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AUSTRALIAN Pork

Assessing soil health implications and potential for carbon mitigation and storage through surface application of pork industry effluent onto farm soil

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Executive Summary

Australian Pork Limited aims to address the objectives of climate friendly farming through soil research, managing natural resources and pig effluent practices to support carbon positive and zero waste sustainability goals by 2025. Within the context of a rapidly growing global demand, agriculture faces the challenge of producing more goods in an increasingly economically and environmentally sustainable manner. For the pork industry, there has been a substantial increase in the demand for its produce over the last five decades, resulting in the development of more intensive and high-density pig farms (Gerber et al. 2005; Stokłosa 2015; Lassaletta et al. 2019; Tzanidakis et al. 2021). This expansion has resulted in increased piggery waste materials such as effluent and manure. If these materials are not managed in an environmentally sensitive way, there is the potential for negative impacts on the surrounding environment and an opportunity cost of lost or inefficient use of resources.

This research investigated the potential of using piggery waste as a resource. It explored the use of piggery effluent as an alternative source of agricultural fertiliser, looking at the impact of the application of effluent onto farm soil in terms of its effect on soil health and the potential for carbon mitigation and storage.

A review of published literature, relating to the use of piggery effluent, identified that pig effluent can significantly improve a range of biological, chemical and physical properties of soil. The most common benefits reported within the literature include: (i) increased soil organic carbon and improved soil carbon balance, (ii) improvements to the soil pH, (iii) improvements to the aeration, bulk density and porosity of the soil, (iv) an increase in microbiological communities within the soil, (v) increased availability of nutrients, and (vi) improvement in the water-holding capacity of the soil (Tirol-Padre et al. 2007; Tadesse et al. 2013; Penha et al. 2015; Liu et al. 2019), all of which have been shown to improve the production and health of important crop species (Adegbidi et al. 2001; Penha et al. 2015; Liu et al. 2019).

On the other hand, the excess accumulation of pig effluent in farm soils can be of environmental concern if not managed appropriately. The accumulation of heavy metals within the soil, for example, may lead to migration into crops or infiltration into water systems, which raises concerns for both animal and human health (Duan et al. 2012; Kwon et al. 2014; Jiao et al. 2021). Pig effluent also significantly elevates soil nutrient levels, which, if not absorbed by the surrounding plant biomass, may infiltrate into surrounding waterways and increase eutrophication events (Carpenter et al. 1998; Schulte et al. 2010). Such effluent can contain various diseases, microorganisms, pathogens, protozoa and viruses which also may pose a risk to animal, human or plant health (De et al. 2003; Johansson et al. 2005). Although these concerns are a challenge to the implementation of pig effluent fertilisers, they can be safely mitigated, and the pre-treatment of pig effluent is a vital component in the safe and confident use of these fertilisers, although in some cases it may not completely eliminate all possible risks.

To obtain a local perspective on the use and management of piggery effluent, six Australian pork producers were consulted: five in Victoria and one in New South Wales. The producers identified a number of benefits associated with using pig effluent as a fertiliser. While their primary motivation appeared to be the need to manage the substantial amount of effluent being produced, additional reasons also included the need to improve crops and pastures, soil health and becoming more economically sustainable. Observed benefits included: (i) increased growth of crops and yields, (ii) positive effects on the soil health, (iii) benefits and savings related to pest control and (iv) economic

benefits and savings accruing from the reduced usage of other fertilisers. Challenges observed included: (i) impacts to several crop species such as barley and wheat which produced large yields that were challenging to harvest, (ii) finding the most suitable time and type of application to use the fertiliser, (iii) nutrient overloading within the soil, (iv) the potential for increased salinity levels due to the high salt content in the effluent, (v) obtaining the appropriate permits and meeting EPA regulations, (vi) meeting the cost of obtaining equipment needed to sustainably apply this practice in the long-term, and (vii) managing odour issues with neighbouring properties. While there were challenges apparent in using pig effluent as a fertiliser, this consultation found that several of the producers were interested in making more use of the effluent on their farms. Producers suggested there was a need for improvements in application technology and for better advice for management of this resource, with many of the land managers expressing interest in the practice of carbon neutral farming.

To determine the impact of effluent use on farm soils, samples of soil from four properties were analysed. Three of the properties were currently using pig effluent in their cropping systems, while the fourth was using it on grazing land. Changes in various chemical and physical properties within the soil and two paddocks were sampled, comparing the results with areas with contrasting effluent histories on each property. Changes in carbon content between effluent treated and non-treated paddocks were generally small, although there was a slight increase in some treated paddocks. While all sites evidenced acidic soil profiles, this was not an uncommon result for land use practices within this study, but the soil pH did generally decrease in effluent treated sites. As anticipated, all sites treated with effluent had greater nutrient concentrations including nitrogen, phosphorus, sulphur and potassium. Micronutrients were, however, differently affected by the effluent application, with manganese, molybdenum and boron not being affected, while copper, iron and zinc were increased. Other heavy metals, such as cadmium, arsenic, chromium, lead, molybdenum, cobalt, and selenium, showed no consistent increase in paddocks treated with effluent. Finally, while three of the four sampled properties showed an increase in salinity (ECe), rarely were these classified as being saline. Also, soil aggregate stability (Emerson dispersion class) was not negatively impacted by effluent use. It is nevertheless anticipated that long-term application may eventually lead to sodicity and soil structural decline.

In summary, this work has indicated that the controlled use of pig effluent fertilisers can have significant benefits to both soil and plant health in agroecosystems. While further investment and research is required to understand the impact of long-term implementation, current indications are clearly positive. However, further consideration of the use of piggery effluent in Australia will also need to take into account the move away from sludge application to a Waste to Energy focus and the associated changes in the types and composition of effluent. In addition, more work is needed on improvements and access to newly emerging storage and application techniques for this method to become more economically sustainable. The findings of this research suggest that if pig effluent fertiliser practices follow all state and territory regulations, are regularly monitored and appropriately applied to the soil, piggery effluent can become a valuable resource for agricultural soils within Australia.

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1. Background to Research

A rapid increase in global population has resulted in significant pressure for agricultural industries to sustainably produce more goods at affordable prices (Putri et al. 2019). The piggery industry has seen a significant increase in global demand with up to four times the growth over the last 50 years, resulting in intensive farming and high pig density on farmlands (Gerber et al. 2005; Stokłosa 2015; Lassaletta et al. 2019; Tzanidakis et al. 2021).

The intensification of pig farming around the world has resulted in increasing amounts of pig effluent. Piggery effluent is commonly used as fertiliser but there is limited research examining its impact on soil and plant health (Gutser et al. 2005; Kiani et al. 2005; Guardini et al. 2012; Lourenzi et al. 2013; Yost et al. 2022). There is some evidence to suggest that the excessive application of effluent fertilisers can pollute air, water and land (Dendooven et al. 1998; Edeogu et al. 2001; Mattila and Joki-Tokola 2003; Dambreville et al. 2006; Sleutel et al. 2006; Berenguer et al. 2008). Further research and investigation into the impact of the surface application pig industry effluent is necessary to inform the decisions of land managers. Well informed, sustainable waste management plans are essential to protect plant and soil health in agroecosystems.

The project aligns with APL's strategic theme of leading community social license and the objective of climate friendly farming. Within this theme, the project aims to build on research into soil, managing natural resources and pig management practices to align with carbon positive and zero waste sustainability goals by 2025.

Specifically, the project is looking to understand the effects of the surface application of piggery effluent on to farm soil in Australia. This use of effluent is believed to be common practice, however, there is little data to show its impacts on soil health or whether it has additional benefits with regards to soil carbon sequestration or overall greenhouse gas emissions.

2. Objectives of the Research Project

The objectives of this project were to:

1. Understand the impacts of surface application of pork industry effluent on farm soil health parameters.
2. Ascertain whether there are additional benefits in regard to soil carbon sequestration and overall greenhouse gas emission impacts from this practice.
3. Gain a better understanding of the decision-making process by producers as to the method of manure disbursement.

3. Review of Literature

Aims

A search of peer reviewed and grey literature was conducted to determine the current state of knowledge concerning the local and global impacts of the use of pork industry effluent on farm soil health and the potential environmental benefits associated with this practice.

Methods

The review was conducted by exploring national and international English-language literature directly related to the use of pork industry effluent on farm soil health. Peer reviewed literature was searched and obtained using the Google Scholar search engine employing the following terms: (i) pork industry effluent management, (ii) pork effluent fertilisers, (iii) soil health, (iv) effluent fertilisers, and (v) pork industry waste. Grey literature was also searched and obtained by conducting Google searches on the abovementioned keywords. Each research paper or published material that was identified during this process that had these keywords either in their title, abstract or presented as a keyword was then selected and scanned for their suitability to this review. Additionally, forward and backward snowballing search strategies were employed to maximise capture of relevant publications.

Results

A rapid increase in the global population over recent decades has resulted in significant pressure on the agricultural industry to sustainably produce more resources at affordable prices (Putri et al. 2019). With the global population expected to exceed 9.7 billion by 2050, it is anticipated that more challenges and pressure will arise within the industry leading into the future (Hofstra and Vermeulen 2016; United Nations 2022). Exacerbating this issue is that the global demand for food is also expected to increase between 35% to 56% by 2050 (Cole et al. 2018; Knorr et al. 2020; Van Dijk et al. 2021). Out of the magnitude of challenges and pressures faced by the agricultural industry, it is anticipated that more action and focus is needed on (i) becoming more environmentally sustainable (such as reducing emissions and waste); (ii) climate change; (iii) improving soil and plant health; and (iv) reducing the cost of production (Riggs and Fields 2018; Fróna et al. 2019; Veeck et al. 2020; Araújo et al. 2021; Rahman et al. 2022).

In particular, the pig industry has seen a significant increase in global demand with over four times the growth in the last 50 years, and as a result, intensive farming and high pig density on farmlands have further added to these challenges (Gerber et al. 2005; Stokłosa 2015; Lassaletta et al. 2019; Tzanidakis et al. 2021). Adding to these challenges, the intensification of pig farming resulted in a significant increase in the amount of pig effluent being produced, which in essence, increases air, land and water pollution if appropriate management is not undertaken to minimise it (Carpenter et al. 1998; Redding 2001; Burton and Turner 2003; Wang et al. 2004; Izmaylov et al. 2022). It is estimated that 100 pigs can produce approximately 2,850 kg of effluent per day, with the global annual production of pig effluent in Asia, Europe, North America, South America and Oceania thought to exceed 1.7 billion tons (Jorgensen and Jensen 2009; Troy 2012). This results in a build-up of effluent that requires appropriate and ongoing management to minimise its potential impact on the surrounding environment.

A strategy that has shown promising signs of targeting the many challenges within the pig industry around the world is the use of effluent as fertiliser (Bouwman and Booij 1998; Li et al. 2015; Izmaylov et al. 2022). It is reported that pig effluent fertilisers are rich in nutrients and have properties that are similar to other conventional fertilisers (APL 2011; Li et al. 2015). When managed appropriately, pig effluent fertilisers can be inexpensive, simple to use, a means of recycling the by-products of pig farming and can also be beneficial to plant and soil health (Kiani et al. 2005; Guardini et al. 2012; Lourenzi et al. 2013). However, the excessive application of pig effluent onto farm soil can have several environmental and human health concerns (Dendooven et al. 1998; Edeogu et al. 2001; De et al. 2003; Mattila and Joki-Tokola 2003; Dambreville et al. 2006; Sleutel et al. 2006; Berenguer et al. 2008; APL 2011). In this regard, this review explores global literature to identify the benefits and effects on plant and soil health when application of pig effluent in agroecosystems. It also explores the current and previously used technology and practises in this field, while identifying gaps in knowledge that may require additional research to inform the successful, sustainable and long-term application of pig effluent fertiliser. The information presented in this review aims to inform land managers and researchers, enabling them to identify emerging issues that may require action, and to underpin decision making regarding environmental sustainability and waste management plans leading into the future.

3.1 What is pig effluent and how is it collected, stored and used?

Pig effluent can be described as the waste products (faeces and urine) produced by a pig and is often mixed with left over feed or other waste products within their housing systems (APL 2015a). In general, pig effluent is made up of approximately 90% water and contains several complex carbohydrates, macro and micro-nutrients, trace elements, salts and several microorganisms (APL 2015a; New Zealand Pork 2017; Scheid et al. 2020). On average, it is estimated that 1 m^3 of pig effluent (with an 8% dry mass content) can contain approximately 6.4 kg of nitrogen, 4.0 kg of phosphorus and 3.0 kg of potassium (Adeniyan et al. 2011; Troy 2012). The quality and quantity of pig effluent and the organic matter within it is strongly determined by the (i) age and condition of the pigs, (ii) feeding methods, and (iii) number or density of pigs (Schepers and Raun 2008; APL 2015a; New Zealand Pork 2017). The type of piggery or housing systems can also influence the quality and quantity of pig effluent and how it is collected and used within the farming system (APL 2015a; New Zealand Pork 2017).

The main type of piggery or housing systems found within Australia and around the world include conventional, deep litter, and outdoor (rotational and feedlot) (Table 1). Each of these systems generally result in a different by-product which may include liquid effluent, solid manure, spent bedding and even left-over food or other waste products (Table 1) (APL 2015a; New Zealand Pork 2017). In each of these systems there are different ways in which the effluent is collected and removed such as (i) flushing channels, which are concrete channels below the flooring of the sheds; (ii) pull plug pits, which store effluent in underfloor pits and are drained when they are near full; (iii) static pits, which are under-floor channels with a slope; (iv) open drains, which flush all waste in an open area along a shed; and (v) manure scrapers, which are blades installed within flushing channels that push waste away (Kruger et al. 1995; APL 2015a). Each of these systems are designed to quickly remove the wastes and store them in specialised areas ready for treatment or decomposition (APL 2015a; New Zealand Pork 2017).

Table 1. Types of pig housing systems and the methods of effluent collection

Type	***Structure***	***How is effluent removed?***	***By-product(s)***
Conventional	Housed inside sheds with fully or partly slatted flooring.	Feed, urine and faeces fall through the flooring into underfloor channels or pits. It is then flushed or drained away with water.	Liquid effluent.
Deep litter	Housed within hooped metal waterproof frames. The floor is bedded with sawdust, straw, rice hulls or loose absorbent material.	Physically removed with bedding material. Sometimes flushed away with water.	Spent bedding.
Rotational outdoor	Housed outside in small huts or shelters on small paddocks. The land is often on a rotation with a pig phase followed by a cropping stage.	Randomly deposited within the small paddocks by the pigs. Active management needed to spread it evenly across paddocks.	Solid and liquid effluent and spent bedding.
Feedlot outdoor	Housed permanently in outdoor pens. Must be located within controlled drainage areas to avoid effluent runoff.	Effluent generated by rainfall is washed within the drainage area within the paddock. May also be directed to a holding pond or manually spread.	Solid and liquid effluent.

(Kruger et al. 1995; APL 2015a; New Zealand Pork 2017).

3.2 Separation methods

Once the pig waste is collected the liquid and solid fractions need to be separated and treated for it to be successfully used within effluent fertiliser programs (APL 2015a). This process can significantly alter the quality of effluent, which in essence, can influence its availability to a plant and impact the surrounding environment (Fangueiro et al. 2012; APL 2015a). One of the biggest challenges in the separation of liquids and solids from pig effluent is the high costs of investment and equipment needed for its sustainable production (Burton 2007). Current technology and separation methods can successfully remove more than 80% of the total solids from pig effluent (Hjorth et al. 2010). Several methods that have been observed to successfully achieve this include (i) screen separators, which are designed to trap solid waste in a wire mesh screen; (ii) decanting / centrifuge separators, which use force and velocity to separate the waste; (iii) presses, which are a belt and rotating system that press the solids and removes moisture; (iv) settling tanks, where effluent is stored in tanks and the process of sedimentation occurs; and (v) cyclones, which are cone-shaped devices that sit vertically on the ground to filter waste (APL 2015a).

Another common method used around the world is the use of holding or sedimentation ponds (APL 2015a). Although these ponds are useful in storing effluent and settling solid fractions to the bottom where they can decompose, it has been noted that biomass accumulation can often build up quicker than it can be decomposed (Birchall 2010; APL 2015a). This is likely due to the specialised microorganisms within the pond being removed when the liquid effluent is used for irrigation or other farm purposes, as well as the increasing addition of daily wastes to the pond (Birchall 2010; APL 2015a). In this regard, further research should investigate the optimal conditions and microorganisms required for the quick and safe decomposition of solid waste within these ponds. This will be useful in reducing solid fractions within these ponds while still allowing the liquid effluent to be taken out at the appropriate rates required for irrigation.

There is evidence suggesting that anaerobic ponds have the potential to remove 60% to 90% of solid biomass by encouraging the growth of bacteria and microorganisms (APL 2015a; Owusu-Twum and Sharara 2020). Although they can reduce solid biomass within the ponds, this method still warrants close investigation as it can produce and increase the release of carbon dioxide, methane, and other acidic and odorous gases into the environment (APL 2015a; Owusu-Twum and Sharara 2020). It is therefore important for these gases to be regularly monitored when using anaerobic pond systems to prevent their release into the environment. This can be achieved by the (i) use of specialised anaerobic tanks or covers that can trap these gases and use them as a source of heat or energy in the form of biogas, although these methods can be expensive to set up and maintain (Craggs and Heubeck 2008; Gaworski et al. 2017). It has also been found that promoting the clumping of particles by adding flocculants before the separation process can improve efficiency (Perez-Sangrador et al. 2012). Research by Walker and Kelly (2003) evaluated the flocculant of polyacrylamide combined with the screening separation process and found a significant increase in the separation of liquids and solids. Similarly, Chelme-Ayala et al. (2011) also found an increase in the separation process when combining a physical-chemical treatment with coagulation-flocculation, sedimentation and oxidation at a bench-scale level.

There is some evidence that the Biosor™ manure biofiltration process, which filters gas, liquids and solids from effluent using an organic bed, can eliminate up to 80% of odours and reduce pollutants by 80% to 90%, although the results have been shown to vary (Buelna et al. 2008). Another separation process, the Biorek process, uses ammonia stripping, anaerobic digestion, reverse osmosis and ultrafiltration. This has been shown to be successful in removing ammonia in pig effluent by up to 99%, although it has a high operational cost (Du Preez et al. 2005). Another method, the SELCO-Ecopurin® process uses polyacrylamide polymer to enhance solids removal from liquid manure. This method has been used in Italy, Spain and the USA and has shown economic success for several years (Martinez-Almela and Barrera 2005). Karakashev et al. (2008) tested different processes for reducing organic matter in pig manure. In their final scheme (PIGMAN concept) employed a combination of steps and achieved reductions of solid organic matter by 96%, nitrogen by 88% and phosphorus by 81% (Karakashev et al. 2008). This concept employed a combination of (i) thermophilic anaerobic digestion, (ii) decanter centrifugation, (iii) post-digestion with an anaerobic blanket, and (iv) the oxygen-limited autotrophic nitrification-denitrification process (Karakashev et al. 2008). The end product of this process can even be directly used to irrigate crops safely (Karakashev et al. 2008). Recent research has suggested that hydrothermal treatment of pig effluent can improve its value and can convert nitrogen (200 °C for 60 minutes) and phosphorus (150 °C for 60 minutes) into a more soluble form that can be used as a fertiliser (Yuan et al. 2018). It has also been reported that this method combined with anaerobic digestion can help to enhance effluent and increase the release of nutrients while sterilising any pathogens within (Barber 2016; Li et al. 2017).

Another method of liquid and solid separation of pig effluent is the use of stockpiling and composting (Larney and Hao 2007; Hjorth et al. 2010; Nolan et al. 2012; APL 2015a; New Zealand Pork 2017). Stockpiling pig waste can reduce the total mass of solids and increase the concentration of stable nutrients (APL 2015a). Although useful in separating liquids and solids over time, this method does increase odour and the release of gases into the environment (e.g., ammonia, methane, nitrous oxide) and is less likely to kill pathogens or any weed seeds within (APL 2015a; Philips et al. 2016). There is some evidence that these gas emissions can be mitigated by pig housing strategies. Philips et al. (2016) reported a 66% and 80% decrease in emissions from the manure excreted in litter-based housing compared with conventional housing with an uncovered anaerobic effluent-treatment pond.

3.3 Composting

Composting pig effluent allows microorganisms to decompose the organic matter into a simpler compound in which nutrients can be deposited into the soil and taken up by a plant (Larney and Hao 2007; New Zealand Pork 2017). Research suggests that aerobic composting is the quickest method that produces the highest quality compost (Larney and Hao 2007; New Zealand Pork 2017). It is suggested that the composted material should have a bulking agent added to it to help reduce moisture content, however, this will lead to an increase in costs (Nolan et al. 2011). It is also noted that composting takes approximately twelve weeks but may be extended by an additional four weeks of curing to help decompose larger compounds (New Zealand Pork 2017). Composting pig effluent also requires specific conditions for its optimal use and is recommended that the carbon to nitrogen ratio should be 30:1 (New Zealand Pork 2017). Lower rates will result in excess nitrogen which will become lost as ammonia gas, while higher rates will result in insufficient nitrogen for the microbial populations, leading to a slower composting rate (New Zealand Pork 2017).

3.4 Biochar

The solid material produced from pig effluent can also be used to produce biochar with the process of pyrolysis which is the heating of the biomass in absence of oxygen (Bridgewater and Peacocke 2000; Cantrell et al. 2007). The char produced from this process can be applied directly to the soil as a conditioner where it results in carbon sequestration and altered soil properties such as bulk density, pH, porosity, and its water holding capacity (Glaser et al. 2002; Laird et al. 2010). The benefits of using biochar derived from pig effluent are that it can (i) be converted in a matter of minutes and (ii) destroy any pathogens and weed seeds. This method has shown to be successful in combination with land spreading as it can reduce nutrient leaching due to its high sorption capacity (Singh et al. 2010). In this regard, future technology and management of pig effluent could consider using biochar to help recycle solid waste material, although its long-term benefits and implications on soil health still need to be investigated further for more confident application.

3.5 Application of effluent

Australian piggeries employ a range of methods to apply effluent to farm soils. Kruger et al. (1995), reporting on effluent management practices in Australian piggeries, found that for raw or treated effluent, 24% of piggeries used tanker spreading, 24% used spray irrigation and 35% pumped or piped effluent onto land.

3.5.1 Flood or furrow irrigation

Flood or farrow methods of irrigation, where effluent is pumped or piped onto the land, are considered to be inefficient and also associated with the risk of contamination of vegetable crops and exposure to farm workers (Pescod 1992).

3.5.2 Sprinklers

A more efficient method of application involves the spraying of effluent using irrigation sprinkler systems where effluent is pumped through a pipe system and sprayed through rotating sprinkler heads. However, this method has issues with control of spread, risk of wind drift and uniformity of application which can be affected by wind and water pressure (Brouwer et al. 1988).

3.5.3 Slurry tankers

A more targeted method of applying effluent to farm soil involves the use of slurry tankers that transport and apply the slurry to the soil. The effectiveness and suitability of this method depends on the choice spreader attachment. A review of slurry spreading systems (Ryan 2005) compared types of spreaders. Three of the reviewed spreaders (splash plate, band, trailing foot) applied the effluent to the surface of the soil, while a fourth type, injector, applied the effluent below the surface level. The splash plate spreader, which consists of a straight pipe with a rubber nozzle directed at a metal plate, while inexpensive and robust, was assessed to be the least environmentally friendly as it released most of the ammonia (NH_3) in slurry and emitted strong odours. It also distributed the remaining nutrients unevenly. The band spreader distributes slurry through several flexible outlets, placed along a boom, which ends just above or on the ground. The trailing foot spreader is similar to the band spreader but with the addition of a shoe at the end of each pipe which parts the crop placing slurry directly on the soil and around the base of the plants. Compared with splash plate spreaders, both of these spreaders were associated with reduced ammonia emissions, uniformity of spread and higher yields. Of the surface spreaders, the review identified the trailing foot spreader as providing the most benefits in terms of emission reduction, protection of soil structure and targeted application. Fuller (1983) identified a number of disadvantages associated with surface spreading of slurry: (i) allows for considerable loss of nitrogen by volatilization to the atmosphere in the inorganic ammonia form (NH_3); (ii) has greater susceptibility to wind, water, and soil erosion; (iii) can attract flies, insects, rodents and vermin; (iv) has slower biodegradation; and (v) metals and nitrates are less apt to be attenuated by the soil.

3.5.4 Injector application

The fourth type of applicator reviewed by Ryan (2005), the slurry injector, includes a distributor and multiple outlets with injector assemblies at ground level. Fuller (1983) suggested that injection of slurry into the soil could prevent immediate as well as future loss of NH_3 and could correct the other problems associated with surface exposure. Similarly, Warner & Godwin (1988) reported results suggesting that the injection technique was suitable for the application of agricultural slurry, with the potential advantages of injection over surface application being that it buries the liquid beneath the surface in a single-pass operation, controlling odours, crop contamination and pathogen activity, and reducing the risk of disease transmission resulting in shorter no-grazing periods in grassland. They also reported that soil injection also eliminates surface run-off from sloping land into water courses, and the associated soil loosening can assist in improved crop root development, water flow and aeration of the soil.

Injection application has been found to halve the release of ammonia compared with band spreading (Rodhe 2005). However, Stamatiadis et al. (1999) reported that sludge injection had both positive and negative effects on soil quality and the sustainability of the practice. An increase in organic matter content and biological activity improved soil fertility, but excessive amounts of ammonium salts contained in liquid sludge resulted in soil nitrification, excessive nitrate formation and acidification. This method of delivering piggery effluent is employed extensively in the Canadian province of Manitoba where nutrient runoff into waterways is a primary concern. About 85% of pig manure in Manitoba is injected about 15 centimetres into the soil of cropland (Manitoba Pork 2017). Manitoba Pork reports that the advantages of manure injection are: (i) reduces odour and greenhouse gases as the manure is minimally exposed to the air; (ii) better for the crops because it gets the manure down to the root zone; (iii) lessens the loss of nutrients, because of minimal handling and exposure to the air; and (iv) almost entirely eliminates runoff. The injection method is also being used in Australia. An 8,000-head piggery near Kingaroy, Queensland, has converted from spreading effluent with irrigators to using slurry tankers with injection attachments (Daly 2021). These tankers can inject effluent 20 centimetres to 30 centimetres into the soil and it is suggested that they can hold up to 30,000 litres, which can be equivalent to $2,000 worth of conventional fertilisers (Daly 2021). While the cost of making the change was substantial, approximately $1 million, the piggery is located in an environmentally sensitive region, a Great Barrier Reef Catchment, where reduction of runoff is a priority.

A recent review of strategies for greenhouse gas emissions mitigation (Sanz-Cobena et al. 2019) identified that while the injection method can deliver the benefits of reduction of air pollution in the forms of odour, improvement of nutrient soil levels at the root level, and reduction of the chances of effluent surface runoff into nearby water sources, it may also have negative impacts. The shallow direct injection of pig effluent in soils may also lead to higher emissions and release of other compounds such as N_2O, NO_3^- and CH_4. The authors suggest that the benefits and negative impacts of direct injection compared to surface application of pig effluent warrants further investigation (Sanz-Cobena et al. 2017; Sanz-Cobena et al. 2019). It would also be of value for future research to investigate the long-term application of pig effluent deeper in the soil to avoid any potential ground water or soil contamination.

3.6 Soil health

3.6.1 Biological properties

Soil quality cannot be directly measured, but is inferable through measuring soil physical, chemical and biological properties (Obade and Lal 2016). In particular, microbial parameters can be used as a sensitive indicator of soil quality (Kaschuk et al. 2010; Asensio et al. 2013). Research has shown that the repeated use of conventional fertilisers can have unintended biological, economic and environmental impacts (Siepel and van de Bund 1988; Gardi et al. 2008). High concentrations of nitrogen from these fertilisers have been shown to decrease the diversity and quantity of many soil microarthropods which are vital in promoting nutrient cycling and soil organic matter (Siepel and van de Bund 1988; Gardi et al. 2008). In addition, high concentrations of phosphorus may also decrease arbuscular mycorrhizal fungi which are key contributors to the soil nutrients and structure (Bronick and Lal 2005). Arbuscular mycorrhizal fungi form symbiotic relationships with plants using a fungal hyphae system (Bronick and Lal 2005). This system improves soil aggregation, structure and the overall productivity of nearby plants (Bronick and Lal 2005). In this regard, it is important to protect and promote soil microbial activity as it can increase the overall quality of soil and plant health.

An extensive review conducted by Yost et al. (2022) which explored more than 40 research papers on the impact of pig effluent found that it has the potential to increase microbial biomass along with soil organic carbon and soil organic matter. Several long-term and short-term studies ranging from three to eighteen years have shown that effluent can increase microbial biomass within the soil (Lalande et al. 2000; Carter and Campbell 2006; Iyyemperumal Shi 2007; da Rosa Couto et al. 2013; Pardo et al. 2014). Furthermore, Yost et al. (2022) reported that the microbial biomass carbon concentration significantly varies across several studies (approximately 15 mg to 560 mg C kg^{-1} soil) when using pig effluent fertilisers. This could be a result of inconsistent testing, data collection, or differences in the climate, crop type, farm systems, pig effluent characteristics and soil type, therefore highlighting the need for wider research in a range of conditions. It is suggested that the lack of studies exploring the microbial biomass of the soil can be explained due to its high cost and time constraints

(Doran and Zeiss 2000; Kibblewhite et al. 2008). Microbial biomass can be measured using a phospholipid fatty acid analysis which measures the abundance of cellular components in the bacteria, fungi and protozoa in the soil (Zhong et al. 2010). Research trends suggest that applying pig effluent fertiliser to the soil will increase phospholipid fatty acid, however, the long-term impact of this is unclear and warrants further investigation (Zhong et al. 2010; Yost et al. 2022). In contrast, the long-term application of conventional fertilisers generally decreases microbial biomass and diversity, and this is believed to be due to changes in the acidification of the soil, although this too warrants future investigation (Zhong et al. 2010). In this regard, the benefits of using pig effluent fertilisers can have several benefits to soil biology compared to conventional fertilisers.

3.6.2 Heavy metal accumulation

Pig effluent fertilisers contain several traces of heavy metals that have the potential to contaminate the surrounding environment and pose a threat to animal and human health if appropriate management is not undertaken to minimise its effect (Feng et al. 2018; Sonne et al. 2019; Awasthi et al. 2020). Mineral additives and heavy metals are commonly used in livestock feed around the world as they are an essential requirement for the improvement and growth of the animal (Nies 1999). These minerals are often added via an incomplete purification process and are not completely absorbed by the animal, which in turn, results in large traces of these minerals being found in the effluent (Cang et al. 2004; Feng et al. 2018; Awasthi et al. 2020). It has been reported that approximately 10% to 20% of copper and zinc, which are common ingredients within pig feed, are absorbed by the animal with the remaining becoming a part of their waste (Ciraj et al. 1999; Ito et al. 2001; Cang et al. 2004; Zhou et al. 2015). This results in excess amounts of these heavy metals in their effluent. The accumulation of heavy metals in pig effluent can vary greatly and is strongly dependent on several factors such as the quality and quantity of feed and animal, however on average pig effluent may contain 538.29 mg/kg of zinc, 151.11 mg/kg of copper, 10.64 mg/kg of chromium, 9.27 mg/kg of nickel, 2.12 mg/kg lead, 1.95 mg/kg selenium, 1.56 mg/kg arsenic, and 0.27 mg/kg cadmium dry matter (Ciraj et al. 1999; Ito et al. 2001; Cang et al. 2004; Zhou et al. 2015).

The accumulation of some heavy metals is an environmental concern and findings suggest that the accumulation of heavy metals in the soil can migrate to crops and raises concern for both animal and human health (Duan et al. 2012; Jiao et al. 2021). When accumulated on the land, these heavy metals can infiltrate and run off into nearby waterways where they negatively impact its quality and the biodiversity that relies upon it (Fan et al. 2013; Kwon et al. 2014). It has been reported in China that the influence of heavy metal pollution not only impacts aquatic ecosystems due to runoff, but heavy metal pollution in cropping systems has cost than economy more than 20 billion Chinese RMB (Kwon et al. 2014). Furthermore, research in Braço do Norte, Brazil (Benedet et al. 2016), Northern China (Gong et al. 2019; Qaswar et al. 2020), Santa Maria, Brazil (Girotto et al. 2013), and Três Passos, all demonstrated increased heavy metal accumulation within the soil as a result of several years of using pig effluent fertiliser. The accumulation of heavy metals can cause serious human health ramifications as they can sometimes be carcinogenic, teratogenic, nephrotoxic, neurotoxic and have even been linked to several other diseases such as cardiovascular and pulmonary diseases and impaired reproduction (Zhang et al. 2014; Zhu et al. 2014; Li et al. 2015; Sfakianakis et al. 2015).

These findings suggest that soils that are commonly fertilised with pig effluent need to be closely managed to prevent excess or unsafe levels within the soil. Out of the large array of heavy metals commonly found within pig effluent around the world (Table 2), copper and zinc are two of the most abundant (Bhattacharyya et al. 2008). Research has shown that in Denmark, copper and zinc have increased by 19% and 24%, respectively, between 1998 and 2014 as a result of using pig effluent fertilisers (Baker et al. 2011). Copper and zinc have been found to adversely affect the health of plants, and microbial ecosystems and pose a threat to human health (Baker et al. 2011) (Table 2). In addition, it is also important to note that several heavy metals exhibit strong antimicrobial activity which imposes long-lasting selection pressure on soil microbes and can increase antibiotic resistance (Zhu et al. 2013; Zhang et al. 2014). According to health specialists, these two heavy metals have been identified as a co-factor for many neurological disorders such as chronic wasting disease, Alzheimer and Parkinson's disease (Nichols et al. 2016). Further research has also shown that certain *Salmonella* strains can be resistant to several heavy metals and can carry associated genes with multiple antimicrobial-resistant factors (Ciraj et al. 1999; Zhang et al. 2014). For instance, copper has been associated with resistance to vancomycin (Zhang et al. 2014), while mercury has shown to be associated with methicillin resistance of *Staphylococcus aureus* which has caused infection in humans for more than five decades (Ito et al. 2001). These non-essential heavy metals are also not easily degradable within the environment (Wilson and Pyatt 2007), therefore their long-term application can, and will, accumulate within the soil. In this regard, it is highly important and necessary for heavy metals and pig effluent to be regulated and appropriately managed on a local, national and global scale. It would also be of value for future research and management of agricultural soils that use pig effluent fertilisers to consider the long-term effect of heavy metal accumulation to ensure that land managers can confidently and safely make suitable decisions regarding their soil health.

Removing or minimising the accumulation of heavy metals in agricultural soils is essential for animal, human, plant and soil health (Wilson and Pyatt 2007). Research suggests that the accumulation and bioavailability of heavy metals derived from pig effluent can be altered and regulated by adding amendments to the soil or effluent (absorbent material), or liquid-solid separation (Morera et al. 2001). It has also been reported that the methods of anaerobic digestion and composting are also a method to treat pig effluent, although these methods have shown varying results in the reduction of heavy metals (Marcato et al. 2008; Hazarika et al. 2017). The physical method of adding amendments to pig effluent or the soil is a potential solution to reducing the accumulation and bioavailability of heavy metals (Fellet et al. 2011; Jiang et al. 2012; Liang et al. 2017). It has been reported that amendments can decrease exchangeable metal concentrations of several heavy metals (Zornoza et al. 2013).

Research has also shown that the use of biochar from prune residue has been effectively used to decrease the bioavailability of copper, lead, titanium, and zinc in mine tailings and could be used in agricultural soils, although this requires further investigation (Fellet et al. 2011). Rice-straw biochar has also been shown to increase the absorption and stabilisation of several heavy metals such as copper, lead and zinc (Jiang et al. 2012; Uchimiya et al. 2012). Research has shown that pig effluent derived biochar (at 450 °C) could immobilise and absorb heavy metal ions (Marcato et al. 2008; Xu et al. 2014), although further research suggests that biochar at 700 °C is the preferred pyrolysis temperature (Meng et al. 2017). In comparison, biochar derived from chicken manure and tomato green waste have been able to reduce the heavy metal cadmium by 26%-43% and 35%-54%, respectively (Yasmin et al. 2017). Another study conducted by Awasthi et al. (2020) highlighted that a combination of bacterial culture and biochar can improve the absorption and degradation of heavy metals in pig effluent. Cui et al. (2016) showed that rice-straw and mushroom residue as an amendment to pig effluent can also reduce the mobility of copper and zinc while also enhancing bacterial communities to assist in the degradation and stabilisation of heavy metals. Biochars and microbial amendments can promote the decomposition of organic waste and increase the composting rate of pig effluent by altering the physiochemical properties and improving the microbial environment (Jiang et al. 2014; Wang et al. 2016). Although this has shown promising results, further research is still required to detail the longer-term effects of bacterial cultures and biochar when using pig effluent as a fertiliser in agroecosystems. A number of methods of stabilising or reducing heavy metal accumulation in soils have also been identified. Additives with the potential to stabilise or reduce heavy metal accumulation in soils have also been identified, including bentonite, hydroxyapatite, lime, mineral elements, rice hull, sawdust, and straw (Lahori et al. 2017; Wang et al. 2020). However, further research is required to determine their long-term impact and economic benefit in agroecosystems (Lahori et al. 2017; Wang et al. 2020).

The method of liquid-solid separation, which has been previously described in this review, has also shown to be a successful method in reducing the accumulation of certain heavy metals in pig effluent (Suzuki et al. 2010). Due to several heavy metals such as copper and zinc being in soluble form in pig effluent, liquid-solid separation can often remove up to 95% of these metals (Suzuki et al. 2010). Despite this reduction, solid fractions that are added to the soil as a fertiliser may still contain a similar number of heavy metals compared to untreated effluent (Popovic et al. 2012). In this regard, it is important to pre-treat pig effluent before applying it to the land to minimise the accumulation of heavy metals within the soil. Recent developments and technology in this field have also suggested several other ways that heavy metals can be reduced in pig effluent such as using the methods of chemical precipitation, electrochemical treatment, ion exchange, or reverse osmosis (Ozverdi and Erdem 2006; Ya et al. 2018; Vaneeckhaute et al. 2019; Maslova et al. 2020). Although these methods can be used to treat heavy metal pollution in pig effluent, they may also produce high levels of secondary wastes and increase costs of treatment and even produce further emissions (Kurniawan et al. 2006). One newly emerging strategy for the control of heavy metals in animal effluent is the use of metal-organic frameworks (Wang et al. 2021). Research by Wang et al. (2021) highlights that the use of the zirconium-based octahedral metal-organic frameworks UiO-66 and UiO-66-NH2 have shown high success at removing several heavy metals such as arsenic, chromium, iron, manganese, and nickel by 76% to 93%. Further research also confirms that these metal-organic frameworks can effectively remove several heavy metals in animal effluent (Luo et al. 2015; Wang and Wang 2015). In this regard, such research may be effectively applied to help reduce the heavy metal concentration in pig effluent in holding or treatment ponds before being applied to the land.

3.7 Soil nutrient overloading

Surface application of pig effluent fertilisers can result in elevated soil nutrient concentrations, which may lead to eutrophication in adjacent waterways, a problem that may take decades to be reduced (Carpenter et al. 1998; Schulte et al. 2010). Compared with conventional fertilisers, pig effluent and other livestock manures contain higher levels of organic nitrogen and phosphorus (Monaco et al. 2008; Robertson and Groffman 2015). Organic nitrogen is released into the soil at a slow rate due to soil microbes mineralising it into ammonium for crop uptake (Monaco et al. 2008; Robertson and Groffman 2015). Several studies have shown that following pig effluent fertilisation, total nitrogen applied to the soil has been recorded to significantly increase (Mbagwu et al. 1994; Schlegel et al. 2015; Yost et al. 2022), with some studies suggesting it could range from <1% to 167%, with concentrations being highly variable between 0.4g N kg^{-1} to 5.5g N kg^{-1} (Mbagwu et al.1994; Schlegel e*t al.* 2015). Likewise, phosphorus has also been reported to significantly increase following pig effluent fertiliser, with some studies suggesting it could range been 8% to 190% (Mbagwu et al. 1994) and be highly variable between 3mg P kg^{-1} to 2,070mg P kg^{-1} (Xun et al. 2016; Gatiboni et al. 2019). Potassium has also been observed to significantly increase in the soil when pig effluent is used as a fertiliser (Xun et al. 2016). Several studies suggest that potassium may increase between 4% to 196% and vary between 30 mg K kg^{-1} to

16,560 mg P kg^{-1} (Mbagwu et al. 1994; Zhong et al. 2010; Xun et al. 2016; Schuster et al. 2019). It is important to note here that these nutrients and their accumulation have been known to vary greatly as a result of effluent composition and crop uptake (Benedet et al. 2020).

Table 2. Common traces of heavy metals found in pig effluent around the world and their use and impact

Heavy metal	**Uses**	**Negative impact**	**References**
Arsenic (As)	• Essential for animal growth	• Can cause abnormal reproduction in high concentrations • Can be harmful to the soil	Uthus 1992
Cadmium (Cd)	• Often combined with zinc and phosphates as an impurity	• Can be harmful to humans in high concentrations: may impact embryos, kidneys and the liver • Affects the growth of livestock • Can lead to various medical abnormalities such as mutagenesis, teratogenesis, and carcinogenesis	Zhu et al. 2014
Chromium (Cr)	• Plays an important role in normalising carbohydrate, lipid, and protein metabolism • Enhances insulin function • Can benefit the growth performance of piglets	• Has a strong adverse impact on the surrounding environment • Can have toxic effects on animal and human health in high concentrations	Wang et al. 2012
Copper (Cu)	• Important role in animal, human and plant nutrition • Used to activate oxidative enzymes for metabolic balance • Promotes pig growth	• Can be toxic to soil microbial catabolism of polycyclic aromatic hydrocarbons • Toxic to several aquatic species, livestock and humans in high concentrations	Armstrong et al. 2004; Zhu et al. 2014; Li et al. 2015
Lead (Pb)	• Significantly reduces gonadotropin binding and alters steroid production in vitro	• Induces deformity and cardiovascular toxicity in several species	Li et al. 2015
Mercury (Hg)	• May accumulate in specific feed which is required for growth and production of the animals, although provides no known benefits.	• Potential neurotoxic agent and neurotoxicant •Is a developmental toxicant	Suksabye et al. 2007
Nickel (Ni)	• Can facilitate animal growth in low concentrations	• High exposure can lead to allergy, cardiovascular and kidney diseases, lung fibrosis, lung and nasal cancer.	Genchi et al. 2020
Selenium (Se)	• Important for enzyme production (glutathione peroxidase) and cellular activity	• Can be toxic in waterways and impact embryos and reproduction in several animals	Lemly 1997
Zinc (Zn)	• Increases the metabolism in over 300 metalloid-enzymes • Improves the absorption of water, electrolytes, feed intake and intestinal mucosal integrity	• Has the potential to increase *E. coli* • Known to impact soil microorganisms and embryos of several species in high concentrations	Bednorz et al. 2013; Zhu et al. 2014

Pig effluent fertiliser also contains a range of macro and micronutrients such as boron, calcium, chlorine, copper, iron, magnesium, manganese, molybdenum, nickel, nitrogen, phosphorus, potassium, and zinc (Benedet et al. 2016; APL 2017; Scheid et al. 2020). Although beneficial in providing a range of nutrients, it is important to note that pig effluent fertilisers, and the nutrients they provide, are only of economic and environmental value if they are directly needed for the crops grown in the area (APL 2015b). Excess nutrients that are not required for plant growth and production may accumulate within the soil, which may lead to environmental issues (APL 2017). It has been recommended that the rate of pig effluent used as fertiliser should aim to target one or more specific nutrient requirements (e.g., phosphorus, potassium, or nitrogen) for the required crop, with the remaining nutrients to be supplemented with conventional fertilisers (APL 2015b). This would allow for excess nutrients that are not required for the specific crop to not accumulate within the soil where it could potentially cause environmental harm.

An alternative method in ensuring all nutrients from pig effluent are utilised is to use rotational cropping systems to ensure that excess nutrients in the soil can be absorbed by different harvesting crops (APL 2015b). Research conducted in Brazil highlighted that pig effluent application over eight years substantially increases the phosphorus content within the soil and the soil surface, and as a consequence, indicates potential environmental contamination to surrounding surface and subsurface waters (Guardini et al. 2012). It is therefore important for land managers to assess nutrient levels in their farms before and after pig effluent application (APL 2017) suggesting the need for regular soil testing to monitor soil fertility and to help maintain appropriate nutrient levels for their soil and crops.

3.8 Soil physical and chemical properties

As recently explored throughout this review, the application of pig effluent to agricultural soils can have various benefits and impacts on soil health. Previous research has identified that the application of pig effluent to agricultural soils can have various benefits to both plant and soil health (Tirol-Padre et al. 2007; Tadesse et al. 2013; Tavares et al. 2019). Of particular interest, the application of pig effluent to agricultural soils has been shown to improve (i) aeration, (ii) bulk density, (iii) porosity, (iv) soil aggregation, and (v) the overall water holding capacity of the soil (Tirol-Padre et al. 2007; Tadesse et al. 2013). The application of pig effluent on agricultural soils has been observed to reduce the bulk density in a range of soil types (Diacono and Montemurro 2010). Pig effluent has a lower bulk density then most soils due to its high concentration of organic carbon, and as a result, when it is added to the soil it can help to reduce the average bulk density of that soil (Haynes and Naidu 1998; Yost et al. 2022). In some cases, the average reduction in bulk density after effluent has been applied may exceed 15% (Haynes and Naidu 1998; Diacono and Montemurro 2010). The application of pig effluent can also increase soil aggregation by increasing the total mass of macroaggregates within the soil (Santos et al. 2022). These changes to the physical structure of the soil can further improve soil porosity by allowing more air and water to freely infiltrate and move throughout the soil (Yost et al. 2022). As a result, these changes can increase the available carbon, water and various nutrients to the surrounding plants within the soil, thus providing a substantial benefit to the environment.

In comparison, pig effluent fertilisers may also be more beneficial than conventional fertilisers which have been known to decrease base cations in the soil, increase soil acidity, generate nutrient loss and subsequently impact crop yields when not managed appropriately (Qaswar et al. 2020). Research has shown that pig effluent and other livestock manure applied over several years can decrease soil bulk density, which in essence can improve soil porosity (Adesanya et al. 2016; Antoneli et al. 2019; Zhou et al. 2020). Several studies have shown a decrease in bulk density after effluent fertiliser ranging between -1% to -29% (Bernal et al. 1992; Schlegel et al. 2015; Adesanya et al. 2016). Although both liquid and solid pig effluent can decrease the bulk density of the soil, research by Adesanya et al. (2016) highlighted that solid effluent provides greater results in sandy loam soils. This has been suggested to be a result of the higher concentration of carbon within the solid effluent (18%) compared to the liquid effluent (4%) (Adesanya et al. 2016). On the other hand, if solid pig effluent is applied to the surface of the soil, it may take longer to yield these results due to it needing to decompose or be mixed within the soil. In this case, liquid effluent or effluent injected directly into the soil may provide greater or quicker results in improving the bulk density of the soil, although this may vary between different soil types.

Soil organic carbon is often difficult to measure and quantify due to it being dependent on the carbon: nitrogen ratio of the effluent, its application rate and type (e.g., surface applied or injected) and its composition (Diacono and Monte-murro 2010). In general, research has shown that pig effluent fertilisers can increase the soil organic carbon within the soil, even if it is applied to the surface of the soil (Yost et al. 2022). Although these rates may vary, the soil organic carbon concentration can be influenced by several factors such as climate, moisture content, soil type, temperature, and the cropping system (Mbagwu et al. 1994; Bao et al. 2013; da Rosa Couto et al. 2013; Schuster et al. 2019; Yost et al. 2022). Overall, pig effluent fertilisers also increase the soil carbon concentration with several studies suggesting it may increase between 1% and 47% and vary between 9g C kg^{-1} to 54g C kg^{-1} (Iyyemperumal and Shi 2007; Brunetto et al. 2012). Increasing soil carbon can have many positive effects on both plant and soil health while also playing an important role in climate change and reducing emissions (Whitehead et al. 2018; Bossio et al. 2020). Although increasing the use of effluent fertilisers can increase soil carbon concentration, it should also be noted that such practice may also increase the concentration of other nutrients, which in essence may result in further environmental impact (Gai et al. 2018). It is therefore recommended that effluent fertiliser be carefully managed to ensure further environmental impact is minimised.

Research has suggested that the effect of pig effluent on the chemical properties of soil is strongly dependent on the composition and pre-treatment methods of the effluent (Haynes and Naidu 1998; Edmeades 2003; Hargreaves et al. 2008). The effect of pig effluent on the soil pH is strongly determined by several factors such as the initial pH of the soil, soil type, and the quality and quantity of effluent used (Yost et al. 2022). Research has suggested that increasing applications of pig effluent on soils can alter soil pH by 1% to 37% (Iyyemperumal and Shi 2007; Schlegel et al. 2015; Das et al. 2017; Martinez et al. 2020). Pig effluent fertiliser adds carbonates to the soil in addition to aluminium and hydrogen, which is likely to be responsible for the changes in soil pH (Lourenzi et al. 2011). It is also noted that one of the major soil constraints related to soil pH is acidification (APL 2017). Acidic soils can become toxic to crops and surrounding plants due to aluminium and manganese becoming more freely available, which can be a result of the long-repeated use of effluent on agricultural soils (APL 2017). In this regard, regular testing of soil pH is suggested when integrating pig effluent fertilisers into the soil. Salinity is also another parameter that should be regularly tested or monitored when using pig effluent fertilisers (APL 2017). The added amounts of chloride and sodium from pig effluent can lead to several soil structural problems such as sodicity, surface sealing and even lead to increased salinity problems, all of which can cause severe damage to cropping systems (MLAL 2002; APL 2015a). With this in mind, it would be of value for future research to consider the long-term impact of salinity on a broader scale when using pig effluent fertilisers. The addition of such information would be useful to land and waterway managers in reducing the potential risks associated with increased salinity.

3.9 Plant benefits and implications

Research has shown that pig effluent fertiliser can have several benefits to plant health and can increase crop production (Adegbidi et al. 2001; Penha et al. 2015; Liu et al. 2019). Research by Penha et al. (2015) showed that after nine years of pig effluent fertiliser in soybean (*Glycine max* L.) (rate of 25m^3 per ha) and maize (*Zea mays* L.) (86m^3 per ha) produced similar yields compared to when they were grown using mineral fertilisers. In Santa Maria, Brazil, research also identified that increasing doses of pig effluent in maize cropping systems also showed similar results, however, increased heavy metal accumulation within the soil was identified (Girotto et al. 2013). This study also showed several physiological changes in the maize such as ascorbate peroxidase activity, decreased plant weight, increased lipid peroxidation, several senescent leaves, and superoxide dismutase activity (Girotto et al. 2013). Similarly, Benedet et al. (2016) also found that the concentration of zinc had increased in the aerial part of the maize with several other changes also observed in the chlorophyll content and stomata density, although crop development was not impacted. Although crop development was not impacted, the accumulation of these heavy metals presents a potential environmental risk. Replacing conventional fertilisers with pig effluent fertiliser has shown little to no significant effect on the nitrogen and phosphorus content of lettuce (*Lactuca sativa* L.) when applied by itself (Liu et al. 2019). Instead, the addition of combining conventional fertilisers with pig effluent fertiliser remains a viable option that has been observed to enhance nutrient utilisation efference and increase crop yield (Liu et al. 2019). The use of pig effluent in willow plantations has shown economic and ecological success as an alternative to conventional fertilisers and a way to recycle effluent (Adegbidi et al. 2001). Due to their highly developed root system, willows can uptake large quantities of effluent, nutrients, and water while it can also reduce percolation and prevent nutrient leaching (Kuzovkina et al. 2009). In this regard, the use of effluent fertiliser in willow plantations can be an alternative use to help recycle and reuse pig waste, although long-term effects such as the accumulation of heavy metals and nutrients within the soil require ongoing investigation. It would also be of value for future research to investigate the use of pig effluent in other plantations such as *Eucalyptus* or Pine, or other species within cropping or plantation systems, although the economic benefit, environmental impact and long-term effect needs to be explored prior to any further action. To be able to successfully integrate pig effluent into cropping systems or plantations and to replace conventional fertilisers, its transport and use needs to be economically viable. This is one of the main limitations in using pig effluent to increase crop production as in most cases the cost of production, use, and treatment of the effluent can exceed those of conventional fertilisers (Bauer et al. 2007). It is, therefore, necessary for future research in this field to commercialise and safely distribute pig effluent to areas that it would be economically viable to use, while gaining the best value for the product.

Another area of consideration when applying pig effluent to soil is the invasion and growth of invasive plants (Bernal et al. 2009). It is of concern that soil amendments and increased nutrient levels may enhance the invasion of weeds in agricultural settings (Bernal et al. 2009). Although this is highly variable and dependent on the soil seedbank, current weed management programs and surrounding weed dynamics of the land, it is important for land managers to recognise this issue. With many weed seeds being destroyed within the pre-treatment of pig effluent, it is still important to recognise the impact that altered nutrient levels may have on emerging or spreading weeds from adjacent land (Milner et al. 2014). With limited knowledge in the global literature on the correlation between pig effluent fertilisers and invasive weeds, such information would be of value for land managers to help them plan and identify this issue to ensure they can mitigate it with appropriate weed management programs.

3.10 Environmental, health and environmental protection considerations

3.10.1 Environmental

While the use of pig effluent on farm soil is beneficial (see Section 4.) it can also be a source of environmental pollution if it is not handled, treated and used appropriately (Briukhanov et al. 2017; Briukhanov et al. 2020). Poor practices associated with effluent and manure management may cause a range of environmental issues such as nutrient overloading, run-off and amenity concerns such as odour generation (APL 2015a). The application of pig effluent fertiliser in excess of crop requirements can also result in the presence of large amounts of nitrogen, phosphorus, and potassium, which may take several years to reduce to sustainable agronomically optimum levels (Schulte et al. 2010). The excess amounts of nutrients can cause severe ecological impacts. Organic matter and nutrients can enter waterways as runoff or eroded soil and can leach into groundwater (APL 2015a). They may be washed into nearby waterways which could lead to eutrophication and subsequently impact native flora and fauna (Velthof et al. 2014) and encourage weed growth (APL 2015a).

To prevent these problems, Australian Pork Limited (APL 2015a) identifies the need to address the following for areas where effluent is reused:

- Be properly managed – nutrient loading rates must be matched to soil conditions and crop requirements; irrigations need to be managed to avert runoff and erosion.
- Be well sited (with buffers to waterways)
- Have suitable soil properties to grow and harvest crops or pastures

One method of effluent application that has been identified as being less likely to be associated with runoff problems is the injection method. This method is discussed more fully in Section 3.5.4.

3.10.2 Health

Like all livestock manure, pig effluent contains various diseases, microorganisms, pathogens, protozoa and viruses that can cause several animal or human health concerns (De et al. 2003; Johansson et al. 2005). If appropriate management is not taken to minimise these risks, then the use of pig effluent as a fertiliser may not be a viable option to reuse the waste in agricultural settings. It has been reported that several contagious and pathogenic diseases can spread through effluent and into waterways or growing crops where they can pose a serious threat, sometimes undetected at first (Cote and Quessy 2005; Johansson et al. 2005; Holley et al. 2008). *Escherichia coli* is a bacterial pathogen that has been reported to spread through pigs and their effluent and if left untreated it can pose a serious threat to animal and human health (Holley et al. 2008). Research has suggested that pig effluent fertiliser that has been applied to vegetable crops has been found to introduce *E. coli* into the soil and subsequently has been recorded to travel into nearby properties via surface runoff (Cote and Quessy 2005; Holley et al. 2008). Exacerbating this issue is that in some cases, *E. coli* populations may not be recorded within the soil until the second year of effluent application, with their populations being dependent on several environmental conditions such as moisture and temperature (Cote and Quessy 2005). These findings suggest the need for regular treatment for *E. coli* in pig farms to prevent its spread via effluent. There are several antibiotics and microbial drugs available for the treatment of *E. coli* in pigs such as apramycin, neomycin, tiamulin and sulphonamides, although these may vary or be described under other names depending on the geographical region, therefore has been recommended that specialised veterinary or local advice be sought (McOrist and Corona-Barrera 2015).

Of those diseases, microorganisms, pathogens, protozoa and viruses that are commonly detected in pigs and their effluent, the most common and ones needing close investigation include *Ascariasis*, Aujeszky's Disease, *Campylobacter* species, classical swine fever, *Erysipelothrix rhusiopathiae*, foot and mouth disease, Listeria, rotavirus, *Salmonella* species (Chinivasagam et al. 2004; Johansson et al. 2005; Sobsey et al. 2006; DPI 2020; Zhou et al. 2020; Cavallero et al. 2021). Of concern here is that some of these pathogens can remain viable for several months within the soil with *Salmonella* species being detected up to 140 days at 10 °C after pig effluent fertilising, and Listeria for 106 days in the winter months (Sobsey et al. 2006; DPI 2020). It is also of concern that anaerobic pond systems and liquid-solid separation methods may not fully achieve a complete reduction in pathogenetic levels and may be dependent on several other environmental factors such as rainfall or temperature (Sobsey et al. 2006; DPI 2020).

With a particular focus on *Ascariasis* (caused by roundworms of the *Ascaris* species), it has been reported that its eggs can survive in pig effluent and constitute a serious sanitary and health risk when used as a fertiliser on crops (Capizzi-Banas et al. 2004; Hadush and Pal 2016; Cavallero et al. 2021). *Ascariasis lumbricoides* and *A. suum* are two of the most widespread *Ascaris* species that can infect both pigs and humans (Zhou et al. 2020). It has been reported that *A. lumbricoides* is responsible for over 60,000 human deaths each year, while *A. suum* is responsible for a significant loss in pig production and can have large economic consequences within the agricultural industry (Katakam et al. 2016; WHO 2022). It has been reported that adult *Ascaris* species can live within a pig's intestines and produce viable eggs which are passed in its waste (CDC 2022). When this waste is used as fertiliser, these pathogens can then survive on crops and when consumed they may be transmitted to humans if they are not appropriately washed, cleaned or cooked for consumption (CDC 2022). Eggs from these pathogens may also be transmitted to humans in contaminated water sources and contaminated soils if appropriate hygiene is not maintained (WHO 2022). One potential solution to treating *Ascaris* species within pig effluent is the addition of lime (Capizzi-Banas et al. 2004). Lime can destroy pathogens within the effluent by increasing the pH (Capizzi-Banas et al. 2004). Despite these methods working on several other pathogens, it has been reported that *Ascaris* eggs can be highly resistant to this method (Capizzi-Banas et al. 2004). The World Health Organization also recommends several medicines such as albendazole (400 mg) and mebendazole (500 mg) to help treat those infected (WHO 2022).

Anaerobic ponds and the pre-treatment of pig effluent are also other methods to help reduce any pathogens that may exist within the waste, although they do not provide 100% reductions (Sobsey et al. 2006; DPI 2020). It has been reported that pathogen reductions following pig effluent fertilisation can be highly variable and dependent on several factors such as climate, drying, soil pH, temperature and UV radiation (Sobsey et al. 2006; DPI 2020). Research by Guan and Holley (2003) suggests that pathogen reductions can vary significantly, with the example of *E. coli* ranging between three to fifty-six days in warm conditions (20°C to 37°C) and longer in cooler conditions. In this regard, the identification, reduction methods, and monitoring of any diseases, microorganisms, pathogens, protozoa and viruses are highly recommended and cautioned when using pig effluent as a fertiliser. With this in mind, it is important for pig farmers to conduct regular surveillance and testing of their livestock and to treat any potential illness in the pigs when required.

3.11 Environmental legislation considerations (Australia)

As explored within this review, pig effluent fertiliser is a valuable asset to a farm and is a cost-effective source of nutrients and organic matter that can improve plant and soil health. In light of this, the use and distribution of pig effluent between farms needs to be managed and carefully monitored. According to the Environment Protection Authority (EPA) in Australia, land managers do not need to supply or gain EPA approval to receive or use livestock manure if they (i) meet the conditions of the livestock manure and effluent determination, and (ii) pose minimal risk to the environment (Agriculture Victoria 2022; EPA 2022). This ensures that all environmental health and safety conditions are regulated and appropriate met. The conditions that land managers need to meet in order to fulfill the requirements of this determination are (i) each consignment must be inspected to ensure it only contains manure, and (ii) the manure is to only be received for the purpose of depositing on the land as a soil amendment or for irrigation purposes (Agriculture Victoria 2022; EPA 2022). It is also important to note here that any further processing or recycling of the manure requires specialised permission from the EPA. For manure that is generated and used on-farm, this determination does not apply, however there is still the responsibility of the land manager to abide by other environmental duties (Agriculture Victoria 2022). This is provided that the waste material is only made up of manure and is for the sole purpose of using it on the farm it was generated (i.e., it cannot be supplied or imported from another farm).

The General Environmental Duty (GED) is also applicable to all land managers and businesses that either export, import or use manure on their land (Agriculture Victoria 2022). This requires land managers to take reasonable steps to prevent any environmental or health risks associated with using manure on their land. In addition, land managers must follow the specific conditions adhered by Agriculture Victoria, WorkSafe Australia and other industry relevant bodies. For farms that export or import manure greater than 20 m^3 per month, they must comply with the manure determination and GED. For quantities less than 20 m^3 that are deposited onto another farm, only the GED applies. It is also noted that when manure is taken off-farm for other purposes such as for a biodigester or composting, it must be taken to a permissioned site and follow specialised environmental protection regulations. In this regard, it is important for land managers to keep records of their manure usage to help demonstrate they are meeting all of the duties under this determination which is designed to support the *Environment Protection Act 2017*. Agriculture Victoria (2022), APL (2015a) and the EPA (2022) also recommend several methods to help minimise the risks of using pig effluent fertiliser on farmland, these include:

- Apply effluent at suitable times where uptake from crops is at its greatest (e.g., before sowing or periods of active plant growth).
- Consult and seek specialised agronomic advice to avoid excess nutrient accumulation within the soil.
- Determine if the effluent is suitable and does not contain any restricted animal material or prohibited pig feed.
- Implement good hygiene practises and personal protective equipment when handling effluent.
- Limit livestock access to manure stockpiles (e.g., composted material or freshly irrigated land with effluent).
- Observe withholding periods (generally 21 days) to ensure that livestock do not graze on the land directly after fertilisation.
- Regularly inspect and remove any foreign material in the manure.
- Spread and use effluent at productive and sustainable rates.

3.12 Best practice decision making on pig effluent disbursement

The decisions regarding the management of pig effluent should be made on a property-by-property basis and may not be suitable for all locations or during all times of the year. A useful tool in making informed decisions regarding the use of pig effluent fertiliser is by using a 'Nutrient Management Plan' (APL 2011). This plan assists producers in quantifying and balancing the nutrients produced and used on their farm and identifies potential risks that may occur, in addition to an action plan or implementation strategy to mitigate these risks (APL 2011). It is important to note that a nutrient management plan will vary depending on the size of the property, number of pigs or livestock, crop type and other localised environmental conditions (APL 2011). In particular, poor nutrient handling may increase the risk of unwanted pollution or increase the accumulation of excess nutrients running into adjacent water ways (Kwon et al. 2014; Jiao et al. 2021). Research has suggested that some effluent handling and utilisation systems may result in a loss of available nutrients within the environment between 8% to 50% (Izmaylov et al. 2022). In this regard, the appropriate handling of pig effluent can contribute towards increase success obtained from this resource. As such a nutrient management plan can help to (i) increase the use and efficiency of nutrients derived from effluent, (ii) reduce farm expenditure and save on the need to use chemical fertilisers, (iii) improve soil structure and crop health, and (iv) limit the potential impact on the surrounding environment (APL 2015a). The use and disbursement of pig effluent between farms or geographically spaced properties also needs to take note of the environmental health and environmental protection considerations (see Section 3.10), in addition to the environmental legislation considerations (see Section 3.11). These considerations may also slightly vary depending on a state-by-state basis and need to be regularly adhered to when using, transporting, or managing pig effluent. Timing is also a critical factor when considering the use of pig effluent fertiliser. It has been reported that the field application of pig effluent must not exceed the soil moisture content above capacity as this can increase runoff and potential impact to the surrounding environment (APL 2015a). It is also important to prevent effluent application onto crops that will be directly eaten raw within four weeks, and to also maintain a livestock withholding period of a minimum 21 days after treated (APL 2015a). Decisions on when to spray effluent regarding weather patterns also needs to be considered. APL (2015a) suggests that effluent should not be irrigated on windy days or on days where rainfall is likely to occur. Applying effluent during those periods may reduce its success and increase any unwanted impact. If these decisions are carefully managed and guided, then the use of pig effluent as a fertiliser in agricultural soils can be a valuable resource within the agricultural industry around Australia.

3.13 Conclusion

The use of pig effluent fertiliser has shown many positive effects to plant and soil health when used and managed appropriately in agroecosystems. Although this method has shown various positive signs, there are still several areas that require ongoing research to ensure they continue to be safe and sustainably used leading into the future. This review has identified the following themes and knowledge gaps requiring further research or development of appropriate practices:

- If managed appropriately, the use of pig effluent can be a valuable asset and an alternative to conventional fertilisers. However, there is the need for a stronger focus on the longer-term impacts of soil health, with a particular focus on the accumulation of soil nutrients and heavy metals. The accumulation of these materials can have negative ramifications to the environment and human health.

- There is a need for investigation of the soil health parameters influenced by pig effluent from a range of soil types across various countries and climatic zones. This will allow for more accurate data sets and provide a greater representation of the influence of pig effluent fertilisers on both plant and soil health.
- There are potential human health risks associated with pig effluent fertilisers. Several diseases, microorganisms, pathogens, protozoa and viruses have the potential to cause animal and human health concerns requiring the identification of appropriate surveillance, mitigation and management strategies.

Overall, this review identifies that the use of pig effluent fertilisers has the potential to contribute to the improvement of soil health, increase crop production, reduce emissions, reduce the need for conventional fertilisers and reduce and reuse waste produced by the pig industry. However, it may be necessary for local, national and/or international government bodies to set strict conditions regarding the sanitation, distribution and use of pig effluent as a fertiliser in cropping systems to ensure the safety of this practice in Australia and around the world.

4. Pork Producer Consultation

This component of the study sought to consult with pork producers to obtain a local perspective and to identify current practices regarding the use of piggery effluent.

4.1 Research methods

Approval for this research was obtained from the Federation University Human Research Ethics Committee (Project number 2022-066).

4.1.1 Participant recruitment

A recruitment flier was developed (see Section 8.1) and was distributed to producers through the APL's e-newsletter. Following two rounds of distribution, and no responses from producers, alternative recruitment strategies were explored. The proposed changes were approved by the Federation University Human Research Ethics Committee. The approved additional recruitment strategies were:

- *Australian Pork Limited to circulate the email invitation and research documents directly to pork producers on behalf of the researchers.*

  This strategy required the approval of APL, which was not forthcoming, and therefore was not employed.
- *Use publicly available contact information to make direct contact with potential participants.*

  The sources of the information included online public directories (such as Dun & Bradstreet Business Directory; Farm Transparency Project Database), producers' websites and social media, and web searches using search terms such as 'pork producer' and 'piggery'. A database of contact information was compiled from these sources, but in view of the very limited contact information available, this direct contact strategy was not employed.
- *Continue recruitment through APL e-newsletter providing links to research documents.*

  This strategy was employed and produced only one response.
- *Invite Soil Health Study participants to participate in the consultation.*

  This strategy was employed and was successful in recruiting four participants.

4.1.2 Interviews

Pork producers were invited to take part in an interview to discuss their management and use of effluent. Five producers responded to the invitation and participated in online interviews. The interviews ranged from 30 to 63 minutes in length and were video recorded. The interviews were conducted by two researchers. Four of the interviews involved a single interviewee and one involved two corporate representatives. Transcripts of the interviews were automatically generated from the recordings, and these were checked against the recordings to ensure accuracy and to clarify where required. One of the interviewees chose to respond to the questions in writing as well as in an interview. Another participated in both the survey (see Section 4.1.3) and an interview. Their written and oral responses were combined for the analysis.

The interviews were based on a set of questions which were informed by the literature review. The questions used are shown in Section 8.2. At the time of recruitment, participants were provided with: a copy of the interview questions; a plain language statement detailing the study, the nature of their involvement and their rights; and a form requesting their formal consent to take part. Return of the signed consent form or recorded verbal consent were required before the interview commenced.

4.1.3 Survey

To broaden the consultation process, an anonymous online survey was also conducted employing the Qualtrics survey platform. The survey presented the same questions as those used in the interviews. The survey was available online for a period of three months and received one full response. The respondent who completed the survey subsequently contacted the researchers by email with feedback about the survey questions. In view of their willingness to engage in discussion, they were invited to take part in a recorded interview to expand on their survey responses. Their survey and interview responses were combined and reported along with the interview responses of the other participants.

4.2 Results

A total of five pork producers provided information for the study. Four of these were family run businesses and one was a national corporation (representing two properties). Information was collected relating to six pork production properties, five of which were located in Victoria, the other in New South Wales. All operations were well established businesses, with the oldest having operated since the 1960s and the newest since 2002. The characteristics of the operations and responses to some of the questions are summarised in Table 3. The following sections provide more detailed observations of the themes arising from the interviews.

4.2.1 Motivation for using effluent

The primary motivation for using effluent appeared to be the need manage the substantial amount of effluent produced by their operations. However, producers also identified a number of additional reasons for making use of effluent. These included improvement of soils, crops and pastures, becoming more economically sustainable by reducing electricity and fertiliser costs, and improving relations with neighbours.

One respondent, who used effluent to produce biogas and for crop irrigation, stressed economic and sustainability motivations: reduce electricity cost; increase revenue through Australian Carbon Credit Units; decrease fertiliser cost; decrease water cost; increase soil organic carbon; increase soil microbial content.

Several producers reported providing effluent to others free of charge. One did so to foster relations with neighbours, offering free effluent as a means of successfully resolving complaints. The neighbour remarked, "Oh well, there was nothing in it for me before, but now there is."

The other provided free effluent to the share farmer leasing their land. This was primarily used as a means of managing the piggery's effluent storage dams. The cost of transportation and application of the effluent was borne by the farmer, making it a beneficial arrangement for the producer.

4.2.2 Benefits of effluent use

Producers reported that they experienced a number of benefits associated with effluent use.

One reported "fabulous growth" and reduced need for supplementary fertiliser. Another reported improved crop yield, a positive effect on soil health "lots of activity in the soil" and an unexpected benefit of savings related to slug control.

> "Slugs in our area are a really a big issue and cost up to $100 a hectare to bait, to kill, and to keep the crop alive and at early stage. And this year, we did 120 hectares paddock we sowed with canola, half of it was spread with effluent and half wasn't. The half that was sprayed with effluent ended up persisting through the slug challenge, whereas we ran out of bait on the other half ... we think that there's something going on with the pig effluent that's actually stopping or checking the slugs from persisting. And so the local agronomists are trying to get some samples of that now because there might be some sort of bacteria or something like that that we can use as biological sort of spread to try and stop the slug problem that's in our area."

Another remarked that the benefits of applying effluent as fertiliser could readily be seen.

> "You can see … where I drive around I know where it's been ... applied ... It's chalk and cheese. You're talking paddocks that look like they've had sheep running around on 'em for 10 years and nothing's grown back. And you look over there and it's just pasture and it's like a crop."

It was felt the economic benefits of using effluent for fertiliser depended on its cost relative to the use of synthetic fertilisers, but it seems that the economic equation for this can be complex and difficult to determine.

> "It's hard to quantify the economic benefits ... where we spread the spent bedding, we think we can get around five years of benefit out of it before we can respread again
> . So … if you're looking for one year kick, it's not really probably worth it cause it's a fair bit of cost in spreading ... But then over the five-year time … because it's a pretty much a slow-release fertiliser so you're probably working on trying to get … especially the phosphorus and potassium sort out of that over the next couple of years really, where as your nitrogen's probably all burned up in the first year."

> "It's really dependent on what the synthetic fertilizer markets doing as well, as soon as the fertilizer drop prices, you know people would just resort back to that just cause it's so much easier to handle …"

Table 3. Characteristics of participating pork producer operations.

	P1	P2	P3	P4a	P4b	P5
Type	Family	Family	Family	Corporate	Corporate	Family
Established	Since 1983	Since 1960s	Since late 1970s	Since 2002	(Older than 4a)	40+ years
Production system	Farrow to finish	Farrow to finish (One site weaner to finish)	Farrow to finish	Farrow to weaner (10 weeks)	Farrow to weaner (7 weeks)	Farrow to finish (Two sites: breeder and grower)
Pig numbers	1,000 sows	2,000 sows weaners approx. 10,000 SPUs	550 sows	2,200 sows; 9,000 weaners (3-10 weeks)	1,500 sows	2,000 sows, approximately 20,000 pigs in total
System type	Indoor, deep litter, nothing outdoors - grower pigs and weaner pigs are all on straw - finishing pigs are on slatted flooring	One site is an indoor grower site	All in indoor sheds, all on concrete floors	Indoor, deep litter, no outdoor		Indoor
Effluent quantity	30-40,000 litres liquid effluent per day. 4,000 tonne spent bedding per year	About 1.5 megalitres of slurry and about 30 megalitres of grey-water	5 megalitres of sludge - 20 megalitres of liquid		About 20 megalitres	About 1,500 t/yr
Effluent storage and management	Covered anaerobic pond for liquid and storage pads for spent bedding.	18 megalitres covered anaerobic lagoon and 85 megalitres grey-water storage. There are times when the grey-water needs to be irrigated because the storage is full, but it may not be the ideal time to irrigate the crop.	Effluent stored in covered lagoon. Liquid put in storage dams.		Effluent stored in dams using a decanter system, solids in one dam and liquids flow to another dam. Solids are removed every six or seven years.	Methane digestors; sedimentation and evaporation pond systems (SEPS); recycle dam

Table 4. continued Characteristics of participating pork producer operations						
	P1	**P2**	**P3**	**P4a**	**P4b**	**P5**
Irrigation	Previously irrigated 300 Ha	150 Ha irrigated	200 Ha irrigated		80 Ha irrigated	1425 ha
Crops	Canola, wheat, barley	Canola, wheat, barley	Pasture – mainly rye grass	Pasture	Canola, barley, wheat	Forage crops (silage) & wheat, canola
Effluent use	Biogas. Spent water from biogas is stored in ponds. Contractor pumps water out and using drag pipe to irrigate cropping land. Straw effluent is stored through the year and spread on the paddocks by the end of March	Biogas. Slurry spread on top of soil. Grey-water is blended with irrigation water through the channel system and is flood irrigated	Irrigate (20 megalitres) at certain times of the year on 200 hectares of beef farm (travelling hard hose) - solid component accumulates in the bottom of covered lagoon and pulled out with a vacuum pump and spread sludge (5 megalitres) on paddocks once a year	Give slurry to local share farmer. Don't sell any	Effluent not used to irrigate crops but used to prepare the ground.	Disperse effluent on farm, sell to others, use it to produce energy and recycle nutrients. Used to reduce clean water requirements by flushing sheds with recycled liquid. Excess used as fertiliser through irrigation.
Dispersal methods	Spent bedding: own spreader tank - spray. Liquids: flat drag line with GPS. Wet weather storage ponds - irrigate prior to cropping. Biodigester has no solid output.	Slurry: vacuum tanker spread on top of the soil - grey-water: blended with irrigation water and flood irrigated.	Travelling hard hose.	Top dressing - tankers	Slurry tanker - agitator used in dam to mix solids in with liquid.	Liquid and solids; top dressing and spraying
What records are kept	AgWorld and agronomists	Don't manage the land.	Use AgriWebb and consultant to assist choosing what to apply where.	Don't manage the land.		Soil tests; fertiliser application rates; crop yields; annual testing of liquid and solid fertiliser/effluent

"... depending where we use it, we get full value or a percentage of the full value. Potentially ... the piggery component should be charging the beef component a fee for the nutrient. It's all very hard to quantify or... every system is different, so I'm not sure how to sort of answer that one. But we I guess we just put a value on it like a compare it directly to a general fertilizer ... would be the short answer."

The potential for using effluent as a source of water was also dependent the economic equation:

"... if we've got the ability to separate it out, we'd be able to find a use … [for] water. If you can have that water back again ... that would absolutely be economically beneficial for us. But obviously just doing the numbers on what does that cost to be able to treat it, to get it back so we can use it again …"

4.2.3 Negatives and challenges associated with effluent use

Impact on crops

While potentially beneficial, the use of effluent on crops and pasture appears to require careful management to prevent undesirable impacts:

"… with the barley, you just overcook it. It just can't handle it like if you get a dry finish it lodges, and we've had varieties of wheat that lodge as well, have been just got over burden with too high a crop and just fallen over and don't yield. So you've just gotta be careful what you what varieties that you use."

"[before having the digester] ... when we used to put on a raw liquid effluent, if you'd picked the time of year wrong, it could burn off the leaves a bit. Because you're putting an inch of nutrient water onto leaves in so vulnerable time stage could burn them off a bit, but with our new system, which we probably should focus on, it's just like grey-water, really like you can handle it."

"... if you use too much and don't crop it, you do get overload of nutrients. So you've gotta be very careful about how much you spread without putting something in the take it out so."

In addition to issues associated with burning and nutrient overload, salt content can also be an issue:

"… in Queensland we've got issues with the salt content in the water. So ... obviously the pigs drink the water ends up in the effluent and then if you spray that out, you get a really high salt load on the on your ... cropping land."

4.2.4 Timing and weather issues

Using effluent as fertiliser can also present some challenges related to timing and weather conditions. Problems can occur if the time that effluent storage emptying needs do not align with crop needs.

"There are times when the grey-water needs to be irrigated because the storage is full, but it may not be the ideal time to irrigate the crop."

Similarly, weather conditions can impact storage and affect the ability to use the stored effluent.

"… other thing would be the time frame of when they need to use it … if your ... dams are a choc-a-block, ... we make sure we're pretty good at keeping the surface water out, but you can't keep what falls out of the sky out of them, so I think that that's the biggest, the hardest part of managing the effluent dams is the weather, the weather and ... the seasons."

"... the last two years because it's been so wet, we haven't been able to do anything even, it's been a real challenge because that effluent systems have been very full and you know then when we want to irrigate the ground's too waterlogged … that varies from year to year. And then you have a drought year and you can have all of your effluent ponds dead empty, which is lovely."

The ability to get farm machinery onto paddocks to spread the effluent also presents some problems in wet weather.

"No, you can't, you can't get on at all. They won't get on the paddocks for a month now after this rain. … you can't get a five- or six-ton tractor across a paddock for another month, six weeks in in this weather."

4.2.5 Regulatory barriers

One producer had been irrigating with raw effluent until 2020 but converted to biogas in view of difficulties in obtaining permits to expand the practice.

"EPA regulations on our permit to get an exemption on the new permit … we were gonna have to fight and prove what we were doing was working ... But we weren't gonna sit around and wait for that to happen and it took us two years to get the permit as it was. It was very, very slow …"

Another noted that EPA regulations can restrict the areas in which effluent can be used.

4.2.6 Economic and practical barriers

One producer indicated that economic considerations were a barrier to adopting improved effluent use practices. While they currently spread the slurry on the surface, they would prefer to drill it into the soil to reduce nitrogen and moisture loss but felt that the cost of equipment was prohibitive.

"… Yeah, it's really difficult. So what you need is an implement that will do it, so you need … your vacuum tanker and then you need an implement that drags behind the vacuum tanker with very deep tines that rip into the ground, and then you have a manifold ... It would be very expensive, but then if you do that you also need a very big tractor to pull it because it's gotta dig down deep into the ground. So you need a large implement to drag behind which might be I don't know, 150,000 or 200,000, and then you need a large enough tractor, which you probably looking at like 350 horsepower, which you're looking at around half a million bucks for one of them."

Another highlighted the difficulties associated with handling and dispersing effluent, compared with synthetic fertilisers.

"So obviously with effluent, it is, it's really hard to get it out and spread it onto a crop. So you know synthetic fertilisers you can just ... you've got pellets or you know it's you've got your spray rigs, it's very easy to get it out and get it consistently across your crop. So that's another negative of the pig effluent. Yeah, just it's challenging."

The cost of transporting raw effluent was also seen as a barrier to its use.

> "... slurry tanker would be one of the most expensive ones because if you've got a cart to your far paddock or more than 4K away it would get very expensive … if it's slurry, ... if it's still got the water in it, it's less valuable per tonne."

4.2.7 Odour issues

The odour associated with piggeries, and the storage and use of piggery effluent, can create problems with neighbouring properties and communities.

> " … when they agitate the dam, they put the stirrer in, that's when you're creating odour, … some ponds we've actually had to cover ponds because of the complaints that we were getting from neighbors about the smell."

One producer dealt with the problem by purchasing the neighbouring property.

> "We had one instance ... we had to buy ... one neighbour out because it was the same, as every time we agitated, or it rained, the pond smelt ... she just couldn't hang her washing out. Couldn't do this. Couldn't do that. So she said you wanna buy my farm and said OK."

Several of the producers have reduced odour problems with the use of biodigesters.

> "... the only problems and barriers historically have been just trying to keep our neighbour relationships robust and we've got around that now by cancelling out all odour. … We used to spread the solids which would've had a very offensive odour and due to us being in a populated area, we then started composting the solids ... to take the odour out of it. … But since then, we've now built a biodigester …. we take the methane to generate power and flare off any excess which destroys the odour from the farm, generates power for our sheds and heating..."
>
> "So although I've done it [irrigate with raw effluent] since like day dot when we started, we did all that and pretty much had no odour issues and or anything while we're doing that. But then when we were forced to put into storage dams ... we ended up with a lot more complaints … now we've gone bigger with the expansion … we've had to go to the biogas flaring system to try ... to stop odours …"

4.2.8 Nutrient management and record keeping

In view of the potential for damage to crops or pasture from inappropriate use of effluent, there is the need for management of effluent application. Some producers reported employing rigorous management techniques using online management systems or agronomist support:

> "... we use AgWorld with our agronomists. They do all the recording … we've been doing variable rate sowing ... we do grid points like on all our paddocks, so everything's monitored that way. And so we do soil tests probably I think every five years now so which is a fair commitment when you're doing grid mapping cause that's it's quite expensive, but then it saves you the money later when you're putting the stuff where you need it actually helps with the fertilizer placements and soil if you've got variable rate showing."

> “… we've got huge amounts of information about our farm and how we do it … we use a farm management program, AgriWebb. We've been using that for about five years, so that has every paddock would have nutrient applications or if we put effluent in so we can treat it as a fertilizer and it would also have production of every paddock. And it works that out how many stock are in there for how many days a year at what stock loading. So we've got a pretty good grasp on our farm and what production happens on different areas of the farm and each paddock.”

One producer reported a less clear picture of nutrient management. They reported that their land manager takes nutrient balance into consideration and adjusts accordingly, however:

> “I'm not sure how much testing he actually does or whether it's sort of he knows how many megalitres of grey-water he's put out and you can work out how much nitrogen’s actually gone out. Just sort of guess at how much urea he would need."

4.2.9 Future use of effluent

Reflecting on their future use of effluent, one producer was interested in making more use of effluent but felt that to do so would increase labour costs and this was prohibitive.

> “I think we got to spread it over more acres and work out how we can do that better... I think we're probably underutilizing it ... It's a job in itself, isn't it? ... we're sort of doing it in the background with all everything else we do, but like we could probably put someone on just to run the effluent ... system and probably pay for that quite nicely, … Interested in increasing use but cost labour could be high.”

Similarly, another was interested in making more use of effluent but felt there was the need for technological developments and for the numbers to add up for it to become feasible.

> "I think it's probably stay the same unless some technology come along to make it different ... if you can have that water back again, that's yeah, that would absolutely be economically beneficial for us. But obviously just doing the numbers on what does that cost to be able to treat it, to get it back so we can use it again and all those sorts of things … we're definitely in an exploratory phase.”

Another identified the need for better management of the resource.

> “… continue using as is but become better organized with getting as much value out of as possible which we’ve already started in the last few years, really analyzing it and getting assistance in making sure we're putting it in the best spots possible.

One producer considered effluent to be a valuable resource but was limited by the amount of available effluent.

> “If we had more to use, I would use more. There is potentially value in drilling it into the soil.’

Another stressed the need for producers to stop seeing effluent as a problem and see it as a resource that needs to be factored into their business accounting.

> .. if they realised ... they've actually got a resource sitting there and it could be ... saving you in fertiliser like we absolutely put a value on what the nutrient is worth in our farm we use in our so we have quite a big cropping and you know sheep and cattle enterprise and you know we even you know even to the point of what you charge from one entity to the other entity ... we buy less fertiliser in our cropping programme because of the pig manure that we have.

4.2.10 Carbon neutral farming

All producers expressed an interest in carbon neutral farming, but one felt that "a carbon neutral piggery system is highly unlikely" for them. Their use of soybeans in the pigs' diets was seen as a particular issue, the beans being sourced from the Americas where their cultivation is associated with rainforest destruction and consequent soil carbon losses.

> "… largely our emissions are coming from ... our manure management systems, our feed production, so the feed that we're feeding the pigs come with a huge amount of emissions. And also our use of soybean, which is a problem for a lot of, you know, intensive livestock industries feeding soybeans through their diets … to a much lesser extent is just from fossil fuel energy as well ... electricity, we're purchasing use of gas, all of those things. So we certainly have got an interest in a carbon neutral farming system. But it's gonna be a big economic transition for us to achieve that.

One producer had a strong commitment to carbon neutral farming and was already participating in the carbon credit economy.

> "I'm probably one of the only carbon credit farmers around this area ... I'm getting paid to do it. So I think it's probably, well, it's only just starting and it's probably still gonna build over the next few years ... now you got all these corporations sort of saying they wanna be carbon neutral ... I think it's in our own industry best practice to be neutral like and have proof of that. So I think that's where everyone should be heading."

Another considered that carbon neutral systems are most beneficial for businesses that can use the credential to receive a better price for their product, but as not all producers will be in the position to do this, they suggested carbon credit trading could be an option.

> "For businesses that are not in the position to market the product, selling the carbon credits through sustainable practices is a better option."

One producer was frustrated with the hype around carbon neutral farming, but recognised elements of the approach that that were beneficial to their operation.

> "… at the moment I'm finding it really frustrating with the amount of noise and media and excitement around all these quirky, I guess fringe potential things that are coming up ... a lot of it ... will probably never come to anything. So I probably don't share the excitement around all the new up and coming things, but the raw kilograms of carbon per kilogram of meat, I follow that and look at different ways that we can improve it on our farm … we get a lot of dairy byproducts and feed that to the pigs. So we are sort of quite low in carbon output because we use recycled feed and we generate our own energy.

4.3 Discussion

Consultation with local producers provided a number of insights concerning the management and use of piggery effluent. However, given the sample size, these insights need to be viewed as indicative for this sample only, rather than representing the broader Australian situation. In 2019-2020, there were 1,134 pig farms in Australia (Agriculture Victoria, 2021), consequently the sample of producers available to this study was insufficient to fully meet the study's consultation aims.

However, despite these limitations, the study has provided a number of points of interest, as detailed in the preceding sections.

It is also noteworthy that while it was very difficult to recruit participants, the producers who did take part were willing to engage in full and open discussion about how they manage and use piggery effluent. Some appeared to appreciate having the opportunity to talk about the issues and displayed considerable passion for the industry and an eagerness to discuss their operations and their plans.

Another finding of the consultation also has potentially important implications. The project was initially based on the assumption that producers commonly sprayed effluent onto farm soil, however, the information provided by the participants suggests that the practice might be changing. While all of the participants have sprayed raw effluent in the past, most have moved to bio-digestion systems and this has implications for the nature of the waste products and their use.

4.3.1 Methodological issues

This consultation project met with unanticipated difficulties in recruiting participants, with only a small sample of producers consenting to take part. There are possibly a number of reasons for this.

- Indirect approach

  Recruitment may have been hampered by the researchers' limited ability to make direct approaches to producers. For privacy reasons, APL was not able to provide the contact details of their network members and very little contact information was publicly available on the internet. Therefore, producers were indirectly invited to take part in the research through news items in APL's regular e-newsletters. a number of rounds of recruitment were undertaken through the newsletters. These produced only one response (a survey completion) from producers.

  In view of the lack of success of the indirect approach, approval was gained to make direct approaches to the small number of producers who had previously been contacted regarding another aspect of the study (Soil Health Study). This approach yielded positive responses from five producers. It may be that individual contact is an important part of recruitment to studies such as this. Any subsequent research may need to make more active use of APL's network, perhaps engaging a number of producers to champion the study within their networks.

- Recruitment strategy and marketing

  The recruitment strategy employed, i.e., placing items in the APL e-newsletter, may have failed to attract the attention of producers. This is possibly associated with placement within the newsletter, the content and visual impact of the news items. For example, in one of the newsletters, the hyperlink to the article was not placed in a prominent position, being one of a number of links in a minor section of the newsletter, and this linked to a simple plain text page that lacked in impact (Figure 1). However, the more visually impactful recruitment flier (see Section 8.1) also failed to attract any responses. Future attempts to recruit producers may need to use more prominent marketing materials and strategies that capture the attention of the reader and engage their interest. However, is likely that these strategies will need to be part of a multi-pronged marketing strategy that also includes the involvement of producer champions.

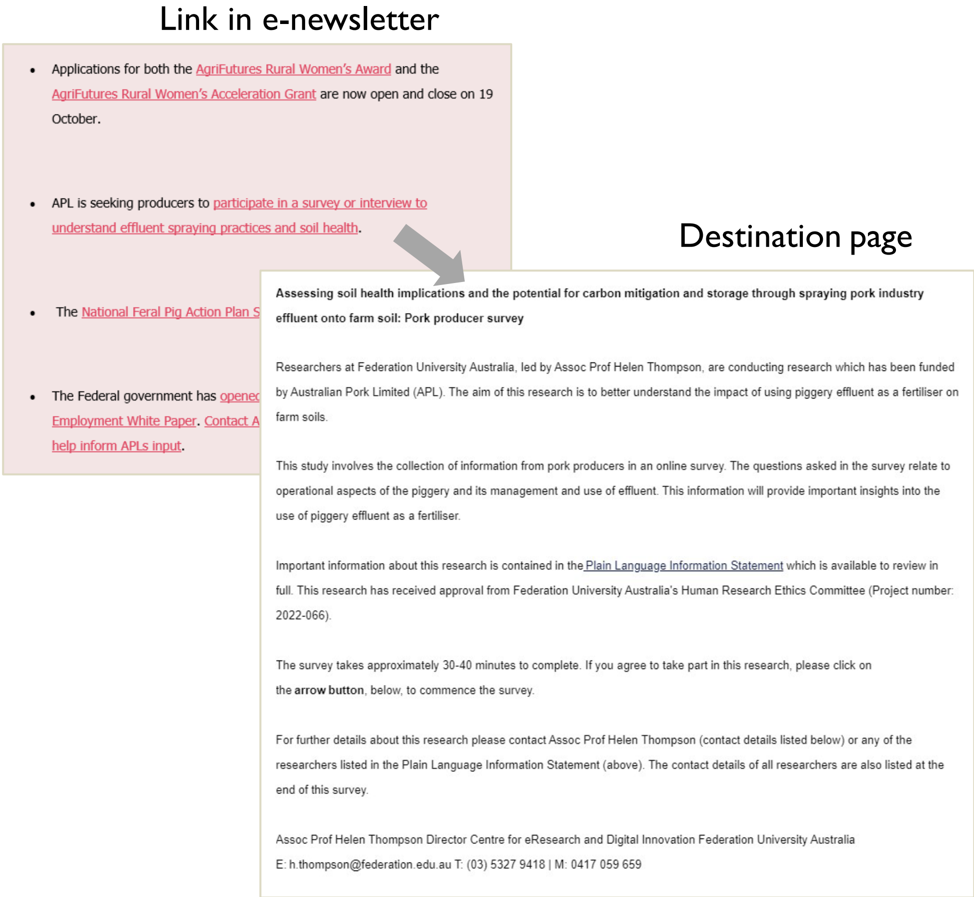


Figure 1. Excerpt from APL e-newsletter showing link and destination page.

- Producer privacy concerns

  It is possible that pork producers are concerned about privacy issues, making them reluctant to share information about their operations. In our initial attempts to recruit, we found there to be little information about individual producers and their operations on the internet. As indicated by one of our participants, pork producers can be the target of activist organisations and therefore are reluctant to attract attention. One participant from the associated Soil Health Study did in fact withdraw from the study because they were concerned that they might be identified.

  However, in contrast, another participant said that, in their experience, producers are very willing to share information and did not consider producer privacy concerns to be the problem. They felt that either "you're asking the wrong people or not asking the right questions." This comment suggests that it could be important to have a more active involvement of producers in the planning stages of any further research undertakings.

- Producer time constraints

  Several respondents suggested that, because of the busy nature of their operations, producers may be reluctant to take on any additional time commitments. In the cases of the soil health study participants who agreed to be interviewed, they might have considered there was a reasonable trade-off. Putting time and energy into the interview was balanced by the free soil sampling the study would be providing.

The problem of recruiting producers to agricultural research is not unique to this project. Weigel et al (2021), in response to recruitment problems, compared a range of recruitment strategies to determine their effectiveness in the recruitment of farmers. They found that emailed invitations were ineffective, with no responses to a total of more than 4,500 emails sent. However, they reported that an association with a respected institution had a significant impact on recruitment, as did a larger monetary payment. Despite the lack of success of emailed invitations, they considered that the use electronic communications was the way forward on both cost effectiveness and breadth of reach grounds. However, the relevance of their findings to this project is difficult to ascertain. The results may depend on the age and/or educational profile of their U.S. farming population which may differ from that of ours.

5. Soil Health Study

This component of the research sought to collect soil data from pork producers to understand the impacts of applying piggery industry effluent on farm soil health parameters. We asked producers to identify paddocks with close proximity (comparable soil types) and similar agricultural management but had contrasting histories in the amount or types of effluent applied. Overall, four producers were included in the soil sampling study. Three of the producers are currently using effluent in cropping systems and the land-use of the fourth property is grazing. The initial plan was to have two cropping sites and two pasture sites, but the other producer using effluent in a grazing enterprise pulled out last minute due to concerns around being identified.

In this project, soil health was defined by changes in chemical and physical properties as outlined below. We did not seek to measure changes in the size (abundance), activity or the community composition of the soil microbial community, given the expensive nature of these biological measurements and the subjective nature of the results for soil health. Importantly, none of the producers raised any issues/concerns regarding biological issues and thus there was no justification for pursuing other aspects (pathogens, diseases, loss of soil function etc.).

5.1 Methods

5.1.1. Participant recruitment

Identification of potential participants, and their recruitment to the study, presented difficulties. Initial contacts with an industry leader failed to yield suitable candidates. Exploration of research networks identified pork producers who were already involved in other research projects, this was partly successful, with some considered that they would be unable to take on additional commitments. Additionally, pork producers tend to have only limited contact information available on the internet, making it difficult to initiate contact. Only a small number of producer contacts were identified from the internet, and through social media, and these were contacted directly by the researchers to invite them to take part in the study.

5.1.2 Soil sampling methods

Soil sampling was carried out in areas where effluent had been commonly dispersed in the past years and comparison areas that had either not received any effluent or had received few applications. Each of the four producers (P1-P4) identified two paddocks with contrasting effluent histories, except three paddocks were sampled for P1. In each paddock, four sampling locations were identified and digital tools such as satellite imagery (google earth, nearmap.com) and NDVI (datafarming.com.au) were used to corroborate producer observations and uniformity in productivity and soils at each site. An illustration of the soil sampling procedure carried out at each producer's farm is shown in Figure 2. At each sampling location (e.g., Sample 1), three soil cores were taken side by side (<1 m apart) to a depth 60-cm and sectioned into 5 depths (0-10, 10-20, 20-30, 30-40 and 40-60 cm). For cores 1 and 2, samples from each depth were bulked so that the composite provide adequate soil for the suite of analyses required. For core 3, samples were air-dried and archived at The University of Melbourne to ensure soil was available for future reference, if required. The principles of soil sampling and sampling handing/processing were guided by Gourley and Weaver (2019) and McDonald et al., (2009).

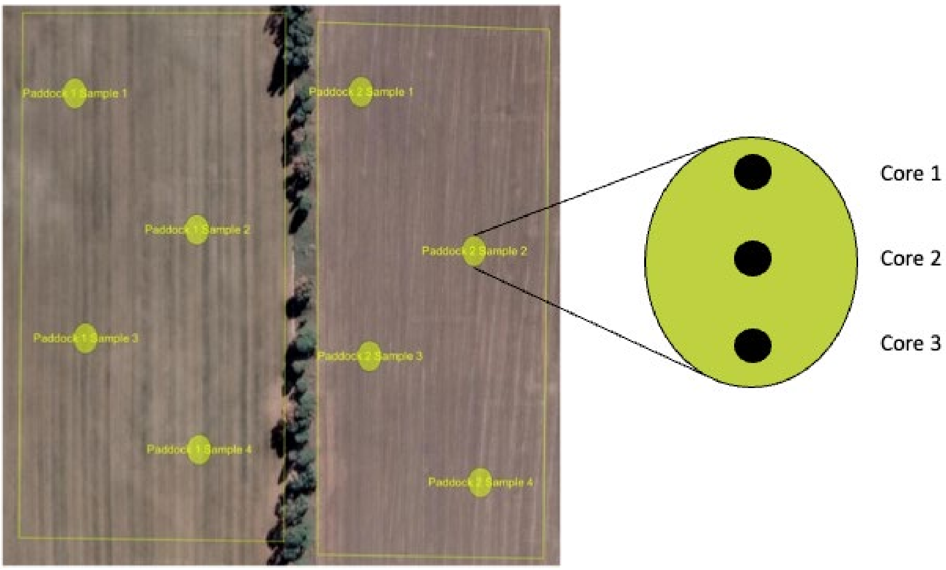


Figure 2. An illustration of the soil sampling procedure carried out at each producer's farm.

Soil samples were analysed for chemical and physical properties as outlined here, according to standard methods for Australasia (Rayment and Lyons, 2011);

1. Wet weight, dry weight (water content), and bulk density (mass of dry sample / core volume using core diameter and sampling depth interval).
2. Dispersion and slaking using Emerson dispersion test (Emerson, 2002).
3. Soil pH water and 0.01 M $CaCl_2$ (1:5). Method 4A1 and 4B3.
4. Electrical conductivity of soil-water extract (1:5). Method 3A1. EC 1:5 was converted to ECe using texture class and salinity (>2 dS/m) was scored.
5. Exchangeable cations (Ca, Mg, K, Na). Method 5A4.
6. Total carbon and nitrogen (dry combustion). Method 62B and 7A5. Organic carbon was estimated from total C using a conversion factor of 1.72.
7. Olsen P determined after extraction by Segmented Flow Analyser (SFA). Method 9C2a.

8. Inorganic N (NH_4^+/NO_3^-) 2M KCl determined by SFA. Method 7C2a.
9. Cowell K determined after extraction using ICP-OES. Method 18B1.
10. Sulfur determined after extraction using ICP-OES. Method 10B3.
11. Micro-nutrients (B, Cu, Fe, Mn, Mo Zn) determined after extraction using ICP-OES. Method 12A1, 12C2, 12E1.
12. Metal determination after digestion with acids using ICP-OES (Cd, As, Cr, Pb, Mo, Co, Se). Method 17B2/17C1.

All data relating to these analyses will be passed back to the producers after project completion.

5.2 Soil analysis results

The full data set for Producer 1, 2, 3 and 4 can be found in Sections 8.2, 8.3, 8.4 and 8.5, respectively. In each section, figures show mean data for each parameter within the soil profile of each paddock (i.e., mean of four soil core locations) (Figure 2). Individual soil sample data are presented in the second table within each of these sections. Categorical Emmerson dispersion class number is presented in the first table within each section.

A simplified summary of the findings is presented in Figure 3, although in view of the small sample size on which it is based, some caution needs to be used in its interpretation. Fuller descriptions of the findings follow.

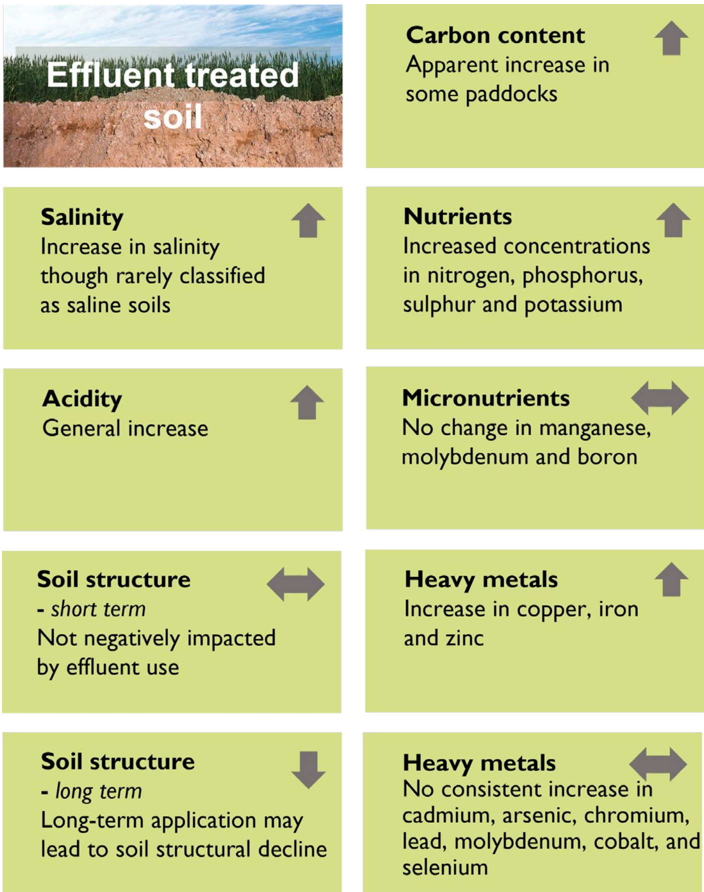


Figure 3. Summary of main soil analysis findings based on sampling from the properties of four pork producers.

Changes in carbon content between effluent treated and non-treated paddocks were generally small (P1, P2) or were absent (P3). At P1 and P2, soil C was 0.2% and 0.25% higher in effluent treated paddocks but this value was less than the variability within each of these paddocks (1.2% and 0.4% for P1 and P2, respectively). In contrast, total C appeared to be decreased at P3 where some (2.1% decrease) and heavy (1.3% decrease) applications of effluent were used. The relative differences between these sites may be due to their inherent fertility, whereby starting at a low base (lower C%) may afford some opportunity for soil C gains and starting at a higher base (higher C%) may lead to a priming effect whereby organic matter is lost due to the supply of other nutrients. The cropping soils had 1.2-2.4 % C (2-4.1 % organic matter) and the grazing soils had 3.6-5.7% C (6.2-9.8 % organic matter). We did not attempt to convert C concentrations into absolute amounts for each sampling depth using estimated bulk density, as bulk density was unchanged.

All sites had acidic soil profiles, but not uncommon for soils within their respective areas and for the land uses. Effluent decreased soil pH at all sites, except P3 (high rainfall, highly acidic soils) and this effect was mainly in surface soils (0-10 and 10-20 cm). For P3, paddocks receiving some and heavy effluent applications were more alkaline (but still acidic at depth) compared with the paddock where no effluent had been used. For P2, the paddock where effluent slurry + grey-water was spread was more acidic (0-40 cm) than that receiving grey-water only.

As expected, paddocks receiving effluent had greater nutrient concentrations than paddocks receiving little or no effluent. For total nitrogen (N), small increases (0.02%) or no change in total N were observed for the less fertile (1.2-2.4 % C, 2-4.1 % organic matter) soils, used for cropping (P1, P2, P4). In contrast, the more fertile soils from Gippsland (3.6-5.7 % C, 6.2-9.8 % organic matter) used for grazing (P3) had lower N concentrations with little impact of some or heavy effluent application. Overall, these differences in total N were proportional to that of total C. Inorganic N in the soil used for grazing was low (<8.3 mg N/kg) with little effect of effluent use. In contrast, the concentrations of inorganic N at the 3 other sites used for cropping were higher (14-74 mg N/kg) and there were consistent increases in inorganic N content with effluent application with 2.6, 15.1 and 60.1 mg N/kg for P4, P2, and P1, respectively. These high levels of inorganic N in the surface soils are predominantly in the nitrate (NO3-) form that is prone to leaching and would contribute to surface soil acidification.

Phosphorus (P) concentration in surface soils (0-10 cm) were elevated by effluent application as expected. The highest P concentrations at P1, P2, P3 and P4 were 39, 100, 59 and 60 mg P/kg, respectively. The estimated increase due to the effluent at each location was 20, 54, 42 and 33 mg P/kg for P1, P2, P3 and P4, respectively. While all properties are considered to have high P content in their surface soils, the topsoils of P2 are very high, which indicates that the rates of effluent applications have exceeded the P demand of the cropping system.

Sulfur (S) concentrations were generally within an expected range, except for P1 which had high S. For P2, P3 and P4, all soil layers (0-40 cm), except the deepest depth, had S concentrations between 7.2-17.5 mg S/kg, with the lowest concentrations occurring at the higher rainfall site. These sites (P1, P2 and P3) had the greatest S concentrations within the lower depth of the soil profile (40-60 cm) highlighting leaching of the mobile sulfate (SO4-) ion. In contrast, P1 had a more uniform distribution of S in the soil profile where effluent had been applied and the concertation was consistently high (29-35.5 mg S/kg) exceeding the 20 mg S/kg upper range expectation for cropping soils.
Potassium (K) concentrations were particularly elevated in soils treated with effluent. The K concentrations ranged from 135, 402.5, 617.5 and 1575 mg K/kg for P3, P4, P1 and P2, respectively.

For P3 and P4, K concentrations were only above the expected range (200 mg K/kg) in the surface soils (0-10 cm). In contrast, for P1 and P2 all layers of the soil profiles at these sites exceeded the expected range, being almost double in effluent treated compared with non-treated paddock (P1) and high for slurry and grey-water mixtures (P2). Concentrations of K at P2 were almost 8 times those expected for an agricultural soil.

Micronutrient concentrations were differently affected by effluent application. In general, manganese (Mn), molybdenum (Mo) and boron (Bo) were not affected by effluent application. The natural concentration of iron (Fe) is generally high in all soils, although was further increase by effluent in P1, P2, P3 but not P4 soils. The greatest increase was seen at P3 where the heavy application of effluent increased extractable Fe concentration by 45%. Copper (Cu) was 3.3, 1.8, 26 and 2.5 times higher in effluent treated than non-treated surface soils (0-10 cm) for P1, P2, P3 and P4, respectively. Albeit the highest Cu concentration was 5.5 mg Cu/kg soil with most soils having less than half of this concentration. Furthermore, zinc (Zn) concentrations were higher where effluent was used, not surprising given that Zn is given to piglets to aid in growth, development, and overall health in Australia. Zn was 1.9, 2.4, 4.9 and 4.1 times higher in effluent treated than non-treated surface soils (0-10 cm) for P1, P2, P3 and P4, respectively. The highest Zn concentration was 15.75 mg Zn/kg soil with the soils ranging from 3-10.2 mg Zn/kg (0-10 cm), with only heavy effluent use or effluent + grey-water elevating Zn to a lesser extent in the 10-20 cm soil layer. Other metals (cadmium, arsenic, chromium, lead, molybdenum, cobalt, selenium) were also determined to assess whether these accumulate in soils with repeated use of effluent. We did not see any consistent increases in these metals in soils receiving effluent than those with little or no effluent application.

The salinity at each location was assessed by the electrical conductivity (ECe) and sodium absorption ratio (SAR) of soil. Both EC (1:5 soil:water) and ECe (saturated extract) were determined (see raw data) but we prefer the use of ECe as it allows the comparison of soils with different textures. Overall, none of the producers' paddocks were classed as saline, having 1.5 dS/m or lower. The exception was for P2 where the ECe for 30-40 cm and 40-60 cm were 1.8 and 2.2 dS/m, respectively, which would impact moderately susceptible pasture species but have no impact on moderately tolerant crop species used at the location. This elevated ECe at this site may be due to the use of grey-water. The SAR also gives an indication of the potential to lead to sodicity. In general, the SAR of all surface soils was non sodic (SAR <3), although the SAR of some deeper layers exceeded this value. The notable exception was P2 40-60 cm where the SAR was 4.87 dS/m where effluent slurry + grey-water was used. This would indicate that this level of sodium in the long-term would lead to sodicity and soil structural decline. However, Emerson dispersion class (Figure 4) data for each site did not indicate any structural decline in soils where effluent had been applied, albeit some signs that the soil solution had high SAR values in some cases that could lead to sodicity and soil dispersion in the longer term.

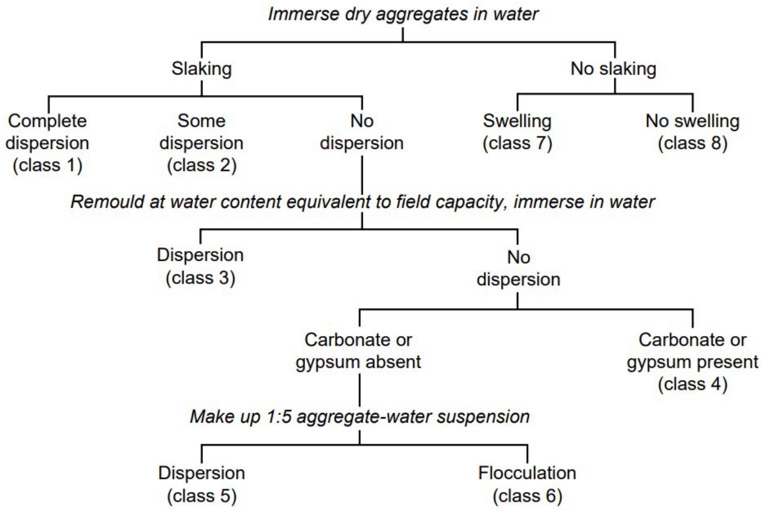


Figure 4. A description of the scheme for determining the Emerson dispersion class number (Emerson, 2002; Moore, 2001).

5.3 Soil analysis discussion

The study reports soil data from four producer's farms from paddocks with contrasting effluent histories. Based on information from the surveys, we chose to focus on soil chemical and physical properties, as no negative impacts of effluent use were observed by the participants, instead they saw the material as a valuable nutrient source and organic amendment for their cropping or grazing enterprises.

Paddocks that receive effluent have the potential to acidify if liquid sludge contains high amounts of ammonium that undergoes nitrification (acidifying process), and the nitrate which is formed is subsequently leached down the soil profile. The study showed some evidence of acidification of surface soils (0-20 cm) in lower rainfall areas used for cropping. This could be due to nitrate leaching, as mentioned, or due to greater export of alkalinity (farm products) via increased crop yield with effluent application, or a combination of both. Future work in this area should consider the nutrient composition of the effluent being applied and paddock productivity data from producers to examine the acidifying potential of traditional and modern effluent types (sludge, grey-water, liquid and solid components of digestate etc).

The study highlights the potential for small gains in total C and N (0-10 cm) in more fertile soils but was not definitive from the large spatial variability. In contrast, a priming effect or loss of total C and N (0-10 cm) was evident in more fertile soils (starting at a higher baseline and probably near their C storage capacity). Given the subtle changes in soil C, and the large existing background C pool, future work would need to do more accurate measurements of bulk density than was done here. We estimated bulk density from the weight of the soils within each depth interval with the known diameter of the soil core. Larger bulk density rings should be used instead. In addition, since the changes in soil C are likely to occur within the soil surface (0-10 cm, but indeed above 20-cm depth) more intensive sampling should occur here and less emphasis on the deeper soil profile.

The literature review highlighted some key issue to look out for in regard to changes in chemical and physical properties. Nutrient loading is an obvious risk of effluent use. We determined the concentrations of macro- (N, P, K and S) as well as micro-nutrients (B, Cu, Fe, Mn, Mo Zn). As expected, paddocks receiving effluent had greater macro-nutrient concentrations than paddocks receiving little or no effluent. Overall, changes in total N were small and proportional to C. Inorganic N in the soil used for grazing was low with little effect of effluent use, potentially reflecting the constant N sink of pasture and its ability to take up inorganic N. In contrast, inorganic N at the 3 other sites used for cropping was higher and proportional to effluent application. These sites also showed pH decreases suspected to be via nitrate leaching. Phosphorus (P) is a critical nutrient when considering applying effluent to paddocks, as it is immobile in soil and can accumulate within the soil surface. This P could move offsite attached to soil particles. For this reason, future work may require strategic sampling for immobile nutrients and contaminants that are potentially accumulated at the soil surface, and where the slope class of the paddock could result in off-site impacts. As is the case here, a sampling depth interval of 0-10 cm may underestimate the P at the soil surface (dilution effect by mixing 0-10 cm layer) and that which has the potential to leave the effluent treated paddocks. Both potassium (K) and sulfur (S) were elevated in paddocks receiving effluent. High S was mainly found at depth as sulfate is mobile, and these elevated levels of S do not indicate any potential problems. For K, it was particularly high (8 times the expected upper range for agricultural soils at one site). Excessive K can lead to stock health problems, but this may not be such an issue for stock grazing stubble in a cropping enterprise. Nevertheless, the elevated S and K levels require further investigation.

Micro-nutrients manganese (Mn), molybdenum (Mo) and boron (Bo) were not affected by effluent application but copper (Cu), Zinc (Zn) and Iron (Fe) were. Other metals (Cd, As, Cr, Pb, Mo, Co, Se) did not accumulate in soils with repeated use of effluent. Heavy metals are also a concern, but less so than other parts of the world where animal feed is (or was) intentionally fortified with metals and the soil-plant systems used for animal feed and effluent dispersal have high heavy metal content. Out of the large array of heavy metals commonly found within pig effluent around the world copper and zinc are two of the most abundant. In Australia, Zn is given to piglets to aid in growth, development, and overall health. Copper and zinc levels were elevated in effluent paddocks but remined low (max 5.5 mg Cu/kg and 16 mg Zn/kg) so adverse effects on plants and animal health should not occur.

The literature review identified that chloride and sodium from pig effluent can lead to salinity and several soil structural problems such as sodicity and surface crusting. While three of the four properties sampled in the study showed an increase in salinity (ECe), rarely were these classified as being saline. The soils that were slightly saline appeared to be deeper within the soil profile where effluent and grey-water were used. Similarly, the SAR of the soil extracts from these deeper layers would be considered sodic (SAR >3), but the SAR of other soils was mostly well below this critical value soil structure was assessed by observations during sampling as well as Emerson dispersion tests of aggregates for slaking and dispersion. soil aggregate stability (Emerson dispersion class) was not negatively impacted by effluent use. It is nevertheless anticipated that long-term application may eventually lead to sodicity and soil structural decline.

6. Implications & Recommendations

Piggery effluent is recognised globally as an important agricultural resource, there being considerable published research exploring its positive and negative impacts. This project looked to add to available knowledge by including a local, Australian perspective.

6.1 Impacts of surface application of pork industry effluent on farm soil health parameters

Overall, the literature review, producer consultation and soil health study showed the controlled use of pig effluent fertilisers to farm soil is beneficial to both soil and plant health. The literature review revealed the main benefits of surface application of effluent to soil were superior soil chemistry (more nutrients, improved pH and soil C balance), better physical properties (lower bulk density, increased porosity, aeration, and water-holding capacity) and subsequent improvements in biological properties (size, activity and diversity of the soil microbial community). Nevertheless, it also highlighted some common issues, such as high nutrient loading and pollution risk, accumulation of heavy metals and being a source various diseases and pathogens, which pose a risk to animal, human or plant health. Based on information from the consultation, we chose to focus on soil chemical and physical properties. No negative impacts of effluent use on soil health had been observed by the participants, which did not warrant the quantification of biological properties, particularly diseases and pathogens. Instead, the producers saw effluent as a valuable nutrient source and organic amendment for their cropping or grazing enterprises. Hence, these piggeries are an important component of an integrated farming system.

The soil health study showed that effluent treated soils had greater macronutrient concentrations (nitrogen, phosphorus, sulphur, and potassium) but micronutrients were differently affected (manganese, molybdenum and boron not affected; copper, iron and zinc were increased). Importantly, it showed that heavy metals (cadmium, arsenic, chromium, lead, molybdenum, cobalt, and selenium) showed no consistent increase in paddocks treated with effluent. Other important chemical aspects were a tendency for surface soil acidification and an increase in salinity of the whole soil profiles, albeit these were rarely classified as being saline. With regards to physical properties, we found no evidence of changes in bulk density and the elevated levels of sodium salts did not negatively impact soil aggregate stability (Emerson dispersion class). The long-term application of saline effluent is anticipated to lead to sodicity and soil structural decline but this hasn't manifested at these properties as yet. The controlled use of pig effluent fertilisers to these farms has had predominantly beneficial outcomes.

There are a number of important considerations to the study. The lack of wider involvement on the consultation/surveys and the small number of participants could mean that the true impacts of surface application of pork industry effluent on farm soil health parameters being experienced by across industry were not captured here. This is an obvious limitation and broader participation in the surveys was needed. Similarly, due to the cost of soil sampling and analyses, only four properties were included in the soil health study. These properties too, may not represent the potential extremes of impacts of surface application of pork industry effluent on farm soil health parameters. Given the hesitation for participation, producers with issues may have simply chosen not to participate. However, it would be expected that those reporting beneficial outcomes should have been more likely to participate. The paddocks of the soil health study were chosen in consultation with the producers, and these are good comparisons albeit for only a few properties.

Future research in this area may need to involve a muti-faceted approach. Diagnosing issues or verifying reported benefits can always be done as case studies and involve ad-hoc soil surveys. With a defined framework it is easier to design sampling and analyses strategies that are fit for purpose. However, capturing broad impacts of industry practices on soil health may need a more targeted approach, since large and all-encompassing soil surveys are cost prohibitive. Further producer consultation will needed to characterise the current practices of the industry, but tracking the implications of these practices on soil health should move from an observational type of approach (e.g., soil survey sampling) to something more targeted. It would be best to focus future research on looking at the impacts of modern effluent, material types and farming systems. For example, focus sites could be established with willing producers who have good records of existing effluent use and baseline soil data, and specific treatments could be tracked through time (quantifiable studies looking at the impacts of specific effluent types and farming practices). Ad-hoc sampling and observational type studies may overlook the true effects of industry practices.

A number of specific issues were highlighted in the current study. Firstly, the soil health study only represents a single point in time, and for some parameters we are unlikely to have captured the absolute spike (e.g., salts and nutrients like N) and potential benefit/risk, nor do we have any idea if these parameters are increasing or decreasing. Temporal data are needed to evaluate impacts correctly and sufficient data are not likely to be obtained unless at a smaller number of sites. Secondly, course sampling intervals, particularly 0-10 cm, could underestimate the actual concentration of immobile nutrients/contaminants (e.g., P) on the soil surface that are at risk of loss from the paddocks with sediments. The effluent was typically surface applied at the participating soil health study properties, with little or no incorporation to soil. A closer investigation of such is warranted in higher rainfall areas with high slope classes (ie., greater erosion risk). Thirdly, the volumes and composition of effluent applied to paddocks is not always well defined. Farm records can usually capture dates of application, but volumes applied, and the composition of effluent are less exact. This will likely continue to be a problem if only using a soil survey approach. Lastly, effluent systems and the amounts and composition being applied to soils are evolving, making it difficult to identify the underlying processes to explain soil survey results. While all the participating producers have sprayed raw effluent in the past, most have moved to anaerobic digestion systems. This shift in practice from traditional ponds and effluent (spraying) to waste-to-energy systems means that the liquid or grey-water (minus solids but containing soluble nutrients and salts) and the solid fraction (containing insoluble nutrients and most of the organic matter) are applied separately and differently. The single sampling time used here cannot capture the impact of any one of the approaches as they vary in space and time (length of practice change and duration since application). The outcomes of the literature review suggest that these two fractions could have very different benefits or limitations of effluent use on soil health which warrant further investigation.

6.2 Soil carbon sequestration and overall greenhouse gas emission impacts

The literature review provided broad evidence of the positive impacts of effluent on organic carbon contents of soil. Organic carbon is added directly to soil in both liquid and solid effluent. However, effluent application can also indirectly influence soil organic carbon by increasing net primary productivity via added nutrients and improving other chemical, physical, and biological properties of soils and subsequently plant growth and performance. For this reason, the project aimed to determine if effluent had resulted in changes in soil carbon balance (storage). We choose not to use the term sequestration, as this implies a level of permanence of the additional carbon, which in this case is not justified. Gains in soil organic carbon with the use of effluent, as mentioned here, are both from carbon in the added materials themselves, or from greater inputs of plant roots and above ground residues, and associated increases in the microbial biomass in soil. All these fractions are labile (easily decomposed by soil microbes) and have high turnover times which would likely be rapidly diminished if effluent application was ceased.

We had expected producers to come forward with sites where they thought effluent had improved soil organic carbon balance. However, many were not sure of the changes in soil carbon in their paddocks, and the deeper core sampling to include soil carbon data was one of the motivations for participating. The results of the soil health study showed that changes in carbon content between effluent treated and non-treated paddocks at each property (medium rainfall) were generally small or were absent and the differences between these paired sites were equal or less to the variability in soil organic carbon within each of the individual paddocks. In contrast, total carbon appeared to be decreased at the property from the high rainfall area where effluent was used. The relative differences between these sites may be due to their inherent fertility, whereby starting at a low base (lower carbon content) may afford some opportunity for soil C gains and starting at a higher base (higher carbon content) may lead to a priming effect whereby organic matter is lost due to the supply of other nutrients. The data collected was from a certified laboratory, but used an estimate of bulk densities, and thus cannot be used for carbon accounting purposes. Given the inherent difficulties of measuring soil carbon (small changes against the large existing soil carbon pool) and accounting for large spatial and temporal variability, this approach is not suitable. Accurate measurements of bulk density, and higher number of soil samples to account for spatial variability are needed, so too are measurements through time.

The study did not attempt to estimate or infer wider carbon mitigation of the farming enterprise, or other greenhouse gases, particularly with various waste management strategies. Since NetZero agriculture is topical at present, a wider greenhouse accounting approach, not just paddock-level emissions but whole of enterprise level (life-cycle assessments) would be useful for future research. The evolution in effluent storage, processing and application to soils comes with changes in effluent forms and composition and these impact infrastructure and labour requirements of the whole business. One notable feature would be the inclusion of anaerobic digestors for energy production. The study highlights the need to consider overall greenhouse gas emission impacts of the whole process and not just that of the end products.

6.3 Producer decision-making

The review of the literature, and our producer consultation, indicated that the management and use of piggery effluent involves the need to take account of a large array of factors. This is made more complex in that decisions need to be made on a property-by-property basis and that those decisions might not be appropriate for all locations in the property or during all times of the year.

Decisions about the use of effluent also need to take note of the environmental health and environmental protection considerations, in addition to the environmental legislation requirements which in Australia may vary across jurisdictions.

The project's consultation process had aimed to add the local perspective to the picture, and while it was limited by the inability to recruit sufficient numbers of participants, those who did take part were willing to share their experiences. This suggests that there would be value in pursuing this line of enquiry further if suitable methods of engagement could be identified.

The experiences of this project suggest that an important element for future research would the involvement of stakeholders in all stages of development and implementation. While the primary stakeholders are the producers, our consultation has shown that agronomists are also playing important roles within the industry.

Future research will need to identify effective recruitment strategies and consider the use of a number of methods of consultation. Single online interview sessions provide useful information but are limited in the amount of information they can capture. To obtain more in-depth information, additional forms of data collection may need to be employed such as focus groups, workshops, or site visits.

7. Literature Cited

Adegbidi, H.G., Volk, T.A., White, E.H., Abrahamson, L.P., Briggs, R.D., Bickelhaupt, D.H. (2001). Biomass and nutrient removal by willow clones in experimental bioenergy plantations in New York State, *Biomass and Bioenergy*, **20(6),** 399–411.

Adeniyan, O.N., Ojo, A.O., Akinbode, O.A., Adediran, J.A. (2011). Comparative study of different organic manures and NPK fertilizer for improvement of soil chemical properties and dry matter yield of maize in two different soils, *Journal of Soil Science and Environmental Management*, **2(1)**, 9–13.

Adesanya, T., Akinremi, O., Zvomuya, F., Lupwayi, N. (2016). Physical properties of an Orthic Black Chernozem after 5 years of liquid and solid pig manure application to annual and perennial crops, *Canadian Journal of Soil Science*, **96(2)**, 145–153.

Agriculture Victoria. (2021). Victorian pig industry fast facts – June 2021, viewed online April 2023 https://agriculture.vic.gov.au/__data/assets/pdf_file/0005/699287/Pig-Fast-Facts-June-2021-Final.pdf

Agriculture Victoria. (2022). The safe use of manure fertiliser on a livestock farm, *Agriculture Victoria*, viewed online, June 2022
https://agriculture.vic.gov.au/support-and-resources/newsletters/sheep-notes-newsletter/autumn-2022/the-safe-use-of-manure-fertiliser

Antoneli, V., Mosele, A.C., Bednarz, J.A., Pulido-Fernández, M., Lozano-Parra, J., Keesstra S. D., Rodrigo-Comino, J. (2019). Effects of applying liquid swine manure on soil quality and yield production in tropical soybean crops (Paraná, Brazil), *Sustainability (Switzerland),* **11(14),** 3898–3909.

APL. (2011). Sustainable piggery effluent utilisation in Australian farming systems. *Australian Pork Ltd,* Australia, 1–44. https://australianpork.infoservices.com.au/downloads/2009-2262-02

APL. (2015a). Piggery manure and effluent management and reuse guidelines, *Australian Pork Ltd,* Australia 1–134. https://australianpork.com.au/sites/default/files/2021-06/PMEG_2014.pdf

APL. (2015b). Project 2013/031- getting the best value from manure nutrients, *Australian Pork Ltd,* Barton, ACT, 1–24. https://australianpork.com.au/sites/default/files/2021-06/PMEG_2014.pdf

APL. (2017). Better nutrient management on pig farms: A guide for interoperating soil and by-product analyses, *Australian Pork Ltd*, Queensland, Australia, 1–44.
<https://australianpork.com.au/soil-and-nutrient-management-guide>

Araújo, S.O., Peres, R.S., Barata, J., Lidon, F., Ramalho, J.C. (2021). Characterising the agriculture 4.0 landscape—emerging trends, challenges and opportunities, *Agronomy,* **11(4)**, 667–705.

Armstrong, T.A., Cook, D.R., Ward, M.M., Williams, C.M., Spears, J.W. (2004) Effect of dietary copper source (cupric citrate and cupric sulfate) and concentration on growth performance and fecal copper excretion in weanling pigs, *Journal of Animal Science*, **82(4),** 1234–1240.

Asensio, V., Covelo, E.F., Kandeler, E. (2013). Soil management of copper mine tailing soil — sludge amendment and tree vegetation could improve biological soil quality, *Science of the Total Environment*, **2013(1),** 456–457.

Awasthi, M.K., Duan, Y., Awasthi, S.K., Liu, T., Chen, H., Pandey, A., Zhang, Z., Taherzadeh, M.J. (2020). Emerging applications of biochar: Improving pig manure composting and attenuation of heavy metal mobility in mature compost, *Journal of Hazardous Materials*, **389(1),** 1–44.

Baker, L.R., White, P.M., Pierzynski, G.M. (2011). Changes in microbial properties after manure, lime, and bentonite application to a heavy metal-contaminated mine waste, *Applied Soil Ecology*, **48(1)**, 1–10.

Bao, Y., Chen, S., Vetsch, J., Randall, G. (2013). Soybean yield and *Heterodera glycinesresponses* to liquid swine manure in nematode suppressive soil and conducive soil, *Journal of Nematology*, **45(1)**, 21–29.
Barber, W.P.F. (2016). Thermal hydrolysis for sewage treatment: a critical review, *Water Research,* **104(1)**, 53–71.

Bauer, P.J., Szogi, A.A., Vanotti, M.B. (2007). Agronomic effectiveness of calcium phosphate recovered from liquid swine manure, *Agronomy Journal,* **99(1)**, 1352– 1356.

Bednorz, C., Oelgeschlager, K., Kinnemann, B., Hartmann, S., Neumann, K., Pieper, R., Bethe, A., Semmler, T., Tedin, K., Schierack, P., Wieler, L.H., Guenther, S. (2013). The broader context of antibiotic resistance: zinc feed supplementation of piglets increases the proportion of multi-resistant *Escherichia coli* in vivo, *International Journal of Medical Microbiology*, **303(1),** 396–403.

Benedet, L., Comin, J.J., Pescador, R., de Oliveira, P.A., Belli Filho, P., De Conti, L., da Rosa Couto, R., Lovato, P.E., Cesco, S., Mimmo, T., Brunetto, G. (2016). Physiological changes in maize grown in soil with copper and zinc accumulation resulting from the addition of pig slurry and deep litter over 10 years, *Water, Air, & Soil Pollution*, **227(11)**, 401–416.

Benedet, L., Ferreira, G.W., Brunetto, G., Loss, A., Lovato, P.E., Lourenzi, C.R., Silva, S.H.G., Curi, N., Comin, J.J. (2020). Use of swine manure in agriculture in southern Brazil: fertility or potential contamination? In: M.L. Larramendy, & S. Soloneski (Eds.), Soil Contamination - Threats and Sustainable Solutions, *IntechOpen,* 1–27.

Berenguer, P., Santiveri, F., Boixadera, J., Lloveras, J. (2008). Fertilisation of irrigated maize with pig slurry combined with mineral nitrogen, *European Journal of Agronomy,* **28(1)**, 635–645.

Bernal, M.P., Roig, A., Lax, A., Navarro, A.F. (1992). Effects of the application of pig slurry on some physico-chemical and physical properties of calcareous soils, *Bioresource Technology*, **42(1)**, 233–239.

Bernal, M.P., Alburquerque, J.A., Moral, R. (2009). Composting of animal manures and chemical criteria for compost maturity assessment, *Bioresource Technology*, **100(22)**, 5444–5453.

Bhattacharyya, P., Tripathy, S., Chakrabarti, K., Chakraborty, A., Banik, P. (2008). Fractionation and bioavailability of metals and their impacts on microbial properties in sewage irrigated soil, *Chemosphere*, **72(4)**, 543–550.

Birchall, S. (2010). Biogas production by covered lagoons – Performance data from Bears Lagoon Piggery, RIRDC Publication No. 10/023, *Rural Industries Research and Development Corporation*, Canberra, 1–39.

Bossio, D.A., Cook-Patton, S.C., Ellis, P.W., Fargione, J., Sanderman, J., Smith, P., Wood, S., Zomer, R.J., von Unger, M., Emmer, I.E., Griscom, B.W. (2020). The role of soil carbon in natural climate solutions, *Natural Sustainability,* **3(1)**, 391–398.

Bouwman, A.F., Booij, H. (1998). Global use and trade of feedstuffs and consequences for the nitrogen cycle, *Nutrient Cycling in Agroecosystems*, **52(1)**, 261–267.

Bridgewater, A.V., Peacocke, G.V.C. (2000). Fast pyrolysis processes for biomass, *Renewable and Sustainable Energy Reviews*, **4(1)**, 1–73.

Brouwer, C., Prins, K., Kay, M., Heibloem, M. (1988). Irrigation water management: irrigation methods, *Training manual*, **9(5),** 5–7.

Briukhanov, A.Y., Vasilev, E.V., Shalavina, E.V., Kucheruk, O.N. (2017). Engineering solutions of environmental problems in organic waste handling, *IOP Conferences Series: Earth and Environmental Science,* **87(4)**, 1–7.
Briukhanov, A., Dorokhov, A., Shalavina, E., Trifanov, A., Vorobyeva, E., Vasilev, E. (2020). Digital methods for agro–monitoring and nutrient load management in the Russian part of the Baltic Sea catchment area, *IOP Conference Series: Earth and Environmental Science,* **578(1),** 1–7.

Bronick, C.J., Lal, R. (2005). Soil structure and management: A review, *Geoderma*,**124(1–2),** 3–22.

Brunetto, G., Comin, J.J., Schmitt, D.E., Guardini, R., Mezzari, C.P., Oliveira, B.S., Moraes, M.P., Gatiboni, L.C., Lovato, P.E., Ceretta, C.A. (2012). Changes in soil acidity and organic carbon in a sandy typic hapludalf after medium-term pig slurry and deep-litter application, *Revista Brasileira de Ciência do Solo*, **36(5),** 1620–1628.

Buelna, G., Dube, R., Turgeon, N. (2008). Pig manure treatment by organic bed bio- filtration, *Desalination*, **231(1)**, 297–304.

Burton, C.H., Turner, C. (2003). Manure management: Treatment strategies for sustainable agriculture, second ed., *Silsoe Research Institute*, Wrest Park, Silsoe, Bedford, UK, 342.

Cang, L., Wang, Y.J., Zhou, D.M., Dong, Y-h. (2004) Heavy metals pollution in poultry and livestock feeds and manures under intensive farming in Jiangsu Province, *Journal of Environmental Science (China),* **16(3),** 371–374.

Cantrell, K., Ro, K., Mahajan, D., Anjom, M., Hunt, P. G. (2007). Role of thermochemical conversion in livestock waste-to-energy treatments: Obstacles and opportunities, *Industrial and Engineering Chemistry Research,* **46(26)**, 8918–8927.

Capizzi-Banas, S., Deloge, M., Remy, M., Schwartzbrod, J. (2004). Liming as an advanced treatment for sludge sanitisation: helminth eggs elimination—Ascaris eggs as model, *Water Research,* **38(14-15),** 3251–3258.

Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., Smith, V.H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications,* **8(3),** 559–568.

Carter, M.R., Campbell, A.J. (2006). Influence of tillage and liquids swine manure on productivity of a soybean-barley rotation and some properties of a fine sandy loam in Prince Edward Island, *Canadian Journal of Soil Science*, **86(4),** 741–748.

Cavallero, S., Rondón, S., Monterrosa, I. A., Šnábel, V., Papajová, I., Goldová, M., Štrkolcová, G., Papajová, I., Goldová, M., Štrkolcová, M., Caraballo, L., Acevedo, N., D'Amelio, S. (2021). Genotyping of *Ascaris* spp. infecting humans and pigs in Italy, Slovakia and Colombia, *Infection, Genetics and Evolution*, **94(1),** 1–8.

CDC. (2022). Parasites – Ascariasis, Centres for disease control and prevention, *Centres for Disease Control and Prevention,* Viewed May 2022
<https://www.cdc.gov/parasites/ascariasis/gen_info/faqs_pigs.html May 2020>

Chelme-Ayala, P., El-Din, M.G., Smith, R., Code, K.R., Leonard, J. (2011). Advanced treatment of liquid swine manure using physic-chemical treatment, *Journal of Hazardous Materials,* **186(1)**. 1632–1638.

Chinivasagam, H.M., Thomas, R.J., Casey, K., McGahan, E., Gardner, E.A., Rafiee, M., Blackall, P.J. (2004). Microbiological status of piggery effluent from 13 piggeries in the southeast Queensland region of Australia, *Journal of Applied Microbiology,* **97(1)**, 883–891.

Ciraj, A.M., Mohammed, M., Bhat, K.G., Shivananda, P.G. (1999) Copper resistance & its correlation to multiple drug resistance in Salmonella typhi isolates from south Karnataka, *Indian Journal of Medical Research,* **110(1)**, 181–182.

Cole, M.B., Augustin, M.A., Robertson, M.J., Manners, J.M. (2018). The science of food security, *NPJ Science of Food*, **2(1)**, 14–22.

Cote, C., Quessy, S. (2005). Persistence of *Escherichia coli* bacteria and salmonella in surface soil following application of liquid hog manure for production of pickling cucumbers, *Journal of Food Production,* **68(5)**, 900–905.

Craggs, R., Park, J., Heubeck, S. (2008). Methane emissions from anaerobic ponds on a piggery and a dairy farm in New Zealand, *Australian Journal of Experimental Agriculture*, **48(2),** 142–146.

Cui, E., Wu, Y., Zuo, Y., Chen, H. (2016). Effect of different biochars on antibiotic resistance genes and bacterial community during chicken manure composting, *Bioresource Technology*, **203(1)**, 11–17.

Daly, J. (2021) This $1 m machine is making the most of pig poo, *ABC News*, viewed online May 2022 <https://www.abc.net.au/news/2021-11-21/machine-making-the-most-out-of-pig-poo/100630156>

da Rosa Couto, R., Comin, J.J., Soares, C.R.F.S., Filho, P.B., Benedet, L., de Moraes, M.P., Brunetto, G., Beber, C.L. (2013). Micro-biological and chemical attributes of a Hapludalf soil with swine manure fertilization, *Pesquisa Agropecuaria Brasileira*, **48(7)**, 774–782.

Dambreville, C., Henault, C., Bizouard, F., Morvan, T., Chaussod, R., Germon, J.C. (2006). Compared effects of long-term pig slurry applications and mineral fertilization on soil denitrification and its end products (N2O, N2), *Biology and Fertility of Soils,* **42(1)**, 490–500.

Das, S., Jeong, S.T., Das, S., Kim, P.J. (2017). Composted cattle manure increases microbial activity and soil fertility more than composted swine manure in a submerged rice paddy, *Frontiers in Microbiology*, **8(1)**, 1702.

De, N.V., Murrell, K.D., Cong, L.D., Cam, P.D., Chau, L.V., Toan, N.D., Dalsgaard, A. (2003). The foodborne trematode zoonoses of Vietnam, *Southeast Asian Journal of Tropical Medicine and Public Health*, **34(1)**, 12–34.

Dendooven, L., Bonhomme, E., Merckx, R., Vlassak, K. (1998). Injection of pig slurry and its effects on dynamics of nitrogen and carbon in a loamy soil under laboratory conditions, *Biology and Fertility of Soils,* **27(1)**, 5–8.

Diacono, M., Montemurro, F. (2010). Long-term effects of organic amendments on soil fertility: A review, *Agronomy for Sustainable Development*, **30(1),** 401–422.

Doran, J.W., Zeiss, M.R. (2000). Soil health and sustainability: Managing the biotic component of soil quality, *Applied Soil Ecology*,**15(1)**, 3–11.

DPI (2020). What is the potential biosecurity risk if piggery pond effluent entered a waterway during a 1-in-25 year rain event? *NSW Department of Primary Industries,* NSW, Australia, 1–12.

Du Preez, J., Norddahl, B., Christensen, K. (2005). The BIOREK® concept: a hybrid membrane bioreactor concept for very strong wastewater, *Desalination,* **183(1)**, 407–415.

Duan, G., Zhang, H., Liu, Y., Jia, Y., Hu, Y., Cheng, W. (2012). Long-term fertilization with pig-biogas residues results in heavy metal accumulation in paddy field and rice grains in Jiaxing of China, *Soil Science and Plant Nutrition*, **58(5)**, 637–646.

Edeogu, I., Feddes, J., Coleman, R., Leonard, J. (2001). Odour emission rates from manure treatment/storage systems, *Water Science and Technology,* **44(9)**, 269–275.

Edmeades, D.C. (2003). The long-term effects of manures and fertilizerson soil productivity and quality: A review, *Nutrient Cycling in Agroecosystems*, **66(1)**, 165–180.

Emerson, W. W. (2002). Emerson dispersion test. *Soil physical measurement and interpretation for land evaluation*, **5**, 190-199.

EPA. (2022). Determinations, *Environment Protection Authority Victoria*, viewed online, June 2022 <https://www.epa.vic.gov.au/determinations>

Fan, J., Ding, W., Ziadi, N. (2013). Thirty-year manuring and fertilization effects on heavy metals in black soil and soil aggregates in northeastern China, *Communications in Soil Science and Plant Analysis*, **44(7)**, 1224–1241.

Fangueiro, D., Lopes, C., Surgy, S., Vasconcelos, E. (2012). Effect of the pig slurry separation techniques on the characteristics and potential availability of N to plants in the resulting liquid and solid fractions, *Biosystems Engineering*, **113(187)**, 187–194.

Fellet, G., Marchiol, L., Delle Vedove, G. Peressotti, A. (2011). Application of biochar on mine tailings: effects and perspectives for land reclamation, *Chemosphere*, **83(9)**, 1262–1267.

Feng, Z., Zhu, H., Deng, Q., He, Y., Li, J., Yin, J., Gao, F., Huang, R., Li, T. (2018). Environmental pollution induced by heavy metal(loid)s from pig farming, *Environmental Earth Sciences*, **77(3)**, 103.

Fróna, D., SzenderÃ¡k, J., Harangi-RÃ¡kos, M. (2019). The challenge of feeding the world. *Sustainability*, **11(20),** 5816–5834.

Fuller, W.H. (1983). Soil injection of sewage sludge for crop production, *College of Agriculture,* University of Arizona (Tucson, AZ).

Gai, X., Liu, H., Liu, J., Zhai, L., Yang, B., Wu, S., Ren, T., Lei, Q., Wang, H. (2018). Long-term benefits of combining chemical fertilizer and manure applications on crop yields and soil carbon and nitrogen stocks in North China Plain, *Agricultural Water Management*, **208(1)**, 384–392.

Gardi, C., Menta, C., Montanarella, L., Cenci, R. (2008). Main threats on soil biodiversity: The case of agricultural activities impacts on soil microarthropods. In: G. Toth, L. Montanarella, & E. Rusco (Eds.), *Threats to soil quality in Europe,* 101–112.

Gatiboni, L. C., Schmitt, D. E., Cassol, P. C., Comin, J. J., Heidemann,J. C., Brunetto, G., da Silveira Nicoloso, R. (2019). Samples disturbance overestimates phosphorus adsorption capacity in soils under long-term application of pig slurry, *Archives of Agronomy and Soil Science*, **65(9)**, 1262–1272.

Gaworski, M., Jabłoński, S., Pawlaczyk-Graja, I. Ziewiecki, R., Rutkowski, P., Wiecyńska, A., Gancarz, R., Łukaszewicz, M. (2017). Enhancing biogas plant production using pig manure and corn silage by adding wheat straw processed with liquid hot water and steam explosion, *Biotechnology Biofuels*, **10(1),** 259–273.

Genchi, G., Carocci, A., Lauria, G., Sinicropi, M.S., Catalano, A. (2020). Nickel: human health and environmental toxicology, *International Journal of Environmental Research and Public Health*, **17(3),** 679–700.

Gerber, P., Chilonda, P., Franceschini, G., Menzi, H. (2005). Geographical determinants and environmental implications of livestock production intensification in Asia, *Bioresource Technology*, **96(2)**, 263–276.

Girotto, E., Ceretta, C.A., Rossato, L.V., Farias, J.G., Tiecher, T.L., De Conti, L., Schmatz, R., Brunetto, G., Schetinger, M.R., Nicoloso, F.T. (2013). Triggered antioxidant defense mechanism in maize grown in soil with accumulation of Cu and Zn due to intensive application of pig slurry, *Ecotoxicology and Environmental Safety*, **93(1),** 145–155.

Glaser, B., Lehmann, J., Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – a review, *Biology and Fertility of Soils,* **35(1)**, 219–230.

Gong, Q., Chen, P., Shi, R. Gao, Y., Zheng, S-A., Xu, Y., Shao, C., Zheng, X. (2019) Health assessment of trace metal concentrations in organic fertilizer in northern China, *International Journal of Environmental Research and Public Health,* **16(6),** 1031.

Gourley, C.J.P., & Weaver D.M. (2019). A guide for fit for purpose soil sampling, Fertilizer Australia, Canberra, Australia.

Guan, T.T.Y., Holley, R.A. (2003). Hog manure management, the environment and human health, *Springer*, 1–168.

Guardini, R., Comin, J.J.S., Danilo, R., Gatiboni, L.C., Tiecher, T., Schmitt, D., Bender, M., Belli, F.P., Oliveira, P.A.V., Brunetto, G. (2012). Phosphorus accumulation and pollution potential in a hapludult fertilized with pig manure, *Revista Brasileira de Ciência do Solo*, **36(4)**, 1333–1342.

Gutser, R., Ebertseder, T., Weber, A., Schraml, M., & Schmidhalter, U. (2005). Short-term and residual availability of nitrogen after long-term application of organic fertilizers on arable land. *Journal of Plant Nutrition and Soil Science*, **168(4)**, 439-446.

Hadush, A., Pal, M. (2016). Ascariasis: public health importance and its status in Ethiopia, *Air Water Borne Diseases,* **5(1)**, 1–4.

Hargreaves, J.C., Adl, M.S., Warman, P.R. (2008). A review of the use of composted municipal solid waste in agriculture, *Agriculture, Ecosystems & Environment*, **123(1–3**), 1–14.

Haynes, R.J., Naidu, R. (1998). Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: A review, *Nutrient Cycling in Agroecosystems*, **51(2)**, 123–137.

Hazarika, J., Ghosh, U., Kalamdhad, A.S., Khwairakpam, M., Singh, J. (2017). Transformation of elemental toxic metals into immobile fractions in paper mill sludge through rotary drum composting, *Ecological Engineering,* **101(1)**, 185–192.

Hazelton, P., & Murphy, B. (2016). *Interpreting soil test results: What do all the numbers mean?* CSIRO publishing, Australia.

Hjorth, M., Christensen, K.V., Christensen, M.L., Sommer, S.G. (2010). Solid-liquid separation of animal slurry in theory and practice: A review, *Agronomy for Sustainable Development,* **30(1)**, 153–180.

Hofstra, N., Vermeulen, L.C. (2016). Impacts of population growth, urbanisation and sanitation changes on global human Cryptosporidium emissions to surface water, *International Journal of Hygiene and Environmental Health*, **219(7)**, 599–605.

Holley, R., Walkty,J., Blank, J., Tenuta, M., Ominski, K., Krause, D., Ng, L-K. (2008). Examination of *Salmonella* and *Escherichia coli* translocation from hog manure to forage, soil, and cattle grazed on the hog-manure treated pasture, *Journal of Environmental Quality,* **37(6),** 2083–2092.

Ito, T., Katayama, Y., Asada, K., Tiensasitorn, C. (2001). Structural comparison of three types of staphylococcal cassette chromosome mec integrated in the chromosome in methicillin-resistant *Staphylococcus aureus*, *Antimicrobial Agents and Chemotherapy*, **45(5),** 1323–1336.

Iyyemperumal, K., Shi, W. (2007). Soil microbial community composition and structure: Residual effects of contrasting N fertilization of swine lagoon effluent versus ammonium nitrate, *Plant and Soil*, **292(1–2)**, 233–242.

Izmaylov, A.; Briukhanov, A.; Shalavina, E.; Vasilev, E. (2022). Pig Manure Management: A methodology for environmentally friendly decision-making, *Animals*, **12(6),** 747

Jiang, T.Y., Jiang, J., Xu, R.K. Li, Z. (2012) Adsorption of Pb(II) on variable charge soils amended with rice-straw derived biochar, *Chemosphere,* **89(3),** 249–256.

Jiang, J., Huang, Y., Liu, X., Huang, H. (2014). The effects of apple pomace, bentonite and calcium superphosphate on swine manure aerobic composting, *Waste Management,* **34(9),** 1595–1602.

Jiao, H., Yin, Q., Fan, C., Wang, L., Zhao, J., Wang, X., Du, K., Lin, H. (2021). Long-term effects of liquid swine manure land surface application in an apple orchard field on soil bacterial community and heavy metal contents in apple (*Malus pumila* Mill.), *Environmental Science and Pollution Research*, ***28*(36)**, 49613–49626.

Johansson, M., Emmoth, E., Salomonsson, A.-C., Albihn, A. (2005). Potential risks when spreading anaerobic digestion residues on grass silage crops: survival of bacteria, moulds and viruses, *Grass Forage Science,* **60(2),** 175–185.

Jorgensen, K., Jensen, L.S. (2009). Chemical and biochemical variation in animal manure solids separated using different commercial separation technologies, *Bioresources Technology*, **100(1)**, 3088–3096.

Karakashev, D., Schmidt, J.E., Angelidaki, I. (2008). Innovative process scheme for removal of organic matter, phosphorus and nitrogen from pig manure, *Water R*esearch, **42(15),** 4083–4090.

Kaschuk, G., Alberton, O., Hungria, M. (2010). Three decades of soil microbial biomass studies in Brazilian ecosystems: lessons learned about soil quality and indicators for improving sustainability, *Soil Biology and Biochemistry,* **42(1),** 1–13.

Katakam, K.K., Thamsborg, S.M., Dalsgaard, A., Kyvsgaard, N.C., Mejer, H. (2016). Environmental contamination and transmission of Ascaris suum in Danish organic pig farms, *Parasites & Vectors,* **9(80),** 1–12.

Kiani, MJ., Abbasi, M.K., Rahim, N. (2005). Use of organic manure with mineral N fertilizer increases wheat yield at Rawalakot Azad Jammu and Kashmir, *Archives of Agronomy and Soil Science*, **51(3),** 299–309.

Kibblewhite, M.G., Ritz, K., Swift, M.J. (2008). Soil health in agricultural systems, *Philosophical Transactions of the Royal Society Biological Sciences*, **363(1492)**, 685–701.

Knorr, D., Augustin, M.A., Tiwari, B. (2020). Advancing the role of food processing for improved integration in sustainable food chains, *Frontiers in Nutrition,* **7(1)**, 34.

Kruger, I., Taylor, G., Ferrier, M., (1995). Australian Pig Housing Series - effluent at work, *NSW Department of Agriculture*, Tamworth, Australia, 22.

Kurniawan, T.A., Chan, G.Y.S., Lo, W.H., Babel, S. (2006). Physico-chemical treatment techniques for wastewater laden with heavy metals, *Chemical Engineering Journal,* **118(1–2),** 83–98.

Kuzovkina, Y.A., Volk, T.A. (2009). The characterization of willow (*Salix* L.) varieties for use in ecological engineering applications: co-ordination of structure, function and autecology, *Ecological Engineering,* **35(8),** 1178–1189.

Kwon, S.I., Jang, Y.A., Owens, G. Kim, M-K., Jung, G-B., Hong, S-C., Chae, M-J., Kim, K-R. (2014) Long-term assessment of the environmental fate of heavy metals in agricultural soil after cessation of organic waste treatments, *Environmental Geochemistry and Health,* **36(4),** 409–419.

Lahori, A.H., Zhang, Z., Guo, Z., Mahar, A., Li, R., Awasthi, M.K., Sial, T.A., Kumbhar, F., Wang, P., Shen, F., Zhao, J., Huang, H. (2017). Potential use of lime combined with additives on (im)mobilization and phytoavailability of heavy metals from Pb/Zn smelter contaminated soils, *Ecotoxicology and Environmental Safety*, **145(1)**, 313–323.

Laird, D.A., Fleming, P., Davis, D.D., Horton, R., Wang, B., Karlen, D.L. (2010). Impact of biochar amendments on the quality of a typical Midwestern agricultural soil, *Geoderma,* **158(3-4)**, 443–449.

Lalande, R., Gagnon, B., Simard, R.R., Côté, D. (2000). Soil microbial biomass and enzyme activity following liquid hog manure application in a long-term field trial, *Canadian Journal of Soil Science,* **80(1),** 263–269.

Larney, F.J., Hao, X. (2007). A review of composting as a management alternative for beef cattle feedlot manure in southern Alberta, Canada, *Bioresource Technology,* **98(17)**, 3221–3227.

Lassaletta, L., Estellés, F., Beusen, A.H.W., Bouwman, L., Calvet, S., van Grinsven, H.J.M., Doelman, J.C., Stehfest, E., Uwizeye, A., Westhoek, Henk. (2019). Future global pig production systems according to the Shared Socioeconomic Pathways, *Science of The Total Environment*, **665(1),** 739–751.

Lemly, A.D. (1997). Environmental implications of excessive selenium: a review, *Biomedical and Environmental Sciences,* **10(4),** 415–435.

Li, C., Wang, X., Zhang, G., Yu, G., Lin, J., Wang, Y. (2017). Hydrothermal and alkaline hydrothermal pretreatments plus anaerobic digestion of sewage sludge for dewatering and biogas production: bench-scale research and pilot-scale verification, *Water Research,* **117(1)**, 49–57.

Li, X.G., Ding, C.F., Liu, J.G., Zhang, T.L. Wang, X.X. (2015). Evident response of the soil nematode community to consecutive peanut monoculturing, *Agronomy Journal,* **107(1)**, 195–203.

Liang, Y.G., Li, X.J., Zhang, J. Zhang, L-G., Cheng, B. (2017). Effect of microscale ZVI/magnetite on methane production and bioavailability of heavy metals during anaerobic digestion of diluted pig manure, *Environmental Science and Pollution Research International,* **24(13),** 12328–12337.

Liu, S., Li, B., Zhang, G., Feng, X., Yang, P., Guo, L., Li, Z., Sun, X. (2019). Effects of Pig Manure Composts on Lettuces Quality and Nitrogen/Phosphorus Utilization Efficiency in Huang-Huai Plain, *IOP conferences Series: Earth and Environmental Science,* **384(2019),** 1–7.

Lourenzi, C.R., Ceretta, C.A., Silva, L.S., Trentin, G., Girotto, E., Lorensini, F., Tiecher, T.L., Brunetto, G. (2011). Soil chemical properties related to acidity under successive pig slurry application, *Revista Brasileira de Ciência do Solo*, **35(5)**, 1827–1836.

Lourenzi, C.R., Ceretta, C.A., Silva, L.S., Girotto, E., Lorensini, F., Tiecher, T.L., De Conti, L., Trentin, G., Brunetto, G. (2013). Nutrients in soil layers under no-tillage after successive pig slurry applications, *Revista Brasileira se Ciencia do Solo*, **37(1)**, 157–67.

Luo, J., Luo, X., Crittenden, J., Qu, J., Bai, Y., Peng, Y., Li, J. (2015). Removal of antimonite (Sb(III)) and antimonate (Sb(V)) from aqueous solution using carbon nanofibers that are decorated with zirconium oxide (ZrO2), *Environmental Science & Technology*, **49(18),** 11115–11124.

Manitoba Pork. (2017). Pigs and the Environment, *Manitoba Pork*, viewed June 2022: https://www.manitobapork.com/images/Pigs_and_the_Environment_-_June_18_2017.pdf Accessed 9 June 2022

McDonald, R. C., Isbell, R. F., Speight, J. G., Walker, J., & Hopkins, M. S. (2009). *Australian soil and land survey: field handbook* (No. Ed. 3). CSIRO publishing, Australia.

Marcato, C.E., Pinelli, E., Pouech, P., Winterton, P., Guiresse, M. (2008). Particle size and metal distributions in anaerobically digested pig slurry, *Bioresource Technology,* **99(7)**, 2340–2348.

Maslova, M., Ivanenko, V., Yanicheva, N., Gerasimova, L. (2020). The effect of heavy metal ions hydration on their sorption by a mesoporous titanium phosphate ion-exchanger, *Journal of Water Process Engineering*, **6(35),** 101233.

Martinez, E., Maresma, A., Biau, A., Berenguer, P., Cela, S., Santiveri, F., Michelena, A., Lloveras, J. (2020). Long-term effects of liquid swine manure on soil organic carbon and Cu/Zn levels in soil and maize, *Nutrient Cycling in Agroecosystems*, **118(2)**, 193–205.

Martinez-Almela, J., Barrera, J.M. (2005). SELCO-Ecopurin pig slurry treatment system, *Bioresource Technology*, **96(1)**, 223–228.

Mattila, P.K., Joki-Tokola, E. (2003). Effect of treatment and application technique of cattle slurry on its utilization by ley: I. Slurry properties and ammonia volatilization, *Nutrient Cycling in Agroecosystems*, **65(1)**, 221–230.

Mbagwu, J.S.C., Unamba-Oparah, I., Nevoh, G.O. (1994). Physico-chemical properties and productivity of two tropical soils amended with dehydrated swine waste, *Bioresource Technology*, **49(2)**, 163–171.

McOrist, S., Corona-Barrera, E. (2015). Intestinal health, Chapter 3: Intestinal diseases of pigs, *Wageningen Academic Publishers*, 51–70.

Meng, J., Wang, L., Zhong, L., Liu. X., Brookes, P.C., Xu, J., Chen, H. (2017). Contrasting effects of composting and pyrolysis on bioavailability and speciation of Cu and Zn in pig manure, *Chemosphere*, **180(1)**, 93–99.

Millner P., Ingram, D., Mulbrg, E., Arikan, O.A. (2014). Pathogen reduction in minimally managed composting of bovine manure, *Waste Manag*ement, **34(1),** 1992–1999.

MLAL. (2002). Safe use of manure and effluent – A technical users manual, *Meat and Livestock Australia* Ltd, Australia 1–38.

Monaco, S., Hatch, D.J., Sacco, D., Bertora, C., Grignani, C. (2008). Changes in chemical and biochemical soil properties induced by 11-yr repeated additions of different organic materials in maize-based forage systems, *Soil Biology and Biochemistry*, **40(3)**, 608–615.

Moore, G. (2001). *Soilguide. A handbook for understanding and managing agricultural soils*. Agriculture Western Australia Bulletin No. 4343.

Morera, M.T., Echeverria, J.C., Mazkiaran, C., Garrido, J.J. (2001). Isotherms and sequential extraction procedures for evaluating sorption and distribution of heavy metals in soils, *Environmental Pollution,* **113(2),** 135–144.

New Zealand Pork. (2017). NZPork: good practice guide nutrient management in pork production (ed 3), New Zealand, 1–42.

Nichols, T.A., Spraker, T.R., Gidlewski, T., Cummings, B., Hill, D., Kong, Q., Balachandran, A., VerCauteren, K.C., Zabel, M.D. (2016). Dietary magnesium and copper affect survival time and neuroinflammation in chronic wasting disease, *Prion,* **10(3)**, 228–250.

Nies, D.H. (1999). Microbial heavy-metal resistance, *Applied Microbiology and Biotechnology*, **51(6),** 730–750.

Nolan, T., Troy, S.M., Healy, M.G., Kwapinski, W., Leahy, J.J., Lawlor, P.G. (2011). Characterization of compost produced from separated pig manure and a variety of bulking agents at low initial C/N ratios, *Bioresource Technology,* **102(14)**, 7131–7138.

Nolan, T., Troy, S.M., Gilkinson, S., Frost, P., Xie, S., Zhan, X., Harrington, C., Healy, M.G., Lawlor, P.G. (2012). Economic analyses of pig manure treatment options in Ireland, *Bioresource Technology*, **105(1)**, 15–33.

Obade, V.P., Lal, R. (2016). A standardized soil quality index ford Diverse field conditions, *Science of the Total Environment*, **541(1)**, 424–434.

Owusu-Twum, M.Y., Sharara, M.A. (2020). Sludge management in anaerobic swine lagoons: A review, *Journal of Environmental Management*, **271(1)**, 110949.

Ozverdi, A., Erdem, M. (2006). Cu2+, Cd2+ and Pb2+ adsorption from aqueous solutions by pyrite and synthetic iron sulphide, *Journal of Hazardous Materials*, **137(1),** 626–632.

Pardo, T., Clemente, R., Epelde, L., Garbisu, C., Bernal, M.P. (2014). Evaluation of the phytostabilisation efficiency in a trace elements contaminated soil using soil health indicators, *Journal of Hazardous Materials,* **268(1)**, 68–76.

Penha, H.G.V., Menezes, J.F.S., Silva, C.A., Lopes, G., Carbalho, C.A., Ramos, S.J., Guilhereme, G. (2015). Nutrient accumulation and availability and crop yields following long-term application of pig slurry in a Brazilian Cerrado soil, *Nutrient Cycling in Agroecosystems*, **101(2)**, 259–269.

Perez-Sangrador, M.P., Leon-Cofreces, C.M., Acítores-Benavente, M., Cruz García-Gonzalez, M. (2012). Solids and nutrient removal from flushed swine manure using polyacrylamides, *Journal of Environmental Management,* **93(1)**, 67–70.

Phillips, F.A., Wiedemann, S.G., Naylor, T.A., McGahan, E.J., Warren, B.R., Murphy, C.M., Parkes, S., Wilson, J. (2016). Methane, nitrous oxide and ammonia emissions from pigs housed on litter and from stockpiling of spent litter, *Animal Production Science*, **56(9),** 1390–1403.

Popovic, O., Hjorth, M., Jensen, L.S. (2012). Phosphorus, copper and zinc in solid and liquid fractions from full-scale and laboratory-separated pig slurry, *Environmental Technology,* **33(8)**, 2119–2131.

Putri, R.F., Naufal, M., Nandini, M., Dwiputra, D.S., Wibirama, S., Sumantyo, J.T.S. (2019). The Impact of population pressure on agricultural land towards food sufficiency (case in West Kalimantan Province, Indonesia), *IOP Conference Series: Earth and Environmental Science,* **256(1)**, 12–50.

Qaswar, M., Yiren, L., Jing, H., Kaillou, L., Mudasir, M., Zhenzhen, L., Hongqian, H., Xianjin, L., Jianhua, J., Ahmed, W., Dongchu, L., Huimin, Z. (2020). Soil nutrients and heavy metal availability under long-term combined application of swine manure and synthetic fertilizers in acidic paddy soil, *Journal of Soils and Sediments,* **20(1), 1093**–2106.

Rahman, M.M., Khan, I., Field, D.L., Techato, K., Alameh, K. (2022). Powering agriculture: Present status, future potential, and challenges of renewable energy applications, *Renewable Energy,* **188(1),** 731–749.

Rayment, G. E., & Lyons, D. J. (2011). *Soil chemical methods: Australasia* (Vol. 3). CSIRO publishing, Australia.

Redding, M.R. (2001). Pig effluent-P application can increase the risk of P transport: two case studies, *Australian Journal of Soil Research*, **39(1),** 161–174.

Riggs, P.K., Fields, M.J., Cross, H.R. (2018). Food and nutrient security for a growing population, *Oxford University Press,* US: Oxford, MS, USA, 3–4.

Robertson, G.P., Groffman, P.M. (2015). Nitrogen transformations. In: E.A. Paul (Ed.), Soil microbiology, ecology and biochemistry, 4th ed *Academic Press,* 421–446.

Rodhe, L., Etana, A. (2005). Performance of slurry injectors compared with band spreading on three Swedish soils with ley, *Biosystems Engineering*, **92(1),** 107–118.

Ryan, D. (2005). A slurry spreader to meet farming needs and environmental concerns, *Teagasc End of Project Report 4783*, Teagasc, Wexford.

Santos, C., Loss, A., Piccolo, M.d.C., Girotto, E., Ludwig, M.P., Decarli, J., Torres, J.L.R., Brunetto, G. (2022). Aggregation index and carbon and nitrogen contents in aggregates of pasture soils under successive applications of pig slurry in Southern Brazil. *Agronomy*, 12, 320.

Sanz-Cobena, A., Lassaletta, L., Aguilera, E., Prado, A., del, Garnier, J., Billen, G., Iglesias, A., Sánchez, B., Guardia, G., Abalos, D., Plaza-Bonilla, D., Puigdueta-Bartolomé, I., Moral, R., Galán, E., Arriaga, H., Merino, P., Infante-Amate, J., Meijide, A., Pardo, G., Álvaro-Fuentes, J., Gilsanz, C., Báez, D., Doltra, J., González-Ubierna, S., Cayuela, M.L., Menéndez, S., Díaz-Pinés, E., Le-Noë, J., Quemada, M., Estellés, F., Calvet, S., van Grinsven, H.J.M., Westhoek, H., Sanz, M.J., Gimeno, B.S., Vallejo, A., Smith, P. (2017). Strategies for greenhouse gas emissions mitigation in Mediterranean agriculture: a review, *Agriculture Ecosystems and Environment*, **238(1)**, 5–24.

Sanz-Cobena, A., Misselbrook, T.H., Hernáiz, P., Vallejo, A. (2019). Impact of rainfall to the effectiveness of pig slurry shallow injection method for NH3 mitigation in a Mediterranean soil, *Atmospheric Environment*, **216(1)**, 116913.

Scheid, D.L., da Silva, R.F., da Silva, V.R., Da Ros, C.O., Pinto, M.A.B., Gabriel, M., Cherubin, M.R. (2020). Changes in soil chemical and physical properties in pasture fertilised with liquid swine manure, *Scientia Agricola*, **77(5)**, e20190017.

Schepers, J.S., Raun, W. (2008). Nitrogen in agricultural systems. *Agronomy Monographs*, **49(17)**, 101–420.

Schlegel, A.J., Assefa, Y., Bond, H.D., Wetter, S.M., Stone, L.R. (2015). Soil physicochemical properties after 10 years of animal waste application, *Soil Science Society of America Journal*, **79(3)**, 711–719.

Schulte, R.P.O., Melland, A.R., Fenton, O., Herlihy, M., Richards K.G., Jordan, P. (2010). Modelling soil phosphorus decline: expectations of Water Framework Directive policies., *Environmental Science & Policy,* **13(6)**, 472–484.

Schuster, N.R., Peterson, J.A., Gilley, J.E., Schott, L.R., Schmidt, A.M. (2019). Soil arthropod abundance and diversity following land application of swine slurry, *Agricultural Sciences,* **10(2)**, 150–163.

Sfakianakis, D.G., Renieri, E., Kentouri, M., Tsatsakis, A.M. (2015). Effect of heavy metals on fish larvae deformities: a review, *Environmental Research,* **137(1)**, 246–255.

Siepel, H., van de Bund, C. (1988). The influence of management practices on the microarthropod community of grassland, *Pedobiologia*, **31(1)**, 339–354.

Singh, B.P., Hatton, B.J., Singh, B., Cowiw, A.L., Kathuria, A. (2010). Influence of biochars on nitrous oxide emission and nitrogen leaching from two contrasting soils, *Journal of Environmental Quality,* **39(4)**, 1224–1235.

Sleutel, S., De Neve, S., Nemeth, T., Toth, T., Hofman, G. (2006). Effect of manure and fertilizer application on the distribution of organic carbon in different soil fractions in long-term field experiments, *European Journal of Agronomy*, **25(1)**, 280–288.

Sobsey, M.D., L.A. Khatib, V.R. Hill, E. Alocilja, Pillai, S. (2006) Pathogens in animal wastes and the impacts of waste management practices on their survival, transport and fate, In: Animal agriculture and the environment: national centre for manure and animal waste management white papers, J.M. Rice, D.F. Caldwell, F.J. Humenik, eds, St. Joseph, MI, USA, *American Society of Agricultural and Biological Engineers*, 609–666.

Sonne, C., Ok, Yong S., Dietz, R., Alstrup, A.K.O. (2019). Pig slurry needs modifications to be a sustainable fertilizer in crop production, *Environmental Research*, **178(1)**, 108718.

Stokłosa, K. (2015). Research on utilization of waste slurry from pig farming, *West Pomeranian University of Technology*, Szczecin. PhD. Dissertation.

Suksabye, P., Thiravetyan, P., Nakbanpote, W. Chayabutra, S. (2007). Chromium removal from electroplating wastewater by coir pith, *Journal of Hazardous Materials,* **141(3),** 637–644.

Suzuki, K., Waki, M., Yasuda, T., Fukumoto, Y., Kurodo, K., Sakai, T., Suzuki, N., Suzuki, R., Matsuba, K. (2010) Distribution of phosphorus, copper and zinc in activated sludge treatment process of swine wastewater, *Bioresource Technology,* **101(23)**, 9399–9404.

Tadesse, T., Dechassa, N., Bayu, W., Gebeyehu, S. (2013). Effects of farmyard manure and inorganic fertilizer application on soil physico-chemical properties and nutrient balance in rain-fed lowland Rice ecosystem, *American Journal of Plant Sciences,* **4(2),** 309–316.

Tavares, R.L., Assis, R.L., Ferreira, R.V., Menezes, J.FS., Simon, G.A., Boldrin, P.F., Cantão, V.C.G. (2019). Long term application of pig manure on the chemical and physical properties of Brazilian Cerrado soil, *Carbon Management*, **10(6)**, 541–549.

Tirol-Padre, A., Ladha, J.K., Regmi, A.P., Bhandari, A.L., Inubushi, K. (2007). Organic amendments affect soil parameters in two long-term rice-wheat experiments, *Soil Science Society of America Journal,* **71(2),** 442–452.

Troy, S.M., Nolan, T., Kwapinski, W., Leahy, J.J., Healy, M.G., Lawlor, P.G. (2012). Effect of sawdust addition on composting of separated raw and anaerobically digested pig manure, *Journal of Environmental Management,* **111(1)**, 70–77.

Tzanidakis, C., Simitzis, P., Arvanitis, K., Panagakis, P. (2021). An overview of the current trends in precision pig farming technologies, *Livestock Science*, **249(1)**,1–14.

Uchimiya, M., Novak, J.M., Ro, K.S. (2012). Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar, *Bioresource Technology*, **107(1)**, 419–428.

United Nations (2022). Population, *United nations*, Viewed: May 2022, https://www.un.org/en/global-issues/population

Uthus, E.O. (1992). Evidence for arsenic essentiality, *Environmental Geochemistry and Health,* **14(1),** 55–58.

Van Dijk, M., Morley, T., Rau, M.L., Saghai, Y. (2021). A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050, *Nature Food,* **2(1),** 494–501.

Vaneeckhaute, C., Darveau, O., Meers, E. (2019). Fate of micronutrients and heavy metals in digestate processing using vibrating reversed osmosis as resource recovery technology, *Water Air and Soil Pollution*, **232(1),** 294.

Veeck, G., Veeck, A., YU, H. (2020). Challenges of agriculture and food systems issues in china and the United States, *Geography and Sustainability*, **1(2)**, 109–117.

Velthof, G.L., Lesschen, J.P., Webb, J., Pietrzak, S., Miatkowski, Z., Pinto, M., Kros, J., Oenema, O. (2014). The impact of the Nitrates Directive on nitrogen emissions from agriculture in the EU-27 during 2000–2008, *Science of the Total Environment,* **464-469 (1),** 1225–1233.

Victorian Resources Online, Agriculture Victoria. *Soil Health Victoria*, accessed 15th June 2022 https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_reports_docs#shv

Walker, P., Kelley, T. (2003). Solids, organic load and nutrient concentration reductions in swine waste slurry using a polyacrylamide (PAM)-aided solids flocculation treatment, *Bioresource Technology*, **90(1),** 151–158.

Wang, L., Dai, X., Man, Z., Li, J., Jiang, Y., Liu, D., Xiao, H., Shah, S. (2021). Dynamics and treatability of heavy metals in pig farm effluent wastewater by using uio-66 and uio-66-nh2 nanomaterials as adsorbents, *Water, Air and Soil Pollution*, **232(1),** 294.

Wang, H.L., Magesan, G.N., Bolan, N.S. (2004). An overview of the environmental effects of land application of farm effluents. (Special Issue: Land application of farm wastes). *New Zealand Journal of Agricultural Research,* **47(4)**, 389–403.

Wang, S., Wang, X. (2015). Multifunctional metal-organic frameworks for photocatalysis, *Small,* **11(26),** 1–16.

Wang, M.Q., Wang, C., Li, H., Du, Y-J., Tao, W-J., Ye, S-S., He, Y-D. (2012). Effects of chromium-loaded chitosan nanoparticles on growth, blood metabolites, immune traits and tissue chromium in finishing pigs, *Biological Trace Elements Research,* **149(2)**, 197–203.

Wang, Q., Wang, Z., Awasthi, M.K., Jiang, Y., Li, R., Ren, X., Zhao, J., Shen, F., Wang, M., Zhang, Z.Q. (2016). Evaluation of medical stone amendment for the reduction of nitrogen loss and bioavailability of heavy metals during pig manure composting, *Bioresource Technology,* **220(1)**, 297–304.

Wang, F., Zhang, S., Cheng, P., Zhang, S., Sun, Y. (2020). Effects of soil amendments on heavy metal immobilization and accumulation by maize grown in a multiple-metal-contaminated soil and their potential for safe crop production, *Toxics*, **8(4)**, 102–118.

Warner, N.L., Godwin, R.J. (1988). An experimental investigation into factors influencing the soil injection of sewage sludge, *Journal of Agricultural Engineering Research*, ***39*(4)**, 287–300.

Weigel, C., Paul, L. A., Ferraro, P. J., & Messer, K. D. (2021). Challenges in recruiting US farmers for policy-relevant economic field experiments. *Applied Economic Perspectives and Policy*, ***43*(2)**, 556-572.

Whitehead, D., Schipper, L.A., Pronger, J., Moinet, G.Y.K., Mudge, P.L., Calvelo Pereira, R., Kirschbaum, M.U.F., McNally, S.R., Beare, M.H., Camps-Arbestain, M. (2018). Management practices to reduce losses or increase soil carbon stocks in temperate grazed grasslands: New Zealand as a case study, *Agriculture, Ecosystems & Environment*, **265(1)**, 432–443.

WHO. (2022). Soil-transmitted helminth infection, *World Health Organization,* Viewed May 2022: <https://www.who.int/news-room/fact-sheets/detail/soil-transmitted-helminth-infections>

Wilson, B.Ã., Pyatt, F.B. (2007). Heavy metal dispersion persistence, and bioaccumulation around an ancient copper mine situated in Anglesey, UK, *Ecotoxicology and Environmental Safety,* **66(2)**, 224–231.

Xu, D., Zhao, Y., Sun, K., Gao, B., Wang, Z., Jin, J., Zhang, Z., Wang, S., Yan, Y., Liu, Z., Wu, F. (2014). Cadmium adsorption on plant and manure-derived biochar and biochar-amended sandy soils: impact of bulk and surface properties, *Chemosphere*, **111(1)**, 320–326.

Xun, W., Xiong, W., Huang, T., Ran, W., Li, D., Zhang, R. (2016). Swine manure and quicklime have different impacts on chemical properties and composition of bacterial communities of an acidic soil, *Applied Soil Ecology*, **100(1),** 38–44.

Ya, V., Martin, N., Chou, Y.-H., Chen, Y.-M., Choo, K.-H., Chen, S.-S., Choo, K-H., Chen, S-S., Li, C-H. (2018). Electrochemical treatment for simultaneous removal of heavy metals and organics from surface finishing wastewater using sacrificial iron anode, *Journal of the Taiwan Institute of Chemical Engineers*, **83(1)**, 107–114.

Yasmin, K.K., Ali, B., Cui, X., Feng, Y., Yang, X., Stoffella, P.J. (2017). Impact of different feedstocks derived biochar amendment with cadmium low uptake affinity cultivar of pak choi (*Brassica rapa* ssb. Chinensis L.) on phytoavoidation of cd to reduce potential dietary toxicity, *Ecotoxicology and Environmental Safety,* **141(1)**, 129–138.

Yost, J.L., Schmidt, A.M., Koelsch, R., Schott, L.R. (2021). Effect of swine manure on soil health properties: A systematic review, *Soil Science Society of America Journal*, **86(1)**, 450-486.

Yuan, T., Cheng, Y., Huang, W., Zhang, Z., Lei, Z., Shimizu, K., Utsumi, M. (2018). Fertilizer potential of liquid product from hydrothermal treatment of swine manure, *Waste Management,* **77(1)**, 166–171.

Zhang, Y., Luo, W., Jia, J. Kong, P., Tong, X., Lu, Y., Xie, L., Ma, F., Giesy, J.P. (2014). Effects of pig manure containing copper and zinc on microbial community assessed via phospholipids in soils, *Environmental Monitoring and Assessment,* **186(8)**, 5297–5306.

Zhong, W., Gu, T., Wang, W., Zhang, B., Lin, X., Huang, Q., Shen, W. (2010). The effects of mineral fertilizer and organic manure on soil microbial community and diversity, *Plant and Soil*, **326(1)**, 511–522.

Zhou, Y.Q., Jeppesen, E., Zhang, Y.L., Niu, C., Shi, K., Liu, X.H., Zhu, G., Qin, B. (2015). Chromophoric dissolved organic matter of black waters in a highly eutrophic Chinese lake: freshly produced from algal scums? *Journal of Hazardous Material*, **299(1)**, 222–230.

Zhou, H., Chen, C., Wang, D., Arthur, E., Zhang, Z., Guo, Z., Peng, X., Mooney, S.J. (2020). Effect of long-term organic amendments on the full-range soil water retention characteristics of a Vertisol, *Soil and Tillage Research*, **202(1)**, 104663.

Zhu, Y-G., Johnson, T.A., Su, J-Q., Qiao, M., Guo, G-X., Stedtfeld, R.D., Hashsham, S.A.., Tiedje, J.M. (2013). Diverse and abundant antibiotic resistance genes in Chinese swine farms, *Proceedings of the National Academy of Sciences*, **110(9),** 3435–3440.

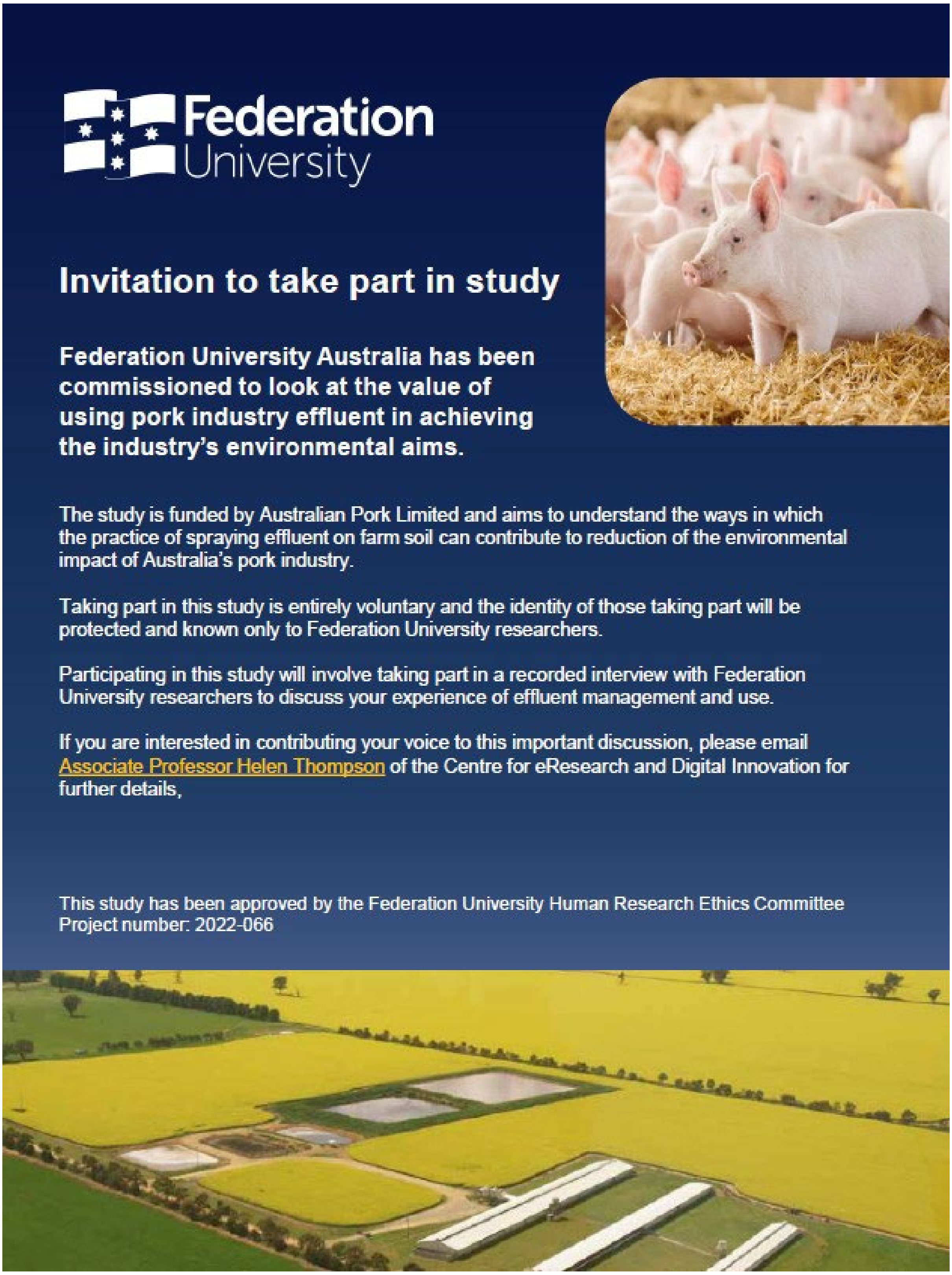
Zhu, B., Liu, L., Li, D.L. Ling, F., Wang, G-X. (2014). Developmental toxicity in rare minnow (*Gobiocypris rarus*) embryos exposed to Cu, Zn and Cd, *Ecotoxicology and Environmental Safety,* **104(1)**, 269–277.

Zhu, Q., Liu, X., Hao, T., Zeng, M., Shen, J., Zhang, F., de Vries, W. (2018.) Modelling soil acidification in typical Chinese cropping systems, *Science of the Total Environment,* **(613–614)**, 1339–1348

Zornoza, R., Faz, A., Carmona, D.M. Acosta, J.A., Mirtiìnez-Martìnez, S., de Vreng, A. (2013). Carbon mineralization, microbial activity and metal dynamics in tailing ponds amended with pig slurry and marble waste, *Chemosphere,* **90(10)**, 2606–2613.

8. Appendix

8.1 Producer consultation - recruitment flyer



Federation University

Invitation to take part in study

Federation University Australia has been commissioned to look at the value of using pork industry effluent in achieving the industry's environmental aims.

The study is funded by Australian Pork Limited and aims to understand the ways in which the practice of spraying effluent on farm soil can contribute to reduction of the environmental impact of Australia's pork industry.

Taking part in this study is entirely voluntary and the identity of those taking part will be protected and known only to Federation University researchers.

Participating in this study will involve taking part in a recorded interview with Federation University researchers to discuss your experience of effluent management and use.

If you are interested in contributing your voice to this important discussion, please email Associate Professor Helen Thompson of the Centre for eResearch and Digital Innovation for further details,

This study has been approved by the Federation University Human Research Ethics Committee
Project number: 2022-066

8.2 Interview and survey questions

1. Are you working on a family farm or for a corporation?
2. Where is the property located?
3. How long has the property been established?
4. What is the size and type of the piggery system? (For example: number of standard pig units and composition of livestock; System types: indoor, deep litter, or outdoor).
5. What production system do you operate? (For example: farrow-to-finish, farrow-to-weaner, or weaner-to-finish piggery).
6. Does the property have an irrigation area and if so, what is its size?
7. How much effluent is produced at the property?
8. What is the system for the management and storage of effluent?
9. In what ways do you make use of piggery effluent? (For example: Do you disperse effluent on your farm, sell to other farms /organisations, use it to produce energy, use it to produce products such as packaged garden fertilizer or compost; to reduce clean/potable water requirement/use, improve waste management, recycle nutrients, supplement irrigation water, other).
10. What has been the primary motivation to use the effluent?
11. Do you have an area that has had repeated application of effluent (dispersed on your farm) that would be of interest to soil sample?
12. What was the motivation for using this specific area? (For example: soil type, landscape/landform, logistics/ease, infrastructure, other?)
13. Do you use all the effluent your farm produces? If not, how much effluent is currently taken away from the farm? Where does the effluent go? How is it used?
14. What is the composition of the effluent you use on-farm (semi or solid waste)?
15. How do you disperse the effluent (For example: As liquid or solid/dried; as top dressing; using aerial spreading; below or within soil)?
16. Why have you chosen this method of effluent dispersal?
17. Is effluent spraying the most common way you recycle nutrients, or do you use it in other ways? (For example: Treated effluent for flushing sheds and on compost windrows)
18. Have you used pig effluent on crops? If so, on what crops have you used effluent on?
19. Have you experienced any positive benefits on soil health, crop productivity or effects on general plant health associated with effluent use?
20. Have you experienced any negative effects on soil health, crop productivity or effects on general plant health associated with effluent use?
21. Are there any problems with or barriers to using effluent?
22. What records are kept relating to waste use, soil health or crop performance? (For example: soil tests, fertiliser application rates, crop yields)?
23. Do you have any existing chemical data of the piggery effluent or soil test data of the paddocks that have received the piggery effluent?
24. Do you have a nutrient management plan? Compliance and certification?
25. What are the economic benefits of using effluent fertilisers compared with/opposed to general fertilisers?
26. Do you intend to continue using effluent as in the past or increase or decrease its usage?
27. Do you have an interest in carbon neutral farming systems? Please expand.

8.3 Producer 1 - Soil analysis data

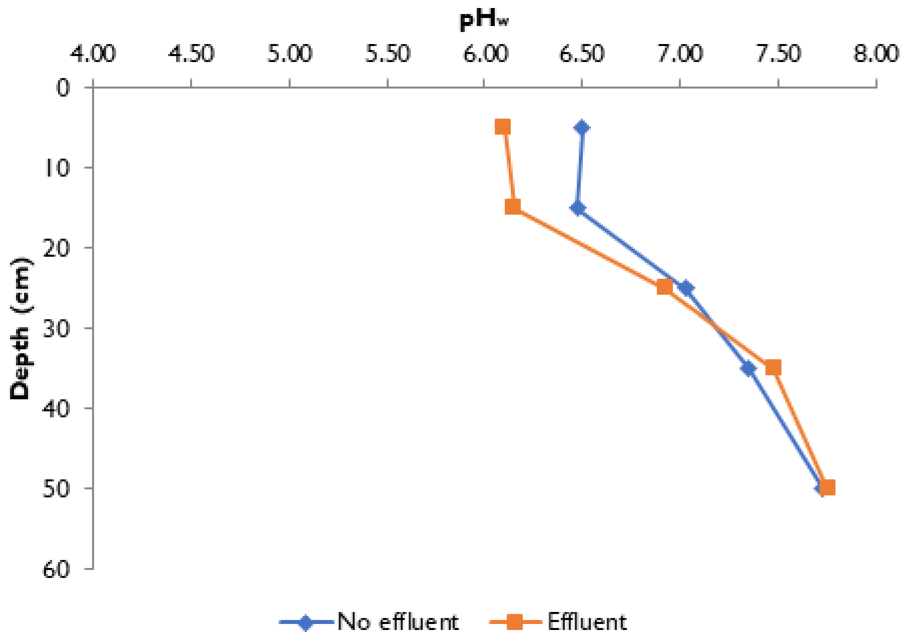


Figure 5. Producer 1: Soil pH in water (pHw) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

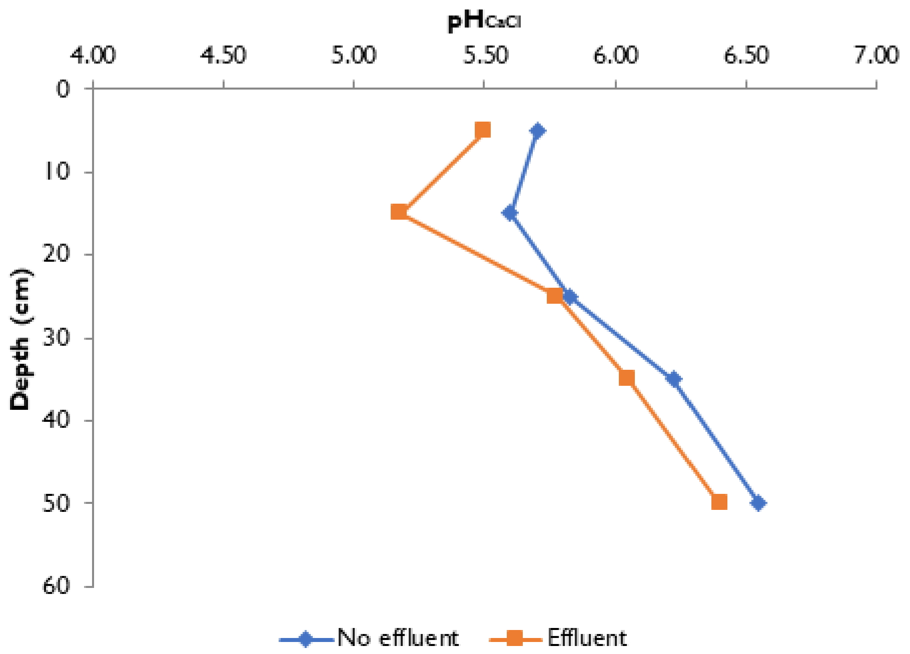


Figure 6. Producer 1: Soil pH in CaC_{l2} (pH_{CaCl}) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

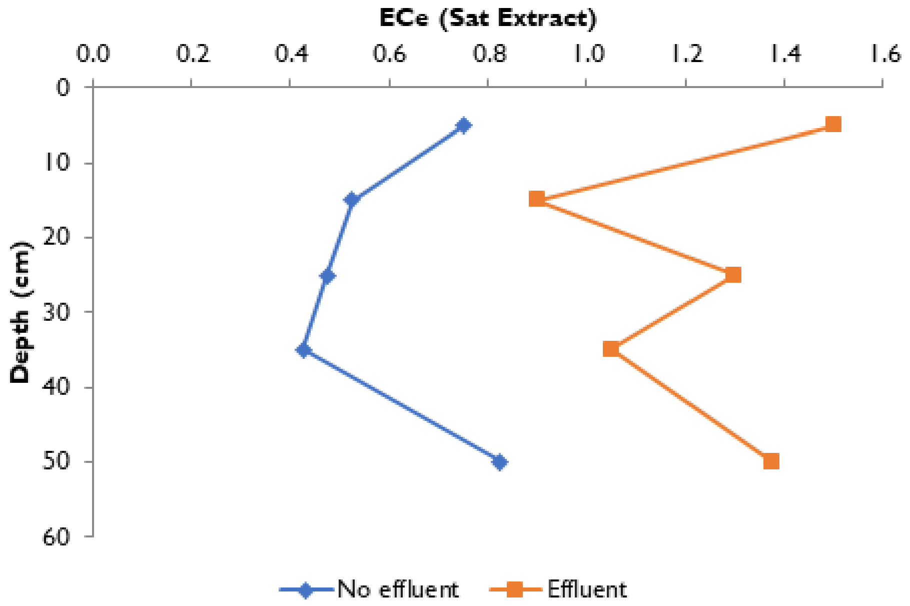


Figure 7. Producer 1: Soil electrical conductivity (saturated extract, ECe) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

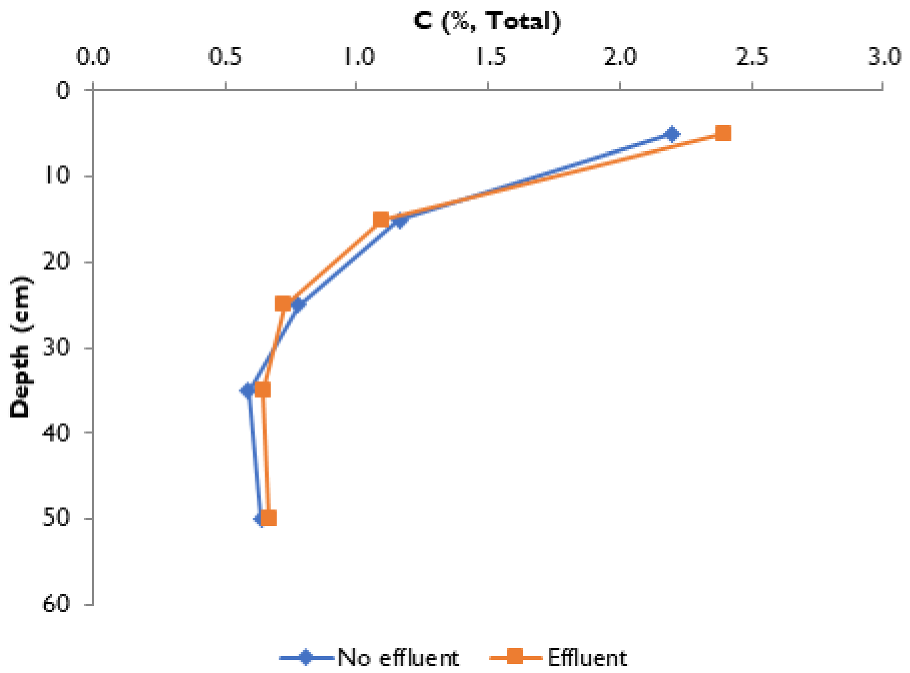


Figure 8. Producer 1: Soil total carbon (C %, Total) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

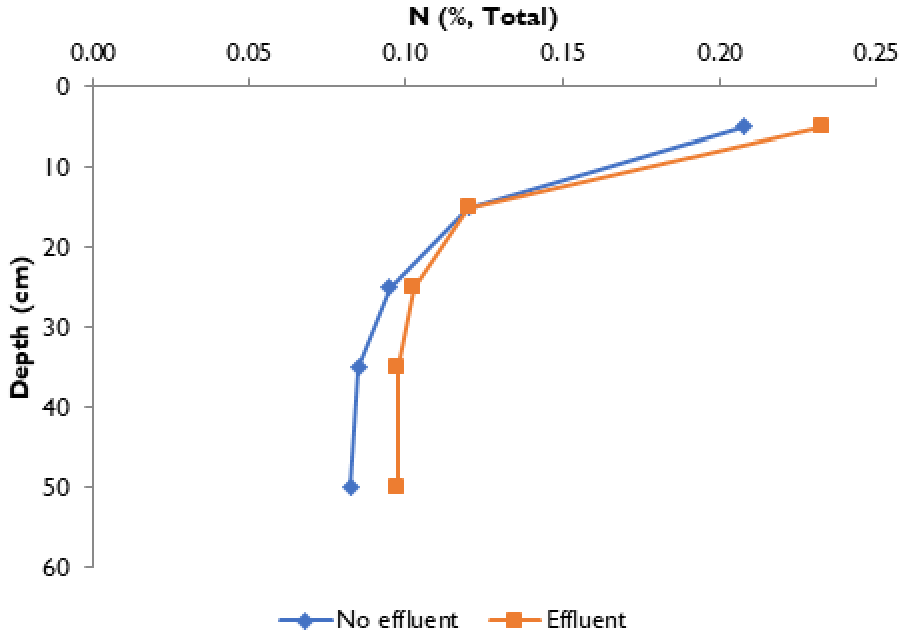


Figure 9. Producer 1: Soil total nitrogen (N %, Total) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

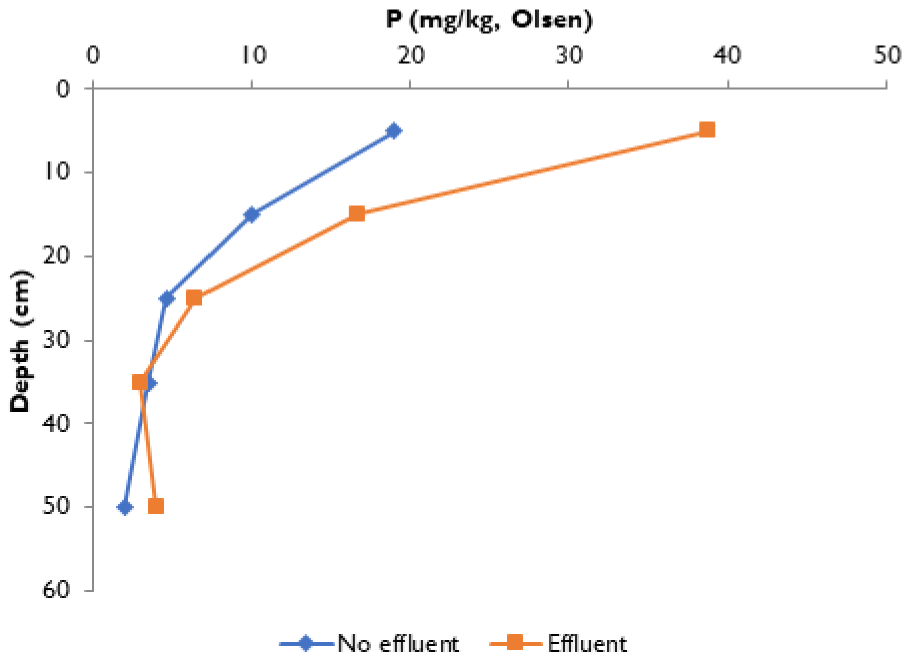


Figure 10. Producer 1: Soil phosphorus (P mg/kg, Olsen) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

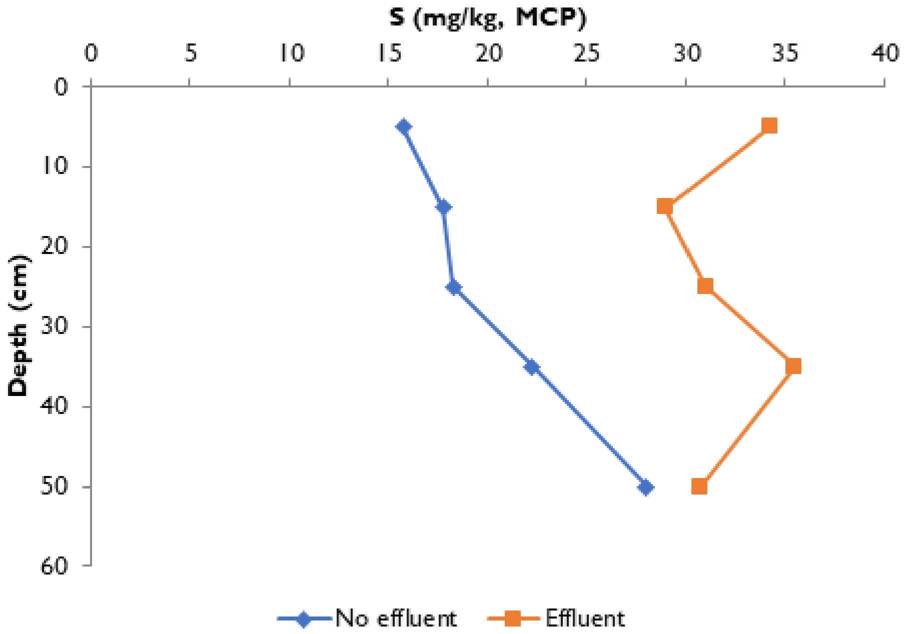


Figure 11. Producer 1: Soil sulfur (S mg/kg, MCP) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

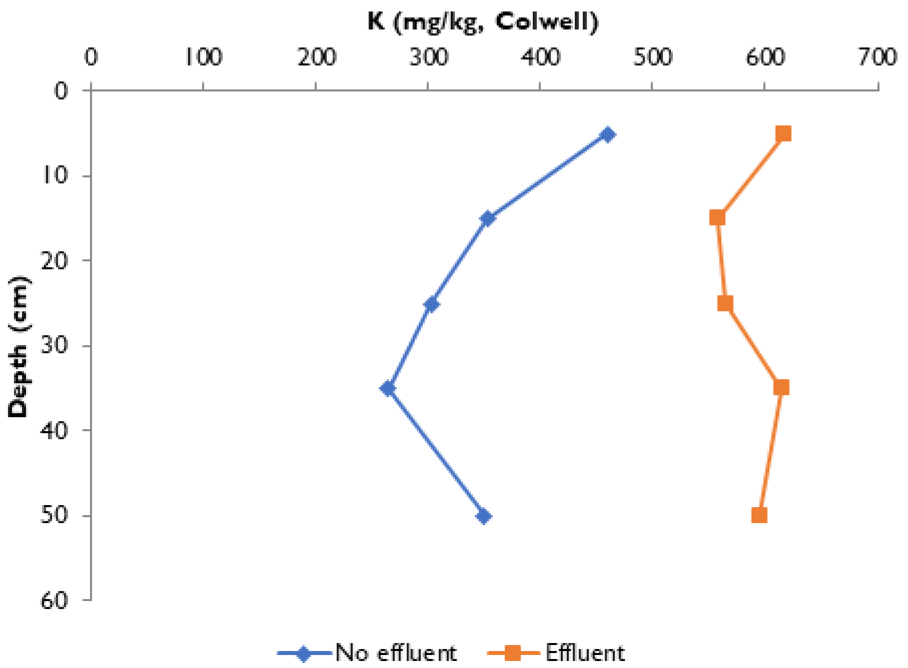


Figure 12. Producer 1: Soil potassium (P mg/kg, Colwell) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

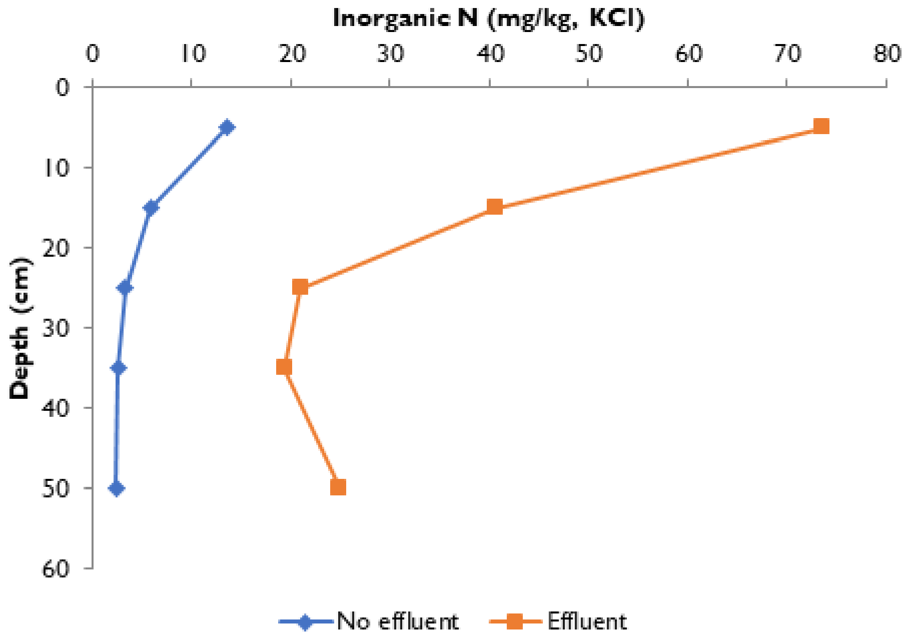


Figure 13. Producer 1: Soil inorganic nitrogen (nitrate, NO_3 + ammonium, NH_4) (Inorganic N mg/kg, KCl) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

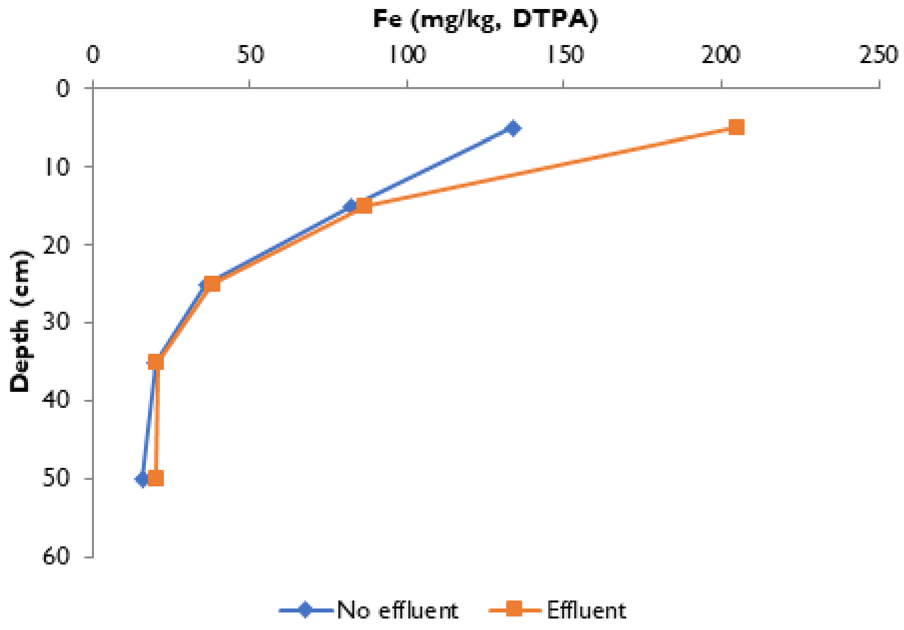


Figure 14. Producer 1: Soil iron (Fe mg/kg, DTPA) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

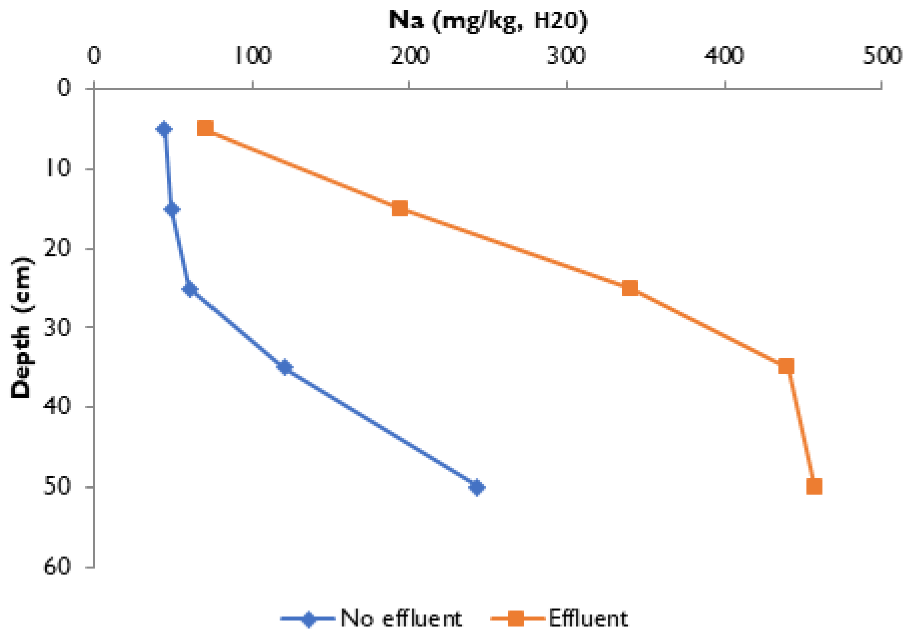


Figure 15. Producer 1: Sodium (Na mg/kg, H_2O) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

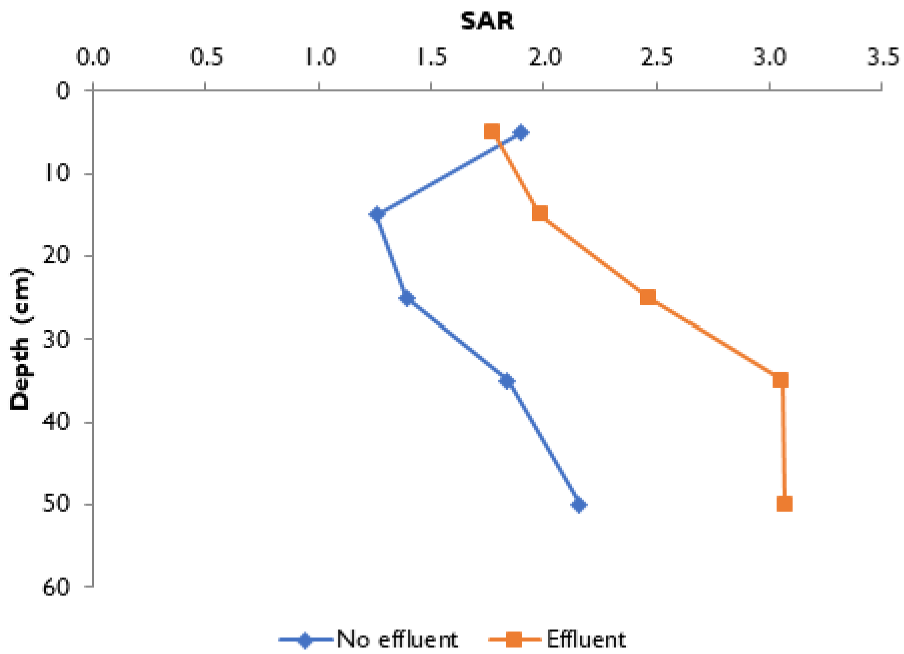


Figure 16. Producer 1: Sodium absorption ratio (SAR) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

Table 5. Producer 1 - Emerson dispersion class for four sampling locations (A, B, C, D) in paddocks receiving effluent or no-effluent.

	No effluent				Effluent			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
0-10 cm	3	3	3	3	3	3	7	7
10-20 cm	3	3	2	3	3	6	3	2
20-30 cm	3	3	2	3	2	6	3	1
30-40 cm	3	3	1	3	1	6	3	1
40-60 cm	3	2	2	3	7	2	3	1

Table 6. Producer 1 - Data for individual samples from four sampling locations and five depths (0-10, 10-20, 20-30, 30-40, 40-60 cm)

Analyte	Unit	Optimum Range		B5 Sample 1-001	B5 Sample 1-001 (10-20)	B5 Sample 1-001 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3			0.6	0.6	1.0
Emerson Class				3	3	3
Acidity						
pH (water)		6.0	7.0	5.9	6.0	6.8
pH (CaCl2)		5.2	7.5	5.1	5.1	5.7
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.11	0.07	0.06
EC (sat ext)	dS/m	0.0	1.5	0.7	0.4	0.4
Chloride	mg/kg	0.0	200	39	12	<10
Nutrients						
Total Carbon	%			2.6	1.2	0.7
Total Nitrogen	%			0.3	0.1	0.1
Nitrate Nitrogen	mg/kg			17.0	6.3	3.3
Ammonium Nitrogen	mg/kg			6.6	1.8	1.5
Phosphorus (Olsen)	mg/kg			31	16	4
Sulphur (MCP)	mg/kg	12	20	24	18	15
Potassium (Colwell)	mg/kg	170	200	560	390	370
Copper	mg/kg	0.3	5.0	1.2	1.3	1.2
Zinc	mg/kg	0.6	5.0	4.2	1.7	0.3
Manganese	mg/kg	0.5	5	93	55	10
Iron	mg/kg	10	100	240	98	44
Boron	mg/kg	1.0	4	1.4	1.0	1.9
Molybdenum	mg/kg			0.1	0.1	0.1
Water Soluble Cations						
Potassium	mg/kg			120	61	100
Calcium	mg/kg			23	13	25
Magnesium	mg/kg			6.5	10.0	38.0
Sodium	mg/kg			46	26	42
Sodium Absorbtion Ratio				2.18	1.32	1.24
Other						
Total Arsenic	mg/kg			10.0	4.4	2.0
Total Cadmium	mg/kg			0.14	0.07	0.03
Total Chromium	mg/kg			90	63	63
Total Cobalt	mg/kg			20	19	12
Total Molybdenum	mg/kg			0.85	0.37	0.11
Total Lead	mg/kg			25	18	13
Total Selenium	mg/kg			0.48	0.40	0.30
Total Vanadium	mg/kg			170	110	88

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B5 Sample 1-001 (30-40)	B5 Sample 1-001 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3			1.2	1.4	
Emerson Class				3	3	
Acidity						
pH (water)		6.0	7.0	7.0	7.1	
pH (CaCl2)		5.2	7.5	5.9	5.7	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.07	0.17	
EC (sat ext)	dS/m	0.0	1.5	0.4	1.1	
Chloride	mg/kg	0.0	200	<10	14	
Nutrients						
Total Carbon	%			0.5	0.6	
Total Nitrogen	%			0.1	0.1	
Nitrate Nitrogen	mg/kg			3.1	2.3	
Ammonium Nitrogen	mg/kg			1.0	0.9	
Phosphorus (Olsen)	mg/kg			3	<2	
Sulphur (MCP)	mg/kg	12	20	21	43	
Potassium (Colwell)	mg/kg	170	200	280	300	
Copper	mg/kg	0.3	5.0	0.9	0.8	
Zinc	mg/kg	0.6	5.0	0.4	0.2	
Manganese	mg/kg	0.5	5.0	4	5	
Iron	mg/kg	10	100	28	19	
Boron	mg/kg	1.0	4.0	2.1	3.1	
Molybdenum	mg/kg					
Water Soluble Cations						
Potassium	mg/kg			74	500	
Calcium	mg/kg			16	44	
Magnesium	mg/kg			29.0	230.0	
Sodium	mg/kg			54	120	
Sodium Absorbtion Ratio				1.86	1.61	
Other						
Total Arsenic	mg/kg			1.9	1.1	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			62	65	
Total Cobalt	mg/kg			10	13	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			14	11	
Total Selenium	mg/kg			0.23	0.29	
Total Vanadium	mg/kg			70	44	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B5 Sample 2-002 (0-10)	B5 Sample 2-002 (10-20)	B5 Sample 2-002 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Sandy Loam	Clay	Sandy Loam
Bulk Density	g/cm^3			0.8	0.9	1.1
Emerson Class				3	3	3
Acidity						
pH (water)		6.0	7.0	6.5	6.2	6.7
pH (CaCl2)		5.2	7.5	5.8	5.4	5.8
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.08	0.09	0.05
EC (sat ext)	dS/m	0.0	1.5	0.8	0.6	0.5
Chloride	mg/kg	0.0	200	19	<10	<10
Nutrients						
Total Carbon	%			2.5	1.5	0.9
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			5.4	3.6	2.4
Ammonium Nitrogen	mg/kg			4.9	2.4	1.3
Phosphorus (Olsen)	mg/kg			23	11	8
Sulphur (MCP)	mg/kg	12	20	16	18	19
Potassium (Colwell)	mg/kg	170	200	410	300	210
Copper	mg/kg	0.3	5.0	0.9	0.7	0.6
Zinc	mg/kg	0.6	5.0	3.5	1.4	1.0
Manganese	mg/kg	0.5	5.0	52	55	22
Iron	mg/kg	10	100	110	110	50
Boron	mg/kg	1.0	4.0	1.2	1.0	0.7
Molybdenum	mg/kg					0.1
Water Soluble Cations						
Potassium	mg/kg			46	38	30
Calcium	mg/kg			28	19	16
Magnesium	mg/kg			8.5	9.3	9.9
Sodium	mg/kg			27	21	25
Sodium Absorbtion Ratio				1.15	0.99	1.21
Other						
Total Arsenic	mg/kg			5.7	10.0	11.0
Total Cadmium	mg/kg			0.12	0.06	0.03
Total Chromium	mg/kg			110	160	160
Total Cobalt	mg/kg			32	32	32
Total Molybdenum	mg/kg			0.50	0.99	1.10
Total Lead	mg/kg			17	21	23
Total Selenium	mg/kg			0.40	0.47	0.57
Total Vanadium	mg/kg			140	260	250

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B5 Sample 2-002 (30-40)	B5 Sample 2-002 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3			1.3	2.1	
Emerson Class				3	2	
Acidity						
pH (water)		6.0	7.0	7.2	8.1	
pH (CaCl2)		5.2	7.5	6.2	6.5	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.04	0.08	
EC (sat ext)	dS/m	0.0	1.5	0.2	0.5	
Chloride	mg/kg	0.0	200	<10	15	
Nutrients						
Total Carbon	%			0.6	0.7	
Total Nitrogen	%			0.1	0.1	
Nitrate Nitrogen	mg/kg			0.9	1.8	
Ammonium Nitrogen	mg/kg			1.4	1.0	
Phosphorus (Olsen)	mg/kg			4	2	
Sulphur (MCP)	mg/kg	12	20	13	16	
Potassium (Colwell)	mg/kg	170	200	130	250	
Copper	mg/kg	0.3	5.0	0.5	0.8	
Zinc	mg/kg	0.6	5.0	0.8	0.8	
Manganese	mg/kg	0.5	5.0	9	7	
Iron	mg/kg	10	100	23	17	
Boron	mg/kg	1.0	4.0	0.6	2.9	
Molybdenum	mg/kg					
Water Soluble Cations						
Potassium	mg/kg			34	820	
Calcium	mg/kg			18	160	
Magnesium	mg/kg			15.0	470.0	
Sodium	mg/kg			30	230	
Sodium Absorbtion Ratio				1.26	2.07	
Other						
Total Arsenic	mg/kg			8.6	3.8	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			150	110	
Total Cobalt	mg/kg			22	23	
Total Molybdenum	mg/kg			0.63	0.12	
Total Lead	mg/kg			19	14	
Total Selenium	mg/kg			0.55	0.45	
Total Vanadium	mg/kg			230	130	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B5 Sample 3-003 (0-10)	B5 Sample 3-003 (10-20)	B5 Sample 3-003 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				3	2	2
Acidity						
pH (water)		6.0	7.0	6.6	6.7	7.4
pH (CaCl2)		5.2	7.5	5.7	5.8	5.7
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.10	0.09	0.08
EC (sat ext)	dS/m	0.0	1.5	0.6	0.6	0.5
Chloride	mg/kg	0.0	200	43	22	<10
Nutrients						
Total Carbon	%			2.3	1.2	0.8
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			6.7	4.2	1.7
Ammonium Nitrogen	mg/kg			5.7	1.8	1.1
Phosphorus (Olsen)	mg/kg			15	8	<2
Sulphur (MCP)	mg/kg	12	20	12	19	21
Potassium (Colwell)	mg/kg	170	200	460	400	330
Copper	mg/kg	0.3	5.0	0.9	1.2	1.6
Zinc	mg/kg	0.6	5.0	3.9	1.3	0.2
Manganese	mg/kg	0.5	5.0	78	38	7
Iron	mg/kg	10	100	120	80	26
Boron	mg/kg	1.0	4.0	1.1	1.4	3.0
Molybdenum	mg/kg					
Water Soluble Cations						
Potassium	mg/kg			68	770	410
Calcium	mg/kg			24	96	110
Magnesium	mg/kg			15.0	300.0	240.0
Sodium	mg/kg			59	120	120
Sodium Absorbtion Ratio				2.33	1.36	1.47
Other						
Total Arsenic	mg/kg			6.9	6.3	2.2
Total Cadmium	mg/kg			0.14	0.07	<0.02
Total Chromium	mg/kg			86	120	110
Total Cobalt	mg/kg			19	17	29
Total Molybdenum	mg/kg			0.57	0.49	<0.05
Total Lead	mg/kg			19	16	12
Total Selenium	mg/kg			0.40	0.37	0.42
Total Vanadium	mg/kg			150	150	74

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B5 Sample 3-003 (30-40)	B5 Sample 3-003 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3					
Emerson Class				1	2	
Acidity						
pH (water)		6.0	7.0	8.0	8.4	
pH (CaCl2)		5.2	7.5	6.9	8.0	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.10	0.16	
EC (sat ext)	dS/m	0.0	1.5	0.6	1.0	
Chloride	mg/kg	0.0	200	<10	32	
Nutrients						
Total Carbon	%			0.6	0.6	
Total Nitrogen	%			0.1	0.1	
Nitrate Nitrogen	mg/kg			0.7	0.9	
Ammonium Nitrogen	mg/kg			0.7	0.7	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	12	20	22	17	
Potassium (Colwell)	mg/kg	170	200	350	490	
Copper	mg/kg	0.3	5.0	1.4	1.5	
Zinc	mg/kg	0.6	5.0	0.2	0.2	
Manganese	mg/kg	0.5	5.0	5	3	
Iron	mg/kg	10	100	13	12	
Boron	mg/kg	1.0	4.0	3.4	5.4	
Molybdenum	mg/kg					
Water Soluble Cations						
Potassium	mg/kg			1300	1900	
Calcium	mg/kg			290	360	
Magnesium	mg/kg			790.0	1200.0	
Sodium	mg/kg			320	530	
Sodium Absorbtion Ratio				2.21	3.02	
Other						
Total Arsenic	mg/kg			1.5	1.5	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			94	94	
Total Cobalt	mg/kg			32	21	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			9	9	
Total Selenium	mg/kg			0.51	0.38	
Total Vanadium	mg/kg			56	43	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B5 Sample 4-004 (0-10)	B5 Sample 4-004 (10-20)	B5 Sample 4-004 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Sandy Loam	Sandy Loam	Clay
Bulk Density	g/cm^3					
Emerson Class				3	3	3
Acidity						
pH (water)		6.0	7.0	7.0	7.0	7.2
pH (CaCl2)		5.2	7.5	6.2	6.1	6.1
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.09	0.05	0.08
EC (sat ext)	dS/m	0.0	1.5	0.9	0.5	0.5
Chloride	mg/kg	0.0	200	49	14	<10
Nutrients						
Total Carbon	%			1.4	0.8	0.7
Total Nitrogen	%			0.1	0.1	0.1
Nitrate Nitrogen	mg/kg			5.8	2.0	0.9
Ammonium Nitrogen	mg/kg			2.0	1.1	1.0
Phosphorus (Olsen)	mg/kg			7	5	2
Sulphur (MCP)	mg/kg	12	20	11	16	18
Potassium (Colwell)	mg/kg	170	200	410	320	300
Copper	mg/kg	0.3	5.0	0.6	0.5	0.9
Zinc	mg/kg	0.6	5.0	3.1	3.0	0.5
Manganese	mg/kg	0.5	5.0	55	37	5
Iron	mg/kg	10	100	64	41	25
Boron	mg/kg	1.0	4.0	0.9	0.7	1.5
Molybdenum	mg/kg			0.1		
Water Soluble Cations						
Potassium	mg/kg			81	54	100
Calcium	mg/kg			24	17	29
Magnesium	mg/kg			15.0	12.0	38.0
Sodium	mg/kg			49	30	57
Sodium Absorbtion Ratio				1.93	1.36	1.64
Other						
Total Arsenic	mg/kg			11.0	9.9	1.5
Total Cadmium	mg/kg			0.09	0.05	<0.02
Total Chromium	mg/kg			73	69	58
Total Cobalt	mg/kg			23	33	12
Total Molybdenum	mg/kg			0.84	0.60	<0.05
Total Lead	mg/kg			29	31	12
Total Selenium	mg/kg			0.54	0.61	0.22
Total Vanadium	mg/kg			200	180	46

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B5 Sample 4-004 (30-40)	B5 Sample 4-004 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3					
Emerson Class				3	3	
Acidity						
pH (water)		6.0	7.0	7.2	7.3	
pH (CaCl2)		5.2	7.5	5.9	6.0	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.08	0.12	
EC (sat ext)	dS/m	0.0	1.5	0.5	0.7	
Chloride	mg/kg	0.0	200	<10	<10	
Nutrients						
Total Carbon	%			0.8	0.7	
Total Nitrogen	%			0.1	0.1	
Nitrate Nitrogen	mg/kg			<0.5	0.7	
Ammonium Nitrogen	mg/kg			1.1	1.3	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	12	20	33	36	
Potassium (Colwell)	mg/kg	170	200	300	360	
Copper	mg/kg	0.3	5.0	0.5	0.6	
Zinc	mg/kg	0.6	5.0	0.2	0.7	
Manganese	mg/kg	0.5	5.0		4	
Iron	mg/kg	10	100	16	16	
Boron	mg/kg	1.0	4.0	2.4	2.5	
Molybdenum	mg/kg				0.1	
Water Soluble Cations						
Potassium	mg/kg			130	210	
Calcium	mg/kg			26	25	
Magnesium	mg/kg			54.0	88.0	
Sodium	mg/kg			79	92	
Sodium Absorbtion Ratio				2.03	1.94	
Other						
Total Arsenic	mg/kg			1.5	1.9	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			84	73	
Total Cobalt	mg/kg			9	13	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			12	14	
Total Selenium	mg/kg			0.31	0.24	
Total Vanadium	mg/kg			60	56	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B6 Sample 1-005 (0-10)	B6 Sample 1-005 (10-20)	B6 Sample 1-005 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3			0.6	0.8	1.3
Emerson Class				3	3	2
Acidity						
pH (water)		6.0	7.0	5.9	5.7	6.8
pH (CaCl2)		5.2	7.5	5.4	4.7	5.2
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.26	0.12	0.06
EC (sat ext)	dS/m	0.0	1.5	1.6	0.7	0.4
Chloride	mg/kg	0.0	200	73	24	12
Nutrients						
Total Carbon	%			2.6	1.1	0.8
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			70.0	37.0	6.8
Ammonium Nitrogen	mg/kg			47.0	10.0	1.2
Phosphorus (Olsen)	mg/kg			78	40	7
Sulphur (MCP)	mg/kg	12	20	35	16	11
Potassium (Colwell)	mg/kg	170	200	700	490	560
Copper	mg/kg	0.3	5.0	4.3	2.8	2.7
Zinc	mg/kg	0.6	5.0	7.0	1.6	0.4
Manganese	mg/kg	0.5	5	23	68	45
Iron	mg/kg	10	100	260	130	62
Boron	mg/kg	1.0	4	1.6	1.7	2.6
Molybdenum	mg/kg			0.0	0.0	0.1
Water Soluble Cations						
Potassium	mg/kg			160	150	760
Calcium	mg/kg			65	37	140
Magnesium	mg/kg			19.0	43.0	330.0
Sodium	mg/kg			59	55	98
Sodium Absorbtion Ratio				1.66	1.46	1.03
Other						
Total Arsenic	mg/kg			5.0	0.9	1.6
Total Cadmium	mg/kg			0.07	0.05	0.05
Total Chromium	mg/kg			48	33	57
Total Cobalt	mg/kg			10	13	14
Total Molybdenum	mg/kg			0.33	<0.05	<0.05
Total Lead	mg/kg			14	10	13
Total Selenium	mg/kg			0.34	0.25	0.33
Total Vanadium	mg/kg			110	34	66

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B6 Sample 1-005 (30-40)	B6 Sample 1-005 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3			1.5	1.8	
Emerson Class				1	7	
Acidity						
pH (water)		6.0	7.0	7.6	8.2	
pH (CaCl2)		5.2	7.5	6.0	7.6	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.13	0.33	
EC (sat ext)	dS/m	0.0	1.5	0.8	2.0	
Chloride	mg/kg	0.0	200	24	63	
Nutrients						
Total Carbon	%			0.7	0.8	
Total Nitrogen	%			0.1	0.1	
Nitrate Nitrogen	mg/kg			8.2	23.0	
Ammonium Nitrogen	mg/kg			1.2	1.9	
Phosphorus (Olsen)	mg/kg			3	6	
Sulphur (MCP)	mg/kg	12	20	11	22	
Potassium (Colwell)	mg/kg	170	200	650	620	
Copper	mg/kg	0.3	5.0	2.8	1.7	
Zinc	mg/kg	0.6	5.0	0.2	0.8	
Manganese	mg/kg	0.5	5.0	32	11	
Iron	mg/kg	10	100	34	32	
Boron	mg/kg	1.0	4.0	4.6	6.4	
Molybdenum	mg/kg					
Water Soluble Cations						
Potassium	mg/kg			3800	3600	
Calcium	mg/kg			630	540	
Magnesium	mg/kg			1600.0	1700.0	
Sodium	mg/kg			520	750	
Sodium Absorbtion Ratio				2.50	3.57	
Other						
Total Arsenic	mg/kg			1.2	1.2	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			66	57	
Total Cobalt	mg/kg			15	11	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			11	9	
Total Selenium	mg/kg			0.39	0.28	
Total Vanadium	mg/kg			50	43	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B6 Sample 2-006 (0-10)	B6 Sample 2-006 (10-20)	B6 Sample 2-006 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3			0.8	0.9	1.4
Emerson Class				3	6	6
Acidity						
pH (water)		6.0	7.0	5.6	5.4	6.0
pH (CaCl2)		5.2	7.5	5.1	4.8	5.1
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.16	0.11	0.12
EC (sat ext)	dS/m	0.0	1.5	1.0	0.7	0.7
Chloride	mg/kg	0.0	200	41	26	13
Nutrients						
Total Carbon	%			2.0	1.1	0.7
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			39.0	26.0	14.0
Ammonium Nitrogen	mg/kg			26.0	18.0	4.5
Phosphorus (Olsen)	mg/kg			33	15	6
Sulphur (MCP)	mg/kg	12	20	39	49	60
Potassium (Colwell)	mg/kg	170	200	510	430	500
Copper	mg/kg	0.3	5.0	3.7	1.4	0.6
Zinc	mg/kg	0.6	5.0	14.0	1.5	0.4
Manganese	mg/kg	0.5	5.0	50	22	7
Iron	mg/kg	10	100	180	81	22
Boron	mg/kg	1.0	4.0	1.2	1.4	2.0
Molybdenum	mg/kg					0.0
Water Soluble Cations						
Potassium	mg/kg			100	100	100
Calcium	mg/kg			48	29	23
Magnesium	mg/kg			18.0	28.0	38.0
Sodium	mg/kg			34	39	67
Sodium Absorbtion Ratio				1.06	1.24	1.99
Other						
Total Arsenic	mg/kg			2.7	10.0	1.6
Total Cadmium	mg/kg			0.10	0.05	0.05
Total Chromium	mg/kg			42	84	67
Total Cobalt	mg/kg			21	13	12
Total Molybdenum	mg/kg			0.20	0.36	<0.05
Total Lead	mg/kg			15	24	13
Total Selenium	mg/kg			0.37	0.80	0.35
Total Vanadium	mg/kg			69	180	62

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B6 Sample 2-006 (30-40)	B6 Sample 2-006 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3			1.1	1.4	
Emerson Class				6	2	
Acidity						
pH (water)		6.0	7.0	6.7	7.3	
pH (CaCl2)		5.2	7.5	5.8	5.7	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.20	0.14	
EC (sat ext)	dS/m	0.0	1.5	1.2	0.9	
Chloride	mg/kg	0.0	200	19	35	
Nutrients						
Total Carbon	%			0.5	0.6	
Total Nitrogen	%			0.1	0.1	
Nitrate Nitrogen	mg/kg			15.0	20.0	
Ammonium Nitrogen	mg/kg			2.2	4.2	
Phosphorus (Olsen)	mg/kg			<2	2	
Sulphur (MCP)	mg/kg	12	20	69	36	
Potassium (Colwell)	mg/kg	170	200	470	500	
Copper	mg/kg	0.3	5.0	0.7	1.4	
Zinc	mg/kg	0.6	5.0	0.2	0.4	
Manganese	mg/kg	0.5	5.0	2	4	
Iron	mg/kg	10	100	15	19	
Boron	mg/kg	1.0	4.0	2.5	4.9	
Molybdenum	mg/kg					
Water Soluble Cations						
Potassium	mg/kg			160	750	
Calcium	mg/kg			24	89	
Magnesium	mg/kg			69.0	340.0	
Sodium	mg/kg			110	190	
Sodium Absorbtion Ratio				2.58	2.05	
Other						
Total Arsenic	mg/kg			1.1	1.8	
Total Cadmium	mg/kg			0.02	0.02	
Total Chromium	mg/kg			71	79	
Total Cobalt	mg/kg			14	25	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			13	13	
Total Selenium	mg/kg			0.28	0.48	
Total Vanadium	mg/kg			47	70	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B6 Sample 3-007 (0-10)	B6 Sample 3-007 (10-20)	B6 Sample 3-007 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Sandy Loam	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				7	3	3
Acidity						
pH (water)		6.0	7.0	6.2	6.2	6.7
pH (CaCl2)		5.2	7.5	5.6	5.4	5.5
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.19	0.13	0.10
EC (sat ext)	dS/m	0.0	1.5	2.0	0.8	0.6
Chloride	mg/kg	0.0	200	37	33	24
Nutrients						
Total Carbon	%			1.8	1.1	0.6
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			59.0	37.0	23.0
Ammonium Nitrogen	mg/kg			11.0	11.0	1.4
Phosphorus (Olsen)	mg/kg			14	8	<2
Sulphur (MCP)	mg/kg	12	20	28	22	24
Potassium (Colwell)	mg/kg	170	200	460	360	260
Copper	mg/kg	0.3	5.0	0.8	0.9	0.9
Zinc	mg/kg	0.6	5.0	2.6	1.6	0.7
Manganese	mg/kg	0.5	5.0	66	45	14
Iron	mg/kg	10	100	130	75	34
Boron	mg/kg	1.0	4.0	1.2	1.5	1.8
Molybdenum	mg/kg					
Water Soluble Cations						
Potassium	mg/kg			110	99	220
Calcium	mg/kg			55	29	31
Magnesium	mg/kg			14.0	34.0	96.0
Sodium	mg/kg			51	74	97
Sodium Absorbtion Ratio				1.59	2.21	1.94
Other						
Total Arsenic	mg/kg			9.4	4.8	2.3
Total Cadmium	mg/kg			0.07	0.04	0.02
Total Chromium	mg/kg			66	63	61
Total Cobalt	mg/kg			58	41	24
Total Molybdenum	mg/kg			1.10	0.26	0.09
Total Lead	mg/kg			17	23	18
Total Selenium	mg/kg			0.46	0.39	0.38
Total Vanadium	mg/kg			150	110	65

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B6 Sample 3-007 (30-40)	B6 Sample 3-007 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3					
Emerson Class				3	3	
Acidity						
pH (water)		6.0	7.0	7.3	7.0	
pH (CaCl2)		5.2	7.5	5.8	5.7	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.12	0.12	
EC (sat ext)	dS/m	0.0	1.5	0.7	0.7	
Chloride	mg/kg	0.0	200	37	35	
Nutrients						
Total Carbon	%			0.6	0.5	
Total Nitrogen	%			0.1	0.1	
Nitrate Nitrogen	mg/kg			16.0	27.0	
Ammonium Nitrogen	mg/kg			1.2	1.2	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	12	20	25	27	
Potassium (Colwell)	mg/kg	170	200	430	410	
Copper	mg/kg	0.3	5.0	0.6	0.5	
Zinc	mg/kg	0.6	5.0	0.2	0.3	
Manganese	mg/kg	0.5	5.0	5	4	
Iron	mg/kg	10	100	12	13	
Boron	mg/kg	1.0	4.0	5.3	2.6	
Molybdenum	mg/kg					
Water Soluble Cations						
Potassium	mg/kg			360	420	
Calcium	mg/kg			44	27	
Magnesium	mg/kg			190.0	190.0	
Sodium	mg/kg			140	130	
Sodium Absorbtion Ratio				2.04	1.94	
Other						
Total Arsenic	mg/kg			1.1	1.2	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			62	65	
Total Cobalt	mg/kg			11	14	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			9	10	
Total Selenium	mg/kg			0.32	0.26	
Total Vanadium	mg/kg			26	33	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B6 Sample 4-008 (0-10)	B6 Sample 4-008 (10-20)	B6 Sample 4-008 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				7	2	1
Acidity						
pH (water)		6.0	7.0	6.7	7.3	8.2
pH (CaCl2)		5.2	7.5	5.9	5.8	7.3
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.22	0.22	0.57
EC (sat ext)	dS/m	0.0	1.5	1.4	1.4	3.5
Chloride	mg/kg	0.0	200	48	55	100
Nutrients						
Total Carbon	%			3.2	1.1	0.9
Total Nitrogen	%			0.3	0.1	0.1
Nitrate Nitrogen	mg/kg			36.0	22.0	32.0
Ammonium Nitrogen	mg/kg			6.5	1.5	1.1
Phosphorus (Olsen)	mg/kg			30	4	<2
Sulphur (MCP)	mg/kg	12	20	35	29	29
Potassium (Colwell)	mg/kg	170	200	800	950	940
Copper	mg/kg	0.3	5.0	2.8	2.6	2.4
Zinc	mg/kg	0.6	5.0	4.2	0.5	0.3
Manganese	mg/kg	0.5	5.0	43	41	16
Iron	mg/kg	10	100	250	62	34
Boron	mg/kg	1.0	4.0	2.4	3.4	3.7
Molybdenum	mg/kg			0.0		
Water Soluble Cations						
Potassium	mg/kg			220	3900	5600
Calcium	mg/kg			71	750	860
Magnesium	mg/kg			72.0	1400.0	1800.0
Sodium	mg/kg			140	610	1100
Sodium Absorbtion Ratio				2.80	3.04	4.90
Other						
Total Arsenic	mg/kg			6.6	0.9	0.8
Total Cadmium	mg/kg			0.08	0.03	<0.02
Total Chromium	mg/kg			50	64	72
Total Cobalt	mg/kg			23	28	12
Total Molybdenum	mg/kg			0.10	<0.05	<0.05
Total Lead	mg/kg			13	11	10
Total Selenium	mg/kg			0.30	0.24	0.29
Total Vanadium	mg/kg			89	35	46

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B6 Sample 4-008 (30-40)	B6 Sample 4-008 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3					
Emerson Class				1	1	
Acidity						
pH (water)		6.0	7.0	8.3	8.5	
pH (CaCl2)		5.2	7.5	6.6	6.6	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.24	0.30	
EC (sat ext)	dS/m	0.0	1.5	1.5	1.9	
Chloride	mg/kg	0.0	200	160	240	
Nutrients						
Total Carbon	%			0.7	0.7	
Total Nitrogen	%			0.1	0.1	
Nitrate Nitrogen	mg/kg			32.0	21.0	
Ammonium Nitrogen	mg/kg			1.6	1.5	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	12	20	37	38	
Potassium (Colwell)	mg/kg	170	200	910	850	
Copper	mg/kg	0.3	5.0	1.9	1.8	
Zinc	mg/kg	0.6	5.0	0.2	0.2	
Manganese	mg/kg	0.5	5.0		9	
Iron	mg/kg	10	100	21	17	
Boron	mg/kg	1.0	4.0	3.5	5.4	
Molybdenum	mg/kg				0.0	
Water Soluble Cations						
Potassium	mg/kg			3600	2400	
Calcium	mg/kg			550	320	
Magnesium	mg/kg			1400.0	1000.0	
Sodium	mg/kg			990	760	
Sodium Absorbtion Ratio				5.10	4.72	
Other						
Total Arsenic	mg/kg			0.8	0.7	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			67	61	
Total Cobalt	mg/kg			13	15	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			8	10	
Total Selenium	mg/kg			0.27	0.27	
Total Vanadium	mg/kg			40	34	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

8.4 Producer 2 - Soil analysis data

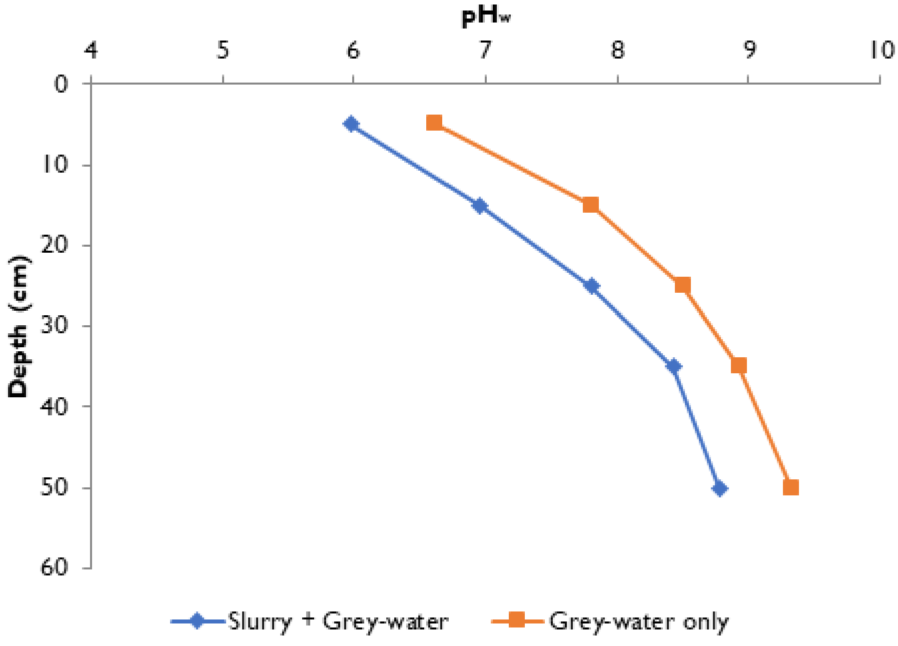


Figure 17. Producer 2: Soil pH in water (pH_w) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

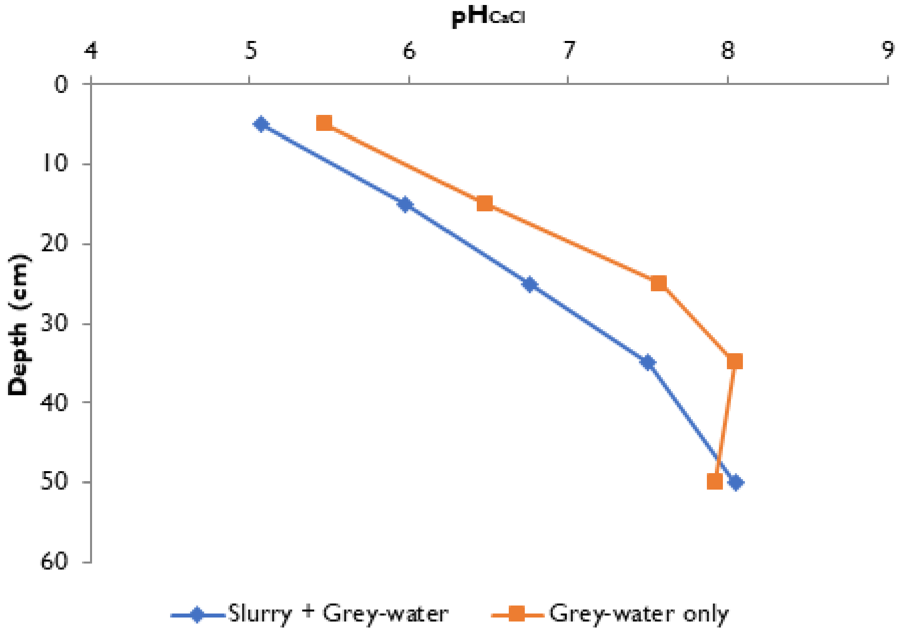


Figure 18. Producer 2: Soil pH in $CaCl_2$ (pH_{CaCl}) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

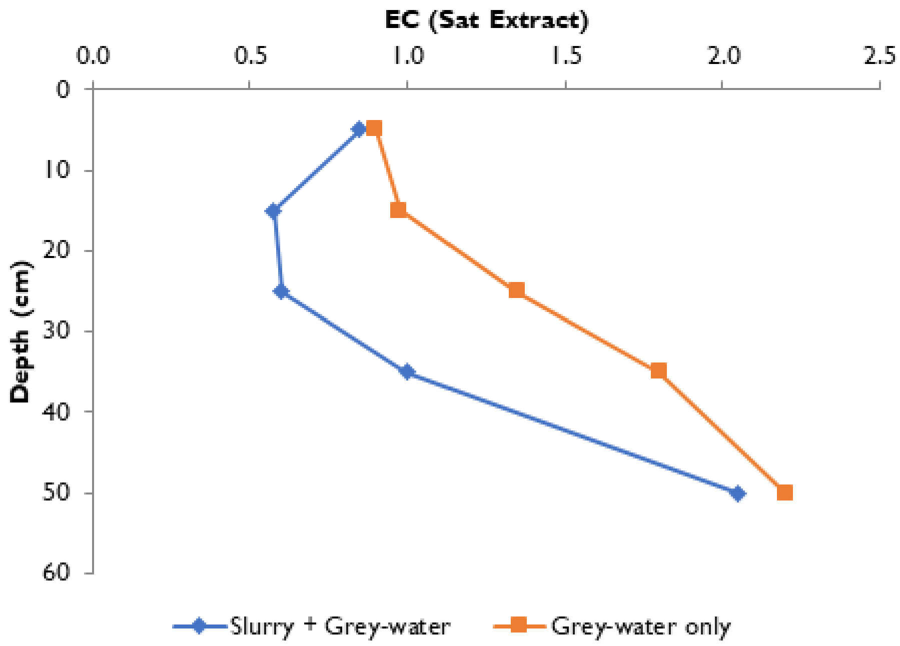


Figure 19. Producer 2: Soil electrical conductivity (saturated extract, ECe) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

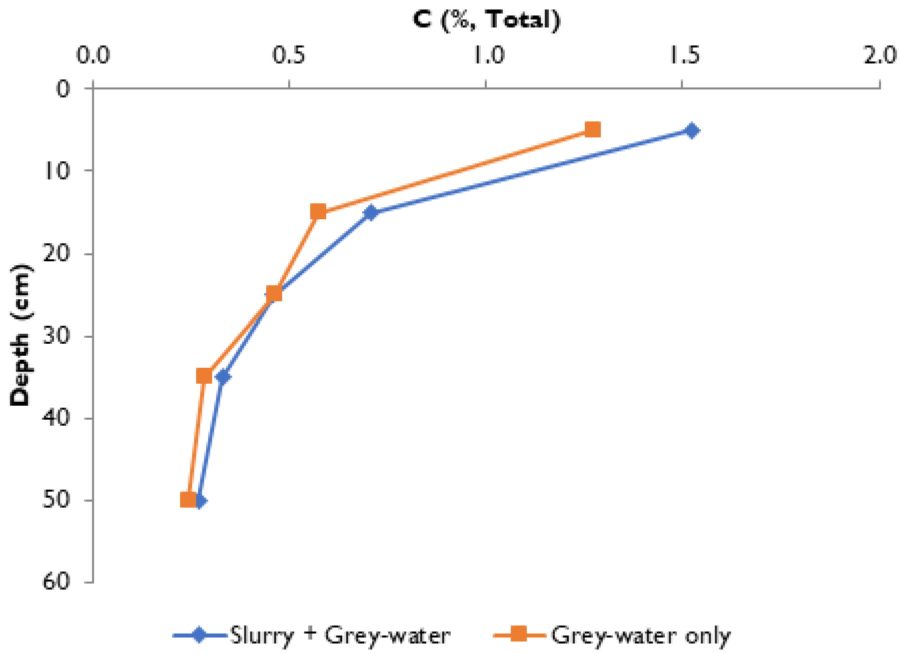


Figure 20. Producer 2: Soil total carbon (C %, Total) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

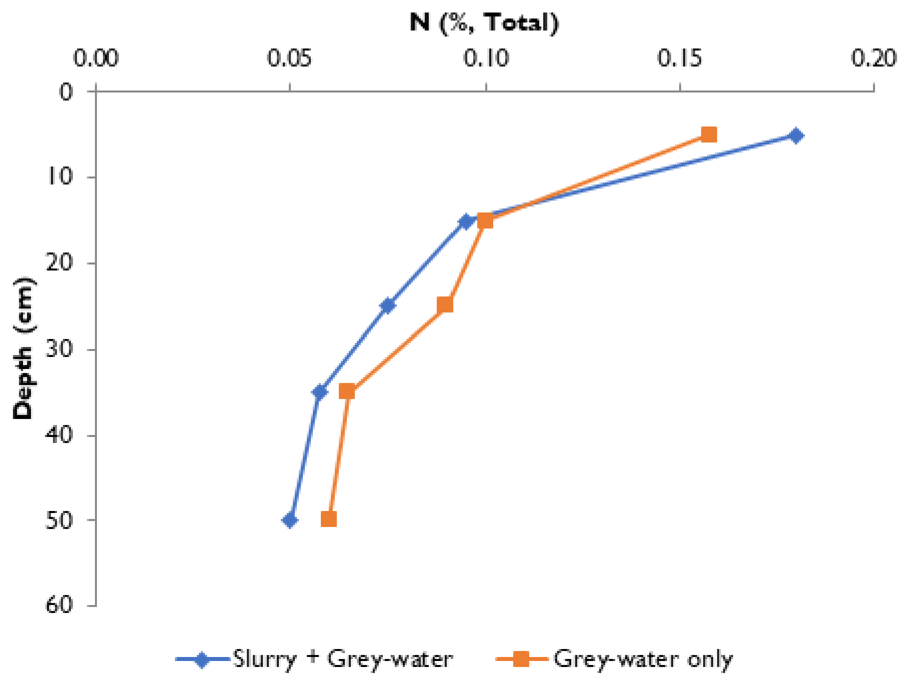


Figure 21. Producer 2: Soil total nitrogen (N %, Total) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

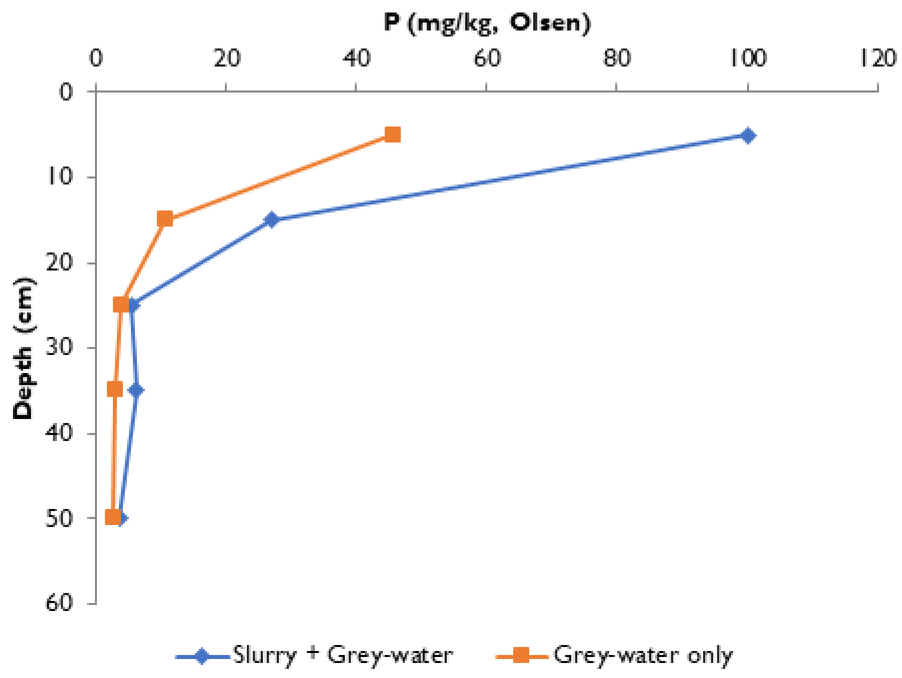


Figure 22. Producer 2: Soil phosphorus (P mg/kg, Olsen) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

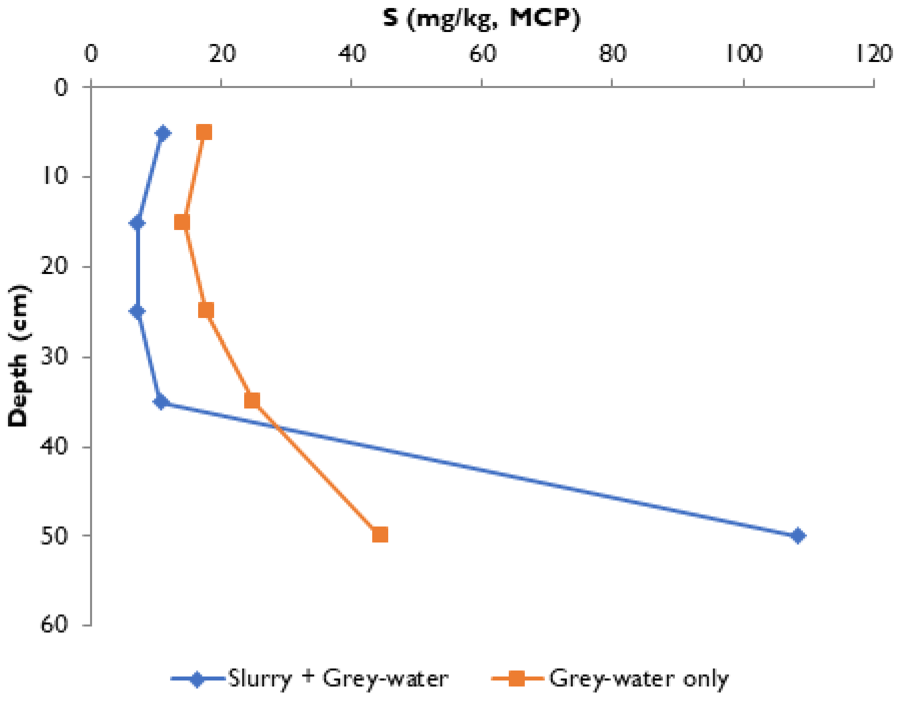


Figure 23. Producer 2: Soil sulfur (S mg/kg, MCP) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

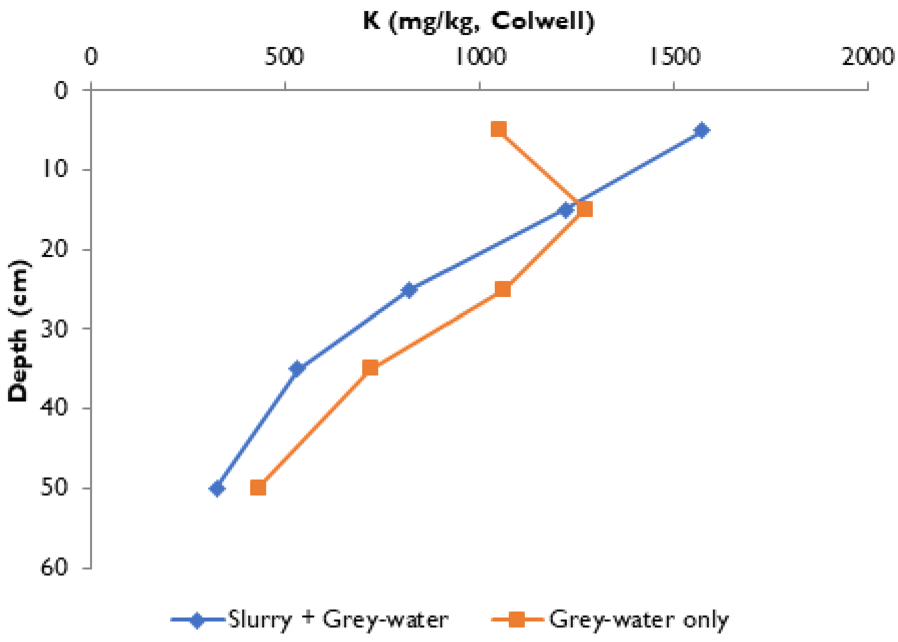


Figure 24. Producer 2: Soil potassium (P mg/kg, Colwell) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

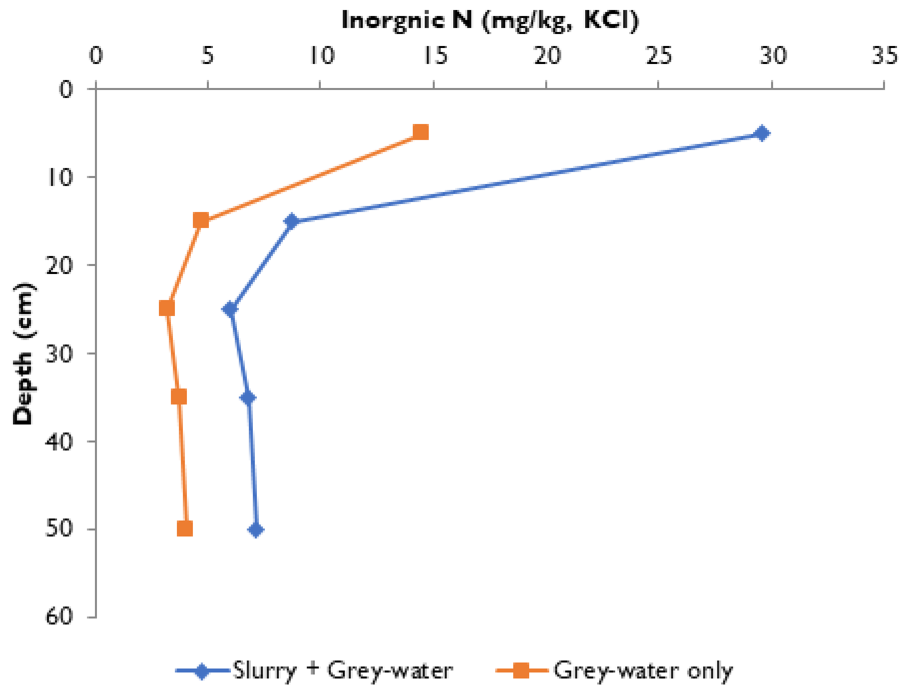


Figure 25. Producer 2: Soil inorganic nitrogen (nitrate, NO_3 + ammonium, NH_4) (Inorganic N mg/kg, KCl) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

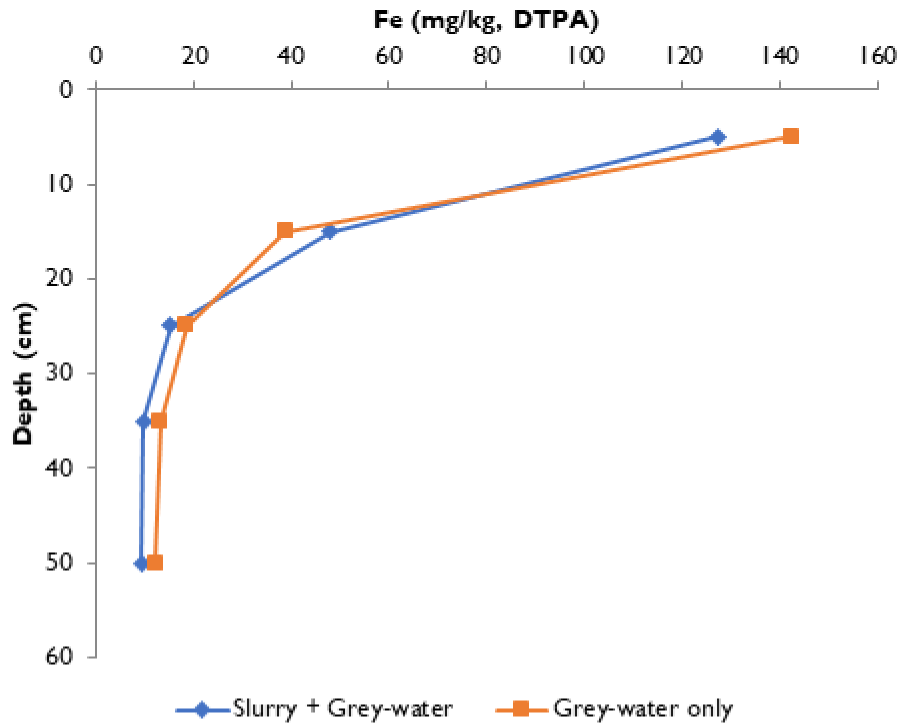


Figure 26. Producer 2: Soil iron (Fe mg/kg, DTPA) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

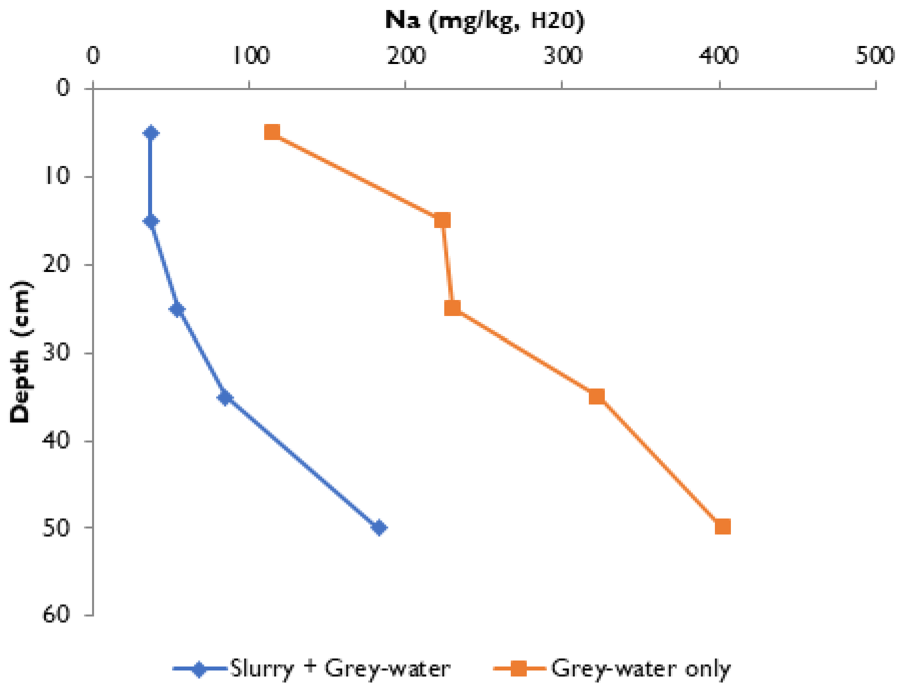


Figure 27. Producer 2: Sodium (Na mg/kg, H_2O) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

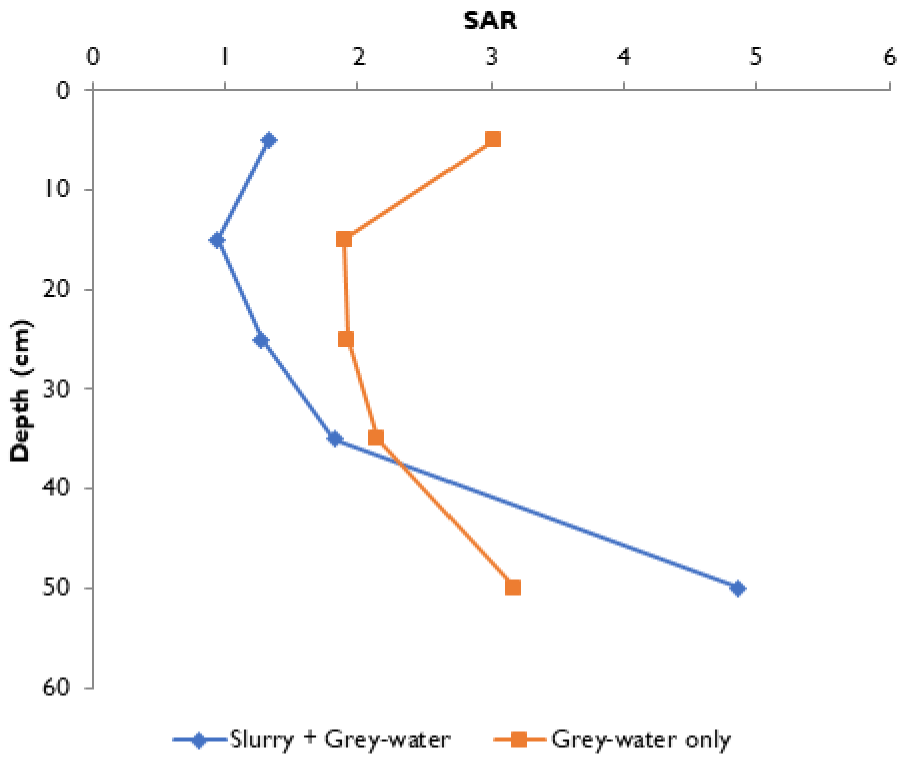


Figure 28. Producer 2: Sodium absorption ratio (SAR) of soils receiving effluent slurry + grey-water (Slurry + grey-water) or grey-water only (Grey-water only) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

Table 7. Producer 2 - Emerson dispersion class for four sampling locations (A, B, C, D) in paddocks receiving effluent slurry + grey-water or grey-water only.

	Grey-water only				**Effluent slurry + grey-water**			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
0-10 cm	2	3	3	2	2	2	2	2
10-20 cm	2	2	2	2	2	2	1	2
20-30 cm	2	2	2	2	2	2	2	2
30-40 cm	2	2	6	2	2	2	2	2
40-60 cm	2	2	6	2	1	2	2	2

Table 8. Producer 2 - Data for individual samples from four sampling locations and five depths (0-10, 10-20, 20-30, 30-40, 40-60 cm)

Analyte	Unit	Optimum Range		K2 Sample 1-001 (0-10)	K2 Sample 1-001 (10-20)	K2 Sample 1-001 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Emerson Class				2	2	2
Acidity						
pH (water)		6.0	7.0	6.2	7.0	7.9
pH (CaCl2)		5.2	7.5	5.2	6.2	6.8
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.09	0.08	0.08
EC (sat ext)	dS/m	0.0	1.5	0.6	0.5	0.5
Chloride	mg/kg	0.0	200	30	<10	15
Nutrients						
Total Carbon	%			1.4	0.8	0.5
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			16.0	6.0	3.3
Ammonium Nitrogen	mg/kg			1.5	0.8	<0.6
Phosphorus (Olsen)	mg/kg			87	24	3
Sulphur (MCP)	mg/kg	12	20	8	6	8
Potassium (Colwell)	mg/kg	170	200	1300	990	750
Copper	mg/kg	0.3	5.0	4.2	2.2	1.7
Zinc	mg/kg	0.6	5.0	2.8	0.8	0.3
Manganese	mg/kg	0.5	5	49	36	15
Iron	mg/kg	10	100	140	65	22
Boron	mg/kg	1.0	4	2.3	2.5	4.3
Water Soluble Cations						
Potassium	mg/kg			110.00	65.00	51.00
Calcium	mg/kg			29.0	47.0	61.0
Magnesium	mg/kg			12.00	25.00	43.00
Sodium	mg/kg			25.00	32.00	49.00
Sodium Absorbtion Ratio				0.99	0.94	1.17
Other						
Total Arsenic	mg/kg			4.50	4.50	4.30
Total Cadmium	mg/kg			0.14	0.08	0.02
Total Chromium	mg/kg			39.00	46.00	49.00
Total Cobalt	mg/kg			12.00	12.00	11.00
Total Molybdenum	mg/kg			0.40	0.29	0.16
Total Lead	mg/kg			19.00	20.00	18.00
Total Selenium	mg/kg			0.42	0.45	0.36
Total Vanadium	mg/kg			49.00	57.00	52.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K2 Sample 1-001 (30-40)	K2 Sample 1-001 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	8.3	8.8	
pH (CaCl2)		5.2	7.5	7.2	7.9	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.11	0.22	
EC (sat ext)	dS/m	0.0	1.5	0.7	1.4	
Chloride	mg/kg	0.0	200	32	72	
Nutrients						
Total Carbon	%			0.4	0.3	
Total Nitrogen	%			0.1	<0.05	
Nitrate Nitrogen	mg/kg			2.6	3.5	
Ammonium Nitrogen	mg/kg			<0.6	0.7	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	12	20	8	10	
Potassium (Colwell)	mg/kg	170	200	580	430	
Copper	mg/kg	0.3	5.0	1.1	1.2	
Zinc	mg/kg	0.6	5.0	0.3	0.3	
Manganese	mg/kg	0.5	5.0	6	3	
Iron	mg/kg	10	100	12	12	
Boron	mg/kg	1.0	4.0	4.9	7.0	
Water Soluble Cations						
Potassium	mg/kg			56.00	5.00	
Calcium	mg/kg			100.0	27.0	
Magnesium	mg/kg			82.00	26.00	
Sodium	mg/kg			79.00	170.00	
Sodium Absorbtion Ratio				1.42	5.60	
Other						
Total Arsenic	mg/kg			4.40	4.50	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			51.00	50.00	
Total Cobalt	mg/kg			12.00	12.00	
Total Molybdenum	mg/kg			0.18	0.16	
Total Lead	mg/kg			18.00	19.00	
Total Selenium	mg/kg			0.40	0.33	
Total Vanadium	mg/kg			67.00	72.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K2 Sample 2-002 (0-10)	K2 Sample 2-002 (10-20)	K2 Sample 2-002 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Orange/Yellow	Brown	Brown
Soil Texture				Clay	Clay	Clay
Emerson Class				3	2	2
Acidity						
pH (water)		6.0	7.0	6.2	6.8	7.5
pH (CaCl2)		5.2	7.5	5.6	5.7	6.6
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.15	0.08	0.09
EC (sat ext)	dS/m	0.0	1.5	0.9	0.5	0.6
Chloride	mg/kg	0.0	200	33	14	12
Nutrients						
Total Carbon	%			1.8	0.8	0.5
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			22.0	7.5	4.9
Ammonium Nitrogen	mg/kg			4.2	0.7	<0.6
Phosphorus (Olsen)	mg/kg			91	33	8
Sulphur (MCP)	mg/kg	12	20	10	6	7
Potassium (Colwell)	mg/kg	170	200	1700	1400	1000
Copper	mg/kg	0.3	5.0	4.2	2.4	1.4
Zinc	mg/kg	0.6	5.0	3.2	0.6	0.3
Manganese	mg/kg	0.5	5.0	56	31	9
Iron	mg/kg	10	100	120	49	16
Boron	mg/kg	1.0	4.0	3.2	2.9	4.9
Water Soluble Cations						
Potassium	mg/kg			120.00	97.00	69.00
Calcium	mg/kg			33.0	54.0	61.0
Magnesium	mg/kg			18.00	35.00	55.00
Sodium	mg/kg			32.00	29.00	43.00
Sodium Absorbtion Ratio				1.11	0.76	0.96
Other						
Total Arsenic	mg/kg			5.20	4.90	4.20
Total Cadmium	mg/kg			0.09	0.07	0.03
Total Chromium	mg/kg			46.00	46.00	51.00
Total Cobalt	mg/kg			11.00	11.00	12.00
Total Molybdenum	mg/kg			0.28	0.21	0.25
Total Lead	mg/kg			17.00	19.00	17.00
Total Selenium	mg/kg			0.49	0.49	0.40
Total Vanadium	mg/kg			62.00	56.00	54.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K2 Sample 2-002 (30-40)	K2 Sample 2-002 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Orange/Yellow	
Soil Texture				Clay	Clay	
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	8.4	9.0	
pH (CaCl2)		5.2	7.5	7.5	8.2	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.13	0.19	
EC (sat ext)	dS/m	0.0	1.5	0.8	1.2	
Chloride	mg/kg	0.0	200	19	36	
Nutrients						
Total Carbon	%			0.3	0.2	
Total Nitrogen	%			0.1	<0.05	
Nitrate Nitrogen	mg/kg			5.4	8.1	
Ammonium Nitrogen	mg/kg			0.6	0.7	
Phosphorus (Olsen)	mg/kg			9	6	
Sulphur (MCP)	mg/kg	12	20	6	6	
Potassium (Colwell)	mg/kg	170	200	670	360	
Copper	mg/kg	0.3	5.0	1.5	0.9	
Zinc	mg/kg	0.6	5.0	0.7	0.4	
Manganese	mg/kg	0.5	5.0	4	3	
Iron	mg/kg	10	100	11	10	
Boron	mg/kg	1.0	4.0	4.8	5.2	
Water Soluble Cations						
Potassium	mg/kg			29.00	13.00	
Calcium	mg/kg			27.0	18.0	
Magnesium	mg/kg			32.00	39.00	
Sodium	mg/kg			74.00	160.00	
Sodium Absorbtion Ratio				2.28	4.86	
Other						
Total Arsenic	mg/kg			5.20	4.20	
Total Cadmium	mg/kg			0.02	<0.02	
Total Chromium	mg/kg			48.00	42.00	
Total Cobalt	mg/kg			12.00	12.00	
Total Molybdenum	mg/kg			0.23	0.16	
Total Lead	mg/kg			20.00	19.00	
Total Selenium	mg/kg			0.34	0.30	
Total Vanadium	mg/kg			56.00	52.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K2 Sample 3-003 (0-10)	K2 Sample 3-003 (10-20)	K2 Sample 3-003 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Red	Brown	Orange/Yellow
Soil Texture				Clay	Clay	Clay
Emerson Class				3	2	2
Acidity						
pH (water)		6.0	7.0	6.0	7.1	7.9
pH (CaCl2)		5.2	7.5	4.9	6.2	6.8
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.11	0.09	0.10
EC (sat ext)	dS/m	0.0	1.5	0.7	0.6	0.6
Chloride	mg/kg	0.0	200	56	32	25
Nutrients						
Total Carbon	%			1.4	0.6	0.5
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			13.0	6.6	5.8
Ammonium Nitrogen	mg/kg			2.3	<0.6	<0.6
Phosphorus (Olsen)	mg/kg			102	19	6
Sulphur (MCP)	mg/kg	12	20	15	8	8
Potassium (Colwell)	mg/kg	170	200	1600	1200	660
Copper	mg/kg	0.3	5.0	7.5	2.1	1.1
Zinc	mg/kg	0.6	5.0	2.9	0.6	0.2
Manganese	mg/kg	0.5	5.0	60	22	5
Iron	mg/kg	10	100	110	29	12
Boron	mg/kg	1.0	4.0	2.7	3.3	4.4
Water Soluble Cations						
Potassium	mg/kg			120.00	85.00	44.00
Calcium	mg/kg			37.0	74.0	42.0
Magnesium	mg/kg			15.00	37.00	25.00
Sodium	mg/kg			31.00	34.00	57.00
Sodium Absorbtion Ratio				1.09	0.81	1.72
Other						
Total Arsenic	mg/kg			5.40	5.00	4.70
Total Cadmium	mg/kg			0.10	0.08	0.02
Total Chromium	mg/kg			50.00	53.00	54.00
Total Cobalt	mg/kg			12.00	13.00	13.00
Total Molybdenum	mg/kg			0.32	0.22	0.17
Total Lead	mg/kg			21.00	20.00	20.00
Total Selenium	mg/kg			0.52	0.49	0.37
Total Vanadium	mg/kg			73.00	70.00	72.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K2 Sample 3-003 (30-40)	K2 Sample 3-003 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Orange/Yellow	
Soil Texture				Clay	Clay	
Emerson Class				6	6	
Acidity						
pH (water)		6.0	7.0	8.5	8.2	
pH (CaCl2)		5.2	7.5	7.9	7.9	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.25	0.66	
EC (sat ext)	dS/m	0.0	1.5	1.6	4.1	
Chloride	mg/kg	0.0	200	36	75	
Nutrients						
Total Carbon	%			0.3	<0.15	
Total Nitrogen	%			0.1	<0.05	
Nitrate Nitrogen	mg/kg			5.7	7.9	
Ammonium Nitrogen	mg/kg			1.4	<0.6	
Phosphorus (Olsen)	mg/kg			6	3	
Sulphur (MCP)	mg/kg	12	20	22	410	
Potassium (Colwell)	mg/kg	170	200	370	260	
Copper	mg/kg	0.3	5.0	1.0	0.9	
Zinc	mg/kg	0.6	5.0	0.2	0.2	
Manganese	mg/kg	0.5	5.0	3	3	
Iron	mg/kg	10	100	9	8	
Boron	mg/kg	1.0	4.0	5.1	5.3	
Water Soluble Cations						
Potassium	mg/kg			17.00	13.00	
Calcium	mg/kg			76.0	340.0	
Magnesium	mg/kg			32.00	100.00	
Sodium	mg/kg			87.00	210.00	
Sodium Absorbtion Ratio				2.11	2.57	
Other						
Total Arsenic	mg/kg			4.60	5.10	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			50.00	50.00	
Total Cobalt	mg/kg			12.00	12.00	
Total Molybdenum	mg/kg			0.15	0.21	
Total Lead	mg/kg			18.00	18.00	
Total Selenium	mg/kg			0.28	0.31	
Total Vanadium	mg/kg			65.00	74.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K2 Sample 4-004 (0-10)	K2 Sample 4-004 (10-20)	K2 Sample 4-004 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Orange/Yellow	Orange/Yellow
Soil Texture				Clay	Clay	Clay
Emerson Class				2	2	2
Acidity						
pH (water)		6.0	7.0	5.5	6.9	7.9
pH (CaCl2)		5.2	7.5	4.6	5.8	6.8
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.20	0.11	0.12
EC (sat ext)	dS/m	0.0	1.5	1.2	0.7	0.7
Chloride	mg/kg	0.0	200	70	23	32
Nutrients						
Total Carbon	%			1.5	0.6	0.4
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			57.0	12.0	7.5
Ammonium Nitrogen	mg/kg			2.2	0.7	<0.6
Phosphorus (Olsen)	mg/kg			120	32	5
Sulphur (MCP)	mg/kg	12	20	11	9	6
Potassium (Colwell)	mg/kg	170	200	1700	1300	880
Copper	mg/kg	0.3	5.0	6.0	2.3	1.2
Zinc	mg/kg	0.6	5.0	3.1	0.5	0.2
Manganese	mg/kg	0.5	5.0	79	27	5
Iron	mg/kg	10	100	140	49	11
Boron	mg/kg	1.0	4.0	2.6	3.1	4.7
Water Soluble Cations						
Potassium	mg/kg			200.00	110.00	90.00
Calcium	mg/kg			32.0	64.0	91.0
Magnesium	mg/kg			16.00	41.00	77.00
Sodium	mg/kg			59.00	53.00	67.00
Sodium Absorbtion Ratio				2.13	1.27	1.25
Other						
Total Arsenic	mg/kg			5.00	5.10	4.50
Total Cadmium	mg/kg			0.09	0.06	<0.02
Total Chromium	mg/kg			47.00	50.00	52.00
Total Cobalt	mg/kg			12.00	12.00	12.00
Total Molybdenum	mg/kg			0.36	0.26	0.19
Total Lead	mg/kg			19.00	18.00	19.00
Total Selenium	mg/kg			0.48	0.58	0.37
Total Vanadium	mg/kg			63.00	72.00	68.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K2 Sample 4-004 (30-40)	K2 Sample 4-004 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Orange/Yellow	
Soil Texture				Clay	Clay	
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	8.5	9.1	
pH (CaCl2)		5.2	7.5	7.4	8.2	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.14	0.24	
EC (sat ext)	dS/m	0.0	1.5	0.9	1.5	
Chloride	mg/kg	0.0	200	40	37	
Nutrients						
Total Carbon	%			<0.15	<0.15	
Total Nitrogen	%			0.1	<0.05	
Nitrate Nitrogen	mg/kg			9.4	6.2	
Ammonium Nitrogen	mg/kg			<0.6	<0.6	
Phosphorus (Olsen)	mg/kg			4	2	
Sulphur (MCP)	mg/kg	12	20	7	8	
Potassium (Colwell)	mg/kg	170	200	510	250	
Copper	mg/kg	0.3	5.0	0.9	1.0	
Zinc	mg/kg	0.6	5.0	0.1	0.2	
Manganese	mg/kg	0.5	5.0	3	3	
Iron	mg/kg	10	100	7	8	
Boron	mg/kg	1.0	4.0	4.7	5.3	
Water Soluble Cations						
Potassium	mg/kg			92.00	15.00	
Calcium	mg/kg			98.0	20.0	
Magnesium	mg/kg			140.00	28.00	
Sodium	mg/kg			99.00	190.00	
Sodium Absorbtion Ratio				1.50	6.43	
Other						
Total Arsenic	mg/kg			4.50	4.50	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			47.00	46.00	
Total Cobalt	mg/kg			12.00	12.00	
Total Molybdenum	mg/kg			0.18	0.18	
Total Lead	mg/kg			19.00	18.00	
Total Selenium	mg/kg			0.36	0.27	
Total Vanadium	mg/kg			75.00	64.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K10 Sample 1-005 (0-10)	K10 Sample 1-005 (10-20)	K10 Sample 1-005 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Emerson Class				2	2	2
Acidity						
pH (water)		6.0	7.0	7.2	8.5	8.9
pH (CaCl2)		5.2	7.5	6.1	6.8	8.4
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.17	0.22	0.31
EC (sat ext)	dS/m	0.0	1.5	1.1	1.4	1.9
Chloride	mg/kg	0.0	200	56	80	150
Nutrients						
Total Carbon	%			1.1	0.5	0.5
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			9.0	1.6	0.9
Ammonium Nitrogen	mg/kg			1.3	1.1	<0.6
Phosphorus (Olsen)	mg/kg			38	7	3
Sulphur (MCP)	mg/kg	12	20	18	14	29
Potassium (Colwell)	mg/kg	170	200	960	1200	860
Copper	mg/kg	0.3	5.0	2.4	1.9	1.3
Zinc	mg/kg	0.6	5.0	1.8	0.4	0.2
Manganese	mg/kg	0.5	5	42	20	6
Iron	mg/kg	10	100	130	28	21
Boron	mg/kg	1.0	4	3.3	5.3	8.2
Water Soluble Cations						
Potassium	mg/kg			80.00	1800.00	1500.00
Calcium	mg/kg			78.0	260.0	220.0
Magnesium	mg/kg			65.00	740.00	760.00
Sodium	mg/kg			170.00	380.00	350.00
Sodium Absorbtion Ratio				3.44	2.72	2.51
Other						
Total Arsenic	mg/kg			4.30	3.70	3.90
Total Cadmium	mg/kg			0.06	0.08	0.02
Total Chromium	mg/kg			41.00	51.00	50.00
Total Cobalt	mg/kg			12.00	12.00	12.00
Total Molybdenum	mg/kg			0.27	0.14	0.15
Total Lead	mg/kg			21.00	21.00	19.00
Total Selenium	mg/kg			0.37	0.45	0.49
Total Vanadium	mg/kg			49.00	56.00	67.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K10 Sample 1-005 (30-40)	K10 Sample 1-005 (40-60)
Depth	cm	Lower	Upper	30-40	40-60
Soil Colour				Brown	Orange/Yellow
Soil Texture				Clay	Clay
Emerson Class				2	1
Acidity					
pH (water)		6.0	7.0	9.1	9.1
pH (CaCl2)		5.2	7.5	7.6	7.9
Salinity					
EC (1:5)	dS/m	0.0	0.6	0.40	0.52
EC (sat ext)	dS/m	0.0	1.5	2.5	3.2
Chloride	mg/kg	0.0	200	220	300
Nutrients					
Total Carbon	%			0.2	<0.15
Total Nitrogen	%			0.1	<0.05
Nitrate Nitrogen	mg/kg			<0.5	1.6
Ammonium Nitrogen	mg/kg			<0.6	<0.6
Phosphorus (Olsen)	mg/kg			<2	<2
Sulphur (MCP)	mg/kg	12	20	51	85
Potassium (Colwell)	mg/kg	170	200	480	340
Copper	mg/kg	0.3	5.0	1.2	0.8
Zinc	mg/kg	0.6	5.0	0.3	0.2
Manganese	mg/kg	0.5	5.0	3	2
Iron	mg/kg	10	100	15	13
Boron	mg/kg	1.0	4.0	14.0	13.0
Water Soluble Cations					
Potassium	mg/kg			1500.00	1800.00
Calcium	mg/kg			230.0	250.0
Magnesium	mg/kg			860.00	1100.00
Sodium	mg/kg			420.00	650.00
Sodium Absorbtion Ratio				2.85	3.94
Other					
Total Arsenic	mg/kg			3.80	3.10
Total Cadmium	mg/kg			<0.02	<0.02
Total Chromium	mg/kg			50.00	43.00
Total Cobalt	mg/kg			13.00	10.00
Total Molybdenum	mg/kg			0.14	0.10
Total Lead	mg/kg			20.00	15.00
Total Selenium	mg/kg			0.48	0.26
Total Vanadium	mg/kg			61.00	46.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K10 Sample 2-006 (30-40)	K10 Sample 2-006 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Orange/Yellow	
Soil Texture				Clay	Clay	
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	8.6	9.0	
pH (CaCl2)		5.2	7.5	7.9	7.5	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.19	0.32	
EC (sat ext)	dS/m	0.0	1.5	1.2	2.0	
Chloride	mg/kg	0.0	200	31	39	
Nutrients						
Total Carbon	%			0.3	<0.15	
Total Nitrogen	%			0.1	0.1	
Nitrate Nitrogen	mg/kg			4.8	4.2	
Ammonium Nitrogen	mg/kg			<0.6	<0.6	
Phosphorus (Olsen)	mg/kg			4	3	
Sulphur (MCP)	mg/kg	12	20	16	40	
Potassium (Colwell)	mg/kg	170	200	850	580	
Copper	mg/kg	0.3	5.0	1.3	1.1	
Zinc	mg/kg	0.6	5.0	0.2	0.2	
Manganese	mg/kg	0.5	5.0	5	3	
Iron	mg/kg	10	100	16	18	
Boron	mg/kg	1.0	4.0	11.0	14.0	
Water Soluble Cations						
Potassium	mg/kg			1900.00	1300.00	
Calcium	mg/kg			290.0	220.0	
Magnesium	mg/kg			900.00	800.00	
Sodium	mg/kg			300.00	370.00	
Sodium Absorbtion Ratio				1.96	2.60	
Other						
Total Arsenic	mg/kg			4.80	4.80	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			53.00	50.00	
Total Cobalt	mg/kg			12.00	11.00	
Total Molybdenum	mg/kg			0.15	0.12	
Total Lead	mg/kg			20.00	20.00	
Total Selenium	mg/kg			0.47	0.33	
Total Vanadium	mg/kg			76.00	72.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K10 Sample 3-007 (0-10)	K10 Sample 3-007 (10-20)	K10 Sample 3-007 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Orange/Yellow
Soil Texture				Clay	Clay	Clay
Emerson Class				2	1	2
Acidity						
pH (water)		6.0	7.0	6.7	8.2	8.9
pH (CaCl2)		5.2	7.5	5.5	7.5	8.3
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.13	0.21	0.25
EC (sat ext)	dS/m	0.0	1.5	0.8	1.3	1.6
Chloride	mg/kg	0.0	200	57	52	48
Nutrients						
Total Carbon	%			1.2	0.7	0.5
Total Nitrogen	%			0.2	0.1	0.1
Nitrate Nitrogen	mg/kg			8.6	1.5	1.4
Ammonium Nitrogen	mg/kg			1.1	<0.6	<0.6
Phosphorus (Olsen)	mg/kg			38	5	2
Sulphur (MCP)	mg/kg	12	20	17	11	16
Potassium (Colwell)	mg/kg	170	200	1200	1600	1300
Copper	mg/kg	0.3	5.0	2.7	1.9	1.3
Zinc	mg/kg	0.6	5.0	0.9	0.3	0.2
Manganese	mg/kg	0.5	5.0	52	12	3
Iron	mg/kg	10	100	130	23	14
Boron	mg/kg	1.0	4.0	3.4	6.2	9.1
Water Soluble Cations						
Potassium	mg/kg			81.00	2600.00	1800.00
Calcium	mg/kg			39.0	290.0	210.0
Magnesium	mg/kg			36.00	990.00	880.00
Sodium	mg/kg			100.00	310.00	280.00
Sodium Absorbtion Ratio				2.78	1.95	1.89
Other						
Total Arsenic	mg/kg			5.10	4.60	5.00
Total Cadmium	mg/kg			0.07	0.03	<0.02
Total Chromium	mg/kg			46.00	54.00	56.00
Total Cobalt	mg/kg			13.00	11.00	11.00
Total Molybdenum	mg/kg			0.34	0.21	0.15
Total Lead	mg/kg			21.00	18.00	19.00
Total Selenium	mg/kg			0.40	0.44	0.36
Total Vanadium	mg/kg			66.00	73.00	74.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K10 Sample 3-007 (30-40)	K10 Sample 3-007 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Orange/Yellow	
Soil Texture				Clay	Clay	
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	9.3	9.7	
pH (CaCl2)		5.2	7.5	8.9	8.2	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.38	0.36	
EC (sat ext)	dS/m	0.0	1.5	2.4	2.2	
Chloride	mg/kg	0.0	200	140	120	
Nutrients						
Total Carbon	%			0.3	0.2	
Total Nitrogen	%			0.1	<0.05	
Nitrate Nitrogen	mg/kg			1.6	4.6	
Ammonium Nitrogen	mg/kg			<0.6	<0.6	
Phosphorus (Olsen)	mg/kg			3	2	
Sulphur (MCP)	mg/kg	12	20	24	45	
Potassium (Colwell)	mg/kg	170	200	810	480	
Copper	mg/kg	0.3	5.0	1.1	0.8	
Zinc	mg/kg	0.6	5.0	0.2	0.1	
Manganese	mg/kg	0.5	5.0	3	2	
Iron	mg/kg	10	100	11	7	
Boron	mg/kg	1.0	4.0	13.0	10.0	
Water Soluble Cations						
Potassium	mg/kg			1400.00	1000.00	
Calcium	mg/kg			160.0	130.0	
Magnesium	mg/kg			890.00	840.00	
Sodium	mg/kg			310.00	370.00	
Sodium Absorbtion Ratio				2.12	2.62	
Other						
Total Arsenic	mg/kg			5.20	4.10	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			56.00	49.00	
Total Cobalt	mg/kg			11.00	11.00	
Total Molybdenum	mg/kg			0.22	0.17	
Total Lead	mg/kg			19.00	16.00	
Total Selenium	mg/kg			0.31	0.24	
Total Vanadium	mg/kg			74.00	67.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K10 Sample 4-008 (0-10)	K10 Sample 4-008 (10-20)	K10 Sample 4-008 (20-30)
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Emerson Class				2	2	2
Acidity						
pH (water)		6.0	7.0	6.3	7.4	8.1
pH (CaCl2)		5.2	7.5	5.1	5.8	7.3
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.09	0.09	0.16
EC (sat ext)	dS/m	0.0	1.5	0.6	0.6	1.0
Chloride	mg/kg	0.0	200	46	28	27
Nutrients						
Total Carbon	%			1.3	0.6	0.4
Total Nitrogen	%			0.1	0.1	0.1
Nitrate Nitrogen	mg/kg			9.0	4.4	2.9
Ammonium Nitrogen	mg/kg			<0.6	<0.6	<0.6
Phosphorus (Olsen)	mg/kg			40	11	4
Sulphur (MCP)	mg/kg	12	20	12	14	10
Potassium (Colwell)	mg/kg	170	200	950	1200	900
Copper	mg/kg	0.3	5.0	3.0	1.8	1.4
Zinc	mg/kg	0.6	5.0	0.6	0.2	0.1
Manganese	mg/kg	0.5	5.0	51	39	12
Iron	mg/kg	10	100	140	46	19
Boron	mg/kg	1.0	4.0	2.3	3.1	4.9
Water Soluble Cations						
Potassium	mg/kg			51.00	790.00	530.00
Calcium	mg/kg			31.0	170.0	170.0
Magnesium	mg/kg			19.00	380.00	78.00
Sodium	mg/kg			60.00	120.00	110.00
Sodium Absorbtion Ratio				2.09	1.17	1.75
Other						
Total Arsenic	mg/kg			5.10	4.00	3.90
Total Cadmium	mg/kg			0.06	0.03	<0.02
Total Chromium	mg/kg			38.00	49.00	51.00
Total Cobalt	mg/kg			13.00	14.00	12.00
Total Molybdenum	mg/kg			0.23	0.17	0.12
Total Lead	mg/kg			20.00	20.00	16.00
Total Selenium	mg/kg			0.34	0.36	0.26
Total Vanadium	mg/kg			63.00	68.00	62.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		K10 Sample 4-008 (30-40)	K10 Sample 4-008 (40-60)	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Orange/Yellow	
Soil Texture				Clay	Clay	
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	8.7	9.5	
pH (CaCl2)		5.2	7.5	7.8	8.1	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.17	0.23	
EC (sat ext)	dS/m	0.0	1.5	1.1	1.4	
Chloride	mg/kg	0.0	200	19	46	
Nutrients						
Total Carbon	%			0.3	0.3	
Total Nitrogen	%			0.1	<0.05	
Nitrate Nitrogen	mg/kg			2.9	3.4	
Ammonium Nitrogen	mg/kg			<0.6	<0.6	
Phosphorus (Olsen)	mg/kg			2	3	
Sulphur (MCP)	mg/kg	12	20	9	8	
Potassium (Colwell)	mg/kg	170	200	750	330	
Copper	mg/kg	0.3	5.0	1.0	1.0	
Zinc	mg/kg	0.6	5.0	0.1	0.1	
Manganese	mg/kg	0.5	5.0	4	3	
Iron	mg/kg	10	100	11	11	
Boron	mg/kg	1.0	4.0	8.5	13.0	
Water Soluble Cations						
Potassium	mg/kg			1800.00	14.00	
Calcium	mg/kg			330.0	130.0	
Magnesium	mg/kg			930.00	100.00	
Sodium	mg/kg			260.00	220.00	
Sodium Absorbtion Ratio				1.66	3.53	
Other						
Total Arsenic	mg/kg			4.60	4.20	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			56.00	50.00	
Total Cobalt	mg/kg			12.00	12.00	
Total Molybdenum	mg/kg			0.18	0.15	
Total Lead	mg/kg			18.00	20.00	
Total Selenium	mg/kg			0.33	0.27	
Total Vanadium	mg/kg			72.00	67.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

8.5 Producer 3 - Soil analysis data

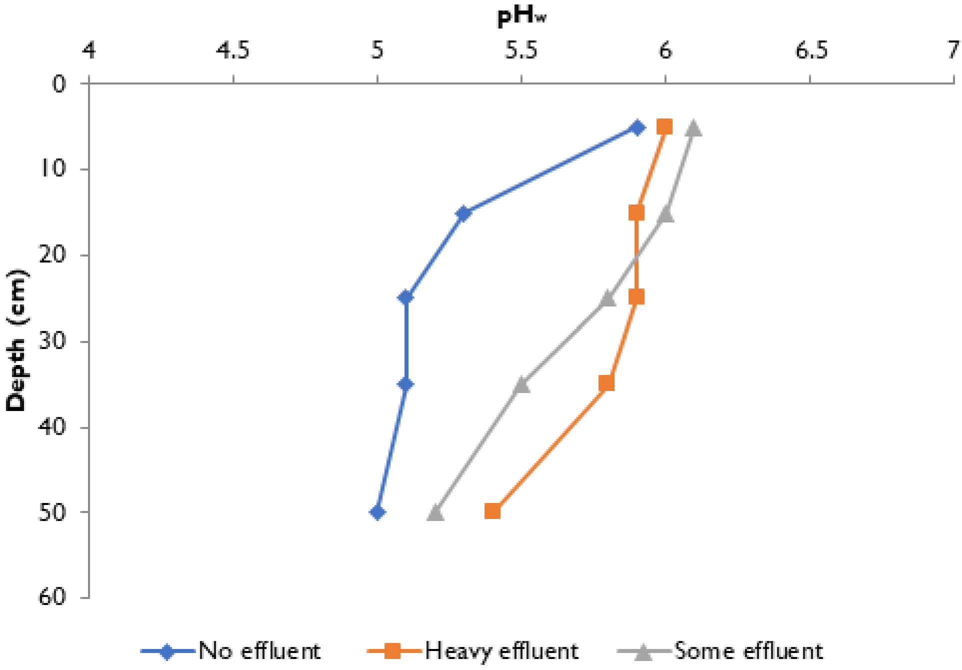


Figure 29. Producer 3: Soil pH in water (pH_w) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

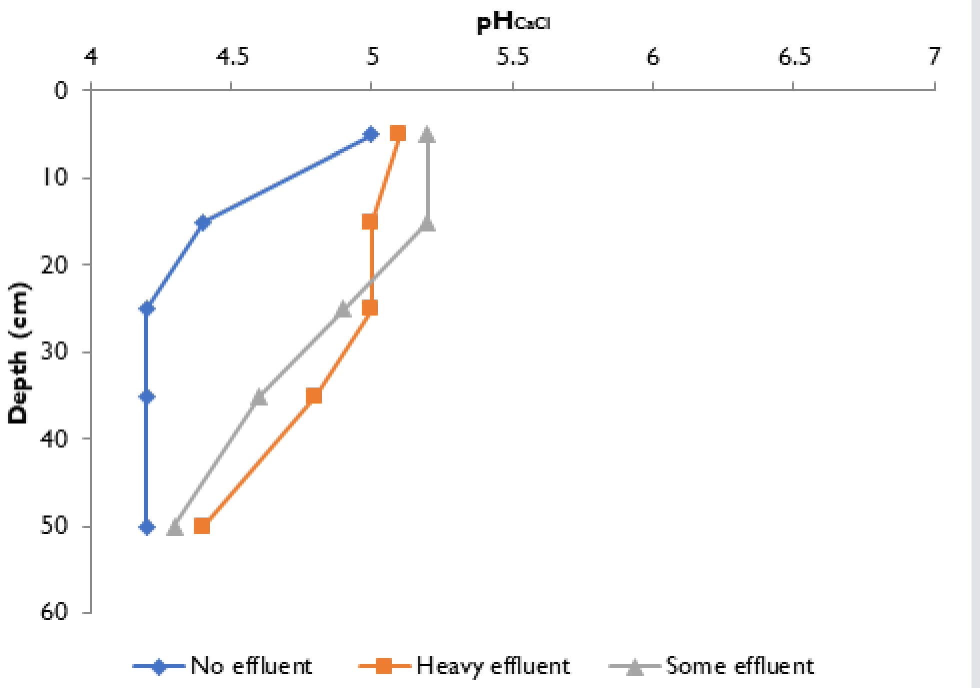


Figure 30. Producer 3: Soil pH in $CaCl_2$ (pH_{CaCl}) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

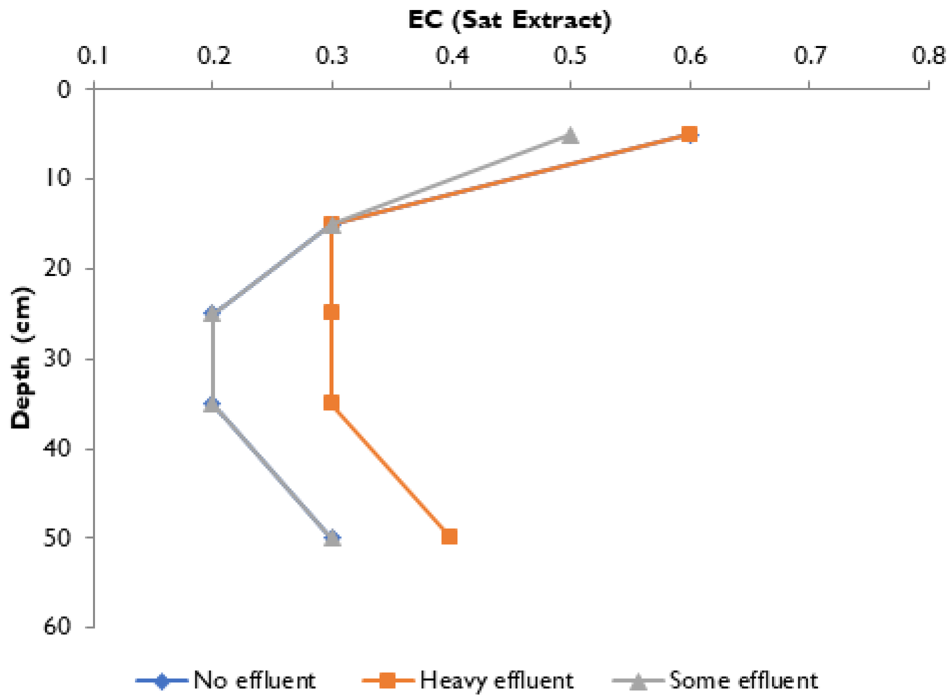


Figure 31. Producer 3: Soil electrical conductivity (saturated extract, ECe) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

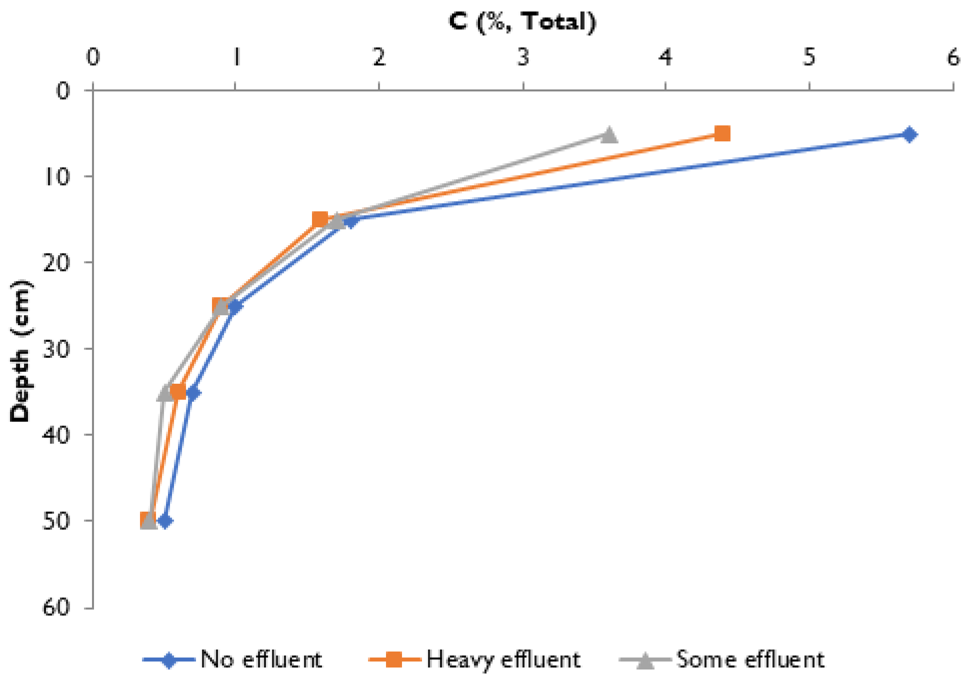


Figure 32. Producer 3: Soil total carbon (C %, Total) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

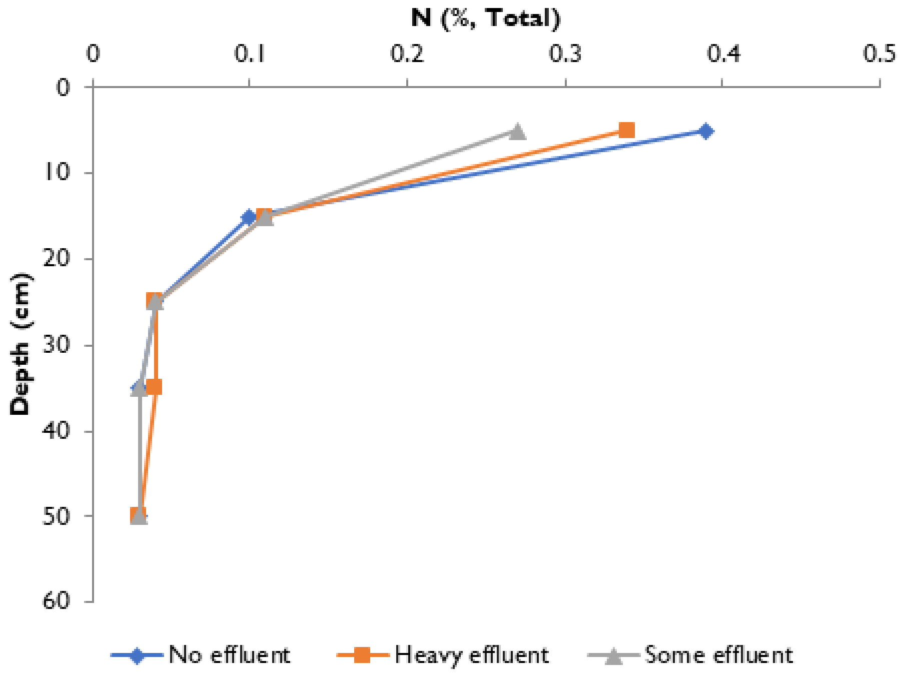


Figure 33. Producer 3: Soil total nitrogen (N %, Total) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

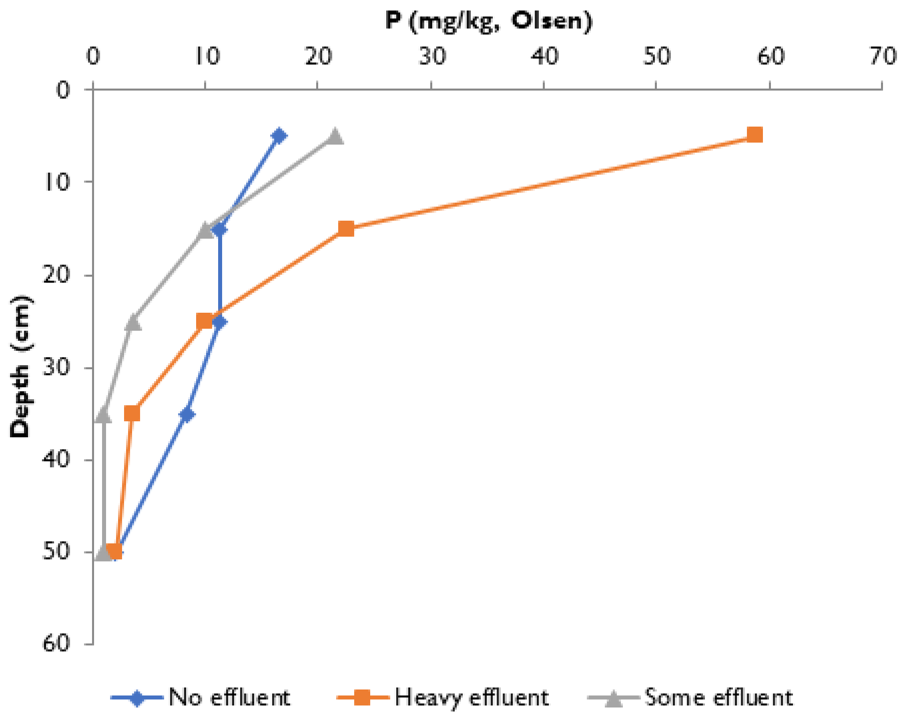


Figure 34. Producer 3: Soil phosphorus (P mg/kg, Olsen) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

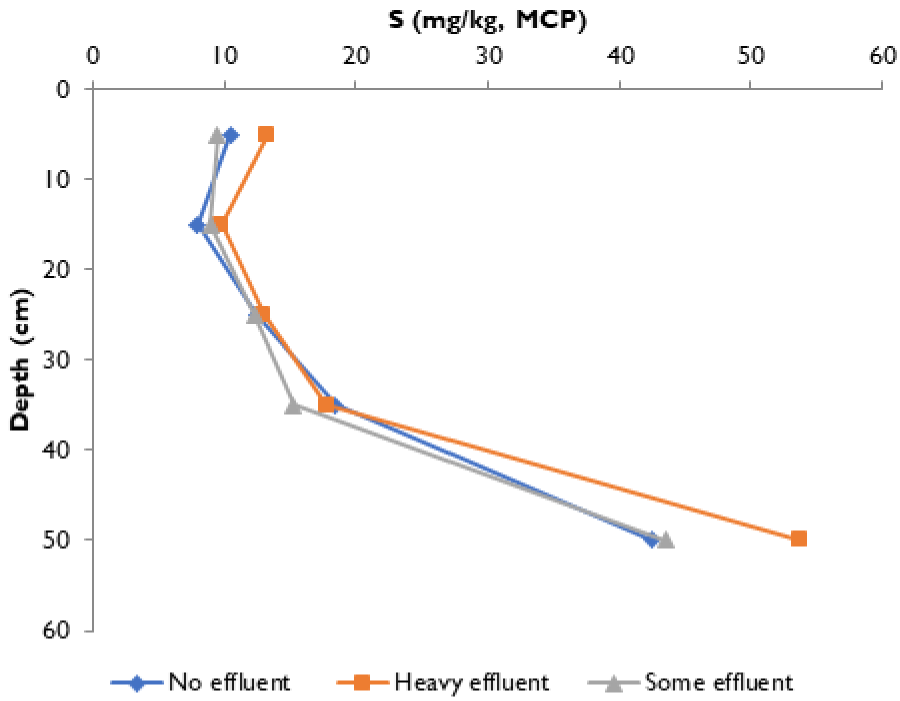


Figure 35. Producer 3: Soil sulfur (S mg/kg, MCP) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

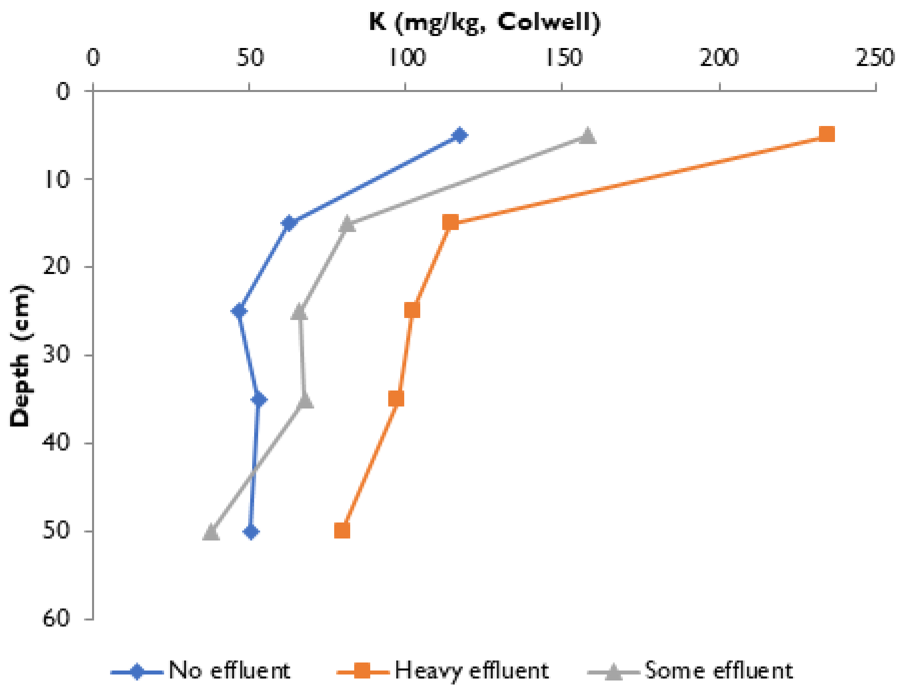


Figure 36. Producer 3: Soil potassium (P mg/kg, Colwell) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

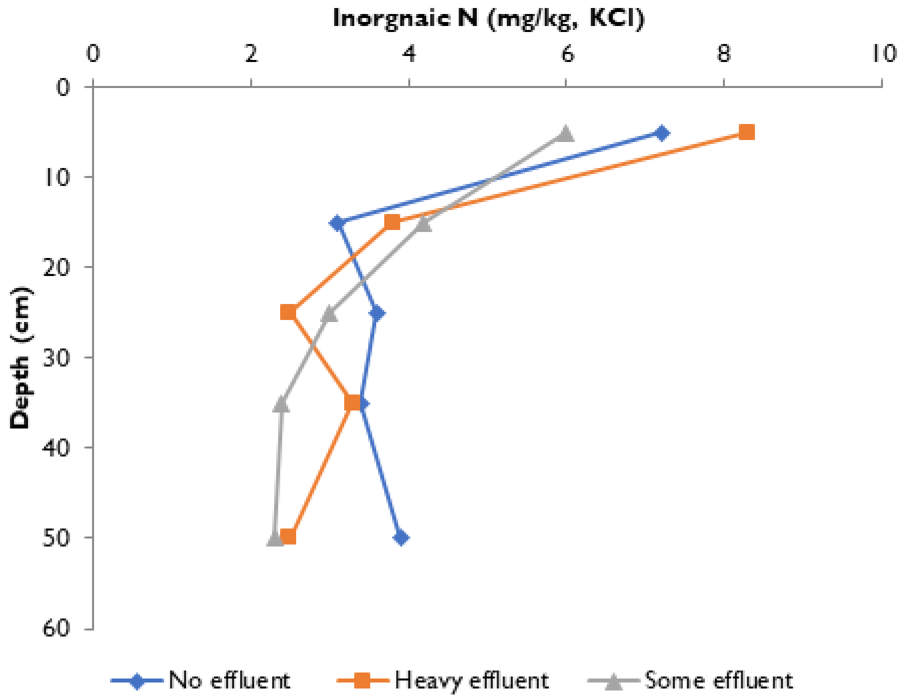


Figure 37. Producer 3: Soil inorganic nitrogen (nitrate, NO_3 + ammonium, NH_4) (Inorganic N mg/kg, KCl) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

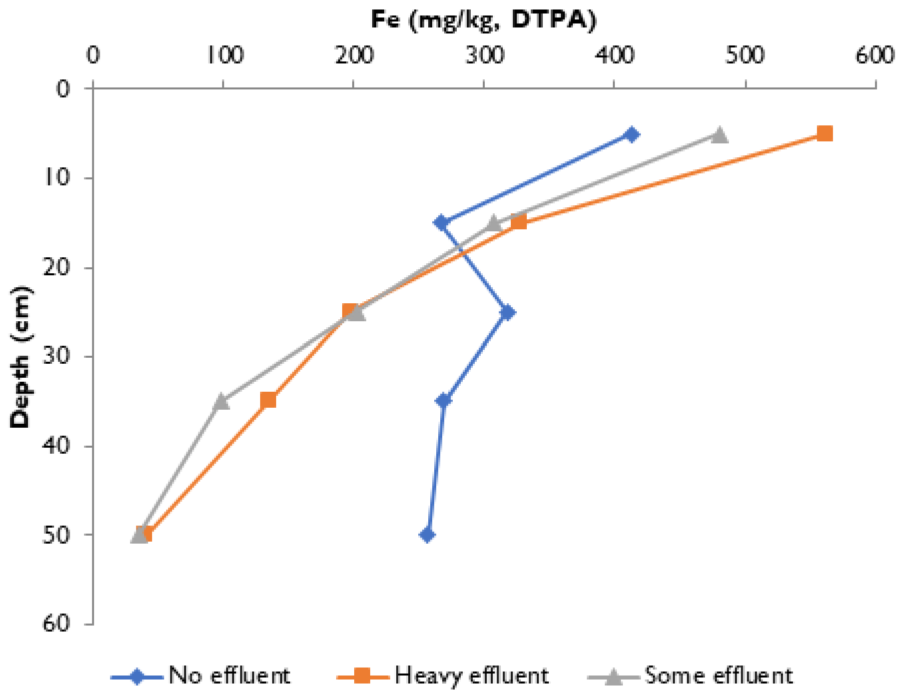


Figure 38. Producer 3: Soil iron (Fe mg/kg, DTPA) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

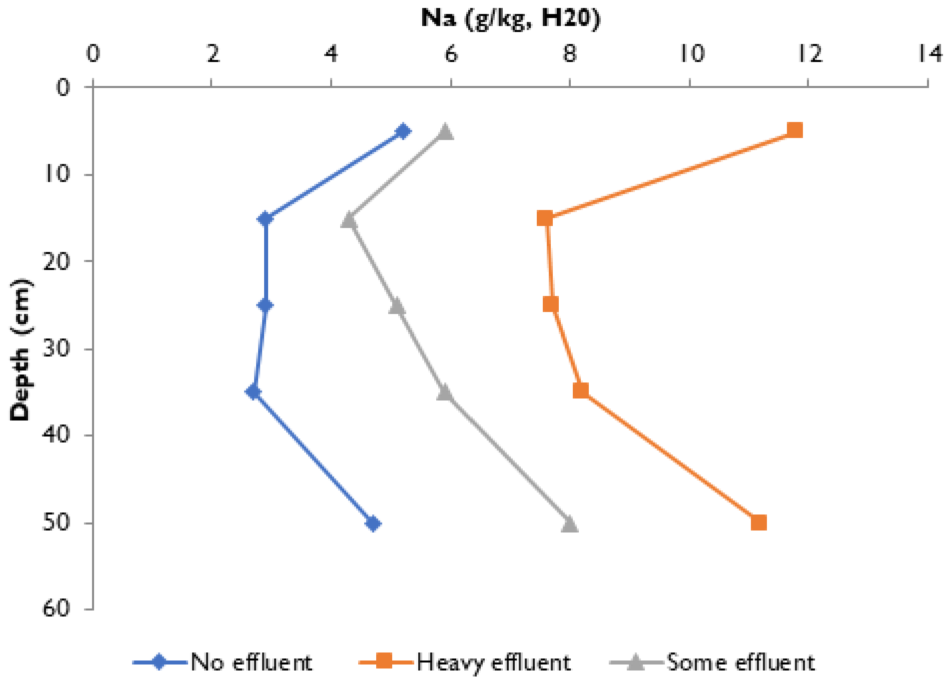


Figure 39. Producer 3: Sodium (Na mg/kg, H_2O) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

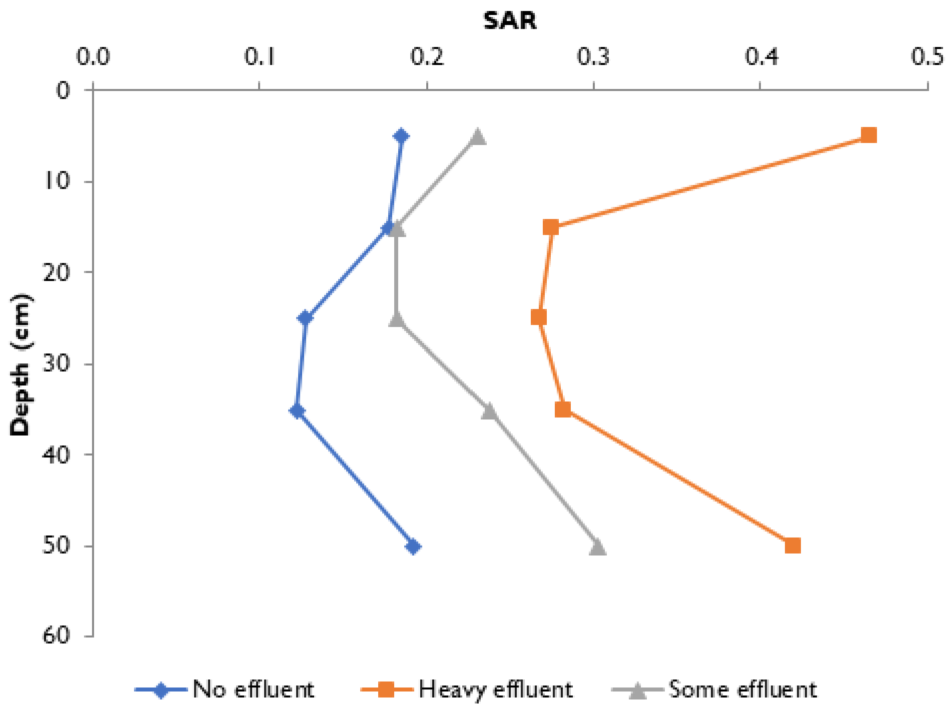


Figure 40. Producer 3: Sodium absorption ratio (SAR) of soils receiving some effluent (some effluent), heavy effluent (heavy effluent) or non-treated (No effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

Table 9. Producer 3 - Emerson dispersion class for four sampling locations (A, B, C, D) in paddocks receiving some effluent, heavy effluent or no-effluent.

	No effluent				Heavy Effluent			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
0-10 cm	7	7	7	7	7	3	7	7
10-20 cm	2	7	7	7	7	2	2	7
20-30 cm	2	8	3	2	3	2	2	2
30-40 cm	7	2	6	6	2	2	2	2
40-60 cm	2	2	6	6	2	6	6	2

	Some effluent			
	A	**B**	**C**	**D**
0-10 cm	7	7	7	7
10-20 cm	7	2	8	7
20-30 cm	2	2	2	2
30-40 cm	2	2	2	2
40-60 cm	6	6	2	2

Table 10. Producer 3 - Data for individual samples from four sampling locations and five depths (0-10, 10-20, 20-30, 30-40, 40-60 cm)

Analyte	Unit	Optimum Range		B3 Sample 1-001	B3 Sample 1-001	B3 Sample 1-001
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Grey	Grey	Grey
Soil Texture				Sandy Loam	Sandy Loam	Sandy Loam
Bulk Density	g/cm^3			1.5	1.9	1.9
Emerson Class				7	2	2
Acidity						
pH (water)		6.0	7.0	5.8	5.3	5.0
pH (CaCl2)		5.2	7.5	4.7	4.1	4.0
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.06	0.03	0.03
EC (sat ext)	dS/m	0.0	1.5	0.6	0.3	0.3
Chloride	mg/kg	0.0	200	<10	<10	<10
Nutrients						
Total Carbon	%			8.4	2.0	1.3
Total Nitrogen	%			0.5	0.1	<0.05
Nitrate Nitrogen	mg/kg			1.8	<0.5	<0.5
Ammonium Nitrogen	mg/kg			6.5	3.2	1.5
Phosphorus (Olsen)	mg/kg			12	5	25
Sulphur (MCP)	mg/kg	12	20	7	2	3
Potassium (Colwell)	mg/kg	170	200	230	110	64
Copper	mg/kg	0.3	5.0	0.2		
Zinc	mg/kg	0.6	5.0	5.9	0.3	0.1
Manganese	mg/kg	0.5	5	14		
Iron	mg/kg	10	100	240	67	110
Boron	mg/kg	1.0	4	0.4	0.1	0.2
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			29.00	21.00	18.00
Calcium	mg/kg			18.0	4.5	12.0
Magnesium	mg/kg			2.90		3.10
Sodium	mg/kg			4.20	2.90	2.50
Sodium Absorbtion Ratio				0.24	0.35	0.17
Other						
Total Arsenic	mg/kg			0.40	0.11	0.30
Total Cadmium	mg/kg			0.26	0.07	0.07
Total Chromium	mg/kg			2.70	2.10	4.40
Total Cobalt	mg/kg			0.39	0.09	0.15
Total Molybdenum	mg/kg			0.10	<0.05	0.11
Total Lead	mg/kg			2.40	0.16	1.10
Total Selenium	mg/kg			0.12	0.06	0.09
Total Vanadium	mg/kg			4.60	3.10	0.94

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B3 Sample 1-001	B3 Sample 1-001	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3			1.9	2.0	
Emerson Class				7	2	
Acidity						
pH (water)		6.0	7.0	5.0	5.1	
pH (CaCl2)		5.2	7.5	4.1	4.4	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.03	0.05	
EC (sat ext)	dS/m	0.0	1.5	0.2	0.3	
Chloride	mg/kg	0.0	200	<10	<10	
Nutrients						
Total Carbon	%			1.3	0.7	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			0.5	1.7	
Ammonium Nitrogen	mg/kg			2.2	1.7	
Phosphorus (Olsen)	mg/kg			25	5	
Sulphur (MCP)	mg/kg	12	20	12	53	
Potassium (Colwell)	mg/kg	170	200	73	84	
Copper	mg/kg	0.3	5.0	<0.01		
Zinc	mg/kg	0.6	5.0	0.1	0.2	
Manganese	mg/kg	0.5	5.0	1	1	
Iron	mg/kg	10	100	410	700	
Boron	mg/kg	1.0	4.0	0.2	0.1	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			12.00	13.00	
Calcium	mg/kg			11.0	9.0	
Magnesium	mg/kg			3.40	3.90	
Sodium	mg/kg			1.80	1.10	
Sodium Absorbtion Ratio				0.12	0.08	
Other						
Total Arsenic	mg/kg			0.46	0.78	
Total Cadmium	mg/kg			0.06	0.06	
Total Chromium	mg/kg			6.70	13.00	
Total Cobalt	mg/kg			0.31	0.62	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			1.80	2.70	
Total Selenium	mg/kg			0.18	0.28	
Total Vanadium	mg/kg			11.00	22.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B3 Sample 2-002	B3 Sample 2-002	B3 Sample 2-002
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Grey	Grey	Brown
Soil Texture				Sandy Loam	Sandy Loam	Clay
Bulk Density	g/cm^3			1.6	2.0	2.0
Emerson Class				7	7	8
Acidity						
pH (water)		6.0	7.0	5.8	5.1	5.0
pH (CaCl2)		5.2	7.5	4.9	4.2	4.3
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.06	0.03	0.04
EC (sat ext)	dS/m	0.0	1.5	0.6	0.3	0.2
Chloride	mg/kg	0.0	200	11	10	<10
Nutrients						
Total Carbon	%			5.7	1.4	0.8
Total Nitrogen	%			0.4	0.1	<0.05
Nitrate Nitrogen	mg/kg			1.6	<0.5	<0.5
Ammonium Nitrogen	mg/kg			5.5	1.0	3.2
Phosphorus (Olsen)	mg/kg			22	28	14
Sulphur (MCP)	mg/kg	12	20	10	6	15
Potassium (Colwell)	mg/kg	170	200	120	73	68
Copper	mg/kg	0.3	5.0	0.2		
Zinc	mg/kg	0.6	5.0	3.6	0.3	0.1
Manganese	mg/kg	0.5	5.0	4		
Iron	mg/kg	10	100	380	270	350
Boron	mg/kg	1.0	4.0	0.4	0.2	0.3
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			30.00	18.00	25.00
Calcium	mg/kg			58.0	15.0	33.0
Magnesium	mg/kg			10.00	4.00	12.00
Sodium	mg/kg			5.50	2.40	2.70
Sodium Absorbtion Ratio				0.18	0.14	0.10
Other						
Total Arsenic	mg/kg			0.44	0.39	0.35
Total Cadmium	mg/kg			0.25	0.10	0.07
Total Chromium	mg/kg			3.20	3.20	6.10
Total Cobalt	mg/kg			0.31	0.18	0.32
Total Molybdenum	mg/kg			0.06	<0.05	<0.05
Total Lead	mg/kg			3.60	2.60	3.00
Total Selenium	mg/kg			0.11	0.09	0.10
Total Vanadium	mg/kg			0.50	2.50	5.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B3 Sample 2-002	B3 Sample 2-002	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3			2.1	1.7	
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	5.0	4.8	
pH (CaCl2)		5.2	7.5	4.3	4.2	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.04	0.06	
EC (sat ext)	dS/m	0.0	1.5	0.2	0.4	
Chloride	mg/kg	0.0	200	<10	15	
Nutrients						
Total Carbon	%			0.4	0.4	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			1.5	3.6	
Ammonium Nitrogen	mg/kg			3.4	1.2	
Phosphorus (Olsen)	mg/kg			3	<2	
Sulphur (MCP)	mg/kg	12	20	20	26	
Potassium (Colwell)	mg/kg	170	200	88	41	
Copper	mg/kg	0.3	5.0	<0.01	<0.01	
Zinc	mg/kg	0.6	5.0	0.1	0.1	
Manganese	mg/kg	0.5	5.0			
Iron	mg/kg	10	100	470	260	
Boron	mg/kg	1.0	4.0	0.2	0.1	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			20.00	13.00	
Calcium	mg/kg			27.0	36.0	
Magnesium	mg/kg			9.70	11.00	
Sodium	mg/kg			2.30	4.30	
Sodium Absorbtion Ratio				0.10	0.16	
Other						
Total Arsenic	mg/kg			0.69	0.52	
Total Cadmium	mg/kg			0.07	0.07	
Total Chromium	mg/kg			11.00	12.00	
Total Cobalt	mg/kg			0.50	0.69	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			6.00	5.60	
Total Selenium	mg/kg			0.19	0.17	
Total Vanadium	mg/kg			21.00	22.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B3 Sample 3-003	B3 Sample 3-003	B3 Sample 3-003
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Orange/Yellow
Soil Texture				Clay Loam	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				7	7	3
Acidity						
pH (water)		6.0	7.0	5.6	5.5	5.4
pH (CaCl2)		5.2	7.5	4.8	4.7	4.4
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.05	0.04	0.03
EC (sat ext)	dS/m	0.0	1.5	0.4	0.2	0.2
Chloride	mg/kg	0.0	200	10	<10	<10
Nutrients						
Total Carbon	%			4.1	2.1	1.2
Total Nitrogen	%			0.3	0.2	0.1
Nitrate Nitrogen	mg/kg			0.7	<0.5	<0.5
Ammonium Nitrogen	mg/kg			5.4	4.0	3.6
Phosphorus (Olsen)	mg/kg			13	5	4
Sulphur (MCP)	mg/kg	12	20	13	12	16
Potassium (Colwell)	mg/kg	170	200	59	43	27
Copper	mg/kg	0.3	5.0	0.1	0.1	
Zinc	mg/kg	0.6	5.0	1.7	0.4	0.1
Manganese	mg/kg	0.5	5.0	5	1	
Iron	mg/kg	10	100	530	380	480
Boron	mg/kg	1.0	4.0	0.6	0.4	0.2
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			14.00	11.00	8.50
Calcium	mg/kg			53.0	39.0	35.0
Magnesium	mg/kg			12.00	11.00	15.00
Sodium	mg/kg			5.00	3.40	3.90
Sodium Absorbtion Ratio				0.16	0.12	0.14
Other						
Total Arsenic	mg/kg			0.55	0.47	0.46
Total Cadmium	mg/kg			0.20	0.13	0.08
Total Chromium	mg/kg			6.90	10.00	13.00
Total Cobalt	mg/kg			0.54	0.59	0.70
Total Molybdenum	mg/kg			0.07	<0.05	<0.05
Total Lead	mg/kg			4.10	4.60	4.20
Total Selenium	mg/kg			0.12	0.15	0.21
Total Vanadium	mg/kg			7.30	14.00	17.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B3 Sample 3-003	B3 Sample 3-003	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm³					
Emerson Class				6	6	
Acidity						
pH (water)		6.0	7.0	5.2	5.1	
pH (CaCl2)		5.2	7.5	4.3	4.1	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.03	0.04	
EC (sat ext)	dS/m	0.0	1.5	0.2	0.2	
Chloride	mg/kg	0.0	200	<10	14	
Nutrients						
Total Carbon	%			0.7	0.5	
Total Nitrogen	%			0.1	<0.05	
Nitrate Nitrogen	mg/kg			<0.5	<0.5	
Ammonium Nitrogen	mg/kg			1.8	3.5	
Phosphorus (Olsen)	mg/kg			4	<2	
Sulphur (MCP)	mg/kg	12	20	22	60	
Potassium (Colwell)	mg/kg	170	200	28	67	
Copper	mg/kg	0.3	5.0		<0.01	
Zinc	mg/kg	0.6	5.0	0.1		
Manganese	mg/kg	0.5	5.0			
Iron	mg/kg	10	100	100	34	
Boron	mg/kg	1.0	4.0	0.3	0.4	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			5.10	12.00	
Calcium	mg/kg			31.0	17.0	
Magnesium	mg/kg			13.00	19.00	
Sodium	mg/kg			3.30	7.60	
Sodium Absorbtion Ratio				0.13	0.30	
Other						
Total Arsenic	mg/kg			0.48	1.00	
Total Cadmium	mg/kg			0.07	0.07	
Total Chromium	mg/kg			18.00	35.00	
Total Cobalt	mg/kg			0.95	1.90	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			5.00	8.40	
Total Selenium	mg/kg			0.18	0.27	
Total Vanadium	mg/kg			24.00	63.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		B3 Sample 4-004	B3 Sample 4-004	B3 Sample 4-004
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Orange/Yellow
Soil Texture				Clay Loam	Clay Loam	Clay
Bulk Density	g/cm^3					
Emerson Class				7	7	2
Acidity						
pH (water)		6.0	7.0	6.2	5.2	5.0
pH (CaCl2)		5.2	7.5	5.5	4.4	4.1
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.07	0.03	0.03
EC (sat ext)	dS/m	0.0	1.5	0.6	0.2	0.2
Chloride	mg/kg	0.0	200	15	<10	<10
Nutrients						
Total Carbon	%			4.4	1.6	0.6
Total Nitrogen	%			0.3	0.1	<0.05
Nitrate Nitrogen	mg/kg			<0.5	<0.5	<0.5
Ammonium Nitrogen	mg/kg			6.9	3.1	4.9
Phosphorus (Olsen)	mg/kg			19	7	2
Sulphur (MCP)	mg/kg	12	20	12	12	16
Potassium (Colwell)	mg/kg	170	200	58	24	27
Copper	mg/kg	0.3	5.0	0.1		<0.01
Zinc	mg/kg	0.6	5.0	1.7	0.2	0.2
Manganese	mg/kg	0.5	5.0	3		
Iron	mg/kg	10	100	500	350	330
Boron	mg/kg	1.0	4.0	0.4	0.3	0.2
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			14.00	9.20	6.70
Calcium	mg/kg			86.0	41.0	19.0
Magnesium	mg/kg			15.00	14.00	12.00
Sodium	mg/kg			6.10	3.00	2.30
Sodium Absorbtion Ratio				0.16	0.10	0.10
Other						
Total Arsenic	mg/kg			0.51	0.33	0.39
Total Cadmium	mg/kg			0.19	0.10	0.06
Total Chromium	mg/kg			9.00	8.30	12.00
Total Cobalt	mg/kg			0.61	0.42	0.58
Total Molybdenum	mg/kg			<0.05	<0.05	<0.05
Total Lead	mg/kg			4.70	4.10	4.90
Total Selenium	mg/kg			0.14	0.13	0.15
Total Vanadium	mg/kg			12.00	14.00	21.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range Lower	Optimum Range Upper	B3 Sample 4-004	B3 Sample 4-004
Depth	cm			30-40	40-60
Soil Colour				Orange/Yellow	Orange/Yellow
Soil Texture				Clay	Clay
Bulk Density	g/cm^3				
Emerson Class				6	6
Acidity					
pH (water)		6.0	7.0	5.0	4.9
pH (CaCl2)		5.2	7.5	4.2	4.1
Salinity					
EC (1:5)	dS/m	0.0	0.6	0.03	0.04
EC (sat ext)	dS/m	0.0	1.5	0.2	0.2
Chloride	mg/kg	0.0	200	12	13
Nutrients					
Total Carbon	%			0.4	0.3
Total Nitrogen	%			<0.05	<0.05
Nitrate Nitrogen	mg/kg			0.5	1.9
Ammonium Nitrogen	mg/kg			3.5	1.5
Phosphorus (Olsen)	mg/kg			<2	<2
Sulphur (MCP)	mg/kg	12	20	20	31
Potassium (Colwell)	mg/kg	170	200	25	<20
Copper	mg/kg	0.3	5.0	<0.01	<0.01
Zinc	mg/kg	0.6	5.0	0.1	
Manganese	mg/kg	0.5	5.0		
Iron	mg/kg	10	100	96	33
Boron	mg/kg	1.0	4.0	0.2	0.3
Molybdenum	mg/kg			<0.01	<0.01
Water Soluble Cations					
Potassium	mg/kg			7.00	5.20
Calcium	mg/kg			30.0	19.0
Magnesium	mg/kg			12.00	16.00
Sodium	mg/kg			3.50	5.70
Sodium Absorbtion Ratio				0.14	0.23
Other					
Total Arsenic	mg/kg			0.41	0.63
Total Cadmium	mg/kg			0.07	0.07
Total Chromium	mg/kg			14.00	20.00
Total Cobalt	mg/kg			0.72	1.10
Total Molybdenum	mg/kg			<0.05	<0.05
Total Lead	mg/kg			5.40	5.50
Total Selenium	mg/kg			0.17	0.19
Total Vanadium	mg/kg			20.00	36.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		P2 Sample 1-005	P2 Sample 1-005	P2 Sample 1-005
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay Loam	Clay	Clay Loam
Bulk Density	g/cm^3			1.9	2.1	2.0
Emerson Class				7	7	3
Acidity						
pH (water)		6.0	7.0	5.8	5.9	5.9
pH (CaCl2)		5.2	7.5	4.8	5.0	5.1
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.05	0.03	0.03
EC (sat ext)	dS/m	0.0	1.5	0.4	0.2	0.2
Chloride	mg/kg	0.0	200	12	<10	<10
Nutrients						
Total Carbon	%			4.2	1.0	0.6
Total Nitrogen	%			0.3	0.1	<0.05
Nitrate Nitrogen	mg/kg			1.2	0.7	<0.5
Ammonium Nitrogen	mg/kg			6.8	2.6	2.7
Phosphorus (Olsen)	mg/kg			54	11	5
Sulphur (MCP)	mg/kg	12	20	11	5	9
Potassium (Colwell)	mg/kg	170	200	69	22	39
Copper	mg/kg	0.3	5.0	2.3		
Zinc	mg/kg	0.6	5.0	15.0	1.6	0.3
Manganese	mg/kg	0.5	5	6		
Iron	mg/kg	10	100	580	200	180
Boron	mg/kg	1.0	4	0.5	0.2	0.2
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			15.00	9.30	5.70
Calcium	mg/kg			37.0	40.0	42.0
Magnesium	mg/kg			11.00		11.00
Sodium	mg/kg			8.90	2.60	2.40
Sodium Absorbtion Ratio				0.33	0.10	0.09
Other						
Total Arsenic	mg/kg			0.59	0.72	1.40
Total Cadmium	mg/kg			0.13	0.08	0.07
Total Chromium	mg/kg			3.10	5.70	8.50
Total Cobalt	mg/kg			0.58	0.32	0.35
Total Molybdenum	mg/kg			0.09	<0.05	0.05
Total Lead	mg/kg			5.00	2.70	5.00
Total Selenium	mg/kg			0.14	0.11	0.14
Total Vanadium	mg/kg			9.50	17.00	42.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		P2 Sample 1-005	P2 Sample 1-005
Depth	cm	Lower	Upper	30-40	40-60
Soil Colour				Orange/Yellow	Orange/Yellow
Soil Texture				Clay	Clay
Bulk Density	g/cm^3			2.3	2.2
Emerson Class				2	2
Acidity					
pH (water)		6.0	7.0	5.9	5.7
pH (CaCl2)		5.2	7.5	5.0	4.7
Salinity					
EC (1:5)	dS/m	0.0	0.6	0.03	0.03
EC (sat ext)	dS/m	0.0	1.5	0.2	0.2
Chloride	mg/kg	0.0	200	<10	<10
Nutrients					
Total Carbon	%			0.3	0.2
Total Nitrogen	%			<0.05	<0.05
Nitrate Nitrogen	mg/kg			<0.5	<0.5
Ammonium Nitrogen	mg/kg			3.0	1.3
Phosphorus (Olsen)	mg/kg			4	<2
Sulphur (MCP)	mg/kg	12	20	9	12
Potassium (Colwell)	mg/kg	170	200	46	36
Copper	mg/kg	0.3	5.0	0.1	
Zinc	mg/kg	0.6	5.0	0.1	0.0
Manganese	mg/kg	0.5	5.0	0	0
Iron	mg/kg	10	100	210	45
Boron	mg/kg	1.0	4.0	0.1	0.2
Molybdenum	mg/kg			<0.01	<0.01
Water Soluble Cations					
Potassium	mg/kg			6.80	7.60
Calcium	mg/kg			26.0	24.0
Magnesium	mg/kg			10.00	18.00
Sodium	mg/kg			1.50	5.60
Sodium Absorbtion Ratio				0.06	0.21
Other					
Total Arsenic	mg/kg			0.38	0.56
Total Cadmium	mg/kg			0.06	0.07
Total Chromium	mg/kg			6.80	13.00
Total Cobalt	mg/kg			0.35	0.71
Total Molybdenum	mg/kg			<0.05	<0.05
Total Lead	mg/kg			2.70	4.40
Total Selenium	mg/kg			0.15	0.19
Total Vanadium	mg/kg			13.00	22.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		P2 Sample 2-006	P2 Sample 2-006	P2 Sample 2-006
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Orange/Yellow
Soil Texture				Clay Loam	Clay	Clay
Bulk Density	g/cm^3			1.7	2.0	2.2
Emerson Class				3	2	2
Acidity						
pH (water)		6.0	7.0	6.0	6.2	6.0
pH (CaCl2)		5.2	7.5	5.1	5.3	5.1
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.06	0.04	0.03
EC (sat ext)	dS/m	0.0	1.5	0.5	0.2	0.2
Chloride	mg/kg	0.0	200	12	<10	<10
Nutrients						
Total Carbon	%			3.9	1.0	0.6
Total Nitrogen	%			0.3	0.1	<0.05
Nitrate Nitrogen	mg/kg			1.6	<0.5	<0.5
Ammonium Nitrogen	mg/kg			5.2	3.1	1.6
Phosphorus (Olsen)	mg/kg			71	21	5
Sulphur (MCP)	mg/kg	12	20	11	8	12
Potassium (Colwell)	mg/kg	170	200	210	95	60
Copper	mg/kg	0.3	5.0	4.3		
Zinc	mg/kg	0.6	5.0	15.0	1.6	0.2
Manganese	mg/kg	0.5	5.0	8		
Iron	mg/kg	10	100	520	250	160
Boron	mg/kg	1.0	4.0	0.6	0.3	0.2
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			34.00	21.00	11.00
Calcium	mg/kg			32.0	43.0	43.0
Magnesium	mg/kg			10.00	13.00	12.00
Sodium	mg/kg			12.00	8.60	8.20
Sodium Absorbtion Ratio				0.47	0.30	0.28
Other						
Total Arsenic	mg/kg			0.92	0.83	0.90
Total Cadmium	mg/kg			0.17	0.09	0.08
Total Chromium	mg/kg			11.00	15.00	15.00
Total Cobalt	mg/kg			0.81	0.62	0.64
Total Molybdenum	mg/kg			0.10	0.10	<0.05
Total Lead	mg/kg			5.00	5.90	7.50
Total Selenium	mg/kg			0.17	0.19	0.18
Total Vanadium	mg/kg			28.00	36.00	36.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		P2 Sample 2-006	P2 Sample 2-006	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3			2.3	2.3	
Emerson Class				2	6	
Acidity						
pH (water)		6.0	7.0	5.8	5.1	
pH (CaCl2)		5.2	7.5	4.8	4.3	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.04	0.05	
EC (sat ext)	dS/m	0.0	1.5	0.2	0.3	
Chloride	mg/kg	0.0	200	11	18	
Nutrients						
Total Carbon	%			0.4	0.3	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			<0.5	<0.5	
Ammonium Nitrogen	mg/kg			2.4	1.5	
Phosphorus (Olsen)	mg/kg			2	<2	
Sulphur (MCP)	mg/kg	12	20	17	71	
Potassium (Colwell)	mg/kg	170	200	35	33	
Copper	mg/kg	0.3	5.0	0.2	0.1	
Zinc	mg/kg	0.6	5.0	0.1	0.1	
Manganese	mg/kg	0.5	5.0			
Iron	mg/kg	10	100	70	31	
Boron	mg/kg	1.0	4.0	0.3	0.3	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			4.70	4.60	
Calcium	mg/kg			45.0	24.0	
Magnesium	mg/kg			14.00	17.00	
Sodium	mg/kg			11.00	11.00	
Sodium Absorbtion Ratio				0.37	0.42	
Other						
Total Arsenic	mg/kg			1.40	0.65	
Total Cadmium	mg/kg			0.06	0.07	
Total Chromium	mg/kg			19.00	28.00	
Total Cobalt	mg/kg			0.94	1.90	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			6.20	6.80	
Total Selenium	mg/kg			0.19	0.20	
Total Vanadium	mg/kg			73.00	47.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		P2 Sample 3-007	P2 Sample 3-007	P2 Sample 3-007
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Orange/Yellow
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				7	2	2
Acidity						
pH (water)		6.0	7.0	6.2	5.9	6.0
pH (CaCl2)		5.2	7.5	5.3	4.9	5.0
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.08	0.05	0.05
EC (sat ext)	dS/m	0.0	1.5	0.5	0.3	0.3
Chloride	mg/kg	0.0	200	<10	<10	14
Nutrients						
Total Carbon	%			4.3	2.3	1.0
Total Nitrogen	%			0.3	0.2	0.1
Nitrate Nitrogen	mg/kg			1.8	<0.5	<0.5
Ammonium Nitrogen	mg/kg			6.8	4.0	2.1
Phosphorus (Olsen)	mg/kg			50	17	9
Sulphur (MCP)	mg/kg	12	20	11	12	14
Potassium (Colwell)	mg/kg	170	200	350	190	180
Copper	mg/kg	0.3	5.0	4.6	0.9	
Zinc	mg/kg	0.6	5.0	18.0	2.8	0.6
Manganese	mg/kg	0.5	5.0	10	3	
Iron	mg/kg	10	100	550	430	170
Boron	mg/kg	1.0	4.0	0.5	0.5	0.5
Molybdenum	mg/kg			<0.01	<0.01	0.0
Water Soluble Cations						
Potassium	mg/kg			47.00	38.00	37.00
Calcium	mg/kg			12.0	32.0	48.0
Magnesium	mg/kg			3.80	13.00	14.00
Sodium	mg/kg			7.20	7.20	11.00
Sodium Absorbtion Ratio				0.46	0.27	0.36
Other						
Total Arsenic	mg/kg			1.40	0.88	0.98
Total Cadmium	mg/kg			0.14	0.12	0.08
Total Chromium	mg/kg			13.00	13.00	21.00
Total Cobalt	mg/kg			0.96	0.68	1.10
Total Molybdenum	mg/kg			0.18	0.06	0.05
Total Lead	mg/kg			5.80	5.20	7.60
Total Selenium	mg/kg			0.22	0.16	0.23
Total Vanadium	mg/kg			42.00	32.00	55.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		P2 Sample 3-007	P2 Sample 3-007
Depth	cm	Lower	Upper	30-40	40-60
Soil Colour				Orange/Yellow	Orange/Yellow
Soil Texture				Clay	Clay
Bulk Density	g/cm^3				
Emerson Class				2	6
Acidity					
pH (water)		6.0	7.0	5.8	5.5
pH (CaCl2)		5.2	7.5	4.8	4.5
Salinity					
EC (1:5)	dS/m	0.0	0.6	0.05	0.08
EC (sat ext)	dS/m	0.0	1.5	0.3	0.5
Chloride	mg/kg	0.0	200	16	28
Nutrients					
Total Carbon	%			0.8	0.5
Total Nitrogen	%			<0.05	<0.05
Nitrate Nitrogen	mg/kg			<0.5	<0.5
Ammonium Nitrogen	mg/kg			2.5	3.7
Phosphorus (Olsen)	mg/kg			3	2
Sulphur (MCP)	mg/kg	12	20	22	87
Potassium (Colwell)	mg/kg	170	200	210	150
Copper	mg/kg	0.3	5.0		0.1
Zinc	mg/kg	0.6	5.0	0.3	
Manganese	mg/kg	0.5	5.0		
Iron	mg/kg	10	100	100	34
Boron	mg/kg	1.0	4.0	0.6	0.7
Molybdenum	mg/kg			<0.01	<0.01
Water Soluble Cations					
Potassium	mg/kg			24.00	14.00
Calcium	mg/kg			42.0	19.0
Magnesium	mg/kg			16.00	17.00
Sodium	mg/kg			11.00	14.00
Sodium Absorbtion Ratio				0.37	0.56
Other					
Total Arsenic	mg/kg			1.10	0.91
Total Cadmium	mg/kg			0.07	0.07
Total Chromium	mg/kg			27.00	36.00
Total Cobalt	mg/kg			1.50	2.40
Total Molybdenum	mg/kg			<0.05	<0.05
Total Lead	mg/kg			8.20	8.30
Total Selenium	mg/kg			0.24	0.26
Total Vanadium	mg/kg			65.00	68.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		P2 Sample 4-008	P2 Sample 4-008	P2 Sample 4-008
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay Loam	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				7	7	2
Acidity						
pH (water)		6.0	7.0	5.9	5.6	5.6
pH (CaCl2)		5.2	7.5	5.0	4.7	4.7
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.10	0.06	0.05
EC (sat ext)	dS/m	0.0	1.5	0.8	0.4	0.3
Chloride	mg/kg	0.0	200	27	15	17
Nutrients						
Total Carbon	%			5.3	2.1	1.2
Total Nitrogen	%			0.4	0.1	0.1
Nitrate Nitrogen	mg/kg			3.7	<0.5	<0.5
Ammonium Nitrogen	mg/kg			6.1	4.0	2.2
Phosphorus (Olsen)	mg/kg			60	41	21
Sulphur (MCP)	mg/kg	12	20	20	14	17
Potassium (Colwell)	mg/kg	170	200	310	150	130
Copper	mg/kg	0.3	5.0	3.6		0.4
Zinc	mg/kg	0.6	5.0	15.0	3.8	1.3
Manganese	mg/kg	0.5	5.0	6		
Iron	mg/kg	10	100	600	430	280
Boron	mg/kg	1.0	4.0	0.8	0.6	0.5
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			63.00	31.00	21.00
Calcium	mg/kg			54.0	39.0	37.0
Magnesium	mg/kg			13.00	13.00	12.00
Sodium	mg/kg			19.00	12.00	9.30
Sodium Absorbtion Ratio				0.60	0.43	0.34
Other						
Total Arsenic	mg/kg			0.71	0.50	1.60
Total Cadmium	mg/kg			0.22	0.05	0.09
Total Chromium	mg/kg			10.00	10.00	18.00
Total Cobalt	mg/kg			1.10	0.58	0.87
Total Molybdenum	mg/kg			0.08	0.08	0.07
Total Lead	mg/kg			6.60	5.30	7.60
Total Selenium	mg/kg			0.19	0.15	0.19
Total Vanadium	mg/kg			14.00	19.00	73.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		P2 Sample 4-008	P2 Sample 4-008	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3					
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	5.5	5.2	
pH (CaCl2)		5.2	7.5	4.6	4.2	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.05	0.06	
EC (sat ext)	dS/m	0.0	1.5	0.3	0.4	
Chloride	mg/kg	0.0	200	19	26	
Nutrients						
Total Carbon	%			0.9	0.6	
Total Nitrogen	%			0.1	0.1	
Nitrate Nitrogen	mg/kg			<0.5	0.5	
Ammonium Nitrogen	mg/kg			3.9	2.4	
Phosphorus (Olsen)	mg/kg			5	4	
Sulphur (MCP)	mg/kg	12	20	23	45	
Potassium (Colwell)	mg/kg	170	200	99	100	
Copper	mg/kg	0.3	5.0	0.2	0.2	
Zinc	mg/kg	0.6	5.0	0.4		
Manganese	mg/kg	0.5	5.0			
Iron	mg/kg	10	100	160	51	
Boron	mg/kg	1.0	4.0	0.5	0.5	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			14.00	16.00	
Calcium	mg/kg			36.0	33.0	
Magnesium	mg/kg			13.00	17.00	
Sodium	mg/kg			9.20	14.00	
Sodium Absorbtion Ratio				0.33	0.49	
Other						
Total Arsenic	mg/kg			0.94	0.87	
Total Cadmium	mg/kg			0.07	0.08	
Total Chromium	mg/kg			19.00	28.00	
Total Cobalt	mg/kg			1.10	1.70	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			6.90	6.80	
Total Selenium	mg/kg			0.17	0.20	
Total Vanadium	mg/kg			47.00	54.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		V3 Sample 1-009	V3 Sample 1-009	V3 Sample 1-009
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay Loam	Clay	Clay
Bulk Density	g/cm^3			1.8	1.8	1.9
Emerson Class				7	7	2
Acidity						
pH (water)		6.0	7.0	5.9	5.9	5.7
pH ($CaCl_2$)		5.2	7.5	5.1	5.1	4.8
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.06	0.04	0.04
EC (sat ext)	dS/m	0.0	1.5	0.5	0.2	0.2
Chloride	mg/kg	0.0	200	10	<10	11
Nutrients						
Total Carbon	%			3.5	1.9	1.1
Total Nitrogen	%			0.3	0.1	0.1
Nitrate Nitrogen	mg/kg			2.0	0.7	<0.5
Ammonium Nitrogen	mg/kg			5.2	4.7	5.0
Phosphorus (Olsen)	mg/kg			19	7	4
Sulphur (MCP)	mg/kg	12	20	11	11	13
Potassium (Colwell)	mg/kg	170	200	150	54	39
Copper	mg/kg	0.3	5.0	0.7		
Zinc	mg/kg	0.6	5.0	2.2	0.6	0.2
Manganese	mg/kg	0.5	5	7		
Iron	mg/kg	10	100	490	370	160
Boron	mg/kg	1.0	4	0.6	0.3	0.3
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			32.00	7.40	7.90
Calcium	mg/kg			50.0	34.0	43.0
Magnesium	mg/kg			11.00		9.50
Sodium	mg/kg			7.80	4.30	6.00
Sodium Absorbtion Ratio				0.26	0.17	0.22
Other						
Total Arsenic	mg/kg			1.70	0.77	0.77
Total Cadmium	mg/kg			0.18	0.11	0.09
Total Chromium	mg/kg			15.00	13.00	15.00
Total Cobalt	mg/kg			0.92	0.87	0.95
Total Molybdenum	mg/kg			0.14	0.06	<0.05
Total Lead	mg/kg			5.50	5.00	4.80
Total Selenium	mg/kg			0.17	0.20	0.17
Total Vanadium	mg/kg			58.00	31.00	44.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		V3 Sample 1-009	V3 Sample 1-009	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3			2.0	1.8	
Emerson Class				2	6	
Acidity						
pH (water)		6.0	7.0	5.4	5.2	
pH (CaCl2)		5.2	7.5	4.5	4.2	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.03	0.05	
EC (sat ext)	dS/m	0.0	1.5	0.2	0.3	
Chloride	mg/kg	0.0	200	<10	15	
Nutrients						
Total Carbon	%			0.6	0.5	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			<0.5	<0.5	
Ammonium Nitrogen	mg/kg			2.1	2.9	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	12	20	17	44	
Potassium (Colwell)	mg/kg	170	200	66	28	
Copper	mg/kg	0.3	5.0	0.0		
Zinc	mg/kg	0.6	5.0	0.1	0.1	
Manganese	mg/kg	0.5	5.0	0	0	
Iron	mg/kg	10	100	73	33	
Boron	mg/kg	1.0	4.0	0.2	0.3	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			8.10	7.30	
Calcium	mg/kg			24.0	20.0	
Magnesium	mg/kg			15.00	17.00	
Sodium	mg/kg			5.60	8.60	
Sodium Absorbtion Ratio				0.22	0.34	
Other						
Total Arsenic	mg/kg			1.10	1.40	
Total Cadmium	mg/kg			0.07	0.07	
Total Chromium	mg/kg			22.00	35.00	
Total Cobalt	mg/kg			1.30	2.30	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			6.20	8.20	
Total Selenium	mg/kg			0.22	0.23	
Total Vanadium	mg/kg			71.00	80.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		V3 Sample 2-011	V3 Sample 2-011	V3 Sample 2-011
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Grey	Brown
Soil Texture				Clay Loam	Clay	Clay
Bulk Density	g/cm^3			1.8	2.2	2.0
Emerson Class				7	2	2
Acidity						
pH (water)		6.0	7.0	6.1	6.0	5.6
pH (CaCl2)		5.2	7.5	5.2	5.1	4.7
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.07	0.04	0.03
EC (sat ext)	dS/m	0.0	1.5	0.6	0.2	0.2
Chloride	mg/kg	0.0	200	14	<10	<10
Nutrients						
Total Carbon	%			3.2	1.3	0.7
Total Nitrogen	%			0.2	0.1	<0.05
Nitrate Nitrogen	mg/kg			1.3	<0.5	<0.5
Ammonium Nitrogen	mg/kg			3.9	2.1	1.4
Phosphorus (Olsen)	mg/kg			17	7	2
Sulphur (MCP)	mg/kg	12	20	10	9	14
Potassium (Colwell)	mg/kg	170	200	260	110	90
Copper	mg/kg	0.3	5.0	0.6		
Zinc	mg/kg	0.6	5.0	1.5	0.2	0.2
Manganese	mg/kg	0.5	5.0	3		
Iron	mg/kg	10	100	490	260	340
Boron	mg/kg	1.0	4.0	0.5	0.3	0.2
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			55.00	30.00	11.00
Calcium	mg/kg			21.0	42.0	28.0
Magnesium	mg/kg			3.20	11.00	12.00
Sodium	mg/kg			6.20	5.00	4.10
Sodium Absorbtion Ratio				0.33	0.18	0.16
Other						
Total Arsenic	mg/kg			1.70	0.77	1.20
Total Cadmium	mg/kg			0.18	0.11	0.07
Total Chromium	mg/kg			12.00	13.00	16.00
Total Cobalt	mg/kg			0.80	0.72	0.89
Total Molybdenum	mg/kg			0.10	0.07	0.05
Total Lead	mg/kg			5.20	5.70	6.00
Total Selenium	mg/kg			0.18	0.18	0.22
Total Vanadium	mg/kg			50.00	32.00	66.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		V3 Sample 2-011	V3 Sample 2-011	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3			2.1	2.1	
Emerson Class				2	6	
Acidity						
pH (water)		6.0	7.0	5.3	5.0	
pH (CaCl2)		5.2	7.5	4.4	4.2	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.03	0.05	
EC (sat ext)	dS/m	0.0	1.5	0.2	0.3	
Chloride	mg/kg	0.0	200	<10	12	
Nutrients						
Total Carbon	%			0.5	0.4	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			<0.5	<0.5	
Ammonium Nitrogen	mg/kg			2.2	1.5	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	12	20	18	68	
Potassium (Colwell)	mg/kg	170	200	38	<20	
Copper	mg/kg	0.3	5.0	0.0	<0.01	
Zinc	mg/kg	0.6	5.0	0.0	<0.02	
Manganese	mg/kg	0.5	5.0			
Iron	mg/kg	10	100	130	25	
Boron	mg/kg	1.0	4.0	0.2	0.2	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			8.90	4.70	
Calcium	mg/kg			26.0	17.0	
Magnesium	mg/kg			15.00	14.00	
Sodium	mg/kg			5.70	8.70	
Sodium Absorbtion Ratio				0.22	0.38	
Other						
Total Arsenic	mg/kg			1.10	0.71	
Total Cadmium	mg/kg			0.06	0.06	
Total Chromium	mg/kg			20.00	33.00	
Total Cobalt	mg/kg			1.20	2.40	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			5.10	6.00	
Total Selenium	mg/kg			0.24	0.28	
Total Vanadium	mg/kg			64.00	56.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		V3 Sample 3-012	V3 Sample 3-012	V3 Sample 3-012
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay Loam	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				7	8	2
Acidity						
pH (water)		6.0	7.0	6.5	6.5	6.1
pH (CaCl2)		5.2	7.5	5.7	5.8	5.3
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.05	0.05	0.04
EC (sat ext)	dS/m	0.0	1.5	0.4	0.3	0.2
Chloride	mg/kg	0.0	200	<10	<10	<10
Nutrients						
Total Carbon	%			3.6	1.9	0.9
Total Nitrogen	%			0.3	0.1	<0.05
Nitrate Nitrogen	mg/kg			0.6	<0.5	<0.5
Ammonium Nitrogen	mg/kg			5.5	4.7	2.1
Phosphorus (Olsen)	mg/kg			19	9	3
Sulphur (MCP)	mg/kg	12	20	7	9	13
Potassium (Colwell)	mg/kg	170	200	62	42	35
Copper	mg/kg	0.3	5.0	0.5	0.2	
Zinc	mg/kg	0.6	5.0	1.0	0.2	0.1
Manganese	mg/kg	0.5	5.0	2	0	
Iron	mg/kg	10	100	370	230	120
Boron	mg/kg	1.0	4.0	0.5	0.4	0.3
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			13.00	11.00	7.00
Calcium	mg/kg			76.0	84.0	67.0
Magnesium	mg/kg			7.70	11.00	9.10
Sodium	mg/kg			4.00	4.50	5.50
Sodium Absorbtion Ratio				0.12	0.12	0.17
Other						
Total Arsenic	mg/kg			0.81	0.91	1.10
Total Cadmium	mg/kg			0.19	0.14	0.09
Total Chromium	mg/kg			9.40	13.00	18.00
Total Cobalt	mg/kg			0.65	0.79	0.96
Total Molybdenum	mg/kg			0.12	0.10	<0.05
Total Lead	mg/kg			4.30	6.70	6.40
Total Selenium	mg/kg			0.12	0.15	0.16
Total Vanadium	mg/kg			27.00	33.00	54.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		V3 Sample 3-012	V3 Sample 3-012	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3					
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	5.7	5.3	
pH (CaCl2)		5.2	7.5	4.7	4.4	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.03	0.04	
EC (sat ext)	dS/m	0.0	1.5	0.2	0.2	
Chloride	mg/kg	0.0	200	<10	<10	
Nutrients						
Total Carbon	%			0.5	0.4	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			<0.5	<0.5	
Ammonium Nitrogen	mg/kg			2.1	1.5	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	12	20	15	40	
Potassium (Colwell)	mg/kg	170	200	67	30	
Copper	mg/kg	0.3	5.0		<0.01	
Zinc	mg/kg	0.6	5.0	0.1		
Manganese	mg/kg	0.5	5.0			
Iron	mg/kg	10	100	92	30	
Boron	mg/kg	1.0	4.0	0.2	0.3	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			3.40	13.00	
Calcium	mg/kg			43.0	34.0	
Magnesium	mg/kg			8.30	20.00	
Sodium	mg/kg			6.60	9.00	
Sodium Absorbtion Ratio				0.24	0.30	
Other						
Total Arsenic	mg/kg			0.43	1.00	
Total Cadmium	mg/kg			0.07	0.06	
Total Chromium	mg/kg			15.00	23.00	
Total Cobalt	mg/kg			0.87	1.40	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			4.80	7.80	
Total Selenium	mg/kg			0.14	0.26	
Total Vanadium	mg/kg			28.00	58.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		V3 Sample 4-001	V3 Sample 4-001	V3 Sample 4-001
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay Loam	Clay Loam	Clay
Bulk Density	g/cm^3					
Emerson Class				7	7	2
Acidity						
pH (water)		6.0	7.0	5.7	5.6	5.7
pH (CaCl2)		5.2	7.5	4.9	4.8	4.8
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.05	0.05	0.03
EC (sat ext)	dS/m	0.0	1.5	0.4	0.4	0.2
Chloride	mg/kg	0.0	200	12	<10	<10
Nutrients						
Total Carbon	%			3.9	1.7	0.7
Total Nitrogen	%			0.3	0.1	<0.05
Nitrate Nitrogen	mg/kg			0.6	<0.5	<0.5
Ammonium Nitrogen	mg/kg			4.8	3.8	2.4
Phosphorus (Olsen)	mg/kg			31	17	5
Sulphur (MCP)	mg/kg	12	20	10	7	9
Potassium (Colwell)	mg/kg	170	200	160	120	100
Copper	mg/kg	0.3	5.0	0.6		0.1
Zinc	mg/kg	0.6	5.0	2.9	0.5	0.2
Manganese	mg/kg	0.5	5.0	6		
Iron	mg/kg	10	100	570	370	190
Boron	mg/kg	1.0	4.0	0.5	0.2	0.3
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			35.00	16.00	29.00
Calcium	mg/kg			34.0	9.7	35.0
Magnesium	mg/kg			10.00	2.20	8.00
Sodium	mg/kg			5.50	3.40	4.60
Sodium Absorbtion Ratio				0.21	0.26	0.18
Other						
Total Arsenic	mg/kg			0.64	0.58	0.52
Total Cadmium	mg/kg			0.11	0.11	0.08
Total Chromium	mg/kg			7.40	7.90	9.20
Total Cobalt	mg/kg			0.57	0.54	0.50
Total Molybdenum	mg/kg			0.09	0.06	<0.05
Total Lead	mg/kg			5.90	3.20	3.90
Total Selenium	mg/kg			0.12	0.16	0.13
Total Vanadium	mg/kg			16.00	22.00	21.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		V3 Sample 4-001	V3 Sample 4-001	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3					
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	5.7	5.4	
pH (CaCl2)		5.2	7.5	4.6	4.2	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.03	0.04	
EC (sat ext)	dS/m	0.0	1.5	0.2	0.2	
Chloride	mg/kg	0.0	200	<10	<10	
Nutrients						
Total Carbon	%			0.5	0.4	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			<0.5	<0.5	
Ammonium Nitrogen	mg/kg			2.1	2.0	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	12	20	11	22	
Potassium (Colwell)	mg/kg	170	200	100	84	
Copper	mg/kg	0.3	5.0	0.0	0.0	
Zinc	mg/kg	0.6	5.0	0.1		
Manganese	mg/kg	0.5	5.0			
Iron	mg/kg	10	100	97	54	
Boron	mg/kg	1.0	4.0	0.3	0.3	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			23.00	22.00	
Calcium	mg/kg			25.0	28.0	
Magnesium	mg/kg			3.90	21.00	
Sodium	mg/kg			5.50	5.50	
Sodium Absorbtion Ratio				0.27	0.19	
Other						
Total Arsenic	mg/kg			0.72	0.50	
Total Cadmium	mg/kg			0.07	0.06	
Total Chromium	mg/kg			15.00	22.00	
Total Cobalt	mg/kg			0.71	1.50	
Total Molybdenum	mg/kg			<0.05	<0.05	
Total Lead	mg/kg			4.70	3.80	
Total Selenium	mg/kg			0.16	0.18	
Total Vanadium	mg/kg			37.00	34.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

8.6 Producer 4 - Soil analysis data

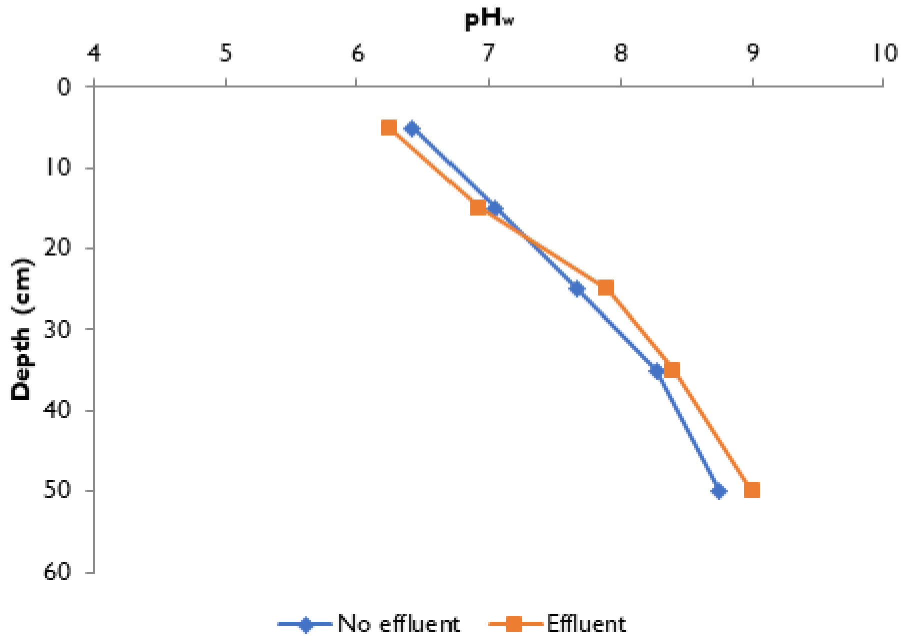


Figure 41. Producer 4: Soil pH in water (pH$_w$) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

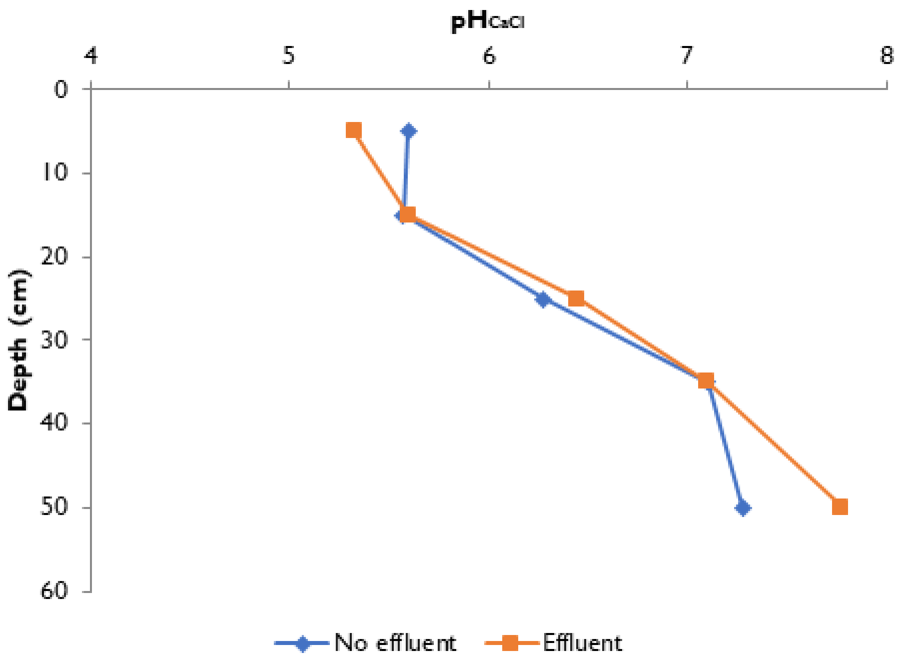


Figure 42. Producer 4: Soil pH in $CaCl_2$ (pH$_{CaCl}$) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

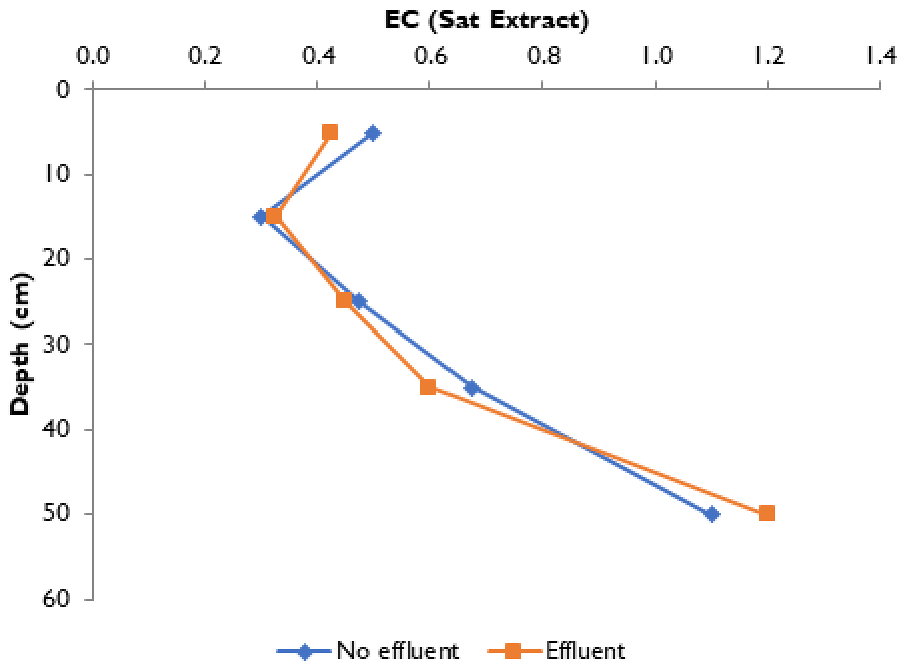


Figure 43. Producer 4: Soil electrical conductivity (saturated extract, ECe) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

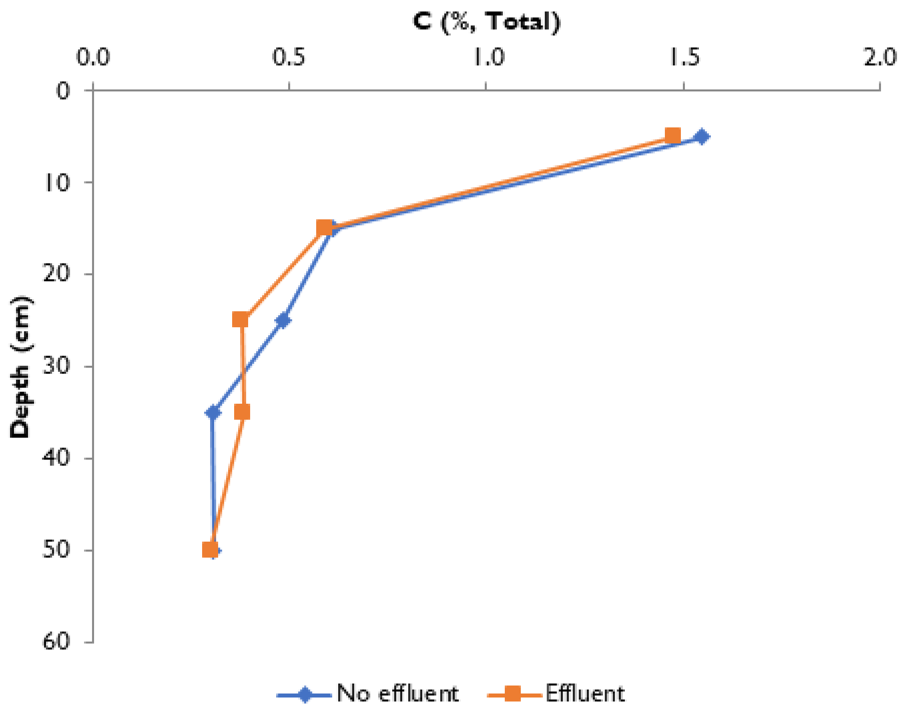


Figure 44. Producer 4: Soil total carbon (C %, Total) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

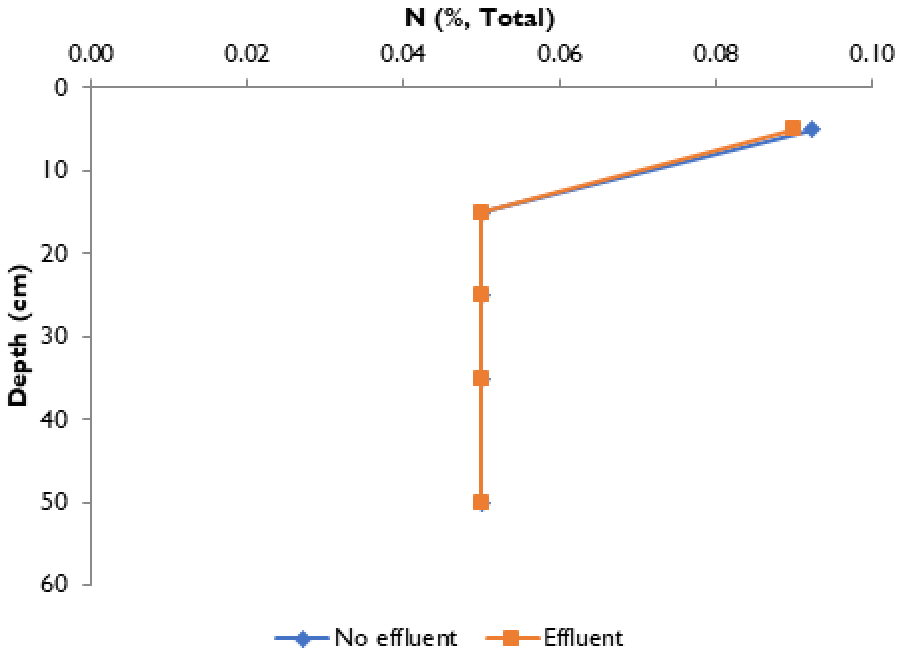


Figure 45. Producer 4: Soil total nitrogen (N %, Total) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4)

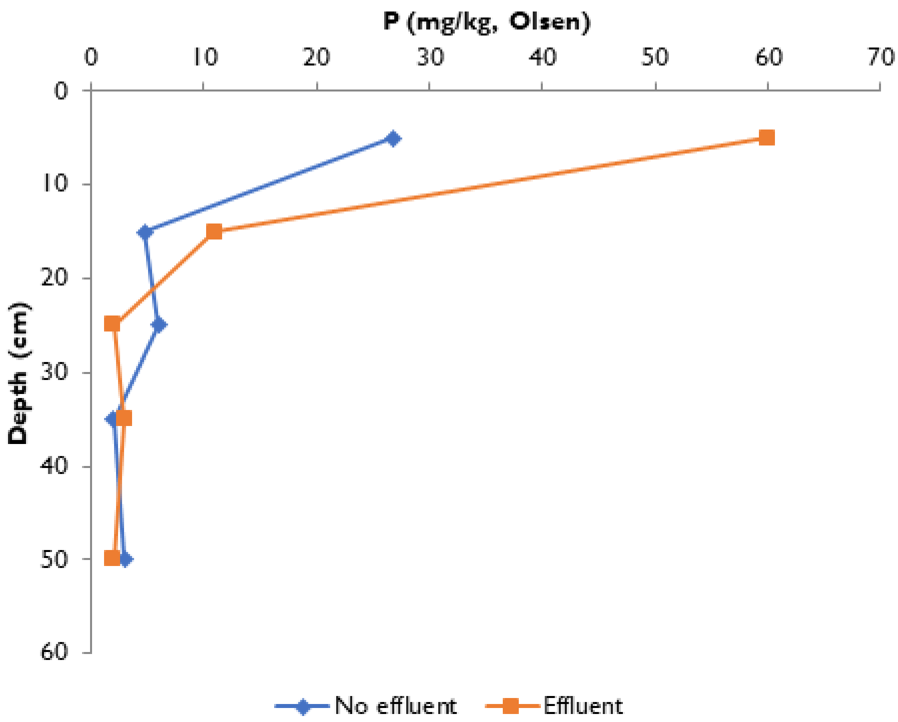


Figure 46. Producer 4: Soil phosphorus (P mg/kg, Olsen) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

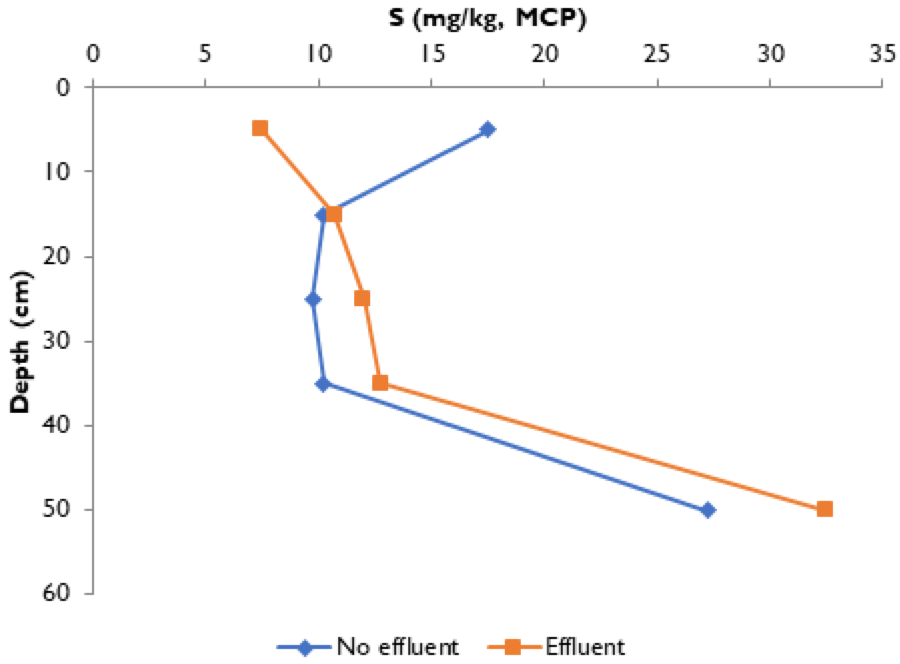


Figure 47. Soil sulfur (S mg/kg, MCP) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

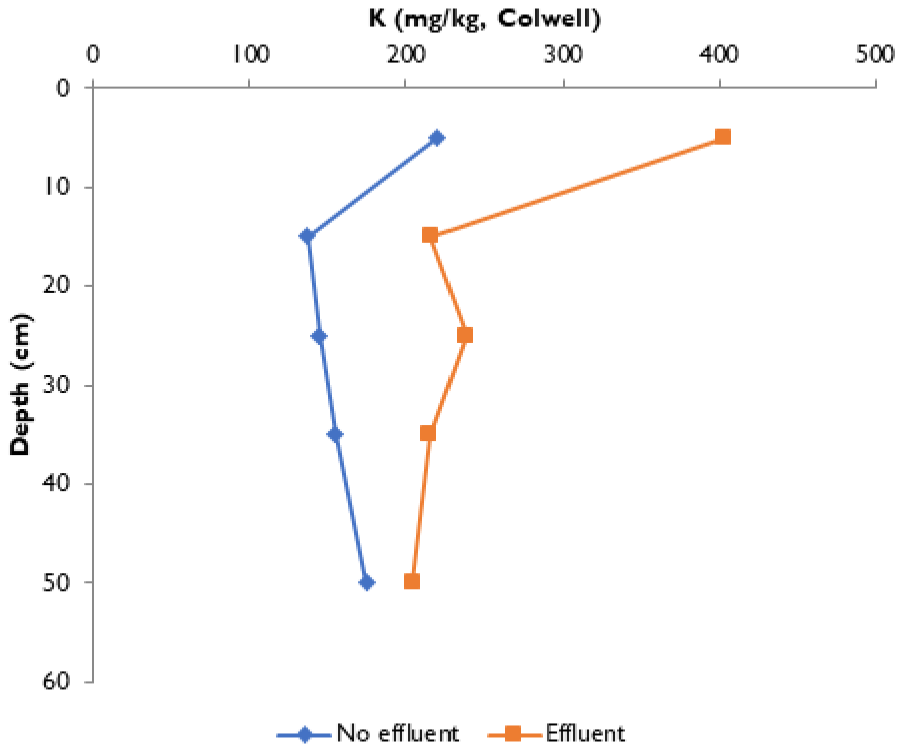


Figure 48. Producer 4: Soil potassium (P mg/kg, Colwell) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

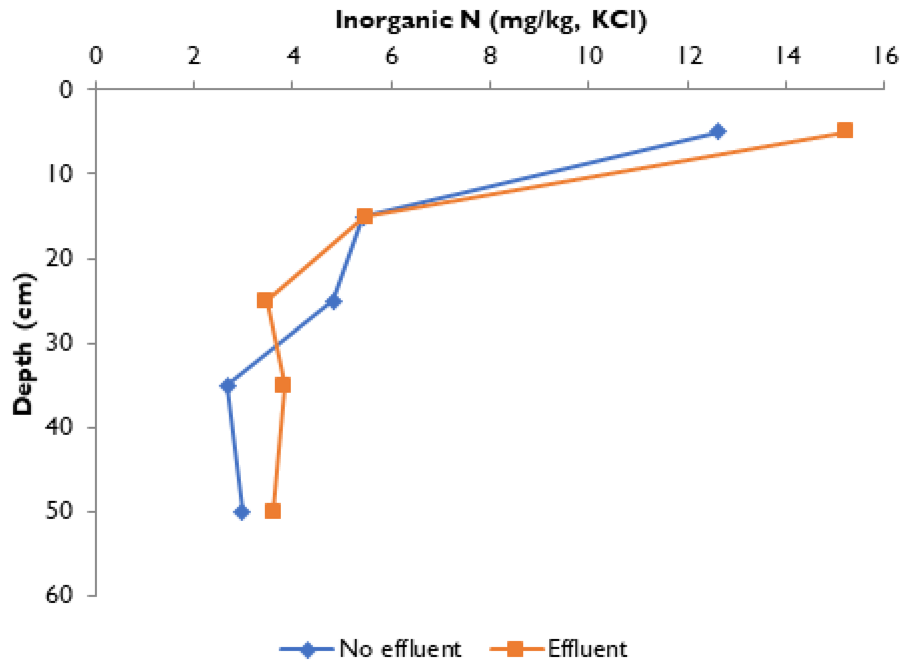


Figure 49. Producer 4: Soil inorganic nitrogen (nitrate, NO_3 + ammonium, NH_4) (Inorganic N mg/kg, KCl) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

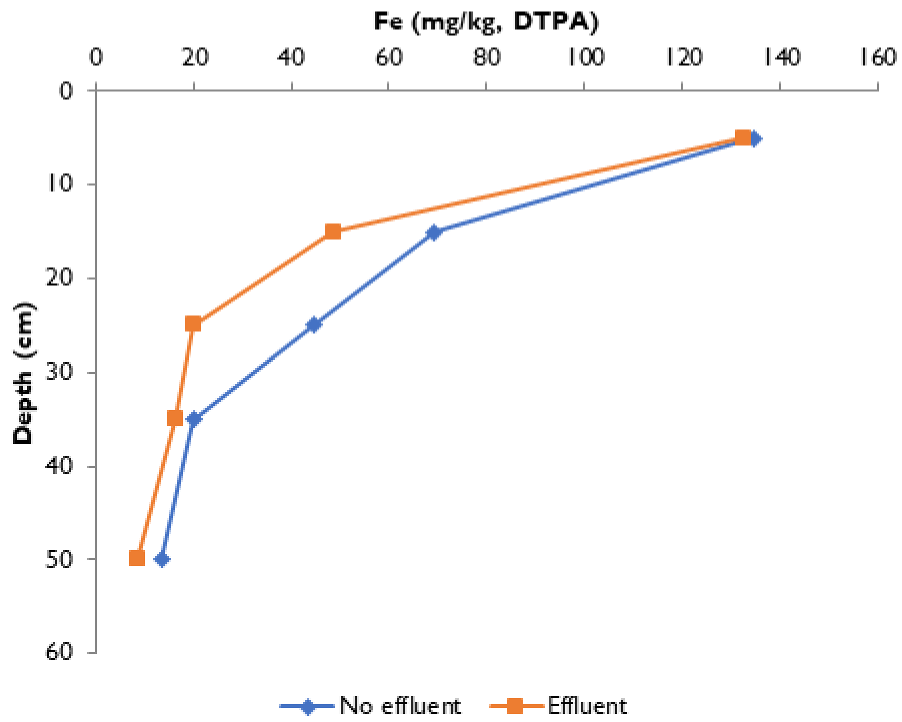


Figure 50. Producer 4: Soil iron (Fe mg/kg, DTPA) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

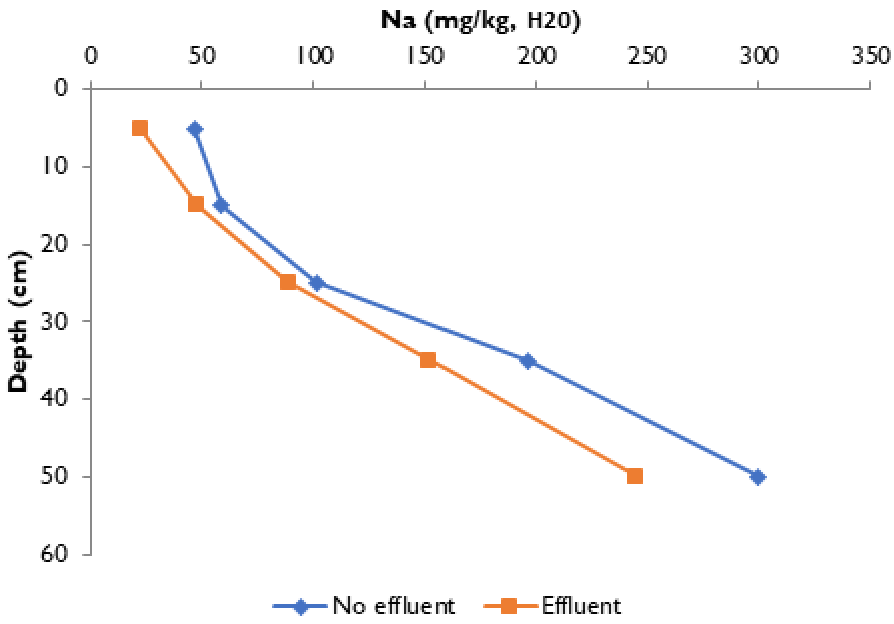


Figure 51. Producer 4: Sodium (Na mg/kg, H_2O) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

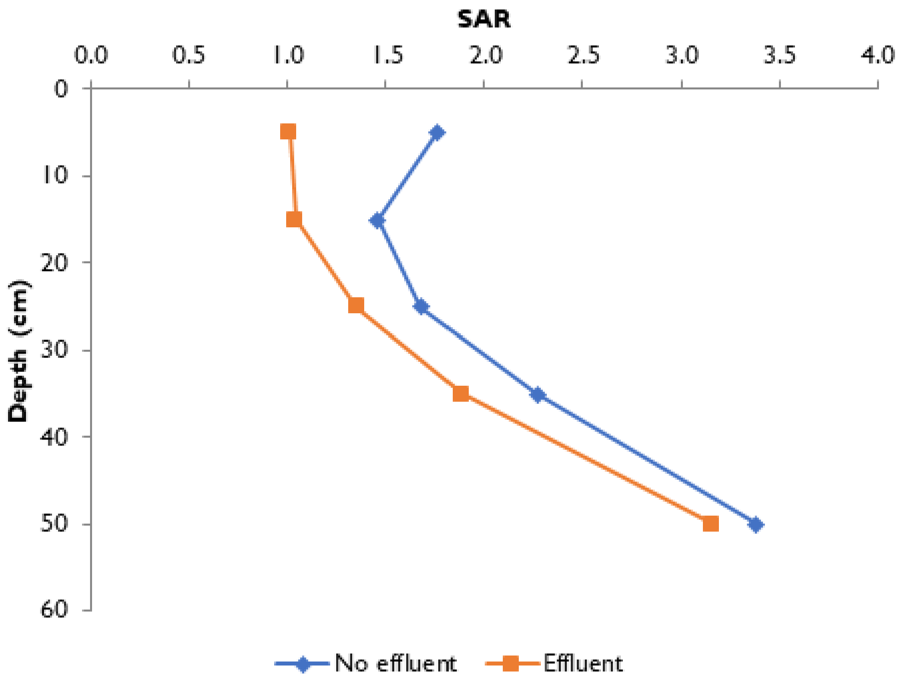


Figure 52. Producer 4: Sodium absorption ratio (SAR) of soils receiving effluent (effluent) or non-treated (no effluent) at various depths (0-10, 10-20, 20-30, 30-40, 40-60 cm). Data are means of soil cores for each paddock (n=4).

Table 11. Producer 4 - Emerson dispersion class for four sampling locations (A, B, C, D) in paddocks receiving effluent or no-effluent.

	No effluent				**Effluent**			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
0-10 cm	3	2	3	3	2	7	2	7
10-20 cm	3	2	2	2	2	2	2	2
20-30 cm	1	1	2	1	2	3	2	2
30-40 cm	1	1	2	1	2	2	2	3
40-60 cm	2	1	2	1	2	2	2	6

Table 12. Producer 4 - Data for individual samples from four sampling locations and five depths (0-10, 10-20, 20-30, 30-40, 40-60 cm)

Analyte	Unit	Optimum Range		Paddock 1 Sample 1-001	Paddock 1 Sample 1-001	Paddock 1 Sample 1-001
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Orange/Yellow
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3			1.9	1.2	1.8
Emerson Class				3	3	1
Acidity						
pH (water)		6.0	7.0	6.5	6.7	7.0
pH (CaCl2)		5.2	7.5	5.7	5.3	5.7
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.09	0.04	0.05
EC (sat ext)	dS/m	0.0	1.5	0.6	0.2	0.3
Chloride	mg/kg	0.0	200	34	13	12
Nutrients						
Total Carbon	%			1.4	0.6	0.4
Total Nitrogen	%			0.1	<0.05	<0.05
Nitrate Nitrogen	mg/kg			9.8	3.0	3.3
Ammonium Nitrogen	mg/kg			9.5	1.4	1.6
Phosphorus (Olsen)	mg/kg			28	7	6
Sulphur (MCP)	mg/kg	9	17	18	11	9
Potassium (Colwell)	mg/kg	170	200	190	100	120
Copper	mg/kg	0.3	5.0	0.8	0.6	0.6
Zinc	mg/kg	0.6	5.0	3.9	0.7	0.5
Manganese	mg/kg	0.5	5	26	13	13
Iron	mg/kg	10	100	120	76	64
Boron	mg/kg	1.0	4	0.6	0.6	0.7
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			26.00	4.70	8.90
Calcium	mg/kg			39.0	48.0	85.0
Magnesium	mg/kg			8.10	18.00	38.00
Sodium	mg/kg			47.00	44.00	58.00
Sodium Absorbtion Ratio				1.79	1.37	1.31
Other						
Total Arsenic	mg/kg			4.30	4.20	3.50
Total Cadmium	mg/kg			0.05	0.02	<0.02
Total Chromium	mg/kg			20.00	23.00	22.00
Total Cobalt	mg/kg			3.80	3.20	3.20
Total Molybdenum	mg/kg			0.22	0.14	0.19
Total Lead	mg/kg			12.00	15.00	11.00
Total Selenium	mg/kg			0.36	0.43	0.42
Total Vanadium	mg/kg			30.00	37.00	33.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 1 Sample 1-001	Paddock 1 Sample 1-001
Depth	cm	Lower	Upper	30-40	40-60
Soil Colour				Orange/Yellow	Brown
Soil Texture				Clay	Clay
Bulk Density	g/cm^3			2.1	1.9
Emerson Class				1	2
Acidity					
pH (water)		6.0	7.0	7.9	8.3
pH (CaCl2)		5.2	7.5	6.7	7.0
Salinity					
EC (1:5)	dS/m	0.0	0.6	0.06	0.11
EC (sat ext)	dS/m	0.0	1.5	0.4	0.7
Chloride	mg/kg	0.0	200	<10	21
Nutrients					
Total Carbon	%			0.3	0.5
Total Nitrogen	%			<0.05	<0.05
Nitrate Nitrogen	mg/kg			1.0	2.2
Ammonium Nitrogen	mg/kg			1.1	0.9
Phosphorus (Olsen)	mg/kg			2	3
Sulphur (MCP)	mg/kg	9	17	6	10
Potassium (Colwell)	mg/kg	170	200	110	140
Copper	mg/kg	0.3	5.0	0.5	0.5
Zinc	mg/kg	0.6	5.0	0.2	0.4
Manganese	mg/kg	0.5	5.0	3	5
Iron	mg/kg	10	100	26	19
Boron	mg/kg	1.0	4.0	0.9	1.1
Molybdenum	mg/kg			<0.01	<0.01
Water Soluble Cations					
Potassium	mg/kg			12.00	16.00
Calcium	mg/kg			120.0	69.0
Magnesium	mg/kg			64.00	45.00
Sodium	mg/kg			83.00	120.00
Sodium Absorbtion Ratio				1.52	2.76
Other					
Total Arsenic	mg/kg			2.80	0.76
Total Cadmium	mg/kg			<0.02	<0.02
Total Chromium	mg/kg			28.00	2.60
Total Cobalt	mg/kg			3.80	5.20
Total Molybdenum	mg/kg			0.09	<0.05
Total Lead	mg/kg			12.00	9.70
Total Selenium	mg/kg			0.36	0.16
Total Vanadium	mg/kg			31.00	2.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 1 Sample 2-002	Paddock 1 Sample 2-002	Paddock 1 Sample 2-002
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Orange/Yellow
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3			1.5	1.7	1.6
Emerson Class				2	2	1
Acidity						
pH (water)		6.0	7.0	7.0	7.9	8.4
pH (CaCl2)		5.2	7.5	6.2	6.3	7.0
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.10	0.07	0.08
EC (sat ext)	dS/m	0.0	1.5	0.6	0.4	0.5
Chloride	mg/kg	0.0	200	40	11	<10
Nutrients						
Total Carbon	%			1.4	0.6	0.4
Total Nitrogen	%			0.1	<0.05	<0.05
Nitrate Nitrogen	mg/kg			11.0	2.2	1.6
Ammonium Nitrogen	mg/kg			1.6	1.3	1.1
Phosphorus (Olsen)	mg/kg			19	2	<2
Sulphur (MCP)	mg/kg	9	17	19	6	7
Potassium (Colwell)	mg/kg	170	200	270	170	180
Copper	mg/kg	0.3	5.0	0.6	0.5	0.5
Zinc	mg/kg	0.6	5.0	1.8	0.3	0.2
Manganese	mg/kg	0.5	5.0	24	10	11
Iron	mg/kg	10	100	58	24	17
Boron	mg/kg	1.0	4.0	0.6	1.0	1.5
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			18.00	15.00	31.00
Calcium	mg/kg			50.0	100.0	180.0
Magnesium	mg/kg			12.00	50.00	130.00
Sodium	mg/kg			62.00	84.00	130.00
Sodium Absorbtion Ratio				2.04	1.71	1.80
Other						
Total Arsenic	mg/kg			0.33	2.40	5.30
Total Cadmium	mg/kg			0.04	<0.02	<0.02
Total Chromium	mg/kg			0.87	21.00	30.00
Total Cobalt	mg/kg			4.60	5.40	11.00
Total Molybdenum	mg/kg			<0.05	0.07	0.17
Total Lead	mg/kg			6.30	12.00	17.00
Total Selenium	mg/kg			0.15	0.37	0.89
Total Vanadium	mg/kg			0.51	23.00	42.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 1 Sample 2-002	Paddock 1 Sample 2-002	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3			1.8	2.0	
Emerson Class				1	1	
Acidity						
pH (water)		6.0	7.0	8.8	9.1	
pH (CaCl2)		5.2	7.5	8.1	7.6	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.13	0.19	
EC (sat ext)	dS/m	0.0	1.5	0.8	1.2	
Chloride	mg/kg	0.0	200	18	40	
Nutrients						
Total Carbon	%			0.3	0.2	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			1.1	1.0	
Ammonium Nitrogen	mg/kg			1.0	0.7	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	9	17	12	25	
Potassium (Colwell)	mg/kg	170	200	210	230	
Copper	mg/kg	0.3	5.0	0.5	0.4	
Zinc	mg/kg	0.6	5.0	0.2	0.1	
Manganese	mg/kg	0.5	5.0	6	4	
Iron	mg/kg	10	100	12	8	
Boron	mg/kg	1.0	4.0	2.3	2.7	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			81.00	110.00	
Calcium	mg/kg			340.0	400.0	
Magnesium	mg/kg			340.00	480.00	
Sodium	mg/kg			300.00	470.00	
Sodium Absorbtion Ratio				2.75	3.75	
Other						
Total Arsenic	mg/kg			4.50	4.90	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			33.00	35.00	
Total Cobalt	mg/kg			11.00	11.00	
Total Molybdenum	mg/kg			0.15	0.15	
Total Lead	mg/kg			16.00	17.00	
Total Selenium	mg/kg			0.70	0.53	
Total Vanadium	mg/kg			43.00	46.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 1 Sample 3-003	Paddock 1 Sample 3-003	Paddock 1 Sample 3-003
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				3	2	2
Acidity						
pH (water)		6.0	7.0	6.2	7.4	8.4
pH (CaCl2)		5.2	7.5	5.4	5.9	7.1
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.08	0.07	0.11
EC (sat ext)	dS/m	0.0	1.5	0.5	0.4	0.7
Chloride	mg/kg	0.0	200	33	<10	<10
Nutrients						
Total Carbon	%			1.9	0.5	0.4
Total Nitrogen	%			0.1	<0.05	<0.05
Nitrate Nitrogen	mg/kg			4.6	<0.5	<0.5
Ammonium Nitrogen	mg/kg			2.7	1.9	2.0
Phosphorus (Olsen)	mg/kg			41	2	<2
Sulphur (MCP)	mg/kg	9	17	19	13	12
Potassium (Colwell)	mg/kg	170	200	270	170	160
Copper	mg/kg	0.3	5.0	1.1	0.7	0.6
Zinc	mg/kg	0.6	5.0	2.3	0.3	0.2
Manganese	mg/kg	0.5	5.0	22	17	8
Iron	mg/kg	10	100	210	47	20
Boron	mg/kg	1.0	4.0	0.9	1.2	1.3
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			18.00	16.00	15.00
Calcium	mg/kg			35.0	110.0	140.0
Magnesium	mg/kg			9.80	52.00	70.00
Sodium	mg/kg			50.00	68.00	120.00
Sodium Absorbtion Ratio				1.93	1.34	2.07
Other						
Total Arsenic	mg/kg			4.60	5.50	6.40
Total Cadmium	mg/kg			0.05	0.03	<0.02
Total Chromium	mg/kg			25.00	45.00	48.00
Total Cobalt	mg/kg			6.10	17.00	13.00
Total Molybdenum	mg/kg			0.20	0.17	0.18
Total Lead	mg/kg			17.00	21.00	21.00
Total Selenium	mg/kg			0.45	0.65	0.75
Total Vanadium	mg/kg			33.00	54.00	60.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 1 Sample 3-003	Paddock 1 Sample 3-003	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3					
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	8.6	8.9	
pH (CaCl2)		5.2	7.5	7.1	7.3	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.13	0.19	
EC (sat ext)	dS/m	0.0	1.5	0.8	1.2	
Chloride	mg/kg	0.0	200	12	12	
Nutrients						
Total Carbon	%			0.3	0.3	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			<0.5	1.3	
Ammonium Nitrogen	mg/kg			2.5	2.2	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	9	17	14	43	
Potassium (Colwell)	mg/kg	170	200	150	150	
Copper	mg/kg	0.3	5.0	0.6	0.6	
Zinc	mg/kg	0.6	5.0	0.2	0.4	
Manganese	mg/kg	0.5	5.0	6	4	
Iron	mg/kg	10	100	17	15	
Boron	mg/kg	1.0	4.0	1.4	1.9	
Molybdenum	mg/kg			<0.01		
Water Soluble Cations						
Potassium	mg/kg			15.00	18.00	
Calcium	mg/kg			140.0	170.0	
Magnesium	mg/kg			80.00	110.00	
Sodium	mg/kg			140.00	210.00	
Sodium Absorbtion Ratio				2.34	3.09	
Other						
Total Arsenic	mg/kg			5.50	5.40	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			45.00	46.00	
Total Cobalt	mg/kg			14.00	13.00	
Total Molybdenum	mg/kg			0.13	0.16	
Total Lead	mg/kg			21.00	20.00	
Total Selenium	mg/kg			0.79	0.74	
Total Vanadium	mg/kg			61.00	60.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 1 Sample 4-004	Paddock 1 Sample 4-004	Paddock 1 Sample 4-004
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				3	2	1
Acidity						
pH (water)		6.0	7.0	6.0	6.2	6.9
pH (CaCl2)		5.2	7.5	5.1	4.8	5.3
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.05	0.04	0.06
EC (sat ext)	dS/m	0.0	1.5	0.3	0.2	0.4
Chloride	mg/kg	0.0	200	21	<10	18
Nutrients						
Total Carbon	%			1.5	0.8	0.7
Total Nitrogen	%			0.1	0.1	<0.05
Nitrate Nitrogen	mg/kg			8.4	5.4	4.5
Ammonium Nitrogen	mg/kg			2.9	3.0	2.1
Phosphorus (Olsen)	mg/kg			19	8	6
Sulphur (MCP)	mg/kg	9	17	14	11	11
Potassium (Colwell)	mg/kg	170	200	150	110	120
Copper	mg/kg	0.3	5.0	1.0	0.8	0.6
Zinc	mg/kg	0.6	5.0	2.0	0.5	1.0
Manganese	mg/kg	0.5	5.0	31	22	16
Iron	mg/kg	10	100	150	130	77
Boron	mg/kg	1.0	4.0	0.4	0.5	0.6
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			8.50	4.20	25.00
Calcium	mg/kg			25.0	34.0	150.0
Magnesium	mg/kg			5.20	14.00	100.00
Sodium	mg/kg			27.00	39.00	99.00
Sodium Absorbtion Ratio				1.28	1.42	1.54
Other						
Total Arsenic	mg/kg			4.10	5.00	4.20
Total Cadmium	mg/kg			0.06	0.03	0.02
Total Chromium	mg/kg			25.00	27.00	31.00
Total Cobalt	mg/kg			5.20	4.70	5.00
Total Molybdenum	mg/kg			0.22	0.27	0.25
Total Lead	mg/kg			15.00	15.00	15.00
Total Selenium	mg/kg			0.42	0.48	0.47
Total Vanadium	mg/kg			34.00	41.00	40.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 1 Sample 4-004	Paddock 1 Sample 4-004
Depth	cm	Lower	Upper	30-40	40-60
Soil Colour				Orange/Yellow	Orange/Yellow
Soil Texture				Clay	Clay
Bulk Density	g/cm^3				
Emerson Class				1	1
Acidity					
pH (water)		6.0	7.0	7.8	8.7
pH (CaCl2)		5.2	7.5	6.5	7.2
Salinity					
EC (1:5)	dS/m	0.0	0.6	0.11	0.21
EC (sat ext)	dS/m	0.0	1.5	0.7	1.3
Chloride	mg/kg	0.0	200	36	85
Nutrients					
Total Carbon	%			0.3	0.2
Total Nitrogen	%			<0.05	<0.05
Nitrate Nitrogen	mg/kg			<0.5	<0.5
Ammonium Nitrogen	mg/kg			1.9	2.1
Phosphorus (Olsen)	mg/kg			2	<2
Sulphur (MCP)	mg/kg	9	17	9	31
Potassium (Colwell)	mg/kg	170	200	150	180
Copper	mg/kg	0.3	5.0	0.6	0.6
Zinc	mg/kg	0.6	5.0	0.5	0.2
Manganese	mg/kg	0.5	5.0	6	10
Iron	mg/kg	10	100	25	12
Boron	mg/kg	1.0	4.0	0.7	1.2
Molybdenum	mg/kg			<0.01	<0.01
Water Soluble Cations					
Potassium	mg/kg			64.00	78.00
Calcium	mg/kg			320.0	240.0
Magnesium	mg/kg			320.00	330.00
Sodium	mg/kg			260.00	400.00
Sodium Absorbtion Ratio				2.46	3.93
Other					
Total Arsenic	mg/kg			4.40	5.00
Total Cadmium	mg/kg			<0.02	<0.02
Total Chromium	mg/kg			33.00	38.00
Total Cobalt	mg/kg			13.00	16.00
Total Molybdenum	mg/kg			0.17	0.16
Total Lead	mg/kg			19.00	19.00
Total Selenium	mg/kg			0.64	0.63
Total Vanadium	mg/kg			42.00	49.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 2 Sample 1-005	Paddock 2 Sample 1-005	Paddock 2 Sample 1-005
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Red	Orange/Yellow
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3			1.5	1.8	2.1
Emerson Class				2	2	2
Acidity						
pH (water)		6.0	7.0	6.2	7.1	8.0
pH (CaCl2)		5.2	7.5	5.1	5.5	6.2
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.05	0.06	0.09
EC (sat ext)	dS/m	0.0	1.5	0.3	0.4	0.6
Chloride	mg/kg	0.0	200	10	<10	<10
Nutrients						
Total Carbon	%			1.4	0.4	0.3
Total Nitrogen	%			0.1	<0.05	<0.05
Nitrate Nitrogen	mg/kg			9.4	5.0	0.8
Ammonium Nitrogen	mg/kg			2.4	2.5	2.1
Phosphorus (Olsen)	mg/kg			62	4	<2
Sulphur (MCP)	mg/kg	9	17	8	16	9
Potassium (Colwell)	mg/kg	170	200	240	130	120
Copper	mg/kg	0.3	5.0	2.4	0.7	0.5
Zinc	mg/kg	0.6	5.0	8.6	0.7	0.3
Manganese	mg/kg	0.5	5	16	22	12
Iron	mg/kg	10	100	170	40	19
Boron	mg/kg	1.0	4	0.6	1.0	0.9
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			17.00	14.00	26.00
Calcium	mg/kg			30.0	97.0	220.0
Magnesium	mg/kg			11.00	67.00	180.00
Sodium	mg/kg			34.00	70.00	140.00
Sodium Absorbtion Ratio				1.35	1.34	1.70
Other						
Total Arsenic	mg/kg			5.60	4.60	5.80
Total Cadmium	mg/kg			0.08	0.04	<0.02
Total Chromium	mg/kg			30.00	37.00	34.00
Total Cobalt	mg/kg			6.10	8.10	11.00
Total Molybdenum	mg/kg			0.32	0.16	0.17
Total Lead	mg/kg			15.00	15.00	16.00
Total Selenium	mg/kg			0.47	0.49	0.65
Total Vanadium	mg/kg			38.00	44.00	44.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 2 Sample 1-005	Paddock 2 Sample 1-005	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Orange/Yellow	
Soil Texture				Clay	Clay	
Bulk Density	g/cm³			1.8	1.9	
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	8.6	9.3	
pH (CaCl2)		5.2	7.5	7.1	8.0	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.09	0.28	
EC (sat ext)	dS/m	0.0	1.5	0.6	1.7	
Chloride	mg/kg	0.0	200	<10	17	
Nutrients						
Total Carbon	%			0.3	0.5	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			0.6	0.6	
Ammonium Nitrogen	mg/kg			2.5	1.7	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	9	17	10	29	
Potassium (Colwell)	mg/kg	170	200	110	140	
Copper	mg/kg	0.3	5.0	0.4	0.4	
Zinc	mg/kg	0.6	5.0	0.2	0.2	
Manganese	mg/kg	0.5	5.0	10	3	
Iron	mg/kg	10	100	14	8	
Boron	mg/kg	1.0	4.0	1.6	1.6	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			31.00	26.00	
Calcium	mg/kg			220.0	150.0	
Magnesium	mg/kg			220.00	140.00	
Sodium	mg/kg			180.00	360.00	
Sodium Absorbtion Ratio				2.05	5.08	
Other						
Total Arsenic	mg/kg			1.80	3.80	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			17.00	33.00	
Total Cobalt	mg/kg			4.60	8.50	
Total Molybdenum	mg/kg			<0.05	0.09	
Total Lead	mg/kg			6.90	13.00	
Total Selenium	mg/kg			0.23	0.35	
Total Vanadium	mg/kg			18.00	35.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 2 Sample 2-006	Paddock 2 Sample 2-006	Paddock 2 Sample 2-006
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Orange/Yellow
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm³			1.3	1.6	2.1
Emerson Class				7	2	2
Acidity						
pH (water)		6.0	7.0	6.2	6.7	7.9
pH (CaCl2)		5.2	7.5	5.4	5.4	6.4
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.08	0.04	0.04
EC (sat ext)	dS/m	0.0	1.5	0.5	0.2	0.2
Chloride	mg/kg	0.0	200	22	<10	<10
Nutrients						
Total Carbon	%			1.7	0.6	0.3
Total Nitrogen	%			0.1	<0.05	<0.05
Nitrate Nitrogen	mg/kg			17.0	5.0	2.3
Ammonium Nitrogen	mg/kg			2.6	2.1	2.3
Phosphorus (Olsen)	mg/kg			65	20	<2
Sulphur (MCP)	mg/kg	9	17	6	4	6
Potassium (Colwell)	mg/kg	170	200	560	320	280
Copper	mg/kg	0.3	5.0	2.0	0.6	0.4
Zinc	mg/kg	0.6	5.0	12.0	1.1	0.3
Manganese	mg/kg	0.5	5.0	36	31	7
Iron	mg/kg	10	100	110	46	22
Boron	mg/kg	1.0	4.0	0.5	0.6	1.0
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			75.00	34.00	27.00
Calcium	mg/kg			28.0	46.0	100.0
Magnesium	mg/kg			7.90	17.00	54.00
Sodium	mg/kg			13.00	17.00	41.00
Sodium Absorbtion Ratio				0.56	0.54	0.82
Other						
Total Arsenic	mg/kg			2.90	4.40	5.50
Total Cadmium	mg/kg			0.07	0.04	0.02
Total Chromium	mg/kg			20.00	26.00	44.00
Total Cobalt	mg/kg			4.40	4.40	6.60
Total Molybdenum	mg/kg			0.16	0.21	0.21
Total Lead	mg/kg			9.70	16.00	18.00
Total Selenium	mg/kg			0.27	0.37	0.48
Total Vanadium	mg/kg			23.00	34.00	48.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 2 Sample 2-006	Paddock 2 Sample 2-006
Depth	cm	Lower	Upper	30-40	40-60
Soil Colour				Brown	Orange/Yellow
Soil Texture				Clay	Clay
Bulk Density	g/cm^3			1.7	2.1
Emerson Class				2	2
Acidity					
pH (water)		6.0	7.0	8.4	8.9
pH (CaCl2)		5.2	7.5	7.0	7.6
Salinity					
EC (1:5)	dS/m	0.0	0.6	0.06	0.09
EC (sat ext)	dS/m	0.0	1.5	0.4	0.6
Chloride	mg/kg	0.0	200	<10	11
Nutrients					
Total Carbon	%			0.4	0.2
Total Nitrogen	%			<0.05	<0.05
Nitrate Nitrogen	mg/kg			<0.5	1.0
Ammonium Nitrogen	mg/kg			1.6	1.9
Phosphorus (Olsen)	mg/kg			<2	<2
Sulphur (MCP)	mg/kg	9	17	7	11
Potassium (Colwell)	mg/kg	170	200	210	200
Copper	mg/kg	0.3	5.0	0.4	0.4
Zinc	mg/kg	0.6	5.0	0.2	0.2
Manganese	mg/kg	0.5	5.0	9	4
Iron	mg/kg	10	100	15	10
Boron	mg/kg	1.0	4.0	1.3	1.7
Molybdenum	mg/kg			<0.01	<0.01
Water Soluble Cations					
Potassium	mg/kg			27.00	27.00
Calcium	mg/kg			120.0	130.0
Magnesium	mg/kg			72.00	110.00
Sodium	mg/kg			64.00	120.00
Sodium Absorbtion Ratio				1.14	1.87
Other					
Total Arsenic	mg/kg			4.40	4.70
Total Cadmium	mg/kg			<0.02	<0.02
Total Chromium	mg/kg			38.00	38.00
Total Cobalt	mg/kg			17.00	11.00
Total Molybdenum	mg/kg			0.11	0.10
Total Lead	mg/kg			19.00	16.00
Total Selenium	mg/kg			0.48	0.58
Total Vanadium	mg/kg			45.00	48.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 2 Sample 3-007	Paddock 2 Sample 3-007	Paddock 2 Sample 3-007
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				2	2	2
Acidity						
pH (water)		6.0	7.0	6.3	7.7	8.5
pH (CaCl2)		5.2	7.5	5.3	6.3	6.9
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.07	0.07	0.10
EC (sat ext)	dS/m	0.0	1.5	0.4	0.4	0.6
Chloride	mg/kg	0.0	200	21	11	28
Nutrients						
Total Carbon	%			1.6	0.6	0.5
Total Nitrogen	%			0.1	<0.05	<0.05
Nitrate Nitrogen	mg/kg			15.0	3.1	1.6
Ammonium Nitrogen	mg/kg			1.8	1.0	1.3
Phosphorus (Olsen)	mg/kg			53	5	<2
Sulphur (MCP)	mg/kg	9	17	9	7	9
Potassium (Colwell)	mg/kg	170	200	260	84	83
Copper	mg/kg	0.3	5.0	2.5	0.6	0.4
Zinc	mg/kg	0.6	5.0	12.0	0.9	0.2
Manganese	mg/kg	0.5	5.0	28	18	9
Iron	mg/kg	10	100	130	33	20
Boron	mg/kg	1.0	4.0	0.8	0.7	0.9
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			29.00	8.10	16.00
Calcium	mg/kg			21.0	110.0	150.0
Magnesium	mg/kg			5.50	49.00	89.00
Sodium	mg/kg			39.00	87.00	160.00
Sodium Absorbtion Ratio				1.96	1.73	2.56
Other						
Total Arsenic	mg/kg			1.80	0.86	3.60
Total Cadmium	mg/kg			0.05	<0.02	<0.02
Total Chromium	mg/kg			14.00	4.10	20.00
Total Cobalt	mg/kg			2.90	5.50	8.10
Total Molybdenum	mg/kg			0.10	<0.05	0.08
Total Lead	mg/kg			9.10	8.70	11.00
Total Selenium	mg/kg			0.25	0.24	0.59
Total Vanadium	mg/kg			16.00	1.90	24.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 2 Sample 3-007	Paddock 2 Sample 3-007	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Brown	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3					
Emerson Class				2	2	
Acidity						
pH (water)		6.0	7.0	9.0	9.5	
pH (CaCl2)		5.2	7.5	7.5	8.1	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.16	0.33	
EC (sat ext)	dS/m	0.0	1.5	1.0	2.0	
Chloride	mg/kg	0.0	200	31	75	
Nutrients						
Total Carbon	%			0.4	0.3	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			4.2	3.8	
Ammonium Nitrogen	mg/kg			0.8	<0.6	
Phosphorus (Olsen)	mg/kg			<2	<2	
Sulphur (MCP)	mg/kg	9	17	14	74	
Potassium (Colwell)	mg/kg	170	200	90	98	
Copper	mg/kg	0.3	5.0	0.4	0.4	
Zinc	mg/kg	0.6	5.0	0.2	0.4	
Manganese	mg/kg	0.5	5.0	6	3	
Iron	mg/kg	10	100	12	8	
Boron	mg/kg	1.0	4.0	1.5	1.9	
Molybdenum	mg/kg			<0.01		
Water Soluble Cations						
Potassium	mg/kg			32.00	33.00	
Calcium	mg/kg			270.0	220.0	
Magnesium	mg/kg			210.00	260.00	
Sodium	mg/kg			340.00	470.00	
Sodium Absorbtion Ratio				3.77	5.08	
Other						
Total Arsenic	mg/kg			3.80	4.20	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			26.00	22.00	
Total Cobalt	mg/kg			5.90	9.40	
Total Molybdenum	mg/kg			0.12	0.14	
Total Lead	mg/kg			12.00	12.00	
Total Selenium	mg/kg			0.60	0.34	
Total Vanadium	mg/kg			36.00	31.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 2 Sample 4-008	Paddock 2 Sample 4-008	Paddock 2 Sample 4-008
Depth	cm	Lower	Upper	0-10	10-20	20-30
Soil Colour				Brown	Brown	Brown
Soil Texture				Clay	Clay	Clay
Bulk Density	g/cm^3					
Emerson Class				7	2	2
Acidity						
pH (water)		6.0	7.0	6.3	6.2	7.2
pH (CaCl2)		5.2	7.5	5.5	5.2	6.3
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.08	0.05	0.06
EC (sat ext)	dS/m	0.0	1.5	0.5	0.3	0.4
Chloride	mg/kg	0.0	200	21	11	<10
Nutrients						
Total Carbon	%			1.2	0.7	0.3
Total Nitrogen	%			0.1	<0.05	<0.05
Nitrate Nitrogen	mg/kg			11.0	1.9	<0.5
Ammonium Nitrogen	mg/kg			1.7	1.3	<0.6
Phosphorus (Olsen)	mg/kg			60	15	<2
Sulphur (MCP)	mg/kg	9	17	7	16	24
Potassium (Colwell)	mg/kg	170	200	550	330	470
Copper	mg/kg	0.3	5.0	1.7	0.7	0.4
Zinc	mg/kg	0.6	5.0	8.3	0.6	0.3
Manganese	mg/kg	0.5	5.0	23	27	17
Iron	mg/kg	10	100	120	76	19
Boron	mg/kg	1.0	4.0	0.6	0.8	1.4
Molybdenum	mg/kg			<0.01	<0.01	<0.01
Water Soluble Cations						
Potassium	mg/kg			91.00	33.00	43.00
Calcium	mg/kg			24.0	54.0	88.0
Magnesium	mg/kg			4.30	16.00	27.00
Sodium	mg/kg			3.60	18.00	14.00
Sodium Absorbtion Ratio				0.18	0.55	0.33
Other						
Total Arsenic	mg/kg			2.20	3.40	4.50
Total Cadmium	mg/kg			0.06	0.03	<0.02
Total Chromium	mg/kg			17.00	28.00	35.00
Total Cobalt	mg/kg			3.10	5.70	8.60
Total Molybdenum	mg/kg			0.16	0.10	0.13
Total Lead	mg/kg			9.00	13.00	16.00
Total Selenium	mg/kg			0.31	0.32	0.45
Total Vanadium	mg/kg			20.00	32.00	45.00

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)

Analyte	Unit	Optimum Range		Paddock 2 Sample 4-008	Paddock 2 Sample 4-008	
Depth	cm	Lower	Upper	30-40	40-60	
Soil Colour				Orange/Yellow	Brown	
Soil Texture				Clay	Clay	
Bulk Density	g/cm^3					
Emerson Class				3	6	
Acidity						
pH (water)		6.0	7.0	7.6	8.3	
pH (CaCl2)		5.2	7.5	6.8	7.4	
Salinity						
EC (1:5)	dS/m	0.0	0.6	0.07	0.08	
EC (sat ext)	dS/m	0.0	1.5	0.4	0.5	
Chloride	mg/kg	0.0	200	10	<10	
Nutrients						
Total Carbon	%			0.4	0.2	
Total Nitrogen	%			<0.05	<0.05	
Nitrate Nitrogen	mg/kg			2.4	<0.5	
Ammonium Nitrogen	mg/kg			0.8	<0.6	
Phosphorus (Olsen)	mg/kg			3	<2	
Sulphur (MCP)	mg/kg	9	17	20	16	
Potassium (Colwell)	mg/kg	170	200	450	380	
Copper	mg/kg	0.3	5.0	0.5	0.4	
Zinc	mg/kg	0.6	5.0	0.6	0.5	
Manganese	mg/kg	0.5	5.0	7	3	
Iron	mg/kg	10	100	24	9	
Boron	mg/kg	1.0	4.0	1.9	2.4	
Molybdenum	mg/kg			<0.01	<0.01	
Water Soluble Cations						
Potassium	mg/kg			38.00	37.00	
Calcium	mg/kg			96.0	110.0	
Magnesium	mg/kg			31.00	42.00	
Sodium	mg/kg			26.00	29.00	
Sodium Absorbtion Ratio				0.59	0.60	
Other						
Total Arsenic	mg/kg			2.10	5.00	
Total Cadmium	mg/kg			<0.02	<0.02	
Total Chromium	mg/kg			21.00	36.00	
Total Cobalt	mg/kg			22.00	9.40	
Total Molybdenum	mg/kg			<0.05	0.11	
Total Lead	mg/kg			17.00	16.00	
Total Selenium	mg/kg			0.30	0.39	
Total Vanadium	mg/kg			23.00	42.00	

* Optimum ranges are a guide only based on the selected crop type

** Analysis performed by Nutrient Advantage (a NATA accredited laboratory)