38 |
| Co | 3.49 | ± | 0.043 | 4.20 | ± | 0.068 | 5.40 | ± | 0.054 | 2.60 | ± | 0.020 |
| Cr | 12.8 | ± | 0.24 | 14.0 | ± | 0.065 | 15.7 | ± | 0.17 | 6.30 | ± | 0.072 |
| Cu | 39.3 | ± | 0.44 | 45.9 | ± | 0.75 | 62.4 | ± | 0.42 | 26.6 | ± | 0.43 |
| Fe | 4410 | ± | 37 | 4960 | ± | 48 | 6490 | ± | 51 | 3310 | ± | 30 |
| Hg | 0.0183 | ± | 0.0019 | 0.0232 | ± | 0.0016 | 0.0295 | ± | 0.00090 | 0.0105 | ± | 0.00030 |
| Li | 5.00 | ± | 0.075 | 5.23 | ± | 0.13 | 8.22 | ± | 0.26 | 2.97 | ± | 0.043 |
| Mg | 8310 | ± | 110 | 8420 | ± | 49 | 11500 | ± | 140 | 5150 | ± | 61 |
| Mn | 273 | ± | 2.8 | 277 | ± | 1.3 | 375 | ± | 4.3 | 159 | ± | 1.0 |
| Mo | 2.49 | ± | 0.024 | 2.95 | ± | 0.058 | 4.02 | ± | 0.027 | 1.74 | ± | 0.025 |
| Na | 8030 | ± | 110 | 9340 | ± | 79 | 13000 | ± | 310 | 1810 | ± | 34 |
| Ni | 11.1 | ± | 0.15 | 13.0 | ± | 0.27 | 16.0 | ± | 0.13 | 6.74 | ± | 0.060 |
| Pb | 2.51 | ± | 0.033 | 2.79 | ± | 0.014 | 3.65 | ± | 0.030 | 2.16 | ± | 0.022 |
| Sb | 0.0375 | ± | 0.0011 | 0.0305 | ± | 0.0013 | 0.0368 | ± | 0.0013 | 0.0247 | ± | 0.00060 |
| Se | 0.905 | ± | 0.073 | 1.06 | ± | 0.060 | 1.45 | ± | 0.064 | 0.831 | ± | 0.041 |
| Sn | 0.0917 | ± | 0.0027 | 0.186 | ± | 0.0047 | 0.261 | ± | 0.0018 | 0.167 | ± | 0.0015 |
| Sr | 186 | ± | 2.1 | 188 | ± | 2.8 | 252 | ± | 4.7 | 102 | ± | 1.7 |
| Th | 0.550 | ± | 0.0071 | 0.842 | ± | 0.012 | 1.32 | ± | 0.0095 | 0.680 | ± | 0.0034 |
| Ti | 245 | ± | 3.8 | 268 | ± | 11 | 354 | ± | 7.8 | 194 | ± | 2.6 |
| TI | 0.0728 | ± | 0.0015 | 0.0914 | ± | 0.0016 | 0.140 | ± | 0.0018 | 0.0584 | ± | 0.0011 |
| U | 0.259 | ± | 0.0029 | 0.303 | ± | 0.0066 | 0.434 | ± | 0.0040 | 0.165 | ± | 0.0013 |
| V | 10.9 | ± | 0.13 | 12.0 | ± | 0.14 | 17.0 | ± | 0.24 | 7.33 | ± | 0.14 |
| Zn | 188 | ± | 2.4 | 250 | ± | 2.2 | 327 | ± | 8.1 | 135 | ± | 3.1 |

Table 4. 45: Heavy metals for cattle carcass

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000176 | ± | 0.00013 | 0.0106 | ± | 0.00030 |
| Al | 0.131 | ± | 0.034 | 612 | ± | 4.4 |
| As | 0.0104 | ± | 0.0039 | 0.0936 | ± | 0.0036 |
| B | 0.204 | ± | 0.043 | 1.69 | ± | 0.089 |
| Ba | 0.0402 | ± | 0.0042 | 5.83 | ± | 0.099 |
| Be | BD | ± | | 0.0127 | ± | 0.0024 |
| Bi | 0.000208 | ± | 0.000087 | 0.00300 | ± | 0.00030 |
| Ca | 105 | ± | 12 | 3680 | ± | 62 |
| Cd | 0.000546 | ± | 0.00013 | 0.00910 | ± | 0.00090 |
| Cl | 1610 | ± | 96 | 2450 | ± | 42 |
| Co | 0.00768 | ± | 0.0015 | 0.165 | ± | 0.0021 |
| Cr | 0.0700 | ± | 0.00070 | 2.85 | ± | 0.042 |
| Cu | 0.327 | ± | 0.064 | 6.19 | ± | 0.12 |
| Fe | 11.8 | ± | 2.3 | 496 | ± | 14 |
| Hg | BD | ± | | 0.00410 | ± | 0.00070 |
| Li | 0.234 | ± | 0.011 | 0.522 | ± | 0.024 |
| Mg | 175 | ± | 21 | 955 | ± | 14 |
| Mn | 0.677 | ± | 0.096 | 11.0 | ± | 0.093 |
| Mo | 0.0277 | ± | 0.0063 | 0.224 | ± | 0.0036 |
| Na | 1240 | ± | 110 | 2980 | ± | 60 |
| Ni | BD | ± | | 1.08 | ± | 0.026 |
| Pb | 0.00194 | ± | 0.00042 | 0.534 | ± | 0.0026 |
| Sb | 0.00103 | ± | 0.00038 | 0.0112 | ± | 0.00050 |
| Se | 0.0550 | ± | 0.017 | 0.467 | ± | 0.047 |
| Sn | 0.00114 | ± | 0.00017 | 0.0340 | ± | 0.00090 |
| Sr | 1.40 | ± | 0.16 | 13.3 | ± | 0.20 |
| Th | 0.0146 | ± | 0.00084 | 0.118 | ± | 0.0052 |
| Ti | 6.69 | ± | 0.64 | 45.4 | ± | 1.2 |
| TI | 0.000163 | ± | 0.000077 | 0.00570 | ± | 0.00020 |
| U | BD | ± | | 0.0230 | ± | 0.00050 |
| V | 0.0217 | ± | 0.0016 | 0.710 | ± | 0.014 |
| Zn | 5.89 | ± | 1.1 | 127 | ± | 1.7 |

Table 4. 46: Heavy metals for cattle carcass culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0816 | ± | 0.0031 | 0.111 | ± | 0.0044 | 0.127 | ± | 0.0065 | 0.0779 | ± | 0.0026 |
| Al | 5050 | ± | 42 | 7310 | ± | 110 | 10200 | ± | 54 | 4580 | ± | 44 |
| As | 1.54 | ± | 0.025 | 1.90 | ± | 0.021 | 2.64 | ± | 0.034 | 0.911 | ± | 0.0063 |
| B | 20.1 | ± | 0.34 | 26.7 | ± | 0.61 | 29.4 | ± | 0.74 | 15.0 | ± | 0.29 |
| Ba | 73.4 | ± | 0.61 | 109 | ± | 1.3 | 136 | ± | 1.2 | 59.4 | ± | 0.63 |
| Be | 0.109 | ± | 0.0076 | 0.129 | ± | 0.0016 | 0.181 | ± | 0.011 | 0.0980 | ± | 0.0038 |
| Bi | 0.0297 | ± | 0.00070 | 0.0439 | ± | 0.00060 | 0.0539 | ± | 0.0010 | 0.0259 | ± | 0.00050 |
| Ca | 22500 | ± | 230 | 29400 | ± | 350 | 39300 | ± | 470 | 17900 | ± | 290 |
| Cd | 0.123 | ± | 0.0017 | 0.158 | ± | 0.0044 | 0.206 | ± | 0.0047 | 0.103 | ± | 0.0028 |
| Cl | 22100 | ± | 430 | 15900 | ± | 240 | 52500 | ± | 1400 | 3080 | ± | 45 |
| Co | 3.33 | ± | 0.038 | 4.46 | ± | 0.041 | 4.95 | ± | 0.039 | 2.59 | ± | 0.035 |
| Cr | 14.5 | ± | 0.20 | 15.1 | ± | 0.18 | 12.7 | ± | 0.15 | 6.20 | ± | 0.068 |
| Cu | 35.5 | ± | 0.40 | 47.6 | ± | 0.51 | 59.0 | ± | 0.57 | 27.5 | ± | 0.33 |
| Fe | 3950 | ± | 24 | 5120 | ± | 39 | 6070 | ± | 82 | 3860 | ± | 88 |
| Hg | 0.0185 | ± | 0.0015 | 0.0207 | ± | 0.0010 | 0.0264 | ± | 0.00050 | 0.0146 | ± | 0.0015 |
| Li | 4.41 | ± | 0.045 | 5.77 | ± | 0.12 | 7.17 | ± | 0.12 | 2.91 | ± | 0.029 |
| Mg | 7600 | ± | 51 | 8340 | ± | 82 | 11900 | ± | 80 | 4880 | ± | 41 |
| Mn | 257 | ± | 2.0 | 273 | ± | 1.3 | 377 | ± | 3.1 | 165 | ± | 1.0 |
| Mo | 2.39 | ± | 0.035 | 3.13 | ± | 0.049 | 3.70 | ± | 0.038 | 1.73 | ± | 0.024 |
| Na | 7620 | ± | 71 | 9560 | ± | 170 | 13000 | ± | 190 | 2360 | ± | 43 |
| Ni | 11.7 | ± | 0.13 | 14.0 | ± | 0.15 | 14.3 | ± | 0.087 | 6.45 | ± | 0.095 |
| Pb | 18.5 | ± | 0.12 | 2.76 | ± | 0.016 | 3.55 | ± | 0.024 | 1.57 | ± | 0.0043 |
| Sb | 0.0839 | ± | 0.00070 | 0.0326 | ± | 0.00050 | 0.0296 | ± | 0.0011 | 0.0250 | ± | 0.00090 |
| Se | 0.814 | ± | 0.061 | 1.14 | ± | 0.075 | 0.933 | ± | 0.072 | 0.678 | ± | 0.039 |
| Sn | 0.0768 | ± | 0.0037 | 0.250 | ± | 0.0027 | 0.176 | ± | 0.0042 | 0.193 | ± | 0.0018 |
| Sr | 174 | ± | 1.4 | 186 | ± | 3.2 | 248 | ± | 4.9 | 111 | ± | 2.5 |
| Th | 0.369 | ± | 0.0052 | 1.21 | ± | 0.014 | 1.03 | ± | 0.0062 | 0.573 | ± | 0.0057 |
| Ti | 185 | ± | 1.9 | 294 | ± | 4.9 | 283 | ± | 6.3 | 212 | ± | 13 |
| TI | 0.0642 | ± | 0.00070 | 0.0977 | ± | 0.00070 | 0.125 | ± | 0.0029 | 0.0594 | ± | 0.00090 |
| U | 0.245 | ± | 0.0024 | 0.338 | ± | 0.0040 | 0.415 | ± | 0.0043 | 0.182 | ± | 0.0027 |
| V | 8.87 | ± | 0.081 | 12.7 | ± | 0.13 | 15.0 | ± | 0.17 | 7.54 | ± | 0.063 |
| Zn | 187 | ± | 1.7 | 255 | ± | 4.6 | 341 | ± | 7.2 | 172 | ± | 4.1 |

Table 4. 47: Heavy metals for sugar beet tailings

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000738 | ± | 0.000072 | 0.0237 | ± | 0.0013 |
| Al | 9.37 | ± | 1.6 | 2710 | ± | 18 |
| As | 0.0845 | ± | 0.018 | 1.25 | ± | 0.032 |
| B | 2.27 | ± | 0.29 | 23.3 | ± | 0.31 |
| Ba | 5.69 | ± | 0.81 | 62.2 | ± | 1.0 |
| Be | 0.00348 | ± | 0.00052 | 0.124 | ± | 0.0093 |
| Bi | 0.000509 | ± | 0.00010 | 0.0174 | ± | 0.00050 |
| Ca | 2080 | ± | 330 | 9590 | ± | 89 |
| Cd | 0.0254 | ± | 0.0049 | 0.218 | ± | 0.0027 |
| Cl | 1690 | ± | 270 | 6060 | ± | 170 |
| Co | 0.408 | ± | 0.065 | 1.79 | ± | 0.032 |
| Cr | 0.388 | ± | 0.070 | 22.4 | ± | 0.49 |
| Cu | 1.17 | ± | 0.14 | 10.2 | ± | 0.12 |
| Fe | 4.06 | ± | 0.59 | 3180 | ± | 54 |
| Hg | BD | ± | | 0.00680 | ± | 0.00070 |
| Li | 0.450 | ± | 0.082 | 2.88 | ± | 0.064 |
| Mg | 1310 | ± | 340 | 3680 | ± | 43 |
| Mn | 29.8 | ± | 4.6 | 111 | ± | 1.3 |
| Mo | 0.0417 | ± | 0.0070 | 0.667 | ± | 0.0093 |
| Na | 3230 | ± | 510 | 5080 | ± | 73 |
| Ni | 0.710 | ± | 0.110 | 10.8 | ± | 0.18 |
| Pb | 0.0153 | ± | 0.0025 | 1.14 | ± | 0.018 |
| Sb | 0.0107 | ± | 0.0017 | 0.0345 | ± | 0.0011 |
| Se | 0.0371 | ± | 0.0082 | 0.203 | ± | 0.024 |
| Sn | 0.00313 | ± | 0.00044 | 0.0688 | ± | 0.00090 |
| Sr | 3.55 | ± | 0.52 | 28.6 | ± | 0.27 |
| Th | 0.0327 | ± | 0.0068 | 0.737 | ± | 0.039 |
| Ti | 4.57 | ± | 0.83 | 53.6 | ± | 0.37 |
| TI | 0.0169 | ± | 0.0025 | 0.0563 | ± | 0.0012 |
| U | 0.0183 | ± | 0.0021 | 0.167 | ± | 0.0042 |
| V | 0.197 | ± | 0.012 | 8.19 | ± | 0.080 |
| Zn | 6.54 | ± | 1.1 | 24.3 | ± | 0.29 |

Table 4. 48: Heavy metals for sugar beet tailings culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, μg/g dw | | | Final, μg/g dw | | | Liquid, μg/g dw | | | Solid, μg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.104 | ± | 0.0023 | 0.138 | ± | 0.0047 | 0.162 | ± | 0.0029 | 0.0670 | ± | 0.0013 |
| Al | 7070 | ± | 47 | 9670 | ± | 420 | 12600 | ± | 70 | 4390 | ± | 28 |
| As | 1.74 | ± | 0.023 | 2.16 | ± | 0.040 | 2.63 | ± | 0.025 | 1.04 | ± | 0.026 |
| B | 24.8 | ± | 0.34 | 30.0 | ± | 0.42 | 33.0 | ± | 1.0 | 16.1 | ± | 0.20 |
| Ba | 90.2 | ± | 0.51 | 122 | ± | 1.4 | 149 | ± | 2.1 | 59.9 | ± | 0.58 |
| Be | 0.121 | ± | 0.0086 | 0.141 | ± | 0.0076 | 0.202 | ± | 0.011 | 0.0876 | ± | 0.0049 |
| Bi | 0.0319 | ± | 0.00030 | 0.0466 | ± | 0.0013 | 0.0590 | ± | 0.0012 | 0.0227 | ± | 0.00050 |
| Ca | 24800 | ± | 110 | 30700 | ± | 550 | 39500 | ± | 600 | 17200 | ± | 210 |
| Cd | 0.161 | ± | 0.0019 | 0.205 | ± | 0.0031 | 0.247 | ± | 0.0033 | 0.104 | ± | 0.0010 |
| Cl | 14500 | ± | 110 | 5310 | ± | 86 | 13400 | ± | 170 | 2060 | ± | 46 |
| Co | 3.67 | ± | 0.023 | 4.73 | ± | 0.035 | 5.32 | ± | 0.055 | 2.50 | ± | 0.020 |
| Cr | 13.6 | ± | 0.12 | 22.4 | ± | 0.19 | 17.6 | ± | 0.17 | 8.09 | ± | 0.16 |
| Cu | 37.6 | ± | 0.21 | 46.8 | ± | 0.45 | 57.7 | ± | 0.72 | 25.0 | ± | 0.26 |
| Fe | 4890 | ± | 38 | 6140 | ± | 62 | 6860 | ± | 130 | 3580 | ± | 63 |
| Hg | 0.0169 | ± | 0.0012 | 0.0247 | ± | 0.0018 | 0.0269 | ± | 0.0014 | 0.00830 | ± | 0.00040 |
| Li | 5.33 | ± | 0.062 | 6.32 | ± | 0.16 | 7.70 | ± | 0.25 | 2.89 | ± | 0.033 |
| Mg | 8760 | ± | 10 | 8490 | ± | 100 | 11100 | ± | 130 | 5940 | ± | 62 |
| Mn | 287 | ± | 1.2 | 300 | ± | 1.8 | 384 | ± | 5.1 | 169 | ± | 1.8 |
| Mo | 2.46 | ± | 0.018 | 3.23 | ± | 0.036 | 3.88 | ± | 0.063 | 1.70 | ± | 0.023 |
| Na | 8300 | ± | 28 | 11100 | ± | 230 | 13500 | ± | 60 | 2470 | ± | 210 |
| Ni | 11.4 | ± | 0.071 | 17.1 | ± | 0.16 | 16.1 | ± | 0.23 | 6.96 | ± | 0.066 |
| Pb | 2.40 | ± | 0.0062 | 2.86 | ± | 0.022 | 3.71 | ± | 0.035 | 1.78 | ± | 0.011 |
| Sb | 0.0418 | ± | 0.0012 | 0.0429 | ± | 0.0011 | 0.043 | ± | 0.0020 | 0.0229 | ± | 0.00060 |
| Se | 1.01 | ± | 0.044 | 1.27 | ± | 0.045 | 1.37 | ± | 0.041 | 0.749 | ± | 0.021 |
| Sn | 0.134 | ± | 0.0025 | 0.406 | ± | 0.0056 | 0.319 | ± | 0.0034 | 0.152 | ± | 0.0029 |
| Sr | 186 | ± | 0.93 | 200 | ± | 4.0 | 250 | ± | 3.4 | 98.9 | ± | 1.2 |
| Th | 0.884 | ± | 0.0048 | 1.35 | ± | 0.012 | 1.49 | ± | 0.015 | 0.603 | ± | 0.0088 |
| Ti | 260 | ± | 0.57 | 332 | ± | 6.1 | 382 | ± | 13 | 197 | ± | 7.2 |
| TI | 0.0822 | ± | 0.0017 | 0.117 | ± | 0.0017 | 0.146 | ± | 0.0022 | 0.0606 | ± | 0.00040 |
| U | 0.281 | ± | 0.0027 | 0.360 | ± | 0.0049 | 0.443 | ± | 0.0062 | 0.175 | ± | 0.0030 |
| V | 12.2 | ± | 0.049 | 14.9 | ± | 0.25 | 17.8 | ± | 0.24 | 7.81 | ± | 0.10 |
| Zn | 186 | ± | 0.46 | 254 | ± | 4.9 | 323 | ± | 2.8 | 143 | ± | 2.4 |

Table 4. 49: Heavy metals for grocery waste

| Heavy metal | Results given as μg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000271 | ± | 0.00016 | 0.00920 | ± | 0.00025 |
| Al | 1.18 | ± | 0.17 | 21.5 | ± | 0.25 |
| As | 0.0159 | ± | 0.0013 | 0.0262 | ± | 0.0032 |
| B | 18.0 | ± | 0.20 | 22.1 | ± | 0.41 |
| Ba | 1.26 | ± | 0.014 | 4.34 | ± | 0.045 |
| Be | BD | ± | | BD | ± | |
| Bi | 0.000183 | ± | | 0.00302 | ± | 0.00015 |
| Ca | 726 | ± | 2.3 | 1650 | ± | 13 |
| Cd | 0.0225 | ± | 0.00081 | 0.0631 | ± | 0.0010 |
| Cl | 1750 | ± | 19 | 8120 | ± | 320 |
| Co | 0.0347 | ± | 0.0015 | 0.0787 | ± | 0.0022 |
| Cr | 0.220 | ± | 0.0064 | 2.64 | ± | 0.037 |
| Cu | 2.54 | ± | 0.020 | 6.86 | ± | 0.044 |
| Fe | 1.08 | ± | 0.60 | 45.0 | ± | 0.26 |
| Hg | BD | ± | | BD | ± | |
| Li | 0.167 | ± | 0.011 | 0.313 | ± | 0.011 |
| Mg | 516 | ± | 5.8 | 818 | ± | 4.2 |
| Mn | 5.78 | ± | 0.012 | 11.4 | ± | 0.090 |
| Mo | 0.138 | ± | 0.0027 | 0.294 | ± | 0.0037 |
| Na | 460 | ± | 13 | 660 | ± | 3.5 |
| Ni | 0.872 | ± | 0.0076 | 1.80 | ± | 0.034 |
| Pb | 0.00324 | ± | 0.00041 | 0.0365 | ± | 0.00048 |
| Sb | 0.000953 | ± | 0.00028 | 0.00359 | ± | 0.00043 |
| Se | 0.0650 | ± | 0.0031 | BD | ± | |
| Sn | BD | ± | | BD | ± | |
| Sr | 4.38 | ± | 0.012 | 12.1 | ± | 0.065 |
| Th | 0.000189 | ± | | 0.00483 | ± | 0.00010 |
| Ti | 4.82 | ± | 0.16 | 7.08 | ± | 0.12 |
| TI | 0.00405 | ± | 0.000042 | 0.00641 | ± | 0.00041 |
| U | 0.000273 | ± | 0.000025 | 0.00653 | ± | 0.00012 |
| V | 0.0180 | ± | 0.00073 | 0.0787 | ± | 0.0057 |
| Zn | 7.27 | ± | 0.16 | 10.3 | ± | 0.025 |

Table 4. 50: Heavy metals for grocery waste culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0901 | ± | 0.0047 | 0.100 | ± | 0.0039 | 0.154 | ± | 0.0043 | 0.0823 | ± | 0.0014 |
| Al | 6530 | ± | 26 | 6400 | ± | 37 | 11200 | ± | 79 | 4780 | ± | 54 |
| As | 1.69 | ± | 0.044 | 1.98 | ± | 0.026 | 2.67 | ± | 0.021 | 1.02 | ± | 0.013 |
| B | 24.6 | ± | 0.96 | 28.8 | ± | 0.52 | 34.5 | ± | 0.70 | 16.5 | ± | 0.40 |
| Ba | 97.8 | ± | 1.5 | 92.8 | ± | 0.88 | 133 | ± | 1.9 | 61.1 | ± | 0.64 |
| Be | 0.126 | ± | 0.0037 | 0.136 | ± | 0.0067 | 0.168 | ± | 0.0066 | 0.0856 | ± | 0.0044 |
| Bi | 0.0607 | ± | 0.0035 | 0.0404 | ± | 0.00054 | 0.0508 | ± | 0.00073 | 0.0243 | ± | 0.00046 |
| Ca | 25300 | ± | 261 | 30100 | ± | 320 | 35300 | ± | 360 | 17400 | ± | 220 |
| Cd | 0.164 | ± | 0.0027 | 0.168 | ± | 0.0032 | 0.216 | ± | 0.0010 | 0.0929 | ± | 0.0014 |
| Cl | 7860 | ± | 350 | 39100 | ± | 950 | 24500 | ± | 470 | 12500 | ± | 310 |
| Co | 3.88 | ± | 0.065 | 4.30 | ± | 0.029 | 5.38 | ± | 0.044 | 2.56 | ± | 0.019 |
| Cr | 11.4 | ± | 0.12 | 13.5 | ± | 0.18 | 19.9 | ± | 0.13 | 7.28 | ± | 0.099 |
| Cu | 43.6 | ± | 0.58 | 46.6 | ± | 0.35 | 57.9 | ± | 0.54 | 28.1 | ± | 0.41 |
| Fe | 4400 | ± | 50 | 4920 | ± | 47 | 6850 | ± | 71 | 3720 | ± | 32 |
| Hg | 0.0175 | ± | 0.0010 | 0.0228 | ± | 0.00074 | 0.0281 | ± | 0.0017 | 0.0142 | ± | 0.0011 |
| Li | 4.90 | ± | 0.13 | 5.37 | ± | 0.035 | 6.53 | ± | 0.14 | 2.68 | ± | 0.065 |
| Mg | 6930 | ± | 89 | 8640 | ± | 54 | 9870 | ± | 88 | 7300 | ± | 85 |
| Mn | 235 | ± | 1.9 | 277 | ± | 2.1 | 371 | ± | 2.8 | 172 | ± | 0.95 |
| Mo | 2.80 | ± | 0.033 | 2.88 | ± | 0.038 | 4.00 | ± | 0.029 | 1.72 | ± | 0.017 |
| Na | 8600 | ± | 98 | 11100 | ± | 99 | 15000 | ± | 210 | 2350 | ± | 35 |
| Ni | 11.7 | ± | 0.16 | 13.3 | ± | 0.071 | 17.6 | ± | 0.19 | 6.30 | ± | 0.11 |
| Pb | 2.30 | ± | 0.014 | 2.75 | ± | 0.020 | 3.53 | ± | 0.018 | 2.07 | ± | 0.011 |
| Sb | 0.0355 | ± | 0.0011 | 0.0331 | ± | 0.00080 | 0.0396 | ± | 0.0013 | 0.0258 | ± | 0.00042 |
| Se | 0.944 | ± | 0.065 | 0.976 | ± | 0.083 | 1.60 | ± | 0.061 | 0.740 | ± | 0.043 |
| Sn | 0.219 | ± | 0.0025 | 0.110 | ± | 0.0024 | 0.192 | ± | 0.0029 | 0.0721 | ± | 0.0018 |
| Sr | 165 | ± | 2.1 | 191 | ± | 2.0 | 253 | ± | 3.9 | 116 | ± | 2.0 |
| Th | 1.02 | ± | 0.014 | 0.778 | ± | 0.0069 | 1.22 | ± | 0.016 | 0.505 | ± | 0.0040 |
| Ti | 260 | ± | 5.4 | 247 | ± | 2.3 | 359 | ± | 4.1 | 210 | ± | 4.0 |
| TI | 0.0964 | ± | 0.00086 | 0.0834 | ± | 0.0016 | 0.118 | ± | 0.0018 | 0.0624 | ± | 0.00071 |
| U | 0.298 | ± | 0.0040 | 0.346 | ± | 0.0036 | 0.445 | ± | 0.0069 | 0.191 | ± | 0.0022 |
| V | 11.2 | ± | 0.14 | 12.2 | ± | 0.12 | 17.4 | ± | 0.20 | 8.63 | ± | 0.13 |
| Zn | 217 | ± | 2.0 | 269 | ± | 4.0 | 371 | ± | 3.0 | 188 | ± | 2.6 |

Table 4. 51: Heavy metals for thermally hydrolyzed biowaste (#1)

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000212 | ± | 0.000037 | 0.0111 | ± | 0.00040 |
| Al | 0.117 | ± | 0.0034 | 251 | ± | 79 |
| As | 0.262 | ± | 0.0063 | 0.555 | ± | 0.0061 |
| B | 2.34 | ± | 0.012 | 3.75 | ± | 0.13 |
| Ba | 0.351 | ± | 0.012 | 57.2 | ± | 0.24 |
| Be | BD | ± | | 0.00454 | ± | 0.0013 |
| Bi | 0.000200 | ± | 0.000033 | 0.0561 | ± | 0.0010 |
| Ca | 219 | ± | 0.30 | 52300 | ± | 220 |
| Cd | 0.000573 | ± | 0.00013 | 0.0772 | ± | 0.0016 |
| Cl | 3650 | ± | 51 | 13700 | ± | 250 |
| Co | 0.0768 | ± | 0.0018 | 0.353 | ± | 0.0057 |
| Cr | 0.319 | ± | 0.012 | 4.48 | ± | 0.015 |
| Cu | 0.160 | ± | 0.0084 | 24.5 | ± | 0.19 |
| Fe | 210 | ± | 6.1 | 5720 | ± | 22 |
| Hg | 0.000671 | ± | 0.00011 | 0.0027 | ± | 0.00075 |
| Li | 0.156 | ± | 0.0057 | 0.644 | ± | 0.011 |
| Mg | 548 | ± | 5.1 | 1280 | ± | 2.5 |
| Mn | 0.483 | ± | 0.0014 | 75.4 | ± | 0.15 |
| Mo | 0.188 | ± | 0.011 | 1.03 | ± | 0.0065 |
| Na | 4130 | ± | 41 | 4740 | ± | 13 |
| Ni | 0.470 | ± | 0.0090 | 2.39 | ± | 0.034 |
| Pb | 0.00108 | ± | 0.00012 | 2.23 | ± | 0.0076 |
| Sb | 0.00667 | ± | 0.00021 | 0.288 | ± | 0.019 |
| Se | 0.255 | ± | 0.0062 | 0.265 | ± | 0.030 |
| Sn | 0.00507 | ± | 0.00066 | 0.207 | ± | 0.0074 |
| Sr | 0.199 | ± | 0.00059 | 49.5 | ± | 0.27 |
| Th | 0.000121 | ± | 0.0000090 | 0.0282 | ± | 0.00024 |
| Ti | 1.83 | ± | 0.036 | 101 | ± | 0.99 |
| TI | 0.0000963 | ± | 0.000026 | 0.00420 | ± | 0.00035 |
| U | 0.000196 | ± | 0.000015 | 0.0385 | ± | 0.00025 |
| V | 0.0604 | ± | 0.0029 | 0.576 | ± | 0.0048 |
| Zn | 1.29 | ± | 0.030 | 60.8 | ± | 0.27 |

Table 4. 52: Heavy metals for thermally hydrolyzed biowaste (#1) culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0994 | ± | 0.0053 | 0.0908 | ± | 0.0041 | 0.180 | ± | 0.0033 | 0.0575 | ± | 0.0024 |
| Al | 6720 | ± | 47 | 5740 | ± | 31 | 11000 | ± | 110 | 3300 | ± | 28 |
| As | 1.68 | ± | 0.023 | 1.90 | ± | 0.026 | 2.56 | ± | 0.026 | 0.955 | ± | 0.0081 |
| B | 23.5 | ± | 0.43 | 24.7 | ± | 0.64 | 29.2 | ± | 0.78 | 13.9 | ± | 0.32 |
| Ba | 99.2 | ± | 2.2 | 93.6 | ± | 0.77 | 129 | ± | 2.2 | 60.6 | ± | 0.72 |
| Be | 0.137 | ± | 0.016 | 0.123 | ± | 0.013 | 0.152 | ± | 0.0049 | 0.0625 | ± | 0.0044 |
| Bi | 0.0473 | ± | 0.0012 | 0.0432 | ± | 0.00067 | 0.0588 | ± | 0.0013 | 0.0263 | ± | 0.00066 |
| Ca | 30600 | ± | 330 | 33400 | ± | 430 | 37700 | ± | 430 | 21500 | ± | 160 |
| Cd | 0.153 | ± | 0.0017 | 0.152 | ± | 0.0048 | 0.205 | ± | 0.0014 | 0.0807 | ± | 0.0020 |
| Cl | 13000 | ± | 180 | 39300 | ± | 770 | 22800 | ± | 180 | 16600 | ± | 210 |
| Co | 3.72 | ± | 0.079 | 4.19 | ± | 0.056 | 5.38 | ± | 0.056 | 2.36 | ± | 0.022 |
| Cr | 11.3 | ± | 0.098 | 12.2 | ± | 0.076 | 17.0 | ± | 0.19 | 5.89 | ± | 0.070 |
| Cu | 43.9 | ± | 0.97 | 46.7 | ± | 0.49 | 58.2 | ± | 0.62 | 27.6 | ± | 0.23 |
| Fe | 5230 | ± | 76 | 5020 | ± | 36 | 7190 | ± | 66 | 3680 | ± | 18 |
| Hg | 0.0184 | ± | 0.00095 | 0.0212 | ± | 0.0014 | 0.0260 | ± | 0.0010 | 0.0125 | ± | 0.00082 |
| Li | 5.03 | ± | 0.085 | 5.19 | ± | 0.11 | 6.02 | ± | 0.22 | 2.13 | ± | 0.039 |
| Mg | 7290 | ± | 65 | 8270 | ± | 70 | 9550 | ± | 110 | 5270 | ± | 30 |
| Mn | 249 | ± | 3.1 | 266 | ± | 1.2 | 366 | ± | 1.3 | 161 | ± | 0.75 |
| Mo | 2.77 | ± | 0.067 | 2.88 | ± | 0.045 | 3.97 | ± | 0.040 | 1.66 | ± | 0.015 |
| Na | 9350 | ± | 83 | 11300 | ± | 140 | 15100 | ± | 270 | 2400 | ± | 25 |
| Ni | 11.4 | ± | 0.27 | 12.4 | ± | 0.15 | 16.0 | ± | 0.24 | 5.85 | ± | 0.073 |
| Pb | 2.54 | ± | 0.018 | 2.73 | ± | 0.022 | 3.52 | ± | 0.018 | 1.72 | ± | 0.012 |
| Sb | 0.0423 | ± | 0.00047 | 0.0404 | ± | 0.0044 | 0.0552 | ± | 0.0013 | 0.0253 | ± | 0.00049 |
| Se | 1.01 | ± | 0.028 | 1.03 | ± | 0.035 | 1.51 | ± | 0.053 | 0.654 | ± | 0.057 |
| Sn | 0.258 | ± | 0.0069 | 0.108 | ± | 0.0040 | 0.294 | ± | 0.0028 | 0.0179 | ± | 0.00035 |
| Sr | 168 | ± | 3.2 | 181 | ± | 2.5 | 242 | ± | 4.0 | 116 | ± | 1.5 |
| Th | 1.01 | ± | 0.022 | 0.755 | ± | 0.0097 | 1.35 | ± | 0.0083 | 0.313 | ± | 0.0037 |
| Ti | 295 | ± | 34 | 238 | ± | 3.5 | 364 | ± | 7.3 | 152 | ± | 2.8 |
| TI | 0.0855 | ± | 0.0020 | 0.0757 | ± | 0.00069 | 0.108 | ± | 0.0022 | 0.0504 | ± | 0.0010 |
| U | 0.281 | ± | 0.0078 | 0.321 | ± | 0.0036 | 0.415 | ± | 0.0055 | 0.170 | ± | 0.0021 |
| V | 11.0 | ± | 0.082 | 11.3 | ± | 0.15 | 16.7 | ± | 0.20 | 6.52 | ± | 0.043 |
| Zn | 238 | ± | 3.4 | 262 | ± | 2.8 | 383 | ± | 7.0 | 165 | ± | 2.0 |

Table 4. 53: Heavy metals for thermally hydrolyzed biowaste (#2)

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000137 | ± | 0.000047 | 0.00923 | ± | 0.00080 |
| Al | 0.379 | ± | 0.032 | 146 | ± | 0.64 |
| As | 0.457 | ± | 0.0052 | 0.677 | ± | 0.011 |
| B | 2.35 | ± | 0.017 | 3.27 | ± | 0.18 |
| Ba | 0.311 | ± | 0.036 | 29.4 | ± | 0.20 |
| Be | 0.000172 | ± | | 0.00566 | ± | 0.0040 |
| Bi | 0.000895 | ± | 0.00025 | 0.834 | ± | 0.0065 |
| Ca | 565 | ± | 75 | 57900 | ± | 210 |
| Cd | 0.00105 | ± | 0.000043 | 0.0292 | ± | 0.0014 |
| Cl | 4640 | ± | 52 | 23300 | ± | 520 |
| Co | 0.170 | ± | 0.00071 | 0.520 | ± | 0.0046 |
| Cr | 1.84 | ± | 0.012 | 6.01 | ± | 0.0032 |
| Cu | 0.0368 | ± | 0.0014 | 14.3 | ± | 0.097 |
| Fe | 929 | ± | 42 | 7750 | ± | 39 |
| Hg | 0.00116 | ± | 0.00021 | 0.00989 | ± | 0.0011 |
| Li | 0.0319 | ± | 0.0024 | 0.270 | ± | 0.0088 |
| Mg | 431 | ± | 3.4 | 1470 | ± | 4.7 |
| Mn | 1.82 | ± | 0.13 | 82.1 | ± | 0.30 |
| Mo | 0.489 | ± | 0.0090 | 1.11 | ± | 0.0061 |
| Na | 6200 | ± | 190 | 6750 | ± | 24 |
| Ni | 1.15 | ± | 0.0039 | 2.94 | ± | 0.044 |
| Pb | 0.00305 | ± | 0.000085 | 2.83 | ± | 0.0096 |
| Sb | 0.147 | ± | 0.0011 | 0.725 | ± | 0.0042 |
| Se | 0.287 | ± | 0.0049 | 0.180 | ± | 0.049 |
| Sn | 0.00400 | ± | 0.000039 | 0.272 | ± | 0.0027 |
| Sr | 0.535 | ± | 0.067 | 44.9 | ± | 0.27 |
| Th | 0.000998 | ± | 0.00016 | 0.0296 | ± | 0.00057 |
| Ti | 1.52 | ± | 0.17 | 105 | ± | 1.3 |
| TI | 0.0000710 | ± | 0.000034 | 0.00359 | ± | 0.00022 |
| U | 0.000741 | ± | 0.000095 | 0.0409 | ± | 0.00043 |
| V | 0.229 | ± | 0.0033 | 0.625 | ± | 0.0041 |
| Zn | 9.60 | ± | 0.20 | 86.0 | ± | 0.48 |

Table 4. 54: Heavy metals for thermally hydrolyzed biowaste (#2) culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.111 | ± | 0.0029 | 0.125 | ± | 0.0049 | 0.136 | ± | 0.0041 | 0.0539 | ± | 0.0013 |
| Al | 6830 | ± | 76 | 7170 | ± | 43 | 10100 | ± | 86 | 2860 | ± | 12 |
| As | 1.72 | ± | 0.024 | 2.02 | ± | 0.023 | 2.56 | ± | 0.019 | 1.05 | ± | 0.0094 |
| B | 23.8 | ± | 0.75 | 25.6 | ± | 0.39 | 30.4 | ± | 0.84 | 15.0 | ± | 0.29 |
| Ba | 96.9 | ± | 2.5 | 97.2 | ± | 0.85 | 125 | ± | 1.7 | 51.1 | ± | 0.65 |
| Be | 0.125 | ± | 0.0099 | 0.118 | ± | 0.0062 | 0.165 | ± | 0.0048 | 0.0707 | ± | 0.0068 |
| Bi | 0.123 | ± | 0.0035 | 0.125 | ± | 0.0011 | 0.160 | ± | 0.0022 | 0.0602 | ± | 0.0011 |
| Ca | 29500 | ± | 550 | 35400 | ± | 440 | 40600 | ± | 470 | 18100 | ± | 230 |
| Cd | 0.144 | ± | 0.0034 | 0.155 | ± | 0.0022 | 0.189 | ± | 0.0047 | 0.0857 | ± | 0.0022 |
| Cl | 6380 | ± | 200 | 17900 | ± | 180 | 33100 | ± | 660 | 19200 | ± | 200 |
| Co | 4.02 | ± | 0.094 | 4.22 | ± | 0.032 | 5.31 | ± | 0.027 | 2.54 | ± | 0.025 |
| Cr | 13.0 | ± | 0.18 | 14.6 | ± | 0.057 | 23.9 | ± | 0.29 | 5.49 | ± | 0.055 |
| Cu | 42.9 | ± | 1.0 | 46.1 | ± | 0.45 | 55.8 | ± | 0.60 | 27.0 | ± | 0.35 |
| Fe | 5290 | ± | 62 | 5770 | ± | 34 | 7580 | ± | 91 | 3340 | ± | 43 |
| Hg | 0.0159 | ± | 0.0014 | 0.0223 | ± | 0.0016 | 0.0271 | ± | 0.0011 | 0.0138 | ± | 0.0010 |
| Li | 5.31 | ± | 0.18 | 5.33 | ± | 0.056 | 6.31 | ± | 0.17 | 2.37 | ± | 0.061 |
| Mg | 6900 | ± | 84 | 8720 | ± | 61 | 9890 | ± | 110 | 5270 | ± | 49 |
| Mn | 250 | ± | 2.8 | 275 | ± | 1.6 | 373 | ± | 1.2 | 156 | ± | 1.2 |
| Mo | 2.86 | ± | 0.065 | 2.99 | ± | 0.026 | 3.64 | ± | 0.040 | 1.69 | ± | 0.018 |
| Na | 9660 | ± | 130 | 11100 | ± | 95 | 14800 | ± | 180 | 2800 | ± | 31 |
| Ni | 12.6 | ± | 0.33 | 13.0 | ± | 0.11 | 18.4 | ± | 0.13 | 6.30 | ± | 0.072 |
| Pb | 4.38 | ± | 0.031 | 2.93 | ± | 0.022 | 3.69 | ± | 0.035 | 1.71 | ± | 0.012 |
| Sb | 0.0531 | ± | 0.00051 | 0.0605 | ± | 0.0013 | 0.0581 | ± | 0.00076 | 0.0292 | ± | 0.00056 |
| Se | 0.932 | ± | 0.56 | 1.19 | ± | 0.026 | 1.35 | ± | 0.085 | 0.757 | ± | 0.037 |
| Sn | 0.265 | ± | 0.0044 | 0.218 | ± | 0.0038 | 0.124 | ± | 0.0016 | 0.0110 | ± | 0.0012 |
| Sr | 173 | ± | 3.1 | 191 | ± | 1.6 | 248 | ± | 3.1 | 106 | ± | 1.5 |
| Th | 1.02 | ± | 0.030 | 1.04 | ± | 0.0083 | 1.01 | ± | 0.014 | 0.300 | ± | 0.0027 |
| Ti | 277 | ± | 3.3 | 312 | ± | 2.9 | 327 | ± | 5.5 | 128 | ± | 2.9 |
| TI | 0.0896 | ± | 0.0023 | 0.0880 | ± | 0.0010 | 0.108 | ± | 0.0026 | 0.0479 | ± | 0.0013 |
| U | 0.284 | ± | 0.0077 | 0.343 | ± | 0.0030 | 0.402 | ± | 0.0070 | 0.167 | ± | 0.0021 |
| V | 11.1 | ± | 0.17 | 13.4 | ± | 0.13 | 15.6 | ± | 0.17 | 6.18 | ± | 0.080 |
| Zn | 234 | ± | 3.4 | 271 | ± | 3.6 | 371 | ± | 4.5 | 170 | ± | 2.6 |

Table 4. 55: Heavy metals for thin stillage

| Heavy metal | Results given as μg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000233 | ± | 0.000021 | 0.00546 | ± | 0.00019 |
| Al | 0.821 | ± | 0.024 | 35.6 | ± | 0.41 |
| As | 0.138 | ± | 0.0027 | 0.133 | ± | 0.0088 |
| B | 7.35 | ± | 0.053 | 8.58 | ± | 0.17 |
| Ba | 4.30 | ± | 0.023 | 5.08 | ± | 0.025 |
| Be | BD | ± | | 0.00204 | ± | 0.0014 |
| Bi | 0.0000729 | ± | | 0.000810 | ± | 0.00010 |
| Ca | 1300 | ± | 6.0 | 2460 | ± | 14 |
| Cd | 0.0353 | ± | 0.00070 | 0.0480 | ± | 0.00076 |
| Cl | 2190 | ± | 12 | 12900 | ± | 320 |
| Co | 0.0230 | ± | 0.00053 | 0.0438 | ± | 0.0021 |
| Cr | 0.167 | ± | 0.0044 | 1.20 | ± | 0.029 |
| Cu | 3.06 | ± | 0.035 | 10.1 | ± | 0.097 |
| Fe | 18.5 | ± | 0.10 | 210 | ± | 0.82 |
| Hg | 0.00141 | ± | 0.0012 | 0.00372 | ± | 0.0015 |
| Li | 1.08 | ± | 0.036 | 1.14 | ± | 0.014 |
| Mg | 4880 | ± | 12 | 4480 | ± | 30 |
| Mn | 96.5 | ± | 0.64 | 101 | ± | 0.32 |
| Mo | 1.04 | ± | 0.0040 | 1.95 | ± | 0.022 |
| Na | 3280 | ± | 20 | 3240 | ± | 28 |
| Ni | 0.263 | ± | 0.0050 | 0.668 | ± | 0.010 |
| Pb | 0.00455 | ± | 0.00043 | 0.0274 | ± | 0.00028 |
| Sb | 0.00111 | ± | 0.00017 | 0.00178 | ± | 0.00023 |
| Se | 0.141 | ± | 0.010 | 0.298 | ± | 0.027 |
| Sn | BD | ± | | 0.00500 | ± | 0.00045 |
| Sr | 13.2 | ± | 0.072 | 15.4 | ± | 0.089 |
| Th | 0.00102 | ± | 0.00042 | 0.00780 | ± | 0.00019 |
| Ti | 25.8 | ± | 0.50 | 29.6 | ± | 0.25 |
| TI | 0.000457 | ± | 0.00010 | 0.00151 | ± | 0.00010 |
| U | 0.000275 | ± | 0.000054 | 0.0120 | ± | 0.00010 |
| V | 0.0203 | ± | 0.00081 | 0.130 | ± | 0.0065 |
| Zn | 78.5 | ± | 0.31 | 74.6 | ± | 0.37 |

Table 4. 56: Heavy metals for thin stillage culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy Metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, μg/g dw | | | Final, μg/g dw | | | Liquid, μg/g dw | | | Solid, μg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0830 | ± | 0.0037 | 0.0567 | ± | 0.00044 | 0.0694 | ± | 0.00033 | 0.0350 | ± | 0.00064 |
| Al | 5590 | ± | 36 | 6410 | ± | 200 | 7070 | ± | 230 | 2910 | ± | 43 |
| As | 1.85 | ± | 0.016 | 1.80 | ± | 0.015 | 2.20 | ± | 0.055 | 1.08 | ± | 0.015 |
| B | 23.3 | ± | 0.41 | 23.1 | ± | 0.58 | 26.0 | ± | 0.84 | 17.0 | ± | 0.71 |
| Ba | 87.2 | ± | 1.2 | 84.3 | ± | 1.3 | 101 | ± | 1.5 | 53.6 | ± | 0.63 |
| Be | 0.116 | ± | 0.012 | 0.114 | ± | 0.0059 | 0.138 | ± | 0.0069 | 0.0768 | ± | 0.0040 |
| Bi | 0.0484 | ± | 0.0016 | 0.0340 | ± | 0.00074 | 0.0414 | ± | 0.00077 | 0.0226 | ± | 0.00055 |
| Ca | 25900 | ± | 210 | 25600 | ± | 450 | 30700 | ± | 710 | 17500 | ± | 290 |
| Cd | 0.146 | ± | 0.0022 | 0.145 | ± | 0.0033 | 0.177 | ± | 0.0020 | 0.0861 | ± | 0.0023 |
| Cl | 26300 | ± | 840 | 19600 | ± | 360 | 37100 | ± | 820 | 10100 | ± | 450 |
| Co | 4.08 | ± | 0.034 | 3.74 | ± | 0.034 | 4.27 | ± | 0.045 | 2.51 | ± | 0.018 |
| Cr | 12.2 | ± | 0.11 | 12.1 | ± | 0.088 | 14.8 | ± | 0.26 | 7.71 | ± | 0.087 |
| Cu | 42.6 | ± | 0.39 | 40.8 | ± | 0.68 | 48.4 | ± | 1.3 | 27.4 | ± | 0.41 |
| Fe | 4480 | ± | 61 | 4460 | ± | 150 | 4930 | ± | 220 | 2660 | ± | 76 |
| Hg | 0.0293 | ± | 0.0024 | 0.0168 | ± | 0.00060 | 0.0235 | ± | 0.0019 | 0.0142 | ± | 0.00095 |
| Li | 5.14 | ± | 0.16 | 5.25 | ± | 0.081 | 6.43 | ± | 0.13 | 2.78 | ± | 0.082 |
| Mg | 7860 | ± | 65 | 7210 | ± | 89 | 8430 | ± | 150 | 6300 | ± | 73 |
| Mn | 267 | ± | 1.4 | 298 | ± | 8.3 | 354 | ± | 14 | 164 | ± | 2.9 |
| Mo | 2.73 | ± | 0.015 | 2.54 | ± | 0.020 | 2.93 | ± | 0.067 | 1.72 | ± | 0.023 |
| Na | 9550 | ± | 110 | 9310 | ± | 380 | 12000 | ± | 400 | 2300 | ± | 51 |
| Ni | 12.0 | ± | 0.11 | 11.3 | ± | 0.19 | 13.7 | ± | 0.16 | 5.80 | ± | 0.083 |
| Pb | 2.49 | ± | 0.014 | 2.50 | ± | 0.016 | 3.05 | ± | 0.045 | 1.62 | ± | 0.0078 |
| Sb | 0.0261 | ± | 0.00044 | 0.0242 | ± | 0.00054 | 0.0235 | ± | 0.00084 | 0.0272 | ± | 0.0010 |
| Se | 1.23 | ± | 0.049 | 1.25 | ± | 0.040 | 1.34 | ± | 0.052 | 0.959 | ± | 0.035 |
| Sn | 0.0287 | ± | 0.0012 | 0.0599 | ± | 0.00081 | 0.0713 | ± | 0.0017 | 0.0469 | ± | 0.00053 |
| Sr | 179 | ± | 3.8 | 179 | ± | 2.5 | 216 | ± | 4.8 | 118 | ± | 2.0 |
| Th | 0.488 | ± | 0.0029 | 0.700 | ± | 0.0065 | 0.814 | ± | 0.014 | 0.337 | ± | 0.0029 |
| Ti | 192 | ± | 3.3 | 204 | ± | 3.1 | 201 | ± | 5.3 | 149 | ± | 12 |
| TI | 0.0752 | ± | 0.0010 | 0.0729 | ± | 0.0020 | 0.0872 | ± | 0.0018 | 0.0488 | ± | 0.0014 |
| U | 0.287 | ± | 0.0022 | 0.303 | ± | 0.0034 | 0.365 | ± | 0.0061 | 0.188 | ± | 0.0022 |
| V | 10.9 | ± | 0.10 | 10.6 | ± | 0.18 | 11.8 | ± | 0.27 | 6.43 | ± | 0.075 |
| Zn | 267 | ± | 3.4 | 277 | ± | 12 | 309 | ± | 11 | 149 | ± | 1.9 |

Table 4. 57: Heavy metals for glycerine with methanol

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000420 | ± | 0.00010 | 0.00517 | ± | 0.00067 |
| Al | 0.265 | ± | 0.052 | 2.86 | ± | 0.052 |
| As | 0.00487 | ± | | 0.0118 | ± | 0.0024 |
| B | BD | ± | | 0.559 | ± | 0.083 |
| Ba | 0.138 | ± | 0.0022 | 0.446 | ± | 0.017 |
| Be | BD | ± | | BD | ± | |
| Bi | 0.00288 | ± | 0.0018 | 0.00464 | ± | 0.00041 |
| Ca | 39.2 | ± | 6.2 | 189 | ± | 3.6 |
| Cd | 0.00251 | ± | 0.00015 | 0.00540 | ± | 0.0012 |
| Cl | BD | ± | | 2430 | ± | 280 |
| Co | 0.00127 | ± | 0.00024 | 0.00304 | ± | 0.00077 |
| Cr | 0.458 | ± | 0.023 | 0.371 | ± | 0.013 |
| Cu | 0.0612 | ± | 0.012 | 0.172 | ± | 0.0031 |
| Fe | 6.52 | ± | 0.39 | 11.8 | ± | 0.55 |
| Hg | BD | ± | | BD | ± | |
| Li | BD | ± | | 0.0138 | ± | 0.0031 |
| Mg | 126 | ± | 1.3 | 138 | ± | 1.5 |
| Mn | 1.65 | ± | 0.032 | 2.20 | ± | 0.023 |
| Mo | 0.00595 | ± | 0.0017 | 0.0187 | ± | 0.00039 |
| Na | 213 | ± | 2.0 | 213 | ± | 3.1 |
| Ni | 0.0454 | ± | 0.0015 | 0.125 | ± | 0.0056 |
| Pb | 0.0192 | ± | 0.0023 | 0.0449 | ± | 0.0011 |
| Sb | 0.00119 | ± | 0.00014 | 0.00352 | ± | 0.00037 |
| Se | 0.0130 | ± | 0.0031 | 0.0406 | ± | 0.030 |
| Sn | 0.00110 | ± | 0.00012 | 0.0118 | ± | 0.00023 |
| Sr | 0.268 | ± | 0.0052 | 0.438 | ± | 0.0097 |
| Th | 0.104 | ± | 0.042 | 0.00686 | ± | 0.00048 |
| Ti | 1.72 | ± | 0.011 | 1.40 | ± | 0.032 |
| TI | 0.00447 | ± | 0.00078 | 0.00451 | ± | 0.00058 |
| U | 0.00250 | ± | 0.00036 | 0.00438 | ± | 0.00047 |
| V | 0.0660 | ± | 0.00074 | 0.0780 | ± | 0.0031 |
| Zn | 2.78 | ± | 0.48 | 3.63 | ± | 0.041 |

Table 4. 58: Heavy metals for glycerine with methanol culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0436 | ± | 0.0011 | 0.0871 | ± | 0.00064 | 0.0953 | ± | 0.0038 | 0.0505 | ± | 0.0013 |
| Al | 6450 | ± | 120 | 8030 | ± | 31 | 8790 | ± | 16 | 4620 | ± | 49 |
| As | 1.67 | ± | 0.027 | 1.99 | ± | 0.038 | 2.44 | ± | 0.026 | 1.07 | ± | 0.0093 |
| B | 24.0 | ± | 0.73 | 26.8 | ± | 0.68 | 30.8 | ± | 0.20 | 14.8 | ± | 0.27 |
| Ba | 88.1 | ± | 0.87 | 101 | ± | 0.88 | 121 | ± | 0.25 | 56.5 | ± | 0.17 |
| Be | 0.125 | ± | 0.011 | 0.135 | ± | 0.011 | 0.137 | ± | 0.0065 | 0.0852 | ± | 0.0055 |
| Bi | 0.0372 | ± | 0.00052 | 0.0375 | ± | 0.00076 | 0.0439 | ± | 0.00094 | 0.0222 | ± | 0.00056 |
| Ca | 21900 | ± | 380 | 28300 | ± | 220 | 33800 | ± | 85 | 16700 | ± | 64 |
| Cd | 0.129 | ± | 0.0025 | 0.158 | ± | 0.0033 | 0.179 | ± | 0.0031 | 0.0898 | ± | 0.0026 |
| Cl | 16400 | ± | 240 | 13700 | ± | 120 | 29600 | ± | 730 | 8260 | ± | 220 |
| Co | 3.86 | ± | 0.038 | 4.32 | ± | 0.036 | 5.09 | ± | 0.041 | 2.60 | ± | 0.0070 |
| Cr | 14.1 | ± | 0.16 | 14.0 | ± | 0.17 | 14.1 | ± | 0.059 | 5.96 | ± | 0.061 |
| Cu | 43.6 | ± | 0.39 | 47.5 | ± | 0.36 | 51.9 | ± | 0.15 | 26.4 | ± | 0.075 |
| Fe | 4660 | ± | 55 | 5370 | ± | 35 | 5810 | ± | 40 | 3390 | ± | 67 |
| Hg | 0.0255 | ± | 0.0011 | 0.0219 | ± | 0.0011 | 0.0280 | ± | 0.0013 | 0.0126 | ± | 0.00022 |
| Li | 5.72 | ± | 0.21 | 5.86 | ± | 0.097 | 7.55 | ± | 0.050 | 2.85 | ± | 0.038 |
| Mg | 8020 | ± | 140 | 9770 | ± | 70 | 11800 | ± | 46 | 6220 | ± | 16 |
| Mn | 244 | ± | 2.7 | 330 | ± | 3.0 | 395 | ± | 2.8 | 155 | ± | 0.61 |
| Mo | 2.57 | ± | 0.019 | 2.93 | ± | 0.041 | 3.44 | ± | 0.021 | 1.67 | ± | 0.015 |
| Na | 10500 | ± | 210 | 9480 | ± | 80 | 13400 | ± | 50 | 2700 | ± | 3.0 |
| Ni | 12.5 | ± | 0.15 | 12.9 | ± | 0.094 | 15.1 | ± | 0.091 | 6.30 | ± | 0.059 |
| Pb | 2.73 | ± | 0.036 | 2.95 | ± | 0.021 | 3.30 | ± | 0.014 | 1.65 | ± | 0.0016 |
| Sb | 0.0305 | ± | 0.0013 | 0.0455 | ± | 0.0015 | 0.0431 | ± | 0.0021 | 0.0305 | ± | 0.0015 |
| Se | 1.02 | ± | 0.060 | 1.23 | ± | 0.065 | 1.31 | ± | 0.064 | 0.818 | ± | 0.053 |
| Sn | 0.101 | ± | 0.0022 | 0.141 | ± | 0.0057 | 0.114 | ± | 0.0022 | 0.0931 | ± | 0.0024 |
| Sr | 172 | ± | 1.1 | 225 | ± | 1.7 | 274 | ± | 0.73 | 128 | ± | 0.51 |
| Th | 0.872 | ± | 0.011 | 0.926 | ± | 0.013 | 0.889 | ± | 0.0058 | 0.507 | ± | 0.0027 |
| Ti | 234 | ± | 6.2 | 305 | ± | 2.6 | 340 | ± | 1.5 | 206 | ± | 0.89 |
| TI | 0.0697 | ± | 0.00062 | 0.0903 | ± | 0.0015 | 0.105 | ± | 0.0010 | 0.0565 | ± | 0.0013 |
| U | 0.290 | ± | 0.0037 | 0.324 | ± | 0.0035 | 0.391 | ± | 0.0011 | 0.185 | ± | 0.0014 |
| V | 10.8 | ± | 0.13 | 13.6 | ± | 0.12 | 15.6 | ± | 0.045 | 7.95 | ± | 0.031 |
| Zn | 238 | ± | 3.5 | 231 | ± | 2.6 | 264 | ± | 0.92 | 147 | ± | 0.55 |

Table 4. 59: Heavy metals for hog slaughterhouse sludge (DAF)

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000275 | ± | 0.00018 | 0.0278 | ± | 0.0013 |
| Al | 0.810 | ± | 0.038 | 308 | ± | 1.6 |
| As | 0.0262 | ± | 0.0014 | 0.237 | ± | 0.010 |
| B | 0.530 | ± | 0.36 | 1.80 | ± | 0.079 |
| Ba | 0.285 | ± | 0.0011 | 14.7 | ± | 0.12 |
| Be | BD | ± | | 0.0121 | ± | 0.0032 |
| Bi | 0.000559 | ± | 0.00013 | 0.0223 | ± | 0.00038 |
| Ca | 1990 | ± | 15 | 5470 | ± | 78 |
| Cd | 0.000208 | ± | 0.000056 | 0.0666 | ± | 0.0018 |
| Cl | 1570 | ± | 370 | 7470 | ± | 660 |
| Co | 0.0485 | ± | 0.0015 | 0.433 | ± | 0.0055 |
| Cr | 0.103 | ± | 0.021 | 25.8 | ± | 0.18 |
| Cu | 0.124 | ± | 0.00045 | 78.1 | ± | 0.90 |
| Fe | 7.35 | ± | 0.19 | 1570 | ± | 9.8 |
| Hg | BD | ± | | 0.0201 | ± | 0.0011 |
| Li | 0.0211 | ± | | 0.400 | ± | 0.0073 |
| Mg | 165 | ± | 1.3 | 443 | ± | 4.2 |
| Mn | 3.38 | ± | 0.032 | 32.0 | ± | 0.22 |
| Mo | 0.0118 | ± | 0.00010 | 7.99 | ± | 0.077 |
| Na | 627 | ± | 19 | 938 | ± | 8.1 |
| Ni | 0.311 | ± | 0.0039 | 10.1 | ± | 0.075 |
| Pb | 0.00393 | ± | 0.00089 | 1.10 | ± | 0.0094 |
| Sb | 0.00430 | ± | 0.00046 | 0.286 | ± | 0.0030 |
| Se | 0.0364 | ± | 0.0096 | 1.38 | ± | 0.024 |
| Sn | 0.000685 | ± | 0.000010 | 1.34 | ± | 0.0097 |
| Sr | 3.47 | ± | 0.046 | 9.28 | ± | 0.074 |
| Th | 0.000312 | ± | 0.00011 | 0.0837 | ± | 0.0015 |
| Ti | 3.58 | ± | 0.060 | 20.7 | ± | 0.33 |
| TI | 0.000745 | ± | 0.000081 | 0.0231 | ± | 0.00050 |
| U | 0.00149 | ± | 0.000018 | 0.851 | ± | 0.012 |
| V | 0.0525 | ± | 0.0045 | 0.656 | ± | 0.078 |
| Zn | 9.11 | ± | 0.11 | 177 | ± | 2.3 |

Table 4. 60: Heavy metals for hog slaughterhouse peptone

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | BD | ± | | 0.000626 | ± | 0.00018 |
| Al | 3.73 | ± | 0.33 | 362 | ± | 1.6 |
| As | 0.0300 | ± | 0.0029 | 0.00774 | ± | 0.0036 |
| B | 0.173 | ± | 0.072 | 0.569 | ± | 0.060 |
| Ba | 0.159 | ± | 0.0039 | 0.624 | ± | 0.011 |
| Be | 0.000713 | ± | 0.00011 | 0.0173 | ± | 0.0017 |
| Bi | 0.000910 | ± | 0.00014 | 0.0605 | ± | 0.0011 |
| Ca | 20.2 | ± | 0.18 | 865 | ± | 16 |
| Cd | 0.0700 | ± | 0.00058 | 0.0921 | ± | 0.0030 |
| Cl | 5000 | ± | 200 | 11100 | ± | 140 |
| Co | 0.00860 | ± | 0.00029 | 0.0180 | ± | 0.00050 |
| Cr | 0.336 | ± | 0.028 | 0.540 | ± | 0.018 |
| Cu | 6.12 | ± | 0.065 | 7.95 | ± | 0.11 |
| Fe | 36.8 | ± | 4.9 | 115 | ± | 1.1 |
| Hg | 0.00881 | ± | 0.0033 | BD | ± | |
| Li | 0.241 | ± | 0.041 | 1.04 | ± | 0.020 |
| Mg | 154 | ± | 6.7 | 982 | ± | 9.8 |
| Mn | 1.17 | ± | 0.0012 | 3.45 | ± | 0.0016 |
| Mo | 0.164 | ± | 0.015 | 0.213 | ± | 0.0040 |
| Na | 38700 | ± | 480 | 60500 | ± | 1000 |
| Ni | 0.0162 | ± | 0.00046 | 0.185 | ± | 0.0056 |
| Pb | 0.00786 | ± | 0.00032 | 0.0291 | ± | 0.00028 |
| Sb | 0.00134 | ± | 0.00013 | 0.00303 | ± | 0.00041 |
| Se | 1.29 | ± | 0.036 | 1.55 | ± | 0.060 |
| Sn | 0.00121 | ± | 0.00021 | BD | ± | |
| Sr | 0.472 | ± | 0.0042 | 1.66 | ± | 0.023 |
| Th | 0.000830 | ± | 0.00022 | 0.0285 | ± | 0.00062 |
| Ti | 17.4 | ± | 0.59 | 34.5 | ± | 0.73 |
| TI | 0.00791 | ± | 0.00019 | 0.0181 | ± | 0.0011 |
| U | 0.00171 | ± | 0.00052 | 0.0318 | ± | 0.0011 |
| V | 0.0558 | ± | 0.0066 | 0.00892 | ± | 0.0036 |
| Zn | 51.2 | ± | 0.59 | 73.3 | ± | 0.98 |

Table 4. 61: Heavy metals for wet distillers grains

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000581 | ± | 0.00011 | 0.00564 | ± | 0.00044 |
| Al | 0.635 | ± | 0.061 | 13.7 | ± | 0.10 |
| As | 0.0445 | ± | 0.0023 | 0.0584 | ± | 0.0041 |
| B | 2.69 | ± | 0.090 | 3.96 | ± | 0.075 |
| Ba | 0.910 | ± | 0.024 | 3.42 | ± | 0.025 |
| Be | BD | ± | | 0.00262 | ± | 0.0016 |
| Bi | 0.000375 | ± | 0.000076 | 0.000422 | ± | 0.00010 |
| Ca | 589 | ± | 13 | 1300 | ± | 12 |
| Cd | 0.0168 | ± | 0.00033 | 0.0410 | ± | 0.0014 |
| Cl | 945 | ± | 27 | 4880 | ± | 200 |
| Co | 0.00959 | ± | 0.00050 | 0.0159 | ± | 0.00098 |
| Cr | 0.0758 | ± | 0.0039 | 0.162 | ± | 0.023 |
| Cu | 1.52 | ± | 0.041 | 10.5 | ± | 0.12 |
| Fe | 5.34 | ± | 0.18 | 107 | ± | 0.79 |
| Hg | 0.00204 | ± | 0.00016 | 0.00177 | ± | 0.00050 |
| Li | 0.387 | ± | 0.027 | 0.494 | ± | 0.011 |
| Mg | 1880 | ± | 51 | 2060 | ± | 14 |
| Mn | 37.1 | ± | 0.76 | 53.0 | ± | 0.37 |
| Mo | 0.477 | ± | 0.015 | 1.41 | ± | 0.013 |
| Na | 1320 | ± | 29 | 1380 | ± | 12 |
| Ni | 0.114 | ± | 0.0032 | 0.194 | ± | 0.0076 |
| Pb | 0.00222 | ± | 0.00063 | 0.0186 | ± | 0.00038 |
| Sb | 0.000366 | ± | 0.00011 | 0.00168 | ± | 0.00029 |
| Se | 0.0472 | ± | 0.0092 | 0.0918 | ± | 0.032 |
| Sn | BD | ± | | 0.00314 | ± | 0.00040 |
| Sr | 4.65 | ± | 0.11 | 8.88 | ± | 0.075 |
| Th | 0.00129 | ± | 0.00033 | 0.00354 | ± | 0.00016 |
| Ti | 10.0 | ± | 0.27 | 14.4 | ± | 0.22 |
| TI | 0.000399 | ± | 0.00012 | 0.000738 | ± | 0.00013 |
| U | 0.0000331 | ± | 0.000023 | 0.00784 | ± | 0.00016 |
| V | 0.0141 | ± | 0.0013 | 0.0492 | ± | 0.0029 |
| Zn | 33.1 | ± | 0.83 | 42.8 | ± | 0.33 |

Table 4. 62: Heavy metals for wet distillers grains culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0795 | ± | 0.0016 | 0.121 | ± | 0.0045 | 0.125 | ± | 0.0064 | 0.0748 | ± | 0.0023 |
| Al | 3580 | ± | 43 | 7110 | ± | 66 | 7390 | ± | 94 | 3570 | ± | 29 |
| As | 1.39 | ± | 0.026 | 1.67 | ± | 0.017 | 2.02 | ± | 0.022 | 0.720 | ± | 0.016 |
| B | 18.9 | ± | 0.56 | 31.4 | ± | 1.2 | 35.6 | ± | 1.1 | 14.8 | ± | 0.56 |
| Ba | 63.8 | ± | 0.81 | 91.1 | ± | 1.5 | 108 | ± | 1.9 | 44.2 | ± | 0.74 |
| Be | 0.0813 | ± | 0.0084 | 0.148 | ± | 0.0072 | 0.171 | ± | 0.012 | 0.0705 | ± | 0.0035 |
| Bi | 0.0288 | ± | 0.00067 | 0.0347 | ± | 0.00049 | 0.446 | ± | 0.00053 | 0.0184 | ± | 0.00057 |
| Ca | 20200 | ± | 440 | 24800 | ± | 510 | 31400 | ± | 650 | 13700 | ± | 370 |
| Cd | 0.127 | ± | 0.0028 | 0.152 | ± | 0.0045 | 0.191 | ± | 0.0052 | 0.0707 | ± | 0.0037 |
| Cl | 23400 | ± | 490 | 3810 | ± | 110 | 40800 | ± | 2000 | 5070 | ± | 610 |
| Co | 2.91 | ± | 0.020 | 3.99 | ± | 0.043 | 4.67 | ± | 0.060 | 1.91 | ± | 0.0023 |
| Cr | 7.86 | ± | 0.16 | 15.9 | ± | 0.064 | 15.5 | ± | 0.17 | 5.92 | ± | 0.10 |
| Cu | 34.9 | ± | 0.56 | 44.9 | ± | 0.76 | 53.7 | ± | 1.1 | 22.1 | ± | 0.46 |
| Fe | 2820 | ± | 91 | 4390 | ± | 54 | 5590 | ± | 39 | 2650 | ± | 24 |
| Hg | 0.0131 | ± | 0.0015 | 0.0204 | ± | 0.0014 | 0.0248 | ± | 0.0011 | 0.0104 | ± | 0.0012 |
| Li | 3.99 | ± | 0.065 | 6.29 | ± | 0.15 | 7.59 | ± | 0.15 | 2.61 | ± | 0.069 |
| Mg | 6080 | ± | 140 | 6910 | ± | 49 | 8650 | ± | 130 | 4400 | ± | 83 |
| Mn | 217 | ± | 4.6 | 272 | ± | 3.1 | 346 | ± | 1.9 | 136 | ± | 1.3 |
| Mo | 2.30 | ± | 0.037 | 3.35 | ± | 0.035 | 3.88 | ± | 0.073 | 1.74 | ± | 0.043 |
| Na | 5720 | ± | 110 | 9940 | ± | 120 | 13900 | ± | 270 | 2270 | ± | 57 |
| Ni | 8.52 | ± | 0.082 | 12.6 | ± | 0.23 | 14.6 | ± | 0.24 | 4.88 | ± | 0.11 |
| Pb | 1.89 | ± | 0.025 | 2.60 | ± | 0.014 | 3.22 | ± | 0.038 | 1.27 | ± | 0.013 |
| Sb | 0.0187 | ± | 0.00055 | 0.0449 | ± | 0.00053 | 0.0352 | ± | 0.0015 | 0.0261 | ± | 0.00098 |
| Se | 0.969 | ± | 0.034 | 1.12 | ± | 0.045 | 1.08 | ± | 0.059 | 0.620 | ± | 0.028 |
| Sn | 0.0439 | ± | 0.00099 | 0.345 | ± | 0.0052 | 0.146 | ± | 0.0033 | 0.174 | ± | 0.00081 |
| Sr | 137 | ± | 2.4 | 178 | ± | 5.2 | 224 | ± | 4.2 | 85.7 | ± | 2.0 |
| Th | 0.415 | ± | 0.0068 | 1.17 | ± | 0.019 | 0.925 | ± | 0.015 | 0.553 | ± | 0.0072 |
| Ti | 125 | ± | 3.6 | 308 | ± | 11 | 292 | ± | 6.9 | 177 | ± | 7.2 |
| TI | 0.0525 | ± | 0.0014 | 0.0905 | ± | 0.0014 | 0.0993 | ± | 0.0020 | 0.0460 | ± | 0.0011 |
| U | 0.224 | ± | 0.0032 | 0.320 | ± | 0.0091 | 0.392 | ± | 0.0073 | 0.153 | ± | 0.0025 |
| V | 6.96 | ± | 0.17 | 12.7 | ± | 0.13 | 13.6 | ± | 0.32 | 6.47 | ± | 0.17 |
| Zn | 181 | ± | 3.7 | 264 | ± | 8.4 | 322 | ± | 7.3 | 124 | ± | 3.2 |

Table 4. 63: Heavy metals for cheese whey

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | BD | ± | | 0.000476 | ± | 0.00033 |
| Al | 0.101 | ± | 0.0059 | 2.80 | ± | 0.21 |
| As | 0.0574 | ± | 0.00077 | 0.00507 | ± | 0.0045 |
| B | 3.68 | ± | 0.067 | 4.48 | ± | 0.073 |
| Ba | 0.101 | ± | 0.00051 | 0.129 | ± | 0.0056 |
| Be | BD | ± | | 0.00118 | ± | 0.00079 |
| Bi | 0.000553 | ± | 0.000070 | 0.00133 | ± | 0.00017 |
| Ca | 5620 | ± | 17 | 6300 | ± | 57 |
| Cd | 0.00101 | ± | 0.00016 | 0.000768 | ± | 0.00029 |
| Cl | 14200 | ± | 54 | 5920 | ± | 58 |
| Co | 0.000868 | ± | 0.00044 | 0.00119 | ± | 0.00065 |
| Cr | 0.485 | ± | 0.031 | 0.0362 | ± | 0.014 |
| Cu | 0.0963 | ± | 0.0032 | 0.237 | ± | 0.0086 |
| Fe | BD | ± | | 0.742 | ± | 0.43 |
| Hg | 0.177 | ± | | 0.00336 | ± | 0.00061 |
| Li | 0.0617 | ± | 0.018 | 0.279 | ± | 0.011 |
| Mg | 1230 | ± | 2.6 | 1100 | ± | 4.7 |
| Mn | 0.0106 | ± | 0.0016 | 0.0849 | ± | 0.0062 |
| Mo | 0.388 | ± | 0.0039 | 0.500 | ± | 0.013 |
| Na | 6310 | ± | 50 | 5090 | ± | 50 |
| Ni | BD | ± | | 0.00395 | ± | 0.0024 |
| Pb | 0.00232 | ± | 0.00023 | 0.184 | ± | 0.0015 |
| Sb | 0.000397 | ± | 0.000016 | 0.000233 | ± | 0.00010 |
| Se | 0.195 | ± | 0.049 | 0.0380 | ± | 0.017 |
| Sn | BD | ± | | 0.00364 | ± | 0.00047 |
| Sr | 1.86 | ± | 0.0097 | 2.09 | ± | 0.033 |
| Th | 0.000639 | ± | 0.00016 | 0.000753 | ± | 0.00015 |
| Ti | 21.7 | ± | 0.097 | 23.3 | ± | 0.58 |
| TI | 0.00172 | ± | 0.000051 | 0.00309 | ± | 0.00027 |
| U | 0.000128 | ± | 0.000032 | 0.000450 | ± | 0.00010 |
| V | 0.0899 | ± | 0.0053 | 0.0287 | ± | 0.0015 |
| Zn | 1.14 | ± | 0.0026 | 1.79 | ± | 0.017 |

Table 4. 64: Heavy metals for cheese whey culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0795 | ± | 0.0016 | 0.130 | ± | 0.0037 | 0.164 | ± | 0.0056 | 0.0710 | ± | 0.0019 |
| Al | 3580 | ± | 43 | 7430 | ± | 130 | 9040 | ± | 260 | 4280 | ± | 94 |
| As | 1.39 | ± | 0.026 | 1.71 | ± | 0.026 | 2.05 | ± | 0.037 | 0.793 | ± | 0.014 |
| B | 18.9 | ± | 0.56 | 30.0 | ± | 0.82 | 35.1 | ± | 0.91 | 15.0 | ± | 0.24 |
| Ba | 63.8 | ± | 0.81 | 91.1 | ± | 1.5 | 112 | ± | 1.3 | 50.0 | ± | 0.99 |
| Be | 0.0813 | ± | 0.0084 | 0.144 | ± | 0.0095 | 0.170 | ± | 0.0082 | 0.0716 | ± | 0.0049 |
| Bi | 0.0288 | ± | 0.00067 | 0.0406 | ± | 0.00067 | 0.0472 | ± | 0.00048 | 0.0218 | ± | 0.00078 |
| Ca | 20200 | ± | 440 | 27400 | ± | 580 | 32500 | ± | 660 | 15800 | ± | 430 |
| Cd | 0.127 | ± | 0.0028 | 0.144 | ± | 0.0011 | 0.163 | ± | 0.0015 | 0.0682 | ± | 0.0022 |
| Cl | 23400 | ± | 490 | 8200 | ± | 260 | 8550 | ± | 180 | 1080 | ± | 71 |
| Co | 2.91 | ± | 0.020 | 4.02 | ± | 0.076 | 4.50 | ± | 0.063 | 2.08 | ± | 0.037 |
| Cr | 7.86 | ± | 0.16 | 12.4 | ± | 0.16 | 14.0 | ± | 0.14 | 7.47 | ± | 0.70 |
| Cu | 34.9 | ± | 0.56 | 41.4 | ± | 0.73 | 48.4 | ± | 0.96 | 22.0 | ± | 0.60 |
| Fe | 2820 | ± | 91 | 4320 | ± | 63 | 5340 | ± | 160 | 2890 | ± | 30 |
| Hg | 0.0131 | ± | 0.0015 | 0.0211 | ± | 0.0010 | 0.0251 | ± | 0.00093 | 0.0118 | ± | 0.00082 |
| Li | 3.99 | ± | 0.065 | 6.11 | ± | 0.15 | 7.47 | ± | 0.14 | 2.72 | ± | 0.060 |
| Mg | 6080 | ± | 140 | 6530 | ± | 89 | 6350 | ± | 68 | 6960 | ± | 98 |
| Mn | 217 | ± | 4.6 | 272 | ± | 2.6 | 309 | ± | 2.5 | 146 | ± | 2.7 |
| Mo | 2.30 | ± | 0.037 | 2.94 | ± | 0.049 | 3.49 | ± | 0.057 | 1.51 | ± | 0.032 |
| Na | 5720 | ± | 110 | 12100 | ± | 240 | 17000 | ± | 290 | 2560 | ± | 44 |
| Ni | 8.52 | ± | 0.082 | 11.7 | ± | 0.21 | 13.3 | ± | 0.21 | 5.08 | ± | 0.10 |
| Pb | 1.89 | ± | 0.025 | 2.70 | ± | 0.015 | 3.23 | ± | 0.020 | 1.44 | ± | 0.010 |
| Sb | 0.0187 | ± | 0.00055 | 0.0426 | ± | 0.00090 | 0.0496 | ± | 0.00074 | 0.0309 | ± | 0.0010 |
| Se | 0.969 | ± | 0.034 | 1.06 | ± | 0.052 | 1.24 | ± | 0.059 | 0.613 | ± | 0.022 |
| Sn | 0.0439 | ± | 0.00099 | 0.254 | ± | 0.0018 | 0.412 | ± | 0.0054 | 0.195 | ± | 0.0038 |
| Sr | 137 | ± | 2.4 | 191 | ± | 4.6 | 217 | ± | 4.1 | 97.7 | ± | 1.9 |
| Th | 0.145 | ± | 0.0068 | 1.10 | ± | 0.015 | 1.47 | ± | 0.021 | 0.630 | ± | 0.0077 |
| Ti | 125 | ± | 3.6 | 347 | ± | 16 | 359 | ± | 11 | 232 | ± | 18 |
| TI | 0.0525 | ± | 0.0014 | 0.0911 | ± | 0.0015 | 0.111 | ± | 0.0019 | 0.0535 | ± | 0.0013 |
| U | 0.224 | ± | 0.0032 | 0.335 | ± | 0.0027 | 0.400 | ± | 0.0055 | 0.168 | ± | 0.0033 |
| V | 6.96 | ± | 0.17 | 12.6 | ± | 0.25 | 15.4 | ± | 0.26 | 7.24 | ± | 0.13 |
| Zn | 181 | ± | 3.7 | 264 | ± | 6.8 | 301 | ± | 5.7 | 143 | ± | 2.3 |

Table 4. 65: Heavy metals for cattle slaughterhouse waste - paunch

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | | ± | | 0.0528 | ± | 0.0078 |
| Al | 1.61 | ± | 0.89 | 628 | ± | 3.1 |
| As | 0.0639 | ± | 0.0020 | 0.143 | ± | 0.0075 |
| B | 2.50 | ± | 0.29 | 8.19 | ± | 0.13 |
| Ba | | ± | | 35.0 | ± | 0.51 |
| Be | | ± | | 0.0135 | ± | 0.0022 |
| Bi | | ± | | 0.0663 | ± | 0.020 |
| Ca | 331 | ± | 45 | 4410 | ± | 69 |
| Cd | | ± | | 0.0448 | ± | 0.0017 |
| Cl | 5240 | ± | 750 | 6910 | ± | 280 |
| Co | 0.0183 | ± | 0.0038 | 0.187 | ± | 0.0018 |
| Cr | | ± | | 1.92 | ± | 0.025 |
| Cu | 0.420 | ± | 0.085 | 5.37 | ± | 0.082 |
| Fe | 9.97 | ± | 3.6 | 434 | ± | 7.2 |
| Hg | | ± | | 0.00469 | ± | 0.0010 |
| Li | 0.808 | ± | 0.12 | 1.21 | ± | 0.033 |
| Mg | 240 | ± | 34 | 633 | ± | 5.6 |
| Mn | 4.00 | ± | 0.58 | 51.8 | ± | 0.72 |
| Mo | 0.0689 | ± | 0.060 | 0.824 | ± | 0.013 |
| Na | 16900 | ± | 360 | 19700 | ± | 550 |
| Ni | 0.389 | ± | 0.049 | 1.51 | ± | 0.030 |
| Pb | 0.00931 | ± | 0.00018 | 0.222 | ± | 0.0018 |
| Sb | 0.000869 | ± | 0.0011 | 0.00651 | ± | 0.00043 |
| Se | 0.0104 | ± | 0.0024 | 0.107 | ± | 0.011 |
| Sn | | ± | | 0.0211 | ± | 0.0011 |
| Sr | 2.52 | ± | 0.35 | 23.8 | ± | 1.0 |
| Th | 0.00120 | ± | 0.00063 | 0.0812 | ± | 0.0012 |
| Ti | 11.1 | ± | 1.6 | 30.3 | ± | 0.92 |
| TI | 0.00592 | ± | 0.00063 | 0.0458 | ± | 0.0010 |
| U | 0.000834 | ± | 0.00078 | 0.0247 | ± | 0.0011 |
| V | 0.0569 | ± | 0.0061 | 1.18 | ± | 0.012 |
| Zn | 1.84 | ± | 0.19 | 30.6 | ± | 0.49 |

Table 4. 66: Heavy metals for cattle slaughterhouse waste - paunch culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, μg/g dw | | | Final, μg/g dw | | | Liquid, μg/g dw | | | Solid, μg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.904 | ± | 0.0055 | 0.0591 | ± | 0.0020 | 0.0627 | ± | 0.0013 | 0.0332 | ± | 0.0017 |
| Al | 6680 | ± | 92 | 4380 | ± | 64 | 5150 | ± | 70 | 2830 | ± | 54 |
| As | 1.45 | ± | 0.033 | 1.69 | ± | 0.023 | 2.29 | ± | 0.027 | 0.854 | ± | 0.015 |
| B | 23.0 | ± | 0.97 | 24.4 | ± | 0.64 | 27.8 | ± | 0.93 | 15.0 | ± | 0.41 |
| Ba | 91.8 | ± | 1.7 | 77.2 | ± | 1.1 | 109 | ± | 2.6 | 46.5 | ± | 0.96 |
| Be | 0.113 | ± | 0.0035 | 0.107 | ± | 0.0027 | 0.138 | ± | 0.0083 | 0.0625 | ± | 0.0025 |
| Bi | 0.0355 | ± | 0.0012 | 0.0273 | ± | 0.00059 | 0.0396 | ± | 0.0012 | 0.0138 | ± | 0.00079 |
| Ca | 27900 | ± | 490 | 24600 | ± | 660 | 31900 | ± | 740 | 15000 | ± | 460 |
| Cd | 0.135 | ± | 0.0038 | 0.138 | ± | 0.0034 | 0.200 | ± | 0.0020 | 0.0724 | ± | 0.0017 |
| Cl | 22400 | ± | 760 | 39900 | ± | 820 | 86400 | ± | 4200 | 22700 | ± | 450 |
| Co | 3.43 | ± | 0.066 | 3.87 | ± | 0.080 | 4.96 | ± | 0.055 | 2.27 | ± | 0.044 |
| Cr | 16.2 | ± | 0.26 | 11.1 | ± | 0.098 | 12.0 | ± | 0.19 | 6.70 | ± | 0.13 |
| Cu | 36.3 | ± | 1.0 | 40.9 | ± | 0.85 | 54.7 | ± | 0.93 | 22.9 | ± | 0.59 |
| Fe | 5390 | ± | 120 | 3770 | ± | 58 | 4640 | ± | 79 | 2810 | ± | 24 |
| Hg | 0.0250 | ± | 0.00047 | 0.0297 | ± | 0.0012 | 0.0308 | ± | 0.00094 | 0.0161 | ± | 0.0010 |
| Li | 5.31 | ± | 0.12 | 4.76 | ± | 0.15 | 6.37 | ± | 0.14 | 2.39 | ± | 0.067 |
| Mg | 6860 | ± | 67 | 6500 | ± | 120 | 8480 | ± | 140 | 4530 | ± | 72 |
| Mn | 264 | ± | 1.7 | 220 | ± | 3.8 | 319 | ± | 2.5 | 152 | ± | 0.93 |
| Mo | 2.38 | ± | 0.065 | 2.52 | ± | 0.041 | 3.31 | ± | 0.058 | 1.49 | ± | 0.042 |
| Na | 9060 | ± | 620 | 9310 | ± | 150 | 13500 | ± | 370 | 2850 | ± | 53 |
| Ni | 11.8 | ± | 0.24 | 11.7 | ± | 0.25 | 14.8 | ± | 0.18 | 5.83 | ± | 0.17 |
| Pb | 2.46 | ± | 0.059 | 2.52 | ± | 0.014 | 3.37 | ± | 0.037 | 1.46 | ± | 0.011 |
| Sb | 0.0369 | ± | 0.0016 | 0.0173 | ± | 0.00068 | 0.0184 | ± | 0.00082 | 0.0154 | ± | 0.0010 |
| Se | 0.842 | ± | 0.064 | 0.965 | ± | 0.022 | 1.02 | ± | 0.048 | 0.589 | ± | 0.036 |
| Sn | 0.194 | ± | 0.0039 | 0.0544 | ± | 0.0010 | 0.0690 | ± | 0.0030 | 0.0338 | ± | 0.0014 |
| Sr | 176 | ± | 4.3 | 150 | ± | 2.4 | 215 | ± | 5.3 | 95.7 | ± | 1.9 |
| Th | 0.955 | ± | 0.020 | 0.766 | ± | 0.0098 | 0.889 | ± | 0.0097 | 0.405 | ± | 0.0072 |
| Ti | 278 | ± | 7.0 | 159 | ± | 2.5 | 148 | ± | 4.3 | 128 | ± | 3.6 |
| TI | 0.0864 | ± | 0.0029 | 0.0741 | ± | 0.00091 | 0.0915 | ± | 0.0020 | 0.0461 | ± | 0.0010 |
| U | 0.295 | ± | 0.0056 | 0.289 | ± | 0.0058 | 0.390 | ± | 0.0069 | 0.156 | ± | 0.0028 |
| V | 10.9 | ± | 0.30 | 9.45 | ± | 0.14 | 10.5 | ± | 0.25 | 5.85 | ± | 0.12 |
| Zn | 210 | ± | 4.2 | 226 | ± | 0.39 | 323 | ± | 8.8 | 139 | ± | 2.9 |

Table 4. 67: Heavy metals for solid hog manure

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000614 | ± | 0.000029 | 0.0300 | ± | 0.0025 |
| Al | 2.21 | ± | 0.057 | 256 | ± | 4.9 |
| As | 0.0952 | ± | 0.0057 | 0.163 | ± | 0.0086 |
| B | 3.31 | ± | 0.052 | 9.91 | ± | 0.22 |
| Ba | 0.952 | ± | 0.020 | 45.2 | ± | 0.29 |
| Be | | ± | | 0.00769 | ± | 0.0016 |
| Bi | 0.000720 | ± | 0.000040 | 0.0211 | ± | 0.0036 |
| Ca | 255 | ± | 1.3 | 18000 | ± | 110 |
| Cd | 0.0212 | ± | 0.00081 | 0.254 | ± | 0.0027 |
| Cl | 13700 | ± | 420 | 4710 | ± | 32 |
| Co | 0.153 | ± | 0.0035 | 0.902 | ± | 0.0048 |
| Cr | 0.448 | ± | 0.011 | 2.96 | ± | 0.050 |
| Cu | 22.2 | ± | 0.73 | 277 | ± | 3.3 |
| Fe | 50.6 | ± | 1.6 | 771 | ± | 5.8 |
| Hg | | ± | | 0.0200 | ± | 0.0020 |
| Li | 0.343 | ± | 0.026 | 0.638 | ± | 0.013 |
| Mg | 130 | ± | 4.0 | 7390 | ± | 26 |
| Mn | 4.74 | ± | 0.064 | 361 | ± | 2.5 |
| Mo | 0.213 | ± | 0.0086 | 1.82 | ± | 0.014 |
| Na | 5300 | ± | 190 | 6380 | ± | 27 |
| Ni | 0.438 | ± | 0.015 | 2.47 | ± | 0.026 |
| Pb | 0.0185 | ± | 0.00035 | 0.325 | ± | 0.0021 |
| Sb | 0.00960 | ± | 0.00065 | 0.0547 | ± | 0.0012 |
| Se | 0.230 | ± | 0.0089 | 2.22 | ± | 0.066 |
| Sn | 0.0103 | ± | 0.00041 | 0.168 | ± | 0.0025 |
| Sr | 0.754 | ± | 0.011 | 27.5 | ± | 0.28 |
| Th | 0.000907 | ± | 0.000010 | 0.0513 | ± | 0.0015 |
| Ti | 4.67 | ± | 0.014 | 46.7 | ± | 0.29 |
| TI | 0.00482 | ± | 0.00010 | 0.0830 | ± | 0.0013 |
| U | 0.0152 | ± | 0.00034 | 0.0590 | ± | 0.0011 |
| V | 0.0590 | ± | 0.0072 | 0.972 | ± | 0.13 |
| Zn | 36.4 | ± | 0.70 | 566 | ± | 6.6 |

Table 4. 68: Heavy metals for solid hog manure culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0721 | ± | 0.0016 | 0.243 | ± | 0.042 | 0.0796 | ± | 0.0043 | 0.0896 | ± | 0.0052 |
| Al | 4550 | ± | 65 | 4470 | ± | 75 | 6380 | ± | 110 | 2220 | ± | 27 |
| As | 1.14 | ± | 0.015 | 1.42 | ± | 0.042 | 1.97 | ± | 0.032 | 0.657 | ± | 0.012 |
| B | 20.6 | ± | 0.70 | 26.3 | ± | 1.2 | 30.3 | ± | 0.73 | 14.7 | ± | 0.34 |
| Ba | 78.8 | ± | 1.7 | 78.0 | ± | 1.0 | 114 | ± | 2.2 | 38.4 | ± | 0.63 |
| Be | 0.106 | ± | 0.0052 | 0.0983 | ± | 0.0060 | 0.140 | ± | 0.0080 | 0.0504 | ± | 0.0020 |
| Bi | 0.0287 | ± | 0.00066 | 0.0479 | ± | 0.0052 | 0.0336 | ± | 0.00051 | 0.0148 | ± | 0.0014 |
| Ca | 28300 | ± | 670 | 27000 | ± | 620 | 32500 | ± | 560 | 15100 | ± | 240 |
| Cd | 0.193 | ± | 0.0026 | 0.220 | ± | 0.0031 | 0.296 | ± | 0.0037 | 0.123 | ± | 0.0036 |
| Cl | 23200 | ± | 1100 | 55800 | ± | 5800 | 43900 | ± | 1200 | 11800 | ± | 1300 |
| Co | 2.87 | ± | 0.070 | 3.43 | ± | 0.036 | 4.56 | ± | 0.072 | 2.04 | ± | 0.049 |
| Cr | 8.99 | ± | 0.14 | 10.9 | ± | 0.13 | 13.9 | ± | 0.13 | 5.95 | ± | 0.037 |
| Cu | 151 | ± | 3.3 | 154 | ± | 3.6 | 171 | ± | 2.2 | 134 | ± | 2.1 |
| Fe | 3760 | ± | 72 | 3740 | ± | 22 | 4850 | ± | 77 | 2100 | ± | 33 |
| Hg | 0.0289 | ± | 0.0026 | 0.0312 | ± | 0.0023 | 0.0350 | ± | 0.0012 | 0.0202 | ± | 0.0011 |
| Li | 4.34 | ± | 0.12 | 4.33 | ± | 0.070 | 6.11 | ± | 0.085 | 1.74 | ± | 0.024 |
| Mg | 7720 | ± | 98 | 7970 | ± | 77 | 10000 | ± | 98 | 4530 | ± | 61 |
| Mn | 337 | ± | 3.2 | 343 | ± | 2.0 | 464 | ± | 6.2 | 170 | ± | 2.0 |
| Mo | 2.57 | ± | 0.049 | 2.91 | ± | 0.052 | 4.00 | ± | 0.052 | 1.66 | ± | 0.031 |
| Na | 31100 | ± | 930 | 8740 | ± | 100 | 12500 | ± | 250 | 2350 | ± | 28 |
| Ni | 8.40 | ± | 0.25 | 10.1 | ± | 0.16 | 14.1 | ± | 0.24 | 4.27 | ± | 0.091 |
| Pb | 1.78 | ± | 0.025 | 2.09 | ± | 0.0078 | 2.74 | ± | 0.015 | 1.12 | ± | 0.0085 |
| Sb | 0.0390 | ± | 0.0013 | 0.0286 | ± | 0.00073 | 0.0369 | ± | 0.00079 | 0.0340 | ± | 0.00031 |
| Se | 1.27 | ± | 0.071 | 1.84 | ± | 0.11 | 1.94 | ± | 0.056 | 1.24 | ± | 0.028 |
| Sn | 0.169 | ± | 0.0046 | 0.102 | ± | 0.0030 | 0.168 | ± | 0.0045 | 0.190 | ± | 0.0037 |
| Sr | 140 | ± | 3.0 | 132 | ± | 2.0 | 188 | ± | 3.9 | 78.1 | ± | 1.5 |
| Th | 0.669 | ± | 0.018 | 0.677 | ± | 0.0092 | 0.939 | ± | 0.0082 | 0.352 | ± | 0.0034 |
| Ti | 212 | ± | 4.7 | 169 | ± | 6.4 | 224 | ± | 8.0 | 122 | ± | 1.9 |
| TI | 0.0873 | ± | 0.0023 | 0.100 | ± | 0.0018 | 0.111 | ± | 0.0021 | 0.0811 | ± | 0.0020 |
| U | 0.232 | ± | 0.0058 | 0.268 | ± | 0.0032 | 0.354 | ± | 0.0065 | 0.134 | ± | 0.0020 |
| V | 8.40 | ± | 0.13 | 8.80 | ± | 0.18 | 12.0 | ± | 0.16 | 4.91 | ± | 0.062 |
| Zn | 356 | ± | 8.2 | 422 | ± | 8.3 | 595 | ± | 12 | 267 | ± | 3.5 |

Table 4. 69: Heavy metals for sewage sludge

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.00420 | ± | 0.00016 | 5.72 | ± | 0.075 |
| Al | 26.7 | ± | 0.48 | 35000 | ± | 270 |
| As | 0.127 | ± | 0.0022 | 2.82 | ± | 0.038 |
| B | 3.88 | ± | 0.21 | 16.7 | ± | 0.47 |
| Ba | 8.56 | ± | 0.24 | 588 | ± | 6.2 |
| Be | | ± | | 0.296 | ± | 0.010 |
| Bi | 0.00826 | ± | 0.000099 | 20.9 | ± | 0.19 |
| Ca | 4540 | ± | 150 | 15400 | ± | 180 |
| Cd | 0.000734 | ± | 0.000042 | 0.977 | ± | 0.0085 |
| Cl | 569 | ± | 21 | 685 | ± | 35 |
| Co | 0.153 | ± | 0.0020 | 3.24 | ± | 0.034 |
| Cr | 0.0342 | ± | 0.0063 | 30.4 | ± | 0.47 |
| Cu | 0.240 | ± | 0.0084 | 326 | ± | 7.5 |
| Fe | 293 | ± | 5.0 | 7050 | ± | 78 |
| Hg | | ± | | 0.691 | ± | 0.0080 |
| Li | 0.704 | ± | 0.088 | 9.61 | ± | 0.13 |
| Mg | 1110 | ± | 17 | 2840 | ± | 37 |
| Mn | 20.6 | ± | 0.40 | 121 | ± | 0.60 |
| Mo | 0.0471 | ± | 0.00025 | 4.13 | ± | 0.029 |
| Na | 965 | ± | 22 | 8440 | ± | 180 |
| Ni | 0.348 | ± | 0.016 | 17.8 | ± | 0.24 |
| Pb | 0.00956 | ± | 0.00017 | 16.3 | ± | 0.057 |
| Sb | 0.00494 | ± | 0.00021 | 0.810 | ± | 0.0063 |
| Se | 0.105 | ± | 0.0062 | 2.60 | ± | 0.068 |
| Sn | 0.00828 | ± | 0.00013 | 6.24 | ± | 0.046 |
| Sr | 36.5 | ± | 0.70 | 198 | ± | 5.1 |
| Th | 0.000303 | ± | 0.000036 | 0.651 | ± | 0.0072 |
| Ti | 0.306 | ± | 0.012 | 200 | ± | 9.0 |
| TI | 0.0000930 | ± | 0.000088 | 0.107 | ± | 0.0017 |
| U | 0.00607 | ± | 0.00023 | 2.30 | ± | 0.024 |
| V | 0.00651 | ± | 0.0014 | 14.6 | ± | 0.21 |
| Zn | 0.615 | ± | 0.022 | 725 | ± | 13 |

Table 4. 70: Heavy metals for sewage sludge culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 1.64 | ± | 0.095 | 1.93 | ± | 0.051 | 2.53 | ± | 0.036 | 1.43 | ± | 0.017 |
| Al | 15800 | ± | 300 | 16400 | ± | 150 | 21000 | ± | 380 | 10400 | ± | 99 |
| As | 2.00 | ± | 0.066 | 2.57 | ± | 0.030 | 3.06 | ± | 0.057 | 1.36 | ± | 0.016 |
| B | 23.1 | ± | 1.1 | 26.1 | ± | 0.41 | 29.0 | ± | 0.67 | 15.4 | ± | 0.62 |
| Ba | 227 | ± | 3.5 | 287 | ± | 5.8 | 359 | ± | 6.0 | 181 | ± | 3.9 |
| Be | 0.193 | ± | 0.014 | 0.187 | ± | 0.0034 | 0.247 | ± | 0.010 | 0.120 | ± | 0.010 |
| Bi | 6.64 | ± | 0.16 | 7.97 | ± | 0.096 | 10.1 | ± | 0.040 | 5.59 | ± | 0.050 |
| Ca | 22700 | ± | 250 | 25700 | ± | 550 | 32100 | ± | 670 | 14900 | ± | 420 |
| Cd | 0.352 | ± | 0.010 | 0.441 | ± | 0.0051 | 0.555 | ± | 0.0051 | 0.269 | ± | 0.0036 |
| Cl | 6040 | ± | 290 | 23000 | ± | 1400 | 10100 | ± | 190 | 7300 | ± | 690 |
| Co | 3.69 | ± | 0.12 | 4.47 | ± | 0.074 | 5.06 | ± | 0.081 | 2.79 | ± | 0.049 |
| Cr | 17.4 | ± | 0.55 | 19.8 | ± | 0.23 | 22.9 | ± | 0.23 | 10.4 | ± | 0.12 |
| Cu | 83.2 | ± | 1.8 | 100 | ± | 2.0 | 128 | ± | 2.8 | 69.0 | ± | 1.5 |
| Fe | 6890 | ± | 140 | 6270 | ± | 39 | 7800 | ± | 110 | 4050 | ± | 76 |
| Hg | 0.490 | ± | 0.018 | 0.208 | ± | 0.0065 | 0.243 | ± | 0.0034 | 0.145 | ± | 0.0037 |
| Li | 6.74 | ± | 0.24 | 7.28 | ± | 0.11 | 9.37 | ± | 0.10 | 3.71 | ± | 0.086 |
| Mg | 5310 | ± | 57 | 6590 | ± | 74 | 8000 | ± | 54 | 3910 | ± | 76 |
| Mn | 199 | ± | 1.3 | 239 | ± | 1.4 | 302 | ± | 2.0 | 143 | ± | 0.53 |
| Mo | 3.06 | ± | 0.11 | 3.78 | ± | 0.059 | 4.78 | ± | 0.067 | 2.27 | ± | 0.057 |
| Na | 6020 | ± | 340 | 7200 | ± | 110 | 8000 | ± | 97 | 1700 | ± | 42 |
| Ni | 12.8 | ± | 0.47 | 16.5 | ± | 0.34 | 17.9 | ± | 0.22 | 7.58 | ± | 0.20 |
| Pb | 6.48 | ± | 0.14 | 7.93 | ± | 0.050 | 9.72 | ± | 0.064 | 5.39 | ± | 0.042 |
| Sb | 0.269 | ± | 0.0083 | 0.165 | ± | 0.0032 | 0.225 | ± | 0.0035 | 0.181 | ± | 0.0049 |
| Se | 1.39 | ± | 0.040 | 1.92 | ± | 0.070 | 2.27 | ± | 0.015 | 1.10 | ± | 0.063 |
| Sn | 3.02 | ± | 0.077 | 1.31 | ± | 0.0080 | 3.78 | ± | 0.027 | 1.09 | ± | 0.013 |
| Sr | 171 | ± | 3.4 | 208 | ± | 5.2 | 253 | ± | 6.3 | 118 | ± | 2.5 |
| Th | 1.22 | ± | 0.032 | 0.952 | ± | 0.019 | 1.43 | ± | 0.0093 | 0.582 | ± | 0.011 |
| Ti | 267 | ± | 5.7 | 218 | ± | 7.1 | 316 | ± | 6.5 | 162 | ± | 4.8 |
| TI | 0.101 | ± | 0.0028 | 0.101 | ± | 0.0021 | 0.133 | ± | 0.0027 | 0.0642 | ± | 0.0020 |
| U | 1.02 | ± | 0.035 | 1.18 | ± | 0.021 | 1.47 | ± | 0.016 | 0.690 | ± | 0.013 |
| V | 13.5 | ± | 0.54 | 14.5 | ± | 0.26 | 19.3 | ± | 0.39 | 9.22 | ± | 0.19 |
| Zn | 257 | ± | 5.6 | 386 | ± | 8.6 | 468 | ± | 11 | 237 | ± | 6.5 |

Table 4. 71: Heavy metals for liquid hog manure

| Heavy metal | Results given as µg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.000564 | ± | 0.00011 | 0.0223 | ± | 0.00052 |
| Al | 2.72 | ± | 0.057 | 477 | ± | 9.0 |
| As | 0.464 | ± | 0.0094 | 0.708 | ± | 0.016 |
| B | 36.2 | ± | 0.74 | 52.1 | ± | 1.4 |
| Ba | 1.90 | ± | 0.020 | 36.0 | ± | 0.30 |
| Be | 0.0200 | ± | | 0.173 | ± | 0.0060 |
| Bi | 0.00148 | ± | 0.00013 | 0.0167 | ± | 0.00031 |
| Ca | 5140 | ± | 150 | 26500 | ± | 490 |
| Cd | 0.00473 | ± | 0.00011 | 0.523 | ± | 0.0026 |
| Cl | 23900 | ± | 430 | 73900 | ± | 1700 |
| Co | 0.519 | ± | 0.0098 | 2.34 | ± | 0.0065 |
| Cr | 1.82 | ± | 0.044 | 9.84 | ± | 0.28 |
| Cu | 3.83 | ± | 0.14 | 587 | ± | 13 |
| Fe | 73.1 | ± | 1.2 | 1590 | ± | 63 |
| Hg | 0.00431 | ± | 0.00030 | 0.0192 | ± | 0.0013 |
| Li | 1.16 | ± | 0.035 | 1.56 | ± | 0.029 |
| Mg | 525 | ± | 13 | 12900 | ± | 220 |
| Mn | 9.57 | ± | 0.23 | 594 | ± | 14 |
| Mo | 0.815 | ± | 0.016 | 9.11 | ± | 0.11 |
| Na | 13100 | ± | 430 | 13600 | ± | 160 |
| Ni | 2.81 | ± | 0.059 | 9.58 | ± | 0.13 |
| Pb | 0.00688 | ± | 0.00066 | 0.781 | ± | 0.0050 |
| Sb | 0.0152 | ± | 0.00036 | 0.0971 | ± | 0.0019 |
| Se | 0.906 | ± | 0.022 | 3.80 | ± | 0.057 |
| Sn | BD | ± | | 0.0563 | ± | 0.0020 |
| Sr | 20.9 | ± | 0.55 | 68.6 | ± | 1.1 |
| Th | 0.000582 | ± | 0.000017 | 0.0455 | ± | 0.00055 |
| Ti | 13.9 | ± | 0.26 | 94.7 | ± | 2.3 |
| TI | 0.00113 | ± | 0.00014 | 0.173 | ± | 0.0023 |
| U | 0.532 | ± | 0.0087 | 2.82 | ± | 0.028 |
| V | 0.684 | ± | 0.017 | 5.67 | ± | 0.089 |
| Zn | 6.22 | ± | 0.29 | 1770 | ± | 33 |

Table 4. 72: Heavy metals for liquid hog culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0869 | ± | 0.0021 | 0.134 | ± | 0.0021 | 0.134 | ± | 0.0026 | 0.0550 | ± | 0.0016 |
| Al | 4520 | ± | 54 | 6840 | ± | 180 | 8320 | ± | 120 | 3160 | ± | 45 |
| As | 1.63 | ± | 0.010 | 1.85 | ± | 0.026 | 2.40 | ± | 0.020 | 0.793 | ± | 0.013 |
| B | 25.2 | ± | 1.0 | 26.2 | ± | 0.72 | 31.9 | ± | 0.95 | 14.5 | ± | 0.35 |
| Ba | 75.6 | ± | 1.3 | 95.2 | ± | 1.3 | 114 | ± | 1.4 | 48.5 | ± | 0.96 |
| Be | 0.111 | ± | 0.0055 | 0.140 | ± | 0.0064 | 0.162 | ± | 0.0052 | 0.0772 | ± | 0.0055 |
| Bi | 0.0315 | ± | 0.00057 | 0.0362 | ± | 0.0010 | 0.0443 | ± | 0.00039 | 0.0187 | ± | 0.00042 |
| Ca | 25000 | ± | 630 | 28500 | ± | 690 | 34700 | ± | 510 | 16800 | ± | 380 |
| Cd | 0.181 | ± | 0.0020 | 0.210 | ± | 0.0031 | 0.263 | ± | 0.0034 | 0.0987 | ± | 0.0026 |
| Cl | 50000 | ± | 2000 | 11500 | ± | 290 | 39300 | ± | 1100 | 14000 | ± | 480 |
| Co | 3.63 | ± | 0.051 | 3.93 | ± | 0.054 | 4.91 | ± | 0.061 | 2.09 | ± | 0.035 |
| Cr | 9.71 | ± | 0.090 | 13.0 | ± | 0.27 | 14.1 | ± | 0.20 | 6.73 | ± | 0.15 |
| Cu | 103 | ± | 2.2 | 114 | ± | 2.6 | 139 | ± | 2.5 | 58.3 | ± | 1.2 |
| Fe | 3860 | ± | 63 | 4820 | ± | 62 | 5730 | ± | 110 | 2930 | ± | 38 |
| Hg | 0.0153 | ± | 0.0012 | 0.0212 | ± | 0.0013 | 0.0232 | ± | 0.00086 | 0.0108 | ± | 0.0016 |
| Li | 4.56 | ± | 0.10 | 5.15 | ± | 0.10 | 6.53 | ± | 0.15 | 2.32 | ± | 0.055 |
| Mg | 6960 | ± | 85 | 8060 | ± | 69 | 9300 | ± | 130 | 4850 | ± | 79 |
| Mn | 279 | ± | 1.6 | 324 | ± | 2.0 | 403 | ± | 4.3 | 182 | ± | 1.2 |
| Mo | 3.48 | ± | 0.058 | 4.05 | ± | 0.064 | 4.99 | ± | 0.074 | 1.90 | ± | 0.039 |
| Na | 8920 | ± | 210 | 9600 | ± | 180 | 13700 | ± | 190 | 1910 | ± | 45 |
| Ni | 10.4 | ± | 0.17 | 11.7 | ± | 0.22 | 14.6 | ± | 0.22 | 5.21 | ± | 0.10 |
| Pb | 2.27 | ± | 0.010 | 2.58 | ± | 0.013 | 3.25 | ± | 0.20 | 1.41 | ± | 0.0060 |
| Sb | 0.0258 | ± | 0.0010 | 0.0455 | ± | 0.0013 | 0.0445 | ± | 0.00033 | 0.0236 | ± | 0.00031 |
| Se | 1.20 | ± | 0.031 | 1.61 | ± | 0.036 | 1.98 | ± | 0.11 | 0.924 | ± | 0.050 |
| Sn | 0.0392 | ± | 0.00071 | 0.264 | ± | 0.0029 | 0.134 | ± | 0.0016 | 0.0372 | ± | 0.0016 |
| Sr | 160 | ± | 3.1 | 182 | ± | 2.6 | 224 | ± | 2.9 | 104 | ± | 1.8 |
| Th | 0.481 | ± | 0.0067 | 0.977 | ± | 0.015 | 0.916 | ± | 0.012 | 0.301 | ± | 0.0061 |
| Ti | 167 | ± | 4.1 | 295 | ± | 7.6 | 305 | ± | 6.0 | 156 | ± | 0.83 |
| TI | 0.0854 | ± | 0.0025 | 0.108 | ± | 0.0022 | 0.125 | ± | 0.0031 | 0.0550 | ± | 0.0014 |
| U | 0.619 | ± | 0.011 | 0.682 | ± | 0.010 | 0.888 | ± | 0.017 | 0.341 | ± | 0.0064 |
| V | 9.31 | ± | 0.19 | 12.4 | ± | 0.24 | 13.9 | ± | 0.23 | 6.57 | ± | 0.14 |
| Zn | 436 | ± | 11 | 486 | ± | 9.3 | 625 | ± | 10 | 257 | ± | 5.2 |

Table 4. 73: Heavy metals for liquid sewage

| Heavy metal | Results given as μg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous substrate | | | Dried substrate | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 1.18 | ± | 0.016 | 10.1 | ± | 0.73 |
| Al | 41.3 | ± | 0.62 | 3490 | ± | 43 |
| As | 0.514 | ± | 0.048 | 0.956 | ± | 0.034 |
| B | 421 | ± | 1.2 | 290 | ± | 13 |
| Ba | 34.4 | ± | 0.57 | 118 | ± | 2.2 |
| Be | BD | ± | | 0.0313 | ± | 0.0023 |
| Bi | 0.0760 | ± | 0.00047 | 6.42 | ± | 0.11 |
| Ca | 68900 | ± | 210 | 63400 | ± | 1700 |
| Cd | 0.0201 | ± | 0.0060 | 0.223 | ± | 0.0039 |
| Cl | 151000 | ± | 600 | 212000 | ± | 9300 |
| Co | 0.270 | ± | 0.015 | 0.803 | ± | 0.0087 |
| Cr | 1.16 | ± | 0.047 | 10.4 | ± | 0.22 |
| Cu | 9.12 | ± | 0.28 | 46.0 | ± | 0.97 |
| Fe | 80.5 | ± | 6.7 | 1320 | ± | 44 |
| Hg | BD | ± | | 0.127 | ± | 0.0027 |
| Li | 10.3 | ± | 0.76 | 8.11 | ± | 0.15 |
| Mg | 19600 | ± | 0 | 13800 | ± | 230 |
| Mn | 69.3 | ± | 0.59 | 103 | ± | 1.5 |
| Mo | 1.14 | ± | 0.012 | 1.62 | ± | 0.018 |
| Na | 132000 | ± | 4300 | 97500 | ± | 1800 |
| Ni | 2.06 | ± | 0.26 | 3.50 | ± | 0.072 |
| Pb | 0.229 | ± | 0.023 | 2.52 | ± | 0.041 |
| Sb | 0.313 | ± | 0.0082 | 0.419 | ± | 0.0072 |
| Se | 0.880 | ± | 0.067 | 1.23 | ± | 0.16 |
| Sn | 0.311 | ± | 0.0080 | 1.58 | ± | 0.024 |
| Sr | 536 | ± | 2.7 | 470 | ± | 12 |
| Th | BD | ± | | 0.0491 | ± | 0.0011 |
| Ti | 10.4 | ± | 0.10 | 37.9 | ± | 1.8 |
| TI | 0.00978 | ± | 0.0042 | 0.0153 | ± | 0.00056 |
| U | 0.710 | ± | 0.0021 | 0.814 | ± | 0.019 |
| V | 0.125 | ± | 0.043 | 1.93 | ± | 0.055 |
| Zn | 10.9 | ± | 0.060 | 114 | ± | 2.1 |

Table 4. 74: Heavy metals for liquid sewage culture
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, μg/g dw | | | Final, μg/g dw | | | Liquid, μg/g dw | | | Solid, μg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.231 | ± | 0.0069 | 0.230 | ± | 0.0036 | 0.309 | ± | 0.0054 | 0.166 | ± | 0.0029 |
| Al | 7000 | ± | 210 | 5900 | ± | 66 | 9680 | ± | 98 | 4360 | ± | 50 |
| As | 1.91 | ± | 0.014 | 1.95 | ± | 0.011 | 2.61 | ± | 0.029 | 0.876 | ± | 0.019 |
| B | 25.6 | ± | 0.71 | 23.9 | ± | 0.54 | 31.5 | ± | 0.68 | 12.8 | ± | 0.44 |
| Ba | 92.7 | ± | 2.1 | 93.0 | ± | 1.7 | 122 | ± | 1.5 | 57.9 | ± | 0.79 |
| Be | 0.130 | ± | 0.011 | 0.114 | ± | 0.0045 | 0.161 | ± | 0.0050 | 0.0786 | ± | 0.0024 |
| Bi | 0.0844 | ± | 0.00069 | 0.115 | ± | 0.0010 | 0.113 | ± | 0.0011 | 0.0472 | ± | 0.00075 |
| Ca | 26000 | ± | 670 | 26400 | ± | 660 | 33400 | ± | 610 | 15800 | ± | 270 |
| Cd | 0.143 | ± | 0.0029 | 0.153 | ± | 0.0024 | 0.189 | ± | 0.0031 | 0.0736 | ± | 0.0029 |
| Cl | 20200 | ± | 390 | 32200 | ± | 1000 | 33000 | ± | 480 | 5470 | ± | 680 |
| Co | 4.00 | ± | 0.049 | 4.15 | ± | 0.056 | 5.16 | ± | 0.040 | 2.06 | ± | 0.032 |
| Cr | 11.0 | ± | 0.099 | 10.2 | ± | 0.14 | 14.0 | ± | 0.13 | 7.13 | ± | 0.098 |
| Cu | 42.9 | ± | 0.48 | 45.5 | ± | 0.60 | 54.7 | ± | 0.53 | 23.1 | ± | 0.36 |
| Fe | 4810 | ± | 73 | 4530 | ± | 44 | 6300 | ± | 100 | 3310 | ± | 33 |
| Hg | 0.0194 | ± | 0.0011 | 0.0214 | ± | 0.00056 | 0.0267 | ± | 0.0014 | 0.0120 | ± | 0.0010 |
| Li | 5.64 | ± | 0.10 | 5.11 | ± | 0.12 | 7.13 | ± | 0.14 | 2.68 | ± | 0.060 |
| Mg | 6610 | ± | 71 | 6930 | ± | 93 | 8620 | ± | 130 | 4260 | ± | 57 |
| Mn | 254 | ± | 1.9 | 262 | ± | 1.6 | 346 | ± | 1.7 | 146 | ± | 1.4 |
| Mo | 2.89 | ± | 0.043 | 2.82 | ± | 0.038 | 3.77 | ± | 0.057 | 1.40 | ± | 0.023 |
| Na | 9560 | ± | 140 | 9420 | ± | 220 | 13800 | ± | 300 | 1870 | ± | 55 |
| Ni | 11.2 | ± | 0.16 | 11.4 | ± | 0.22 | 14.8 | ± | 0.17 | 5.14 | ± | 0.086 |
| Pb | 2.70 | ± | 0.018 | 2.72 | ± | 0.025 | 3.42 | ± | 0.028 | 1.50 | ± | 0.0085 |
| Sb | 0.0405 | ± | 0.0011 | 0.0272 | ± | 0.00059 | 0.0390 | ± | 0.0012 | 0.0264 | ± | 0.00075 |
| Se | 1.14 | ± | 0.055 | 1.15 | ± | 0.056 | 1.60 | ± | 0.063 | 0.637 | ± | 0.024 |
| Sn | 0.153 | ± | 0.0024 | 0.0635 | ± | 0.0015 | 0.199 | ± | 0.0026 | 0.212 | ± | 0.0037 |
| Sr | 185 | ± | 3.6 | 191 | ± | 4.4 | 240 | ± | 2.9 | 103 | ± | 1.5 |
| Th | 0.867 | ± | 0.0061 | 0.643 | ± | 0.0071 | 1.14 | ± | 0.0068 | 0.677 | ± | 0.0070 |
| Ti | 279 | ± | 5.9 | 216 | ± | 4.9 | 342 | ± | 5.3 | 189 | ± | 2.6 |
| TI | 0.0834 | ± | 0.0014 | 0.0801 | ± | 0.0012 | 0.106 | ± | 0.0017 | 0.0547 | ± | 0.00083 |
| U | 0.310 | ± | 0.0055 | 0.318 | ± | 0.0039 | 0.421 | ± | 0.0049 | 0.181 | ± | 0.0026 |
| V | 12.3 | ± | 0.18 | 11.3 | ± | 0.17 | 15.2 | ± | 0.19 | 7.38 | ± | 0.15 |
| Zn | 250 | ± | 4.7 | 255 | ± | 5.0 | 325 | ± | 3.6 | 138 | ± | 2.3 |

### *4.6 Heavy metals for substrates used in the ARC Pilot Plant,* please refer to Section 4.2 for explanations

Table 4. 75: Heavy metals for ARC Pilot Plant (1) mixture
Dairy manure and glycerine

| Heavy metal | Results given as µg/g dw | | |
|---|---|---|---|
| | Aqueous mixture | | |
| | Mean | | Std dev |
| Ag | 0.00103 | ± | 0.000087 |
| Al | 4.95 | ± | 0.10 |
| As | 0.0877 | ± | 0.00041 |
| B | 8.70 | ± | 0.11 |
| Ba | 0.693 | ± | 0.0040 |
| Be | 0.000554 | ± | 0.000054 |
| Bi | 0.00351 | ± | 0.00019 |
| Ca | 73.0 | ± | 2.0 |
| Cd | 0.00297 | ± | 0.000068 |
| Cl | 3240 | ± | 36 |
| Co | 0.419 | ± | 0.0052 |
| Cr | 0.560 | ± | 0.0057 |
| Cu | 1.26 | ± | 0.017 |
| Fe | 51.7 | ± | 0.53 |
| Hg | 0.00204 | ± | 0.00017 |
| Li | 0.211 | ± | 0.015 |
| Mg | 189 | ± | 1.8 |
| Mn | 3.84 | ± | 0.017 |
| Mo | 0.169 | ± | 0.0034 |
| Na | 2580 | ± | 62 |
| Ni | 0.652 | ± | 0.0058 |
| Pb | 0.0138 | ± | 0.00025 |
| Sb | 0.00561 | ± | 0.00013 |
| Se | 0.304 | ± | 0.0035 |
| Sn | 0.00500 | ± | 0.00032 |
| Sr | 2.03 | ± | 0.0041 |
| Th | 0.0141 | ± | 0.0067 |
| Ti | 2.78 | ± | 0.052 |
| TI | 0.00172 | ± | 0.000090 |
| U | 0.598 | ± | 0.013 |
| V | 0.304 | ± | 0.0025 |
| Zn | 4.31 | ± | 0.039 |

Table 4. 76: Heavy metals for ARC Pilot Plant (1) culture
Dairy manure and glycerine
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.0168 | ± | 0.00052 | 0.0283 | ± | 0.0010 | 0.0607 | ± | 0.0040 | 0.0180 | ± | 0.0010 |
| Al | 731 | ± | 6.3 | 1650 | ± | 13 | 3200 | ± | 56 | 808 | ± | 5.5 |
| As | 0.167 | ± | 0.0047 | 0.360 | ± | 0.010 | 0.722 | ± | 0.0078 | 0.301 | ± | 0.0047 |
| B | 21.4 | ± | 0.32 | 23.0 | ± | 0.90 | 45.4 | ± | 1.9 | 19.1 | ± | 0.67 |
| Ba | 24.5 | ± | 0.32 | 47.7 | ± | 0.32 | 79.6 | ± | 0.64 | 29.3 | ± | 0.37 |
| Be | 0.0401 | ± | 0.0047 | 0.0480 | ± | 0.0095 | 0.106 | ± | 0.0082 | 0.0300 | ± | 0.0028 |
| Bi | 0.0761 | ± | 0.0012 | 0.0574 | ± | 0.00063 | 0.119 | ± | 0.0015 | 0.0379 | ± | 0.00090 |
| Ca | 9740 | ± | 150 | 14800 | ± | 270 | 19800 | ± | 450 | 14100 | ± | 260 |
| Cd | 0.0960 | ± | 0.0023 | 0.165 | ± | 0.0031 | 0.318 | ± | 0.0041 | 0.110 | ± | 0.0020 |
| Cl | 13400 | ± | 420 | 18600 | ± | 77 | 37500 | ± | 760 | 8390 | ± | 250 |
| Co | 1.07 | ± | 0.0074 | 1.70 | ± | 0.011 | 3.96 | ± | 0.055 | 1.04 | ± | 0.018 |
| Cr | 3.64 | ± | 0.27 | 9.60 | ± | 0.11 | 23.2 | ± | 1.4 | 6.31 | ± | 0.17 |
| Cu | 33.1 | ± | 0.51 | 54.8 | ± | 0.47 | 112 | ± | 1.5 | 32.9 | ± | 0.45 |
| Fe | 462 | ± | 12 | 1720 | ± | 34 | 2490 | ± | 15 | 1010 | ± | 19 |
| Hg | 0.00505 | ± | 0.0014 | 0.0118 | ± | 0.00089 | 0.0207 | ± | 0.0013 | 0.00821 | ± | 0.00070 |
| Li | 1.38 | ± | 0.022 | 1.46 | ± | 0.035 | 4.66 | ± | 0.19 | 0.752 | ± | 0.015 |
| Mg | 3080 | ± | 29 | 3860 | ± | 55 | 8700 | ± | 130 | 2790 | ± | 79 |
| Mn | 101 | ± | 0.15 | 151 | ± | 1.2 | 292 | ± | 4.9 | 118 | ± | 2.9 |
| Mo | 0.856 | ± | 0.011 | 1.78 | ± | 0.017 | 3.78 | ± | 0.032 | 1.03 | ± | 0.0082 |
| Na | 3670 | ± | 47 | 3890 | ± | 67 | 12300 | ± | 200 | 1680 | ± | 23 |
| Ni | 1.79 | ± | 0.025 | 4.15 | ± | 0.032 | 7.26 | ± | 0.13 | 2.42 | ± | 0.049 |
| Pb | 0.296 | ± | 0.0035 | 0.982 | ± | 0.014 | 1.69 | ± | 0.0081 | 0.513 | ± | 0.0026 |
| Sb | 0.0313 | ± | 0.0010 | 0.0733 | ± | 0.0033 | 0.130 | ± | 0.0026 | 0.0513 | ± | 0.0014 |
| Se | 0.313 | ± | 0.069 | 0.986 | ± | 0.025 | 2.24 | ± | 0.057 | 0.504 | ± | 0.064 |
| Sn | 0.0745 | ± | 0.00074 | 0.221 | ± | 0.0029 | 0.365 | ± | 0.0025 | 0.147 | ± | 0.0031 |
| Sr | 36.7 | ± | 0.36 | 64.9 | ± | 0.54 | 110 | ± | 0.89 | 50.7 | ± | 0.45 |
| Th | 0.131 | ± | 0.0021 | 0.287 | ± | 0.0026 | 0.470 | ± | 0.0046 | 0.144 | ± | 0.0017 |
| Ti | 40.4 | ± | 0.98 | 69.1 | ± | 2.0 | 119 | ± | 1.1 | 46.6 | ± | 0.75 |
| TI | 0.0414 | ± | 0.00068 | 0.0759 | ± | 0.0024 | 0.133 | ± | 0.0036 | 0.0426 | ± | 0.0013 |
| U | 0.684 | ± | 0.0055 | 1.29 | ± | 0.017 | 2.39 | ± | 0.041 | 0.802 | ± | 0.020 |
| V | 1.97 | ± | 0.025 | 3.31 | ± | 0.16 | 7.38 | ± | 0.076 | 2.35 | ± | 0.023 |
| Zn | 117 | ± | 1.2 | 183 | ± | 2.1 | 482 | ± | 5.1 | 132 | ± | 1.5 |

Table 4. 77: Heavy metals for ARC Pilot Plant (2) mixture
Wet distillers grains from ethanol production

| Heavy metal | Results given as µg/g dw | | |
|---|---|---|---|
| | Aqueous mixture | | |
| | Mean | | Std dev |
| Ag | | ± | |
| Al | 1.34 | ± | 0.039 |
| As | 0.0662 | ± | 0.00078 |
| B | 3.67 | ± | 0.045 |
| Ba | 1.16 | ± | 0.0039 |
| Be | | ± | |
| Bi | | ± | |
| Ca | 805 | ± | 12 |
| Cd | 0.0262 | ± | 0.000090 |
| Cl | 867 | ± | 29 |
| Co | 0.0125 | ± | 0.00018 |
| Cr | 0.0844 | ± | 0.0016 |
| Cu | 1.96 | ± | 0.018 |
| Fe | 7.33 | ± | 0.048 |
| Hg | 0.00167 | ± | 0.00045 |
| Li | 0.772 | ± | 0.045 |
| Mg | 2590 | ± | 50 |
| Mn | 56.8 | ± | 1.1 |
| Mo | 0.636 | ± | 0.0078 |
| Na | 1950 | ± | 31 |
| Ni | 0.140 | ± | 0.0039 |
| Pb | 0.000406 | ± | 0.000095 |
| Sb | 0.000739 | ± | 0.000031 |
| Se | 0.0687 | ± | 0.017 |
| Sn | | ± | |
| Sr | 6.21 | ± | 0.036 |
| Th | 0.0000442 | ± | 0.0000066 |
| Ti | 12.2 | ± | 0.34 |
| TI | 0.000375 | ± | 0.000039 |
| U | 0.0000530 | ± | 0.000011 |
| V | 0.00751 | ± | 0.00025 |
| Zn | 47.0 | ± | 1.3 |

Table 4. 78: Heavy metals for ARC Pilot Plant (2) culture
Wet distillers grains from ethanol production
Includes initial culture, final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.00609 | ± | 0.00057 | 0.0165 | ± | 0.00024 | 0.0265 | ± | 0.00042 | 0.0126 | ± | 0.00044 |
| Al | 15.2 | ± | 0.11 | 210 | ± | 0.97 | 275 | ± | 1.6 | 151 | ± | 0.94 |
| As | 0.0627 | ± | 0.0024 | 0.241 | ± | 0.0079 | 0.480 | ± | 0.010 | 0.188 | ± | 0.0041 |
| B | 4.65 | ± | 0.087 | 20.1 | ± | 0.21 | 57.9 | ± | 1.2 | 12.7 | ± | 0.15 |
| Ba | 3.69 | ± | 0.032 | 19.8 | ± | 0.23 | 29.0 | ± | 0.25 | 18.1 | ± | 0.18 |
| Be | 0.00150 | ± | 0.00070 | 0.0132 | ± | 0.0028 | 0.0181 | ± | 0.0014 | 0.0112 | ± | 0.0037 |
| Bi | 0.00210 | ± | 0.00023 | 0.204 | ± | 0.0010 | 0.236 | ± | 0.0020 | 0.132 | ± | 0.0010 |
| Ca | 1530 | ± | 12 | 10000 | ± | 100 | 16200 | ± | 160 | 9520 | ± | 60 |
| Cd | 0.0431 | ± | 0.0013 | 0.0954 | ± | 0.0027 | 0.219 | ± | 0.0026 | 0.0766 | ± | 0.0019 |
| Cl | 4700 | ± | 60 | 5120 | ± | 510 | 34100 | ± | 770 | 4830 | ± | 85 |
| Co | 0.0195 | ± | 0.00045 | 0.814 | ± | 0.0068 | 2.42 | ± | 0.016 | 0.506 | ± | 0.0078 |
| Cr | 0.179 | ± | 0.011 | 6.79 | ± | 0.094 | 16.1 | ± | 0.23 | 5.50 | ± | 0.072 |
| Cu | 10.8 | ± | 0.080 | 30.7 | ± | 0.29 | 80.0 | ± | 0.68 | 23.2 | ± | 0.17 |
| Fe | 106 | ± | 0.55 | 5200 | ± | 51 | 9800 | ± | 44 | 4350 | ± | 26 |
| Hg | 0.00215 | ± | 0.00036 | 0.00882 | ± | 0.0011 | 0.0181 | ± | 0.00052 | 0.00881 | ± | 0.0012 |
| Li | 0.578 | ± | 0.0097 | 1.73 | ± | 0.027 | 8.48 | ± | 0.16 | 0.465 | ± | 0.018 |
| Mg | 2090 | ± | 9.6 | 6710 | ± | 33 | 6720 | ± | 57 | 6660 | ± | 46 |
| Mn | 59.3 | ± | 0.16 | 214 | ± | 0.66 | 296 | ± | 1.6 | 195 | ± | 0.59 |
| Mo | 1.52 | ± | 0.011 | 6.28 | ± | 0.080 | 19.7 | ± | 0.16 | 3.87 | ± | 0.043 |
| Na | 1790 | ± | 12 | 6750 | ± | 47 | 32300 | ± | 260 | 1540 | ± | 13 |
| Ni | 0.230 | ± | 0.0018 | 6.18 | ± | 0.067 | 17.0 | ± | 0.10 | 4.33 | ± | 0.028 |
| Pb | 0.0289 | ± | 0.00034 | 0.478 | ± | 0.0016 | 1.50 | ± | 0.0098 | 1.04 | ± | 0.0031 |
| Sb | 0.00230 | ± | 0.00018 | 0.103 | ± | 0.0020 | 0.209 | ± | 0.0012 | 0.0798 | ± | 0.0012 |
| Se | 0.248 | ± | 0.023 | 0.516 | ± | 0.034 | 1.38 | ± | 0.056 | 0.238 | ± | 0.033 |
| Sn | 0.00648 | ± | 0.00057 | 0.233 | ± | 0.0041 | 0.600 | ± | 0.0049 | 0.111 | ± | 0.0026 |
| Sr | 9.76 | ± | 0.082 | 39.1 | ± | 0.49 | 67.2 | ± | 0.68 | 35.0 | ± | 0.47 |
| Th | 0.00379 | ± | 0.00020 | 0.0755 | ± | 0.00047 | 0.0844 | ± | 0.0010 | 0.0489 | ± | 0.0010 |
| Ti | 16.7 | ± | 0.27 | 42.3 | ± | 0.76 | 61.0 | ± | 0.42 | 37.0 | ± | 0.24 |
| TI | 0.000740 | ± | 0.00012 | 0.0157 | ± | 0.00041 | 0.0287 | ± | 0.00051 | 0.0121 | ± | 0.00043 |
| U | 0.00796 | ± | 0.00019 | 0.273 | ± | 0.0019 | 0.422 | ± | 0.0043 | 0.253 | ± | 0.0022 |
| V | 0.0342 | ± | 0.0017 | 1.17 | ± | 0.0099 | 1.84 | ± | 0.019 | 0.932 | ± | 0.022 |
| Zn | 50.6 | ± | 0.35 | 131 | ± | 1.3 | 259 | ± | 1.2 | 113 | ± | 0.83 |

*4.7 Heavy metals for inoculum used in this study*, please refer to Section 4.2 for explanations

Table 4. 79: Heavy metals for inoculum
Inoculum after collection and before use in cultures

| Heavy metal | Results given as μg/g dw | | | | | |
|---|---|---|---|---|---|---|
| | Aqueous inoculum | | | Dried inoculum | | |
| | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.00114 | ± | 0.00099 | 0.109 | ± | 0.0043 |
| Al | 2.88 | ± | 0.68 | 4640 | ± | 97 |
| As | BD | ± | | 1.37 | ± | 0.033 |
| B | 8.32 | ± | 0.17 | 26.3 | ± | 0.88 |
| Ba | 2.26 | ± | 0.0034 | 90.1 | ± | 1.4 |
| Be | BD | ± | | 0.150 | ± | 0.012 |
| Bi | BD | | | 0.0619 | ± | 0.0020 |
| Ca | 735 | ± | 20 | 23100 | ± | 660 |
| Cd | 0.00615 | ± | 0.00071 | 0.122 | ± | 0.0037 |
| Cl | 16600 | ± | 150 | 35000 | ± | 1600 |
| Co | 0.567 | ± | 0.027 | 4.32 | ± | 0.11 |
| Cr | BD | | | 7.16 | ± | 0.19 |
| Cu | 0.626 | ± | 0.16 | 33.6 | ± | 0.63 |
| Fe | 265 | ± | 26 | 3860 | ± | 120 |
| Hg | 0.0213 | ± | 0.0042 | 0.0223 | ± | 0.0022 |
| Li | 1.12 | ± | 0.034 | 4.76 | ± | 0.10 |
| Mg | 214 | ± | 3.3 | 8060 | ± | 140 |
| Mn | 3.97 | ± | 0.066 | 209 | ± | 3.4 |
| Mo | 0.253 | ± | 0.028 | 2.17 | ± | 0.054 |
| Na | 7880 | ± | 61 | 10500 | ± | 190 |
| Ni | 2.24 | ± | 0.052 | 12.1 | ± | 0.41 |
| Pb | 0.123 | ± | 0.0057 | 2.45 | ± | 0.042 |
| Sb | 0.00839 | ± | 0.0018 | 0.0287 | ± | 0.00058 |
| Se | 0.155 | ± | 0.050 | 0.334 | ± | 0.12 |
| Sn | BD | ± | | 0.0706 | ± | 0.0019 |
| Sr | 15.7 | ± | 0.51 | 150 | ± | 4.9 |
| Th | 0.0384 | ± | 0.0097 | 0.774 | ± | 0.022 |
| Ti | 7.58 | ± | 0.00028 | 183 | ± | 5.3 |
| TI | 0.00107 | ± | 0.53 | 0.109 | ± | 0.0033 |
| U | | ± | | 0.494 | ± | 0.012 |
| V | 0.369 | ± | 0.036 | 8.86 | ± | 0.24 |
| Zn | 8.88 | ± | 1.3 | 201 | ± | 5.5 |

Table 4. 80: Inoculum mixture and post digestion separation fractions, 44-day
Initial culture was ioculum after 7-day pre-culture incubation
Final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | | | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | 0.133 | ± | 0.0036 | 0.160 | ± | 0.0022 | 0.225 | ± | 0.0037 | 0.115 | ± | 0.0030 |
| Al | 6050 | ± | 93 | 7600 | ± | 52 | 9670 | ± | 49 | 5290 | ± | 24 |
| As | 1.65 | ± | 0.047 | 2.24 | ± | 0.022 | 2.73 | ± | 0.030 | 1.15 | ± | 0.015 |
| B | 27.8 | ± | 1.3 | 29.1 | ± | 0.46 | 35.6 | ± | 0.77 | 16.3 | ± | 0.14 |
| Ba | 97.6 | ± | 2.1 | 103 | ± | 1.0 | 127 | ± | 1.4 | 61.9 | ± | 0.77 |
| Be | 0.146 | ± | 0.0089 | 0.148 | ± | 0.016 | 0.180 | ± | 0.0073 | 0.115 | ± | 0.0082 |
| Bi | 0.0601 | ± | 0.0015 | 0.0483 | ± | 0.0012 | 0.0501 | ± | 0.0012 | 0.0246 | ± | 0.00062 |
| Ca | 23900 | ± | 470 | 26100 | ± | 430 | 33000 | ± | 250 | 18300 | ± | 230 |
| Cd | 0.126 | ± | 0.0084 | 0.156 | ± | 0.0031 | 0.187 | ± | 0.0023 | 0.0975 | ± | 0.0019 |
| Cl | 25500 | ± | 980 | 22800 | ± | 650 | 17900 | ± | 140 | 7660 | ± | 93 |
| Co | 4.98 | ± | 0.085 | 5.07 | ± | 0.040 | 5.91 | ± | 0.032 | 2.93 | ± | 0.016 |
| Cr | 8.15 | ± | 0.16 | 11.1 | ± | 0.062 | 15.5 | ± | 0.13 | 8.99 | ± | 0.060 |
| Cu | 39.3 | ± | 1.0 | 50.7 | ± | 0.41 | 61.1 | ± | 0.47 | 32.0 | ± | 0.34 |
| Fe | 4430 | ± | 48 | 5430 | ± | 29 | 6430 | ± | 33 | 3910 | ± | 30 |
| Hg | 0.0276 | ± | 0.0022 | 0.0301 | ± | 0.0021 | 0.0302 | ± | 0.0016 | 0.0191 | ± | 0.00067 |
| Li | 5.52 | ± | 0.16 | 6.93 | ± | 0.12 | 8.58 | ± | 0.12 | 3.58 | ± | 0.027 |
| Mg | 8910 | ± | 120 | 8300 | ± | 64 | 10000 | ± | 49 | 5600 | ± | 45 |
| Mn | 233 | ± | 1.3 | 259 | ± | 1.9 | 324 | ± | 1.4 | 161 | ± | 1.2 |
| Mo | 2.43 | ± | 0.063 | 3.21 | ± | 0.030 | 3.84 | ± | 0.050 | 1.82 | ± | 0.035 |
| Na | 11200 | ± | 240 | 11600 | ± | 93 | 16100 | ± | 130 | 3130 | ± | 37 |
| Ni | 13.9 | ± | 0.18 | 12.3 | ± | 0.11 | 15.8 | ± | 0.14 | 6.92 | ± | 0.098 |
| Pb | 2.82 | ± | 0.033 | 2.69 | ± | 0.022 | 3.26 | ± | 0.0088 | 1.71 | ± | 0.011 |
| Sb | 0.0313 | ± | 0.0016 | 0.0438 | ± | 0.00069 | 0.0511 | ± | 0.00087 | 0.0297 | ± | 0.00087 |
| Se | 0.900 | ± | 0.053 | 1.44 | ± | 0.092 | 1.59 | ± | 0.071 | 0.920 | ± | 0.034 |
| Sn | 0.0858 | ± | 0.0040 | 0.297 | ± | 0.0017 | 0.500 | ± | 0.0024 | 0.195 | ± | 0.0041 |
| Sr | 160 | ± | 3.0 | 191 | ± | 3.2 | 241 | ± | 3.2 | 118 | ± | 2.2 |
| Th | 1.13 | ± | 0.018 | 1.14 | ± | 0.013 | 1.50 | ± | 0.016 | 0.713 | ± | 0.0057 |
| Ti | 239 | ± | 5.4 | 301 | ± | 4.0 | 358 | ± | 6.6 | 227 | ± | 2.8 |
| TI | 0.129 | ± | 0.0032 | 0.0889 | ± | 0.0010 | 0.106 | ± | 0.00086 | 0.0592 | ± | 0.0013 |
| U | 0.580 | ± | 0.012 | 0.362 | ± | 0.0029 | 0.440 | ± | 0.0050 | 0.215 | ± | 0.0014 |
| V | 11.5 | ± | 0.27 | 15.3 | ± | 0.12 | 18.9 | ± | 0.10 | 9.52 | ± | 0.091 |
| Zn | 220 | ± | 3.7 | 283 | ± | 4.2 | 350 | ± | 5.3 | 193 | ± | 4.3 |

Table 4. 81: Inoculum mixture and post digestion separation fractions, 30-day
Includes final culture and post culture separation fractions using dried sample.

| Heavy metal | Cultures | | | | Post-digestion separation fractions | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Initial, µg/g dw | Final, µg/g dw | | | Liquid, µg/g dw | | | Solid, µg/g dw | | |
| | | Mean | | Std dev | Mean | | Std dev | Mean | | Std dev |
| Ag | | 0.0998 | ± | 0.0025 | 0.130 | ± | 0.0028 | 0.0671 | ± | 0.0020 |
| Al | | 6630 | ± | 29 | 7850 | ± | 270 | 4090 | ± | 34 |
| As | | 2.05 | ± | 0.016 | 2.50 | ± | 0.030 | 1.07 | ± | 0.012 |
| B | | 26.4 | ± | 0.62 | 30.5 | ± | 0.82 | 14.5 | ± | 0.58 |
| Ba | | 96.7 | ± | 0.60 | 124 | ± | 1.3 | 56.7 | ± | 0.80 |
| Be | | 0.136 | ± | 0.0067 | 0.171 | ± | 0.011 | 0.0704 | ± | 0.0057 |
| Bi | | 0.0385 | ± | 0.0010 | 0.0533 | ± | 0.0010 | 0.0262 | ± | 0.00055 |
| Ca | | 29900 | ± | 270 | 35000 | ± | 410 | 16900 | ± | 230 |
| Cd | | 0.168 | ± | 0.0039 | 0.203 | ± | 0.0028 | 0.0851 | ± | 0.0011 |
| Cl | | 29300 | ± | 300 | 71400 | ± | 1700 | 18300 | ± | 530 |
| Co | | 4.40 | ± | 0.029 | 5.39 | ± | 0.055 | 2.82 | ± | 0.023 |
| Cr | | 14.0 | ± | 0.14 | 15.0 | ± | 0.11 | 6.57 | ± | 0.044 |
| Cu | | 46.9 | ± | 0.27 | 58.0 | ± | 0.64 | 27.6 | ± | 0.40 |
| Fe | | 4980 | ± | 20 | 5780 | ± | 58 | 3790 | ± | 34 |
| Hg | | 0.0231 | ± | 0.00066 | 0.0309 | ± | 0.0017 | 0.0130 | ± | 0.00070 |
| Li | Not done | 5.53 | ± | 0.072 | 6.77 | ± | 0.31 | 2.62 | ± | 0.076 |
| Mg | | 8700 | ± | 53 | 10300 | ± | 68 | 5420 | ± | 67 |
| Mn | | 275 | ± | 0.83 | 348 | ± | 0.80 | 179 | ± | 0.96 |
| Mo | | 2.95 | ± | 0.015 | 3.62 | ± | 0.038 | 1.67 | ± | 0.038 |
| Na | | 11500 | ± | 95 | 13500 | ± | 120 | 2580 | ± | 36 |
| Ni | | 13.8 | ± | 0.069 | 16.0 | ± | 0.21 | 6.35 | ± | 0.073 |
| Pb | | 2.88 | ± | 0.022 | 3.72 | ± | 0.012 | 1.85 | ± | 0.014 |
| Sb | | 0.0297 | ± | 0.0019 | 0.0313 | ± | 0.00073 | 0.0212 | ± | 0.00090 |
| Se | | 1.16 | ± | 0.042 | 1.18 | ± | 0.063 | 0.788 | ± | 0.041 |
| Sn | | 0.111 | ± | 0.0016 | 0.0484 | ± | 0.0016 | 0.0252 | ± | 0.0015 |
| Sr | | 193 | ± | 1.8 | 236 | ± | 3.9 | 120 | ± | 1.3 |
| Th | | 0.850 | ± | 0.0070 | 0.734 | ± | 0.0053 | 0.353 | ± | 0.0030 |
| Ti | | 266 | ± | 1.6 | 226 | ± | 3.2 | 177 | ± | 3.1 |
| TI | | 0.0837 | ± | 0.0020 | 0.105 | ± | 0.0014 | 0.0562 | ± | 0.0015 |
| U | | 0.348 | ± | 0.0032 | 0.413 | ± | 0.0034 | 0.180 | ± | 0.0027 |
| V | | 12.8 | ± | 0.075 | 14.7 | ± | 0.14 | 7.56 | ± | 0.11 |
| Zn | | 269 | ± | 1.8 | 346 | ± | 6.4 | 187 | ± | 1.7 |

## 5.0 Heavy Metal Results Compared to CCME Soil and Water Guidelines

Generally, for the batch cultures, it was expected that the heavy metals would be increased in the digestate due to loss of solids during digestion. This expectation was not seen in all the heavy metal results. However, the general trend for the results showed that there was an increase in the heavy metal concentrations during digestion. There is no obvious reason for the discrepancies. However, one reason could be that the substrate matrix was such that the heavy metals may not have been evenly distributed throughout the initial culture mixture during drying and regrinding even though great care was taken to mix samples. This is a consistent problem with biowaste substrates. As well, the initial and final culture samples for the substrates were not always analyzed for heavy metals at the same time, since they were produced 30 days apart. For each substrate, the final culture digestate, separated liquid and separated solid samples were analyzed for heavy metals at the same time. Since these samples were produced during digestion, they were likely more homogenous than the initial culture mixtures due to the break down of components during the digestion process. Comparison of these samples showed that there was an increase in the heavy metal concentration in the liquid fraction compared to the digestate and a decrease in the solid fraction compared to digestate and separated liquid. These results showed that the heavy metals generally remained in the liquid fraction of the digestate and were not largely associated with the solid fraction.

The CCME soil and water guidelines, shown in Tables 2.2 and 2.3, were used to compare the heavy metal results for the batch culture and the ARC Pilot Plant substrates and samples. The CCME guidelines for soils are given in mg/kg or μg/g and for water, μg/L. The heavy metal results in the tables for this report are given in μg/g and the μg/L results were calculated from these results in order to match the units from the guidelines.

The comparison results are shown in Tables 5.1 to 5.5 for soil and Tables 5.6 to 5.10 for water. The comparison to CCME guidelines was done to evaluate the digestion products for land application and agricultural water use. The comparison for soil included substrate and all post-digestion samples. The comparison for water was only for the separated liquid fraction.

The soil comparisons were for substrate alone, digestate (culture mixture after incubation) and separated liquid and solid fractions. Results for aqueous available heavy metals were also compared and not entered in the tables, since only chicken broiler manure had a Cu result that was higher than the CCME guideline (Table 5.1).

For Tables 5.1 to 5.5, columns labeled “Heavy metals related to: unmixed substrate, digestate (substrate plus inoculum), separated liquid, separated solid”, the results were taken from the reports obtained from the Analytical Chemistry Laboratory, Environmental Management Group at ARC. Many of the results for Cu, Se and Zn were above the CCME guidelines, especially for manures. The inoculum had fairly high values for Cu, Se and Zn (Tables 4.79 to 4.81), so that adding substrate to batch culture mixtures did not always dilute these heavy metals to values below the guideline limit. This finding indicated that for anaerobic digestion, the inoculum will have an influence on heavy metal concentrations.

In order to get a clearer indication as to whether the substrates influenced the heavy metal results, calculations were done to subtract the inoculum heavy metal results from the culture mixture heavy metal results for each of the substrates. In order to do this, the following assumptions were made. The first assumption was that during anaerobic digestion, the inoculum in the culture mixture behaved in the same manner as when the inoculum was incubated alone. The second assumption was that the proportion of substrate in the separated liquid and solid fractions was the same as the proportion of substrate in the initial culture mixture. Given that the cultures contained biological activity, these assumptions were loosely applied. Therefore, the results from the subtraction of heavy metals in the inoculum were interpreted in a general sense and not to specific soil and water applications. For the tables, the heavy metals were entered in the columns, labeled “Heavy metals related to substrate in culture with values for inoculum subtracted”, only if it was clear that the subtraction of heavy metals from the substrate left a value that was higher than the lowest CCME guideline value.

This approach clearly showed that heavy metals from most vegetable/fruit/grain waste (Table 5.2) and waste associated with animals (Table 5.3) did not have elevated heavy metal levels for soil application. For the substrates used in this study, the potato plant vine substrate had elevated Cr and Ni (Table 5.2). These heavy metals were diluted when inoculum was added to the culture mixture. There was elevated heavy metals in the separated liquid for grocery waste (Se, Table 5.2), poultry slaughterhouse waste (Se, Table 5.3), thermally hydrolyzed biowaste #1 (Se and Zn, Table 5.3) and thermally hydrolyzed biowaste #2 (Zn, Table 5.3). However, for agricultural water applications, the non-manure substrates had many heavy metal values that were above the CCME guidelines (Tables 5.7 and 5.8).

The manure substrates (Tables 5.1 and 5.6) and the sewage sludge (Tables 5.3 and 5.8) contained elevated heavy metal concentrations. Even the liquid sewage with low solids had elevated soil application values for Se (Table 5.3) and water application values for Al and Fe (Table 5.8). Clearly, these substrates would create a problem for disposal of post-digestion products.

For the ARC Pilot Plant substrates, no inoculum was added. Therefore, it was expected that the heavy metals in the digestion samples would be similar to the substrates that were used. For the ARC Pilot Plant 1, Cu, Se and Zn levels were above CCME soil guidelines for the separated liquid (Table 5.4). The Zn was elevated for the dairy manure #1 substrate (Table 4.29) and the digestate from the batch culture had elevated Cu and Zn in the separated liquid after the inoculum heavy metals were subtracted (Table 5.1). For the water CCME guidelines, shown in Table 5.9, ARC Pilot Plant 1 did not have any elevated heavy metals that were different from the dairy manure #1 substrate or the glycerine (data for substrates relating to CCME water guidelines not shown).

ARC Pilot Plant 2 had elevated soil Cu and Zn values in the separated liquid (Table 5.4) and these heavy metals were not seen for the wet distillers grain substrate or the batch culture digestate samples after the inoculum heavy metals were subtracted (Table 5.2). For the water CCME guidelines, shown in Table 5.9, the ARC Pilot Plant 2 liquid sample had elevated Ni that was not seen for the wet distillers grain substrate (data for substrates relating to CCME water guidelines not shown). The CCME guideline for Ni in irrigation water is 200 μg/L and the ARC Pilot Plant value was calculated to be 230 μg/L. The wet distillers grain substrate only had 44 μg/L of Ni, so this heavy metal must have come from another source.

It is likely that the results for the wet distillers grain for the ARC Pilot Plant 2 sample could be related to the continuous process that occurs in the ARC Pilot Plant system. Dairy manure (#1) had been used in the ARC Pilot Plant from April, 2008 to November, 2008. The wet distillers grain was gradually added to the digester in November, 2008. By January, 2009 the digester was fed 100% wet distillers grain and the ARC Pilot Plant 2 digestate sample was taken in February, 2009. It is possible that residual dairy manure remained in the digester since only two hydraulic retention times (14 day each) with 100% wet distillers grain passed through the system before collection of the digestate sample. As well, heavy metals can combine with sulfur and form insoluble precipitates that could remain in a digester.

The overall conclusion for the heavy metals is that non-manure substrates do not appear to give elevated heavy metal values for soil application, but do have elevated values for agricultural water use. The fact that most digestion systems use manures as an inoculum for methanogenic bacteria indicates that levels of heavy metals in digestion products may need to be considered before these products are disposed in an environment. The continuously stirred reactors are designed to have a stream of substrates moving through their systems, and heavy metals may be retained or precipitated in a digester for a period of time after the substrate is used. This observation should be investigated further.

An examination of minimum acceptable ratios of nitrogen and phosphorus to metals set out in the Guidelines for the Application of Municipal Wastewater Sludge to Agricultural Lands by Alberta Environment may give more information as to whether the manure and sewage sludge post-digestion products could be used for soil and agricultural application.

Table 5. 1: CCME soil guideline comparison for manures.
Please see explanation in Section 5.0

| Biowaste substrates[a] | Heavy metals above the CCME soil quality guideline concentrations for given soil types[b] | | | | |
|---|---|---|---|---|---|
| | A | P/R | I | C | |
| Manures (see footnote for sample types) | Heavy metals related to: unmixed substrate, digestate (substrate plus inoculum), separated liquid, separated solid | | | | Heavy metals related to substrate in culture with values for inoculum subtracted |
| ***Cattle bed pack*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Se,Zn | Se,Zn | Zn | Zn | Se,Zn |
| Solid[a] | | | | | |
| ***Dairy manure #1*** | | | | | |
| Substrate[a] | Zn | Zn | | | Not applicable |
| Digestate[a] | Zn | Zn | | | Zn |
| Liquid[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | Cu,Zn |
| Solid[a] | | | | | |
| ***Dairy manure #2*** | | | | | |
| Substrate[a] | Cu | Cu | | | Not applicable |
| Digestate[a] | Cu | Cu | | | Cu |
| Liquid[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | Cu,Se,Zn |
| Solid[a] | | | | | |
| ***Chicken laying hen*** | | | | | |
| Substrate[a] | Se,Zn | Se,Zn | Zn | Zn | Not applicable |
| Digestate[a] | Se,Zn | Se,Zn | Zn | Zn | Se,Zn |
| Liquid[a] | Cu,Se,Zn | Cu,Se,Zn | Zn | Zn | Cu,Se,Zn |
| Solid[a] | | | | | |
| ***Chicken broiler*** | | | | | |
| Aqueous substrate[c] | Cu | Cu | Cu | Cu | Not applicable |
| Substrate[a] | Cu,Zn | Cu,Zn | Cu,Zn | Cu,Zn | Not applicable |
| Digestate[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | Cu,Zn |

| | | | | | |
|---|---|---|---|---|---|
| Liquid[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | Cu,Se,Zn |
| Solid[a] | Cu,Se | Cu,Se | Cu | Cu | Cu,Se |
| ***Solid hog*** | | | | | |
| Substrate[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | Not applicable |
| Digestate[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | Cu,Se,Zn |
| Liquid[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | Cu,Se,Zn |
| Solid[a] | Cu,Zn | Cu,Zn | Cu | Cu | Cu,Zn |
| ***Liquid hog*** | | | | | |
| Substrate[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Se,Zn | Cu,Se,Zn | Not applicable |
| Digestate[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | |
| Liquid[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | Cu,Se,Zn |
| Solid[a] | Zn | Zn | | | Zn |

[a] Substrates from Section 3.0; Substrate refers to substrate only; Digestate refers to mixture with inoculum after incubation; Liquid refers to liquid portion of digestate after separation; Solid refers to solid portion of digestate after separation.
[b] A – Agricultural; P/R – Parks and Residential; I – Industrial; C – Commercial
[c] Aqueous substrate is wet substrate diluted with water to 2 g TS. See section 2.3

Table 5. 2: CCME soil guideline comparison for vegetable/fruit/grain.
Please see explanation in Section 5.0

| Biowaste substrates[a] | Heavy metals above the CCME soil quality guideline concentrations for given soil types[b] | | | | |
|---|---|---|---|---|---|
| | A | P/R | I | C | |
| Vegetable/fruit/grain (see footnote for sample types) | Heavy metals related to: unmixed substrate, digestate (substrate plus inoculum), separated liquid, separated solid | | | | Heavy metals related to substrate in culture with values for inoculum subtracted |
| ***Potato tuber*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Zn | Zn | | | |
| Solid[a] | | | | | |
| ***Potato process*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Zn | Zn | | | |
| Solid[a] | | | | | |
| ***Potato plant vines*** | | | | | |
| Substrate[a] | Cr,Ni | Cr,Ni | Cr,Ni | Cr,Ni | Not applicable |
| Digestate[a] | | | | | |
| Liquid[a] | | | | | |
| Solid[a] | | | | | |
| ***Sugar beet tailings*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Zn | Zn | | | |
| Solid[a] | | | | | |
| ***Grocery*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Se,Zn | Se,Zn | Zn | Zn | Se |

| | | | | | |
|---|---|---|---|---|---|
| Solid[a] | | | | | |
| ***Glycerine*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Zn | Zn | | | |
| Solid[a] | | | | | |
| ***Thin stillage*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Zn | Zn | | | |
| Solid[a] | | | | | |
| ***Wet distillers grains*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Zn | Zn | | | |
| Solid[a] | | | | | |

[a] Substrates from Section 3.0; Substrate refers to substrate only; Digestate refers to mixture with inoculum after incubation; Liquid refers to liquid portion of digestate after separation; Solid refers to solid portion of digestate after separation.

[b] A – Agricultural; P/R – Parks and Residential; I – Industrial; C – Commercial

Table 5. 3: CCME soil guideline comparison for human and other animal waste.
Human waste and non-manure animal waste. Please see explanation in Section 5.0

| Biowaste substrates[a] | Heavy metals above the CCME soil quality guideline concentrations for given soil types[b] | | | | |
|---|---|---|---|---|---|
| | A | P/R | I | C | |
| | Heavy metals related to: unmixed substrate, digestate (substrate plus inoculum), separated liquid, separated solid | | | | Heavy metals related to substrate in culture with values for inoculum subtracted |
| **Waste associated with animals (see footnote for sample types)** | | | | | |
| ***Beef slaughterhouse paunch*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Zn | Zn | | | |
| Solid[a] | | | | | |
| ***Hog slaughterhouse sludge*** | | | | | |
| Substrate[a] | Cu | Cu | | | Not applicable |
| Digestate[a] | Not done | | | | |
| Liquid[a] | | | | | |
| Solid[a] | | | | | |
| ***Hog slaughterhouse peptone*** | | | | | |
| Substrate[a] | Se | Se | | | Not applicable |
| Digestate[a] | Not done | | | | |
| Liquid[a] | | | | | |
| Solid[a] | | | | | |
| ***Poultry slaughterhouse waste*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Se,Zn | Se,Zn | | | Se |
| Solid[a] | | | | | |
| ***Thermally hydrolyzed biowaste #1*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |

| | | | | | |
|---|---|---|---|---|---|
| Liquid[a] | Se,Zn | Se,Zn | Zn | Zn | Se,Zn |
| Solid[a] | | | | | |
| ***Thermally hydrolyzed biowaste #2*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Zn | Zn | Zn | Zn | Zn |
| Solid[a] | | | | | |
| ***Cheese whey*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Zn | Zn | | | |
| Solid[a] | | | | | |
| ***Cattle carcass*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Zn | Zn | | | |
| Solid[a] | | | | | |
| **Waste associated with humans** | | | | | |
| ***Sewage sludge*** | | | | | |
| Substrate[a] | Cu,Se,Zn | Ba,Cu,Se,Zn | Cu,Zn | Cu,Zn | Not applicable |
| Digestate[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | Cu,Se,Zn |
| Liquid[a] | Cu,Se,Zn | Cu,Se,Zn | Cu,Zn | Cu,Zn | Cu,Se,Zn |
| Solid[a] | Cu,Zn | Cu,Zn | | | Cu,Se,Zn |
| ***Liquid sewage*** | | | | | |
| Substrate[a] | | | | | Not applicable |
| Digestate[a] | Zn | Zn | | | |
| Liquid[a] | Se,Zn | Se,Zn | | | Se |
| Solid[a] | | | | | |

[a] Substrates from Section 3.0; Substrate refers to substrate only; Digestate refers to mixture with inoculum after incubation; Liquid refers to liquid portion of digestate after separation; Solid refers to solid portion of digestate after separation.
[b] A – Agricultural; P/R – Parks and Residential; I – Industrial; C – Commercial

Table 5. 4: CCME soil guideline comparison for ARC Pilot Plant samples.
Please see explanation in Section 5.0

| Substrates[a] | CCME soil quality guidelines exceeded for heavy metal and soil types[b] | | | |
|---|---|---|---|---|
| | A | P/R | I | C |
| **ARC Pilot Plant 1; Heavy metals related to dairy manure #1 and glycerine** | | | | |
| Mixture for digestion | | | | |
| Digestate (after incubation) | | | | |
| Separated liquid | Cu,Zn,Se | Cu,Zn,Se | Cu,Zn | Cu,Zn |
| Separated solid | | | | |
| **ARC Pilot Plant 2; Heavy metals related to wet distillers grain** | | | | |
| Mixture for digestion | | | | |
| Digestate (after incubation) | | | | |
| Separated liquid | Cu,Zn | Cu,Zn | | |
| Separated solid | | | | |

[a] ARC Pilot Plant 1 - substrate mixture of dairy #1 and glycerine; ARC Pilot Plant 2 - substrate was wet distillers grain, Digestate refers to mixture after incubation; Liquid refers to liquid portion of digestate after separation; Solid refers to solid portion of digestate after separation.
[b] A – Agricultural; P/R – Parks and Residential; I – Industrial; C – Commercial

Table 5. 5: CCME soil guideline comparison for inoculum.
Please see explanation in Section 5.0

| **Inoculum[a] used in batch cultures and incubated for 30 and 45 days (see footnote for sample type)[a]** | CCME soil quality guidelines exceeded for heavy metal and soil types[b] | | | |
|---|---|---|---|---|
| | A | P/R | I | C |
| Inoculum (after collection) | Zn | Zn | | |
| Inoculum (before use in cultures) | Zn | Zn | | |
| Inoculum (after 30 d incubation) | Zn | Zn | | |
| Separated liquid | Zn | Zn | | |
| Separated solid | | | | |
| Inoculum (after 45 d incubation) | Zn | Zn | | |
| Separated liquid | Zn | Zn | | |
| Separated solid | | | | |

[a] Inoculum (after collection) - Inoculum from collection pails; Inoculum (before use in cultures) - Inoculum after 7 day incubation and before mixture with substrate; Inoculum (after 30 day/45 day incubation) - refers to inoculum after incubation; Liquid refers to liquid portion of inoculum after separation; Solid refers to solid portion of inoculum after separation.

[b] A – Agricultural; P/R – Parks and Residential; I – Industrial; C – Commercial

Table 5. 6: CCME water guideline comparison for manures
Separated liquid from digestate after digestion. Please see explanation in Section 5.0

| Biowaste substrates[a] | Heavy metals above the CCME water quality guideline concentrations for agricultural use | | |
|---|---|---|---|
| | Irrigation water | Livestock water | |
| **Manures** | **Heavy metals related to separated liquid containing substrate and inoculum** | | **Heavy metals related to separated liquid with values for inoculum subtracted** |
| ***Cattle bed pack*** | | | |
| Separated liquid | Al,B,Cd,Cl,Co,Cu,Fe, Mn,Mo,Ni,Se,U,V,Zn | Al,As,Ca,Cu,Ni,Pb,Se,V | Al,As,B,Cl,Co,Cu,Fe,Mn,Mo,Ni,Se,V,Zn |
| ***Dairy manure #1*** | | | |
| Separated liquid | Al,B,Cd,Cl,Co,Cu,Fe, Mn,Mo,Ni,Pb,Se,U,V, Zn | Al,As,Ca,Cu,Pb,Se,V | Al,B,Cl,Co,Cu,Fe,Mn,Mo,Se,U,V,Zn |
| ***Dairy manure #2*** | | | |
| Separated liquid | Al,B,Cd,Cl,Co,Cu,Fe, Mn,Mo,Ni,Se,U,V, Zn | Al,As,Ca,Cu,Pb,Se,V | Al,B,Cd,Cu,Fe,Mn,Mo,Se,U,V,Zn |
| ***Chicken laying hen*** | | | |
| Separated liquid | Al,B,Cd,Cl,Co,Cu,Fe, Mn,Mo,Ni,Se,U,V,Zn | Al,As,Ca,Cu,Se,V | Ca,Cd,Cl,Cu,Mn,Mo,Se,Zn |
| ***Chicken broiler*** | | | |
| Separated liquid | Al,B,Cd,Cl,Co,Cu,Fe, Mn,Mo,Ni,Se,U,V,Zn | Al,As,Ca,Cu,Pb,Se,V | Cu,Mn,Mo,Se,Zn |
| ***Solid hog*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Se,U,V, Zn | Al,As,Ca,Cu,Pb,Se,V | Al,Cd,Cu,Fe,Mn,Mo,Se,Zn |
| ***Liquid hog*** | | | |
| Separated liquid | Al,BCd,Cl,Co,Cu,Fe,M n,Mo,Ni,Se, U,V,Zn | Al,As,Ca,Cu,Pb,Se,V | Al,Cu,Fe,Mn,Mo,Se, |

Table 5. 7: CCME water guideline comparison for vegetable/fruit/grain
Separated liquid from digestate after digestion. Please see explanation in Section 5.0

| Biowaste substrates[a] | Heavy metals above the CCME water quality guideline concentrations for agricultural use | | |
|---|---|---|---|
| | Irrigation water | Livestock water | |
| **Vegetable/fruit/grain** | **Heavy metals related to separated liquid containing substrate and inoculum** | | **Heavy metals related to separated liquid with values for inoculum subtracted** |
| ***Potato tuber*** | | | |
| Separated liquid | Al,B,Cd,Cl,Co,Cu,Fe, Mn,Mo,Ni,Se,U,V,Zn | Al,As,Ca,Cu,Pb,Se,V | Al,Cd,Fe |
| ***Potato process*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Pb,Se,U, V,Zn | Al,As,Ca,Cu,Pb,Se,V | Al,Fe,Mn |
| ***Potato plant vines*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Se,U,V, Zn | Al,As,Ca,Cu,Hg,Ni,V,Zn | Al,As,B,Cd,Fe,Hg,Mn,Mo,Ni,V |
| ***Sugar beet tailings*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Se,U,V, Zn | Al,As,Ca,Cu,Pb,Se,V | Al,Fe,Mn,Mo,V |
| ***Grocery*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Se,U,V, Zn | Al,As,Ca,Cu,Pb,Se,V | Al,Fe,Mn,Mo,V |
| ***Glycerine*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Se,U,V, Zn | Al,As,Ca,Cu,Pb,Se,V | Cl,Mn |
| ***Thin stillage*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, | Al,As,Ca,Cu,Fe,Pb,Se,V | Mn |

| | | | |
|---|---|---|---|
| | Fe,Mn,Mo,Ni,Se,U,V, Zn | | |
| ***Wet distillers grains*** | | | |
| Separated liquid | Al,B,Cd,Cl,Co,Cu,Fe, Mn,Mo,Ni,Se,U,V,Zn | Al,As,Ca,Cu,Pb,V | Al,Fe,Mn,Mo, |

Table 5. 8: CCME water guideline comparison for human and other animal

Human waste and non-manure animal waste. Separated liquid from digestate after digestion. Please see explanation in Section 5.0

| Biowaste substrates[a] | Heavy metals above the CCME water quality guideline concentrations for agricultural use | | |
|---|---|---|---|
| | Irrigation water | Livestock water | |
| | **Heavy metals related to separated liquid containing substrate and inoculum** | | **Heavy metals related to separated liquid with values for inoculum subtracted** |
| **Waste associated with animals** | | | |
| ***Beef slaughterhouse paunch*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Se,U,V, Zn | Al,As,Ca,Cu,Pb,V | Cl |
| ***Poultry slaughterhouse waste*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Se,U,V, Zn | Al,As,Ca,Pb,Se,V | Al,Fe,Mn,Mo |
| ***Thermally hydrolyzed biowaste #1*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Cu,Fe, Mn,Mo,Ni,Se,U,V,Zn | Al,As,Ca,Cu,Pb,Se,V | Al,Fe,Mn,Mo,V,Zn |
| ***Thermally hydrolyzed biowaste #2*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Se,U,V, Zn | Al,As,Ca,Cu,Fe,Pb,Se,V | Al,Fe,Mn,Zn |
| ***Cheese whey*** | | | |
| Separated liquid | Al,B,Cd,Cl,Co,Cu,Fe, Mn,Mo,Ni,Se,U,V,Zn | Al,As,Ca,Cu,Pb,V | Al |
| ***Cattle carcass*** | | | |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Se,U,V, Zn | Al,As,Ca,Cu,Pb,V | Al,Fe,Mn |
| **Waste associated with humans** | | | |
| ***Sewage sludge*** | | | |

| | | | |
|---|---|---|---|
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu, Fe,Mn,Mo,Ni,Pb,Se,U, V,Zn | Al,As,Ca,Cu,Hg,Pb,Se,V | Al,As,Cd,Cu,Fe,Hg,Mn,Mo,Ni,Pb,Se,U,V,Zn |
| ***Liquid sewage*** | | | |
| Separated liquid | Al,B,Cd,Cl,Co,Cu,Fe, Mn.Mo,Ni,Se,U,V,Zn | Al,As,Ca,Cu,Pb,Se,V | Al,Fe |

Table 5. 9: CCME water guideline comparison for ARC Pilot Plant samples
Separated liquid from digestate after digestion. Please see explanation in Section 5.0

| Biowaste substrates[a] | Heavy metals above the CCME water quality guideline concentrations for agricultural use | |
|---|---|---|
| | Irrigation water | Livestock water |
| **ARC Pilot Plant 1 (dairy #1 and glycerine); Heavy metals for separated liquid** | | |
| Separated liquid | Al,B,Cd,Cl,Co,Cu,Fe,Mn,Mo,Ni,Se,U,V,Zn | Al,As,Cu,Se,U,V |
| **ARC Pilot Plant 2 (wet distillers grains); Heavy metals for separated liquid** | | |
| Separated liquid | B,Cu,Fe,Mn,Mo,Ni,Zn | Cu |

Table 5. 10: CCME water guideline comparison for inoculum
Separated liquid from digestate after digestion. Please see explanation in Section 5.0

| **Inoculum used in study and incubated for 30 and 45 days** | Heavy metals above the CCME water quality guideline concentrations for agricultural use | |
|---|---|---|
| | Irrigation water | Livestock water |
| Separated liquid | Al,As,B,Cd,Cl,Co,Cu,Fe,Mn,Mo,Ni,Se,U,V,Zn | Al,As,Ca,Cu,Pb,Se,V |

## 6.0 Summary

The following summary points have been taken from this study:

- Manure and non-manure substrates contained sufficient amounts of carbon, nitrogen, phosphorous and potassium for anaerobic digestion.
- Carbon, nitrogen, phosphorous and potassium remained in post-digestion samples.
- Some substrates contained high values of nitrogen and sulphur that can cause toxicity in a digester.
- Substrates with low VS may have low organic carbon concentrations.
- Manure substrates used in this study had elevated heavy metal concentrations that exceeded the CCME guidelines for specified soil and CCME water guidelines for agricultural use (irrigation and livestock applications).
- Non-manure substrates used in this study did not have elevated heavy metal concentrations that exceeded the CCME specified soil guidelines except for grocery waste, poultry slaughterhouse waste and thermally hydrolyzed biowaste.
- Non-manure substrates gave elevated heavy metal concentrations that exceeded the CCME water guidelines for agricultural use (irrigation and livestock applications).
- Heavy metals were generally concentrated during anaerobic digestion due to loss of solids. When digestate was separated into liquid and solid fractions, most of the heavy metals were associated with the liquid fraction and not with the solid fraction, giving elevated levels in the liquid.
- Heavy metals from manures may be retained in large digester systems due to incomplete purging of substrates and precipitation. This should be investigated further.
- Electrical conductivity results or salt concentration for substrates, digestates and separated liquids were high using the 2% TS method.
- Manure substrates generally had higher salt concentrations than non-manure substrates associated with animals or vegetable/grain substrates.
- Vegetable/grain substrates had the lowest overall salt concentrations compared to manure and non-manure substrates associated with animals.

- Salt concentrations for separated solids were generally less than those for separated liquid. However, repeated application of separated solids to land without proper monitoring could lead to salt accumulation. More work needs to be done to reduce salts in the solid fraction and to determine salt accumulation for different soil types.

## 7.0 Acknowledgements

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## PART B: EVALUATION OF PATHOGEN IN BIOWASTE AND DIGESTATE

### 1.0 Introduction

There are many different types of waste products that are used for anaerobic digestion, however, biowaste that contains manure has a high density of coliform bacteria (1,2,3,4,5,6). The coliform bacteria can include pathogens associated with human illness, such as *Salmonella* and other zoonotic pathogens such as *Campylobacter* and *Listeria* (7,8,9,10). Generally, methods used to denote contamination in waste use indicator organisms like fecal coliform bacteria. For water, detection and enumeration of this group of organisms are used to determine the suitability of water for domestic and industrial use (11). In the United States, sludge from wastewater treatment plants must fulfill the density requirements from the US Environmental Protection Agency (USEPA) for fecal coliform as an indicator or *Salmonella* as a pathogen (12).

In the discussion presented by Pell (13) on pathogenic microbes in manure, there is mention that in the past, most environmental concerns about biowaste management have focused on nutrient overload, water quality or odour problems. There are no regulations concerning pathogens in biowaste that are used for anaerobic digestion. With an emerging biogas industry in Alberta, large amounts of effluent from anaerobic digesters will be produced. There is a lack of information as to whether pathogens are present in anaerobic digester effluent and if present, whether they will pose a threat to public, animal and plant health. We have found no information on regulations for handling effluent from anaerobic digesters for Alberta, although there is information on wastewater systems (14). Alberta Agriculture and Rural Development guidelines mention that land application of digestate is under the Agricultural Operations Practices Act and Regulations as it applies to manure (15). The Canadian Council for the Ministers of the Environment (CCME), in their guidelines for organism content in compost containing only yard waste, mention that fecal coliform of fecal origin should be < 1000 Most Probable Number (MPN) /g of Total Solids (TS) calculated on a dry weight basis and *Salmonella* < 3 MPN/4 g TS (16) and compost containing other feedstock should contain fecal coliform at < 1000 MPN/g TS or *Salmonella*, < 3 MPN/4g TS. The compost with other feedstock must be exposed to temperatures of 55°C or higher for a specified time depending on the type of compost.

The USEPA have imposed regulations under Title 40 of the Code of Federal Regulations (CFR), Part 503 to control the use and disposal of biosolids (17). Biosolids are defined as the recyclable organic solid product produced during wastewater treatment processes. Part 503 of the rule gives the requirements for the use of biosolids in order to prevent contamination to the public and the environment. One requirement is for the control of pathogens or disease-causing organisms and the reduction of vector attraction to the biosolids. Pathogens can be bacteria, viruses and parasites and vectors include rodents, flies, mosquitoes and disease-carrying and transferring organisms. The rules described in Part 503 ensure that pathogen levels are safe for the biosolids to be land applied or surface disposed. The criteria for biosolid Class A are the same as the CCME guidelines for compost with other feedstock, with fecal coliform < 1000 MPN/ g TS or *Salmonella* < 3 MPN/4 g TS. A biosolid is considered Class B if pathogens are reduced to levels that do not pose a risk to the public and environment. Measures must be taken to prevent crop harvesting, animal grazing and public assess to areas where Class B biosolid have been applied until the area is considered safe. The Class B biosolid requirements are that fecal coliform must be < 2 x 106 MPN/g TS. For this biosolid, the fecal coliform is used as an indicator of average density of bacterial and viral pathogens.

We conducted a small-scale study on undigested biowaste and effluent after anaerobic digestion of biowaste using the USEPA microbiology testing methods for fecal coliform (18) and *Salmonella* (19) for biosolids and used the results to assess local biowaste samples. Due to time and funding restrictions, we were only able to perform selected analyses on chosen biowaste samples.

## 2.0 Objectives

- to assess the levels of fecal coliform used as a contamination indicator and *Salmonella* used as pathogen indicator for selected biowaste samples,
- to evaluate reduction of fecal coliform and *Salmonella* using thermophilic anaerobic digestion processes.

The results from this study will provide preliminary data for development of guidelines for handling and utilizing biowaste in Alberta.

### 3.0 Biowaste and Sample Collection

All samples were collected into sterile plastic bags or bottles and tested within 2-3 hours after collection, unless otherwise stated. All samples were collected specifically for this study except sample 3.4, which was collected and stored at ARC, Vegreville, Alberta. This sample was being used in the ARC fully automated anaerobic digestion system ARC Pilot Plant (referred to as ARC Pilot Plant from here on) at the time of this study. The digestion system operated at 55°C. All dairy and chicken manure samples were collected from the same farm in the winter months. The farm was chosen because of its close proximity to the testing laboratory, allowing valid testing of fecal coliform and *Salmonella* within the required time frame for the USEPA microbiological testing methods.

The following samples were tested in this study:

| | |
|---|---|
| 3.1 | Dairy manure taken from within dairy cows. Three dairy manure samples collected on two occasions from 5 dairy cows. Sample 1 was a manure mixture from cows 1 and 2, and Sample 2 was a mixture from cows 3 and 4. Sample 3 was from cow 5. One sample was tested for *Salmonella* only. |
| 3.2 | Dairy manure from one cow that was collected from the barn and tested for *Salmonella* only. |
| 3.3 | Dairy manure collected from the general barn area. Some of the freshly collected manure was taken to the Edmonton ARC laboratory. The remainder of the manure was transported to Vegreville and digested in the ARC Pilot Plant. At this time the digester was running dairy manure at 55°C and 14-day hydraulic retention time. The freshly collected dairy manure was fed into the digester over 10 days. The last feeding of manure was 15 hours before the sample was taken for analysis. |
| 3.4 | Dairy manure that was used routinely for digestion at the ARC Pilot Plant. The dairy manure was collected from the same farm as samples 3.1 to 3.3 and stored for 2 months at 4°C. The stored sample and a random sample from the digester hopper were tested. The dairy manure from the hopper was diluted in the laboratory and left at 22°C for 1 hour. As well, after a 14-day hydraulic |

| | |
|---|---|
| | retention time in the ARC Pilot Plant, a digested sample from the dairy manure was collected and tested. |
| 3.5 | Chicken manure, collected from chicken cages in the barn. |
| 3.6 | Chicken manure, collected from the general barn area and included straw bedding. |
| 3.7 | Household kitchen waste, mostly vegetable and fruit waste collected daily over a 7-day period and held at 4-6°C until testing. |
| 3.8 | Broken eggs, including shell, collected at a grocery retail store that was close to the testing laboratory |
| 3.9 | Wet distillers grain from an ethanol production plant, collected in barrels and stored at -20°C until testing in the ARC Pilot Plant. This sample was collected for use in the ARC Pilot Plant and was chosen for pathogen analysis because it was a non-manure based biowaste. A diluted sample with 8% TS was taken for fecal coliform and *Salmonella* testing. |

## 4.0 Testing Methods

All dehydrated culture media were purchased from Neogen (MI, USA) and testing was carried out in a Biolevel II lab, Alberta Research Council, Edmonton. A 5-tube MPN method was used as described in the USEPA methods to derive population estimates for the fecal coliform and *Salmonella*.

### *4.1 Total solid measurements of biowaste*

Total solid analysis was done for biowaste using a forced-air oven-drying method at 70°C for 48 hours. The method assumes only water is removed. The results are reported as a percent of the sample's wet weight.

### *4.2 Testing for fecal coliform*

The biowaste and anaerobic digester effluent were evaluated for fecal coliform using the USEPA Method 1680 (17). Briefly, the method uses a MPN procedure to derive a population estimate for fecal coliform bacteria, Lauryl-Tryptose broth and EC culture-specific media and elevated temperature to isolate and enumerate fecal coliform organisms. The basis for the test is that fecal coliform bacteria, including *Escherichia coli* (*E. coli*), are commonly found in the feces of humans and other warm-blooded animals. These bacteria indicate the potential presence of other bacterial and viral pathogens. Total solids determination was done on the biowaste samples and used to calculate and report fecal coliform as MPN/g dry weight.

### *4.3 Testing for Salmonella sp.*

The biowaste and anaerobic digester effluent were evaluated for *Salmonella* using the USEPA Method 1682 (18). Briefly, the method is for the detection and enumeration of *Salmonella* by enrichment with tryptic soy broth and selection with modified semisolid Rappaport-Vassiliadis medium. Presumptive identification was done using xylose-lysine desoxycholate agar and confirmation was done using lysine-iron agar, triple sugar iron agar and urea broth. Serological testing was done. Total solids were determined on a representative biowaste sample and used to calculate *Salmonella* density as MPN per 4 g dry weight.

### *4.4 Quality control*

Milorganite (CAS 8049-99-8, Milwaukee Metropolitan Sewerage District, UNGRO Corp. ON), a heat-dried Class A biosolid proven by USEPA was used and spiked with appropriate control bacteria. *E.coli* (ATCC# 25922) was used as the positive control for the fecal coliform test and negative control for the *Salmonella* test. *Salmonella typhimurium* (ATCC# 14028) was used as the positive control for the *Salmonella* test. *Enterobacter aerogenes* (ATCC# 13048) and *Pseudomonas* (ATCC# 27853) were used as negative controls for the fecal coliform test.

## 5.0 Results and Discussion

Table 5.1 gives the total solid, fecal coliform and *Salmonella* MPN for the biowaste samples.

Table 5. 1: Summary of microbiology testing results of selected biowaste samples

| #[a] | Samples | Total solids (% of wet weight) | Fecal coliform (MPN/g TS) | *Salmonella* (MPN/4g TS) |
|---|---|---|---|---|
| 3.1 | Dairy manure taken from within dairy cows | | | |
| | Sample 1 | 13 | $5.6 \times 10^6$ | < 0.18 |
| | Sample 2 | 15 | $1.1 \times 10^7$ | < 0.18 |
| | Sample 3 | 14[b] | Not done | < 0.18 |
| 3.2 | Dairy manure from general barn area | | | |
| | | 14[b] | Not done | < 0.18 |
| 3.3 | Dairy manure from general barn area | | | |
| | | 15 | $1.1 \times 10^7$ | $4.0 \times 10^0$ |
| | Anaerobic digestion effluent of dairy manure after 15 h digestion | | | |
| | | 10 | < 0.18 | < 0.18 |
| 3.4 | Dairy manure used at ARC Pilot Plant | | | |
| | Dairy manure stored for 2 months at 4°C | | | |
| | | 14 | $8.8 \times 10^4$ | < 0.18 |
| | Dairy collected from ARC Pilot Plant hopper before anaerobic digestion | | | |
| | | 10 | $1.8 \times 10^4$ | $2.1 \times 10^0$ |
| | Anaerobic digestion effluent of dairy manure after 14 day hydraulic retention time | | | |
| | | 9 | <0.18 | < 0.18 |
| 3.5 | Chicken manure from cages | | | |
| | | 37 | $4.3 \times 10^6$ | < 0.18 |
| 3.6 | Chicken manure from general barn area with straw bedding | | | |
| | | 78 | $2.1 \times 10^6$ | < 0.18 |
| 3.7 | Household kitchen waste | | | |
| | | Not done | No growth | No growth |
| 3.8 | Broken eggs | | | |
| | | Not done | No growth | No growth |
| 3.9 | Wet distillers grains | | | |
| | | 8 | <0.18 | < 0.18 |

[a] Sample # relating to Section 3 [b] Estimated TS values

Dairy manure samples from the same facility were tested in this study. The samples were from the general barn area and taken from within cows. When tested, the density of fecal coliform that was found in all samples ranged from 8.8 x $10^4$ MPN/g TS to 1.1 x $10^7$ MPN/g TS. *Salmonella*, 4 x $10^0$ MPN/4g TS, was found in one sample collected from the general barn area. Storage of the dairy manure at 4°C for 2 months decreased the fecal coliform 2- to 3-log. A random dairy manure sample was collected from the hopper of the ARC Pilot Plant and tested. It contained 1.8 x $10^4$ MPN/g TS fecal coliform and 2.1 x $10^0$ MPN/4g TS *Salmonella*. In both cases where dairy manure was digested at 55°C in the ARC Pilot Plant, the fecal coliform and *Salmonella* were decreased to below detection (<0.18 MPN/g TS for fecal coliform and <0.18 MPN/4g TS for *Salmonella*).

The chicken manures, kitchen waste, eggs and wet distillers grain were not put through digestion. Both chicken manure samples had fecal coliform, 4.3 x $10^6$ and 2.1 x $10^6$ MPN/g TS. No *Salmonella* was detected. There were no fecal coliform and *Salmonella* in the kitchen waste, eggs and wet distillers grains.

This brief study showed that bacteria common to manures were detected in the dairy and chicken manure samples. According to the USEPA guidelines for a Class A biosolid, the fecal coliform density was above the accepted level in all manure samples, and for a Class B biosolid, the fecal coliform density was above the accepted level in the freshly collected manure samples. The increased fecal coliform levels indicate that pathogenic bacteria could be present in these samples. This was verified by the fact that one fresh dairy sample contained 4.0 x $10^0$ MPN/4g TS and a random hopper sample from the ARC Pilot Plant contained 2.1 x $10^0$ MPN/4g TS *Salmonella*. The result from the hopper sample would have been considered acceptable according to the USEPA standards. Nevertheless, both samples of dairy manure were tested to contain below detection levels of both fecal coliform and *Salmonella* after anaerobic digestion at 55°C and 14-day hydraulic retention time in the ARC Pilot Plant digesters. For sample 3.3, based on the feeding style of the ARC Pilot Plant continuous stirred tank reactor digester system and the time the dairy manure was in the digester, there was about 15 hours of digestion between the last feed time and the time a sample was taken for analysis.

Bendixen (20) looked at the animal and human pathogen reduction in Danish biogas plants. It was reported that pathogen survival was greatly reduced at thermophilic digestion temperatures (50°C to 55°C) but not at low and mesophilic temperatures (5°C to 45°C). Biogas plant construction, function and management need to be monitored in order to assure pathogen destruction and policies need to be in place to classify the digested effluent for proper disposal.

The requirements in the USEPA standards (17) for sewage sludge use and disposal indicate that sewage sludge should be analyzed for enteric viruses and viable helminth ova. There are also requirements given for vector attraction reduction and reduction of volatile solids. As well, other pathogens should be investigated. For example, human norovirus strains have been found in livestock, indicating a route for zoonotic transmission (21). As well, policies have been made concerning plant pathogens that relate to anaerobic digestion facilities in Germany (22).

## 6.0 Summary

- Using the USEPA Class A biosolids and CCME guideline for compost of <1000 MPN/g TS for fecal coliform, all the freshly collected manures (dairy and chicken) were above the accepted level.
- Using the USEPA Class B biosolids guidelines of $<2 \times 10^6$ MPN/g TS for fecal coliform, all the freshly collected manure samples (dairy and chicken) were above the accepted level.
- For one fresh dairy manure, the *Salmonella* exceeded the USEPA Class A biosolids and CCME guideline for compost of <3 MPN/4 g TS.
- Storage of dairy manure at 4°C for 2 months decreased fecal coliform concentration.
- Anaerobic digestion at 55°C and 14-day hydraulic retention time in the ARC Pilot Plant reduced fecal coliform and *Salmonella* to below detection levels. Fifteen hours of digestion in a continuous stirred tank reactor system appeared to be `adequate for reduction.

- Household kitchen waste, broken eggs and wet distillers grains contained either no fecal coliform and *Salmonella* or levels below detection using the MPN method.

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