Land application of sewage sludge (biosolids) in Australia: risks to the environment and food crops
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ABSTRACT

Australia is a large exporter of agricultural products, with producers responsible for a range of quality assurance programs to ensure that food crops are free from various contaminants of detriment to human health. Large volumes of treated sewage sludge (biosolids), although low by world standards, are increasingly being recycled to land, primarily to replace plant nutrients and to improve soil properties; they are used in agriculture, forestry, and composted. The Australian National Biosolids Research Program (NBRP) has linked researchers to a collective goal to investigate nutrients and benchmark safe concentrations of metals nationally using a common methodology, with various other research programs conducted in a number of states specific to regional problems and priorities. The use of biosolids in Australia is strictly regulated by state guidelines, some of which are under review following recent research outcomes. Communication and research between the water industry, regulators and researchers specific to the regulation of biosolids is further enhanced by the Australian and New Zealand Biosolids Partnership (ANZBP). This paper summarises the major issues and constraints related to biosolids use in Australia using specific case examples from Western Australia, a member of the Australian NBRP, and highlights several research projects conducted over the last decade to ensure that biosolids are used beneficially and safely in the environment. Attention is given to research relating to plant nutrient uptake, particularly nitrogen and phosphorus (including that of reduced phosphorus uptake in alum sludge-amended soil); the risk of heavy metal uptake by plants, specifically cadmium, copper and zinc; the risk of pathogen contamination in soil and grain products; change to soil pH (particularly following lime-amended biosolids); and the monitoring of faecal contamination by biosolids in waterbodies using DNA techniques. Examples of products that are currently produced in Western Australia from sewage sludge include mesophilic anaerobically digested and dewatered biosolids cake, lime-amended biosolids, alum sludge and compost.

Key words | agriculture, alum sludge, composting, dewatered biosolids cake (DBC), forestry, lime amended biosolids (LAB), pathogens

INTRODUCTION

There is a gradual progression towards improved wastewater treatment and wastewater sludge management throughout the world (LeBlanc et al. 2008). In Australia, the secondary treatment of sewage sludge is common, with a unanimous view amongst state regulators in the short and medium term to manage the stabilised sludge (biosolids) in a beneficial way to take advantage of nutrients and desirable soil enhancing properties; though in the long term newer technology and economic drivers may dictate future trends (Dixon & Anderson 2007). Overall the quantity of biosolids produced in Australia (360,000 dry tones yr⁻¹) is low by world standards and furthermore produced in a continent...
with relatively low population density, but nevertheless the management is subject to much public scrutiny (Gale 2007). Using Western Australia as an example, the discharge of sewage sludge into the Swan River ceased in the mid 1900s as a means to prevent water pollution. In the 1970s, the benefits of sewage sludge as a soil amendment and nutrient source were exploited by market gardeners, who collected dried sewage sludge from drying ponds for vegetable production. However, potential health risks in the late 1980s led to the construction of three incinerators to handle a large proportion of the sludge, but by 1990 all three units were shut down due to high costs and odour issues. During this period, the sludge was also used in compost or landfilled. A number of problems associated with sludge drying beds, such as lack of space, odours, flies and risks to groundwater contamination, resulted in them being progressively decommissioned. As a result, wastewater treatment plants were amplified or, in some cases, newly constructed to process sludge and to use established processes to achieve stabilisation and significant pathogen reduction. The metropolitan area in Western Australia is currently serviced by three major WWTPs producing a total of 21,000 dry t biosolids yr⁻¹. Two are advanced secondary treatment plants that stabilise sludge by mesophilic anaerobic digestion and then use enclosed centrifuges to rapidly dewater the biosolids to 20% total solids, with discharge of effluent via outfalls to the ocean. The third stabilises primary and extended aeration sludge by the addition of lime, although previously it produced pelletised biosolids by thermal drying (Bridle et al. 2000) using an indirect rotary drum dryer, with pellets used for energy recovery at the plant. The majority of the biosolids (80%) are beneficially used for direct land application in agriculture and forestry, with the remainder used for unrestricted use via composting (17%) and research (3%). The inland towns consist of smaller WWTPs, which commonly dose the sludge with alum (Al₂(SO₄)₃) to reduce the concentration of phosphorus in effluent that is discharged to inland waterways. Western Australia is unique in that the government owned Water Corporation is the sole industry responsible for managing more than 100 wastewater treatment facilities in both metropolitan and rural regions (Rigby & Narendranathan 2010), whereas other states are under the responsibility of numerous water utilities. Consequently there is no typical biosolids management system that applies readily across Australia (Gale 2008).

Currently, the end-use of biosolids varies in each state, as determined by state water industries and is driven by the quality of the product and available options for beneficial use or disposal that commonly includes agricultural land application, forestry, composting and blending with other products, mine-site rehabilitation, stockpiling, landfill or incineration for energy recovery. Where biosolids are applied to land in Australia, they are governed by a national regulatory framework (NRMMC 2004) and state guidelines have been developed to ensure minimal risks to the environment, including land and water resources, and the community. Overall, the beneficial use of biosolids that meet regulatory requirements for direct land application is promoted in Australia. Guidelines from overseas, predominantly the USA (USEPA 1995) and preliminary research investigations during the 1990s in eastern Australia (Osborne et al. 1995) were used initially as a basis for biosolids application in New South Wales (NSW EPA 1997), and then subsequently adapted for use elsewhere throughout Australia, for example, DEP et al. (2002) and EPA Victoria (2004). Biosolids that do not meet regulatory requirements are not suitable for direct land application, for example large quantities of biosolids have accumulated in stockpiles in Melbourne due to high levels of contaminants. The benefits and risks of the land application of biosolids for a range of soils and climatic regions within Australia, has been examined in detail by the Australian National Biosolids Research Program (NBRP) (McLaughlin et al. 2007b), enabling existing guidelines and overseas data, particularly for metal contaminant loadings to be reviewed in the light of regional-specific data. Other potential areas of concern in Australia have included pathogens and organic contaminants, including pharmaceuticals and endocrine disruptors (Warne et al. 2006). Recent investigation by Clarke et al. (2008) showed levels of dioxin-like compounds in Australian sewage sludge were well below European proposed guidelines and hence the land application of biosolids was not likely to pose a problem for these contaminants. Constant monitoring of the quality of biosolids (contaminant and pathogen) conducted by the Water Corporation established that a number of parameters were below detection limits listed in the guidelines and has
resulted in the adoption of less stringent monitoring of that parameter, with attention given instead to newly emerging contaminants of concern. Throughout Australasia, collaboration between practitioners, users and regulators for the reform of biosolids regulation is further facilitated by the Australian and New Zealand Biosolids Partnership (ANZBP) (Speers et al. 2009).

This paper discusses the main research programs conducted in Western Australia to assess the suitability and risk of biosolids relating to the direct land application for food and forestry production, some under the auspices of the Australian NBRP. The key research programs covered in this paper include nutrient availability (predominantly nitrogen and phosphorus), effect on soil acidity, bioavailability of heavy metals, the risk of pathogen transfer, methods to reduce fly breeding and methods for detection of faecal contamination. Biosolids products which have been studied include dewatered biosolids cake (DBC), lime-amended biosolids (LAB) and alum sludge. The paper highlights examples of the research direction taken to better address environmental and health risks attributed to the use of biosolids in Australia.

RESEARCH PROGRAMS RELATING TO THE BENEFICIAL USE AND RISKS OF BIOSOLIDS

Research on plant nutrients

Land in Australia has only been used for broad-scale farming over the last 200 years. Many of the soils are highly weathered, environmentally fragile with low organic matter and are often sandy, infertile and acidic (Moore 2002). Therefore, to achieve productivity, soils are managed to increase concentrations of organic matter and regular applications of fertiliser are required to replace plant nutrients removed in produce. The Australian NBRP was established by the CSIRO in Australia in 2002 to co-ordinate research relating to the benefits and risks of using biosolids in agriculture (McLaughlin et al. 2007b); and arose at a time when other options for long term disposal of sludge, such as landfill was considered environmentally unsustainable.

The two main plant nutrients in biosolids, nitrogen (N) and phosphorus (P) have been investigated as a substitute for commercially applied fertiliser. Final loading rates in Australia have typically been determined by estimating the amount of plant available N in the biosolids and the crop nutrient uptake requirement for N, often termed the nitrogen limited biosolids application rate (NLBAR) (DEP et al. 2002). At the majority of sites throughout Australia, the application of biosolids had a positive effect on crop yields (McLaughlin et al. 2007b). In Western Australia, the NLBAR has been estimated to be approximately 8 t dry solids (DS) ha$^{-1}$ for wheat in dryland agriculture, equivalent to 70 kg of plant available N ha$^{-1}$, with grain yield of wheat at the NLBAR comparable to yields obtained using farmer rates of commercial inorganic fertiliser in the year of application (Pritchard & Collins 2006). The NLBAR may be higher in other regions, such as sub-tropical Queensland where higher yielding crops have a higher requirement for N (Barry & Bell 2006). The NLBAR has assumed that 10–25% of the organic N in biosolids is mineralized in the first year, though recent research in Queensland (Pu et al. 2008) and Western Australia indicate this to be higher. Rigby et al. (2010a) showed that the efficiency of N in biosolids relative to inorganic N in a Mediterranean type climate in Western Australia is dependent on the treatment method of the biosolids; 39% in DBC, 65% in alum sludge and 65% in LAB. The findings that a greater proportion of N is available in alum sludge and LAB is consistent with findings elsewhere that the method of stabilization used to produce the biosolids will affect N availability (Smith et al. 1998; Morris et al. 2005; Pu et al. 2008). A problem with underestimating N mineralization is that excess N may enter water bodies through runoff and/or leaching and lead to eutrophication of water bodies and/or gaseous losses contributing to greenhouse emissions; hence research is continuing in this area.

A concern of using the NLBAR to determine land application rates is that the loading rate of P is higher than typically applied through a commercial fertiliser application. In Australia, for example, loading rates of P in biosolids can range from 140 to 560 kg P ha$^{-1}$ at any one site, in contrast to typical inorganic fertiliser P applications of around 20 kg P ha$^{-1}$, and therefore best agronomic management practices need be used to prevent environmental problems (Pritchard et al. 2007). There are differences, however between P applied as inorganic P fertiliser
or applied as biosolids P. Biosolids contain between 90–95% inorganic forms of P (Barry & Bell 2006), are less soluble than inorganic P fertiliser, and in dryland broadacre agriculture are approximately 67% as effective as inorganic P fertiliser (Pritchard 2005). However, the relatively high loading rates of biosolids P do not necessarily pose a problem on many soil types; for example, P deficient soils with high P sorption properties have a low risk of P leaching. Consequently the P limiting biosolids application rate (PLBAR) is less restrictive than N loading rates and largely determined by soil properties (Pritchard & Penney 2003). Given the finite nature of P as a dwindling resource (Evans 2009), there is a need to further conserve and recycle P. Hence there is a need to better use the P in land applied biosolids, and to reduce the discharge of P in effluent lost to waterways, such as through struvite recovery or similar processes.

Heavy metals (copper, zinc and cadmium)

Cadmium (Cd), copper (Cu) and zinc (Zn) were considered to be the metals of greatest environmental concern for long-term biosolids use Australia (McLaughlin et al. 2007b). The NBRP investigated the solubility of these three metals by comparing them to metal salts across a range of sites and environmental conditions throughout Australia. State research units existed in New South Wales, South Australia, Queensland, Victoria and Western Australia (Figure 1).

A common experimental methodology was used by each state research group, applying biosolids products at multiples of the NLBAR, and metal salts treatments applied with the highest rates designed to simulate repeat and long-term biosolids use, and induce phytotoxicity in plants. A number of publications have arisen in response to the research findings that characterize how metals in biosolids behave across the diverse soils and environmental conditions throughout Australia, e.g. in McLaughlin et al. (2006, 2007a) and Heemsbergen et al. (2009); these outcomes can be considered by regulators and industry for improving regulatory guidelines. A major finding was that that grain Cd concentrations grown on biosolids-amended soils were below the current food standard of 0.1 mg kg$^{-1}$ (wheat), even when biosolids were applied in excess of crop N requirement, though uptake varied depending on soil type.

To take account of different soil types and solubility principles of Cd, McLaughlin et al. (2007a) suggested that the single protective maximum soil concentration for Cd (1.0 mg Cd kg$^{-1}$) was problematic and the maximum permitted Cd concentration should be more restrictive (0.3 mg Cd kg$^{-1}$) in acidic sands and less restrictive in heavier soil types (2.6 mg Cd kg$^{-1}$) to ensure wheat grain would not exceed Cd food standards. Critical concentrations of Cu and Zn examined by the NBRP in terms of both the soil microbial activity and plant phytotoxicity response indicated that soil parameters such as pH, cation exchange capacity (CEC) and clay content were main determinants in predicting microbial survival to soil concentrations of Cu and Zn (Broos et al. 2007); whereas soil pH, CEC and organic matter content were the main determinants in plant survival (Warne et al. 2008a,b). Heemsbergen et al. (2009) explain the development of Cu and Zn added contaminant limits (ACL) for biosolids and conclude that the current single soil quality guidelines in Australia (100–200 mg Cu kg$^{-1}$ and 200–250 mg Zn kg$^{-1}$; NRMMC 2004) do not reflect different soil physiochemical properties. These authors hence proposed a new framework for Cu and Zn in soils receiving biosolids to protect 95% of species. From the research conducted, it is unlikely that biosolids applied to soils in Australia will exceed the maximum allowable soil contaminant concentration (MACC) at any given site, given the stringent soil monitoring procedures.

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**Figure 1** | Locations of field experiments in the Australian National Biosolids Research Program (from McLaughlin et al. 2007a).
required prior to application. For example, for acidic sands, the most vulnerable soils for metal phytotoxicity and food chain hazards, soil concentrations in the surface (0 – 10 cm) in biosolids applied at 4.5 times the recommended agronomic rate (based on N), remained below MACC for Cd, Cu and Zn (Pritchard & Collins 2006). It should be noted that the majority of biosolids currently produced in Western Australia are typically domestic in origin and therefore have a low industrial trade waste input, which is reflected in the lower metals concentrations compared with many sludges produced elsewhere in industrialized nations. In addition, repeat applications of biosolids with a frequency less than 5 years are uncommon.

Lime-amended biosolids (LAB)

The production of lime-amended biosolids is restricted to a few WWTPs in Australia and often as a short term solution to sludge stabilisation. Subiaco WWTP (Western Australia) applies quicklime (CaO) post-treatment to dewatered sludge cake (combined primary and activated sludge) to increase the pH of the mixture and significantly reduce pathogens. The land application of LAB is comparable to equivalent amounts of agricultural lime in neutralizing soil acidity, though the main benefit for crop growth appears to be from the nutrient value of the recycled nutrients (typically N and P) (Pritchard et al. 2008). Research elsewhere has also shown LAB to have a similar neutralizing value to an equivalent application of agricultural lime (Stehouwer & Macneal 2004; Cooper 2005). Compared to DBC, the cumulative mineralizable portion of organic N in LAB is higher in the first season (Rigby et al. 2010a) therefore the plant available nitrogen value of LAB needs to be considered when calculating loading rates of biosolids based on N to ensure N is not applied to soil in excess of plant uptake.

Alum sludge

Many rural wastewater treatment facilities use alum dosing (Al₂(SO₄)₃) to reduce the concentration of P in effluent, which is a government licence requirement to minimise the pollution of inland waterways with P. The alum when added to the wastewater treatment process forms a precipitate, which is removed with the sludge and then typically landfilled. The use of alum sludge (7% Al) as a potential fertiliser source for plant growth has recently been examined in Australia as a beneficial use option by Rigby et al. (2008) and is under further investigation. The application of alum sludge caused a reduction in shoot uptake of P when applied at the N value of the sludge to meet plant requirements; however, satisfactory crop production could be achieved where the initial soil P status was adequate. There has been a limited amount of research into the land application of alum sludge elsewhere, although the prevention of P loss in biosolids-amended soils with alum or iron sulphate (Huang et al. 2007) and the co-application of biosolids with potable water treatment residuals following alum dosing (Ippolito et al. 2002, 2006; Agin-Birikorang et al. 2008; Wagner et al. 2008) has been investigated.

Forestry

Forestry plantations are a large potential market for biosolids use in Western Australia with 5,500 ha of softwood plantations available for the application of biosolids, which are used to replace inorganic fertilizer applications of N and P at various stages throughout the rotation. Dumbrell & McGrath (2002) investigated the response of pines to the application of DBC in a 17 year-old Pinus pinaster plantation on deep sand and showed that biosolids treatments applied at 17 and 34 t DS ha⁻¹ increased tree volume increment compared with the nil fertiliser control. The standard mineral fertiliser treatment (500 kg ha⁻¹ di-ammonium phosphate + 250 kg ha⁻¹ urea) produced the largest volume increment in the first year only relative to the control treatment, relative volume increments in the biosolids treatments increased greatly in the second year and continued to increase in the third year, whilst the response to the mineral fertiliser treatment was constant and then declined. Biosolids applied at 34 t DS ha⁻¹ significantly increased foliar concentrations of N, P, Zn and manganese (Mn) above all other treatments over three years. Both the mineral fertiliser treatment and biosolids treatment at 17 t DS ha⁻¹ significantly increased foliar concentrations of N for two years and P for three years above the control treatment. Dumbrell (2006) showed that eight years after the start of the experiment, the trees in the biosolids treatments continued to grow at a faster rate than
the trees in both the nil and mineral fertiliser treatments, with the longevity of response yet to be determined. Surface soil (0–10 cm) samples and groundwater monitoring did not detect any indication of pathogens (thermo-tolerant coliforms or salmonella), pesticides, and total N or P from any treatment. Concentrations of heavy metals in the 0–10 cm surface soil were below environmental DEP et al. (2002). The mineral fertiliser treatment was the only treatment to significantly increase bicarbonate extractable P in the surface soil after treatment. Concentrations of nitrate in groundwater remained unchanged in samples taken from bores within the plantation, though levels of nitrate were excessive beneath stockpiles on biosolids outside the study area (Dumbrell & McGrath 2003). The major constraints identified from this study relate to the high cost of transport and application, on site storage provisions, and the time required for stockpiling and application. The minor constraints were related to the social aspects, such as odour and public access, and the required operational condition of the plantation. Elsewhere in Australia, the application of biosolids in forestry improved the growth of trees, such as in Eucalypts following mine-site rehabilitation and was largely dependent on the N value (Kelly 2006). Recent research by Kelly & Cowie (2008) has focused on the role of biosolids (and other organic wastes) in forestry plantations to ascertain the long term enhancement of soil carbon to better understand the role of recycled organics in the mitigation or sequestration of greenhouse gases.

Vectors in stockpiled biosolids and the centralised biosolids storage facility

In Western Australia over the last decade, areas along the Swan Coastal Plain have reported excessive fly breeding. In particular, the blood-sucking stable fly (Stomoxys calcitrans) is of most concern as it breeds in organic mediums, including manures (Penney & Dadour 2002). Dewatered biosolids cake, traditionally stockpiled in earthen bunds in paddocks prior to agricultural land application, provided a medium for fly breeding and placed the Water Corporations land application program at risk of closure. Therefore, in 2002, the Water Corporation commenced a project to determine the attractiveness and breeding capacity of flies in DBC over 12-months and investigated the seasonal variation and response of fly breeding in fresh and aged DBC. The study identified the chemical and physical components that rendered biosolids attractive as a fly breeding medium by examining the relationship between the moisture level, pH, the ammonia content and specific organic matter content; and correlated the above information to determine management controls to prevent the breeding and emergence of flies. Covering the stockpiles during fly breeding season for 10–12 weeks was determined the most effective control method. The building of a centralised biosolids storage facility (CBSF) was developed to overcome the problems of fly breeding and to alleviate on-site storage problems. There are limited facilities to store DBC at the WWTPs (150 to 300 t DS), with holding space only available for a maximum of 36 hours in overhead hoppers. Biosolids will be transported daily to the CBSF by trucks from WWTPs and stored for a minimum of 10 weeks prior to carting to agricultural properties. The facility is the first of its kind in Australia and has been designed to be vector proof to prevent the breeding of flies. It has been noted that fly attractiveness and breeding is not an issue in

Composting

A number of private companies further process biosolids and produce products suitable for use in domestic markets, sourced from Perth and regional areas in Western Australia and accounted for 5,000 t DS yr⁻¹ in 2009. Until recently the percentage of compost being utilised in areas such as horticulture and turf was minimal, however with changes to the availability of raw materials such as chicken manure, this market is also expanding. There are many methods available for composting and blending material to produce a product that meets the market demands. However, the typical composting process consists of: initial blending of raw materials, windrowing to control temperature, and mixing and final blending. During the first stage, biosolids are blended with other products such as sawdust and green waste, which is windrowed for approximately 10 to 16 weeks, during which time the rows are turned at least twice a week. Once the biosolids compost has met the unrestricted use requirement (DEP et al. 2002), aliquots of the mix are taken and depending on market demand are blended with peat, sand, loams or mulch.
lime-amended biosolids because of the lower moisture content. A further problem with stockpiling biosolids for lengthy periods includes the potential for nutrient rich leachate to contaminate groundwater.

Pathogens

Research into public health risks associated with the storage and land application of biosolids in Australia are ongoing and address global issues identified by Gerba & Smith (2005) as needed to better protect water and food supplies, by Horswell et al. (2007) to quantify numbers and survival patterns of pathogens in land applied sludge and by Lang et al. (2007) who note that few published data are available to quantify pathogen decay in sludge-amended soils under temperate agricultural conditions. The risk of enteric pathogens surviving in the soil and transferring to cereal grains following the land application of DBC in Australia has been investigated by Crute et al. (2005). Enteric pathogens (Escherichia coli, Enterococci and bacteriophage) decreased over time in soil in both field and pot experiments following the application of DBC and fell to below detection after 6 to 7 months, prior to the grain being harvested. Enteric pathogens were not detected on the lower leaves of the wheat plants sampled in the field 12 weeks after biosolids application at agronomic application rates. Research into the survival patterns of Salmonella typhimurium, E. coli, bacteriophage (MS2) and adenovirus, artificially inoculated into biosolids-amended soils and nill-biosolids soil at sites in Western Australia and South Australia is under further investigation and considers concerns expressed by Sidhu & Toze (2009) that much of the published data for the detection of enteric pathogens in biosolids is non-comparable due to the lack of standardised methods and because very few authors have mentioned detection limits of the methods used. Elsewhere in Australia, Levitan et al. (2008) has examined public health risks associated with pathogens following the land application of DBC in forestry, and is under further investigation. In Victoria, the survival of enteric pathogens has been investigated in digested liquid biosolids and stockpiled biosolids by Rouch et al. (2008). The research suggested that air-drying sludge reduced pathogen content to a level that may be acceptable for direct land application after 1 year, rather than the current withholding period of 3 years and is under further investigation.

Faecal contamination of waterways

Australia guidelines for the land application of biosolids (NRMNC 2004) attempt to prevent surface water contamination of nutrients, pathogens and other contaminants in many agricultural regions by restricting spreading close to vulnerable sites, which could potentially cause a decline in water quality, for example increased nutrient loads (eutrophication). In complex farming systems, the cause of water pollution may not be clear as contaminants may include inorganic fertilisers, livestock excreta, or more recently biosolids. Ho et al. (2008) used polymerase chain reaction (PCR) amplification of published priming sequences and restriction site profiling of amplified DNA across the 16S rRNA gene of anaerobic gastrointestinal bacteria to distinguish faecal material between human and animals and trace biosolids in farming systems. Other researchers have shown molecular source tracking by PCR can discriminate between human and animal faecal material and has potential to track the source of faecal contamination in water (Nebra et al. 2003; Dorai-Raj et al. 2005). Ho et al. (2008) examined 31 primer pairs of common gastrointestinal bacteria, Bacteroides spp. and Bifidobacteria spp. for human and animal faecal material. Three Bacteroides sp. primer pairs were investigated with moderate success; two were useful for cow and sheep faecal materials, and biosolids, whilst the third primer was specific only for biosolids. All three primer pairs were unable to PCR-amplify Bacteroides spp. sequences in faecal material of kangaroo. One Bifidobacteria spp. primer pair investigated was useful for sheep, cow and kangaroo faecal material, and biosolids. The serial dilution of water contaminated by livestock excreta and biosolids is being examined further to enable the sensitivity of this method to be applied in the field and thus better track the source of water pollution.

CONCLUSIONS

A number of research programs across Australia have investigated the benefits and risks associated with the land
application of biosolids for food production. The level of treatment of sewage sludge in Australia is generally high with government regulations in place concerning the quality of the biosolids and land application guidelines. Large centralised wastewater treatments plants are a relatively recent development in the history of Australia. The major issues relating to the land application of biosolids in Australia has been investigated as a coordinated approach by the Australian National Biosolids Research Program, involving several field experimental sites and a number of research organisations with the aim to ensure that biosolids pose minimal risks to public health and the environment. Research over the last decade has centered mostly on that of the benefits and risks of nutrients (N and P) and heavy metals (Cd, Cu and Zn), with a national approach ensuring that key outcomes could be used to derive regulations. Consideration has been given to the unique soil and climatic conditions in Australia. Individual states and researchers have been responsible for more localised research specific to their needs, and although not all presented in this paper, examples from Western Australia have illustrated major research activities in agriculture and forestry, with composting already established as a sound long-term market. The positive aspects of biosolids as a fertiliser and a soil amendment have created a demand for a resource, which has often been ‘wasted’: Farmers have benefited from crop and soil improvement as a result of biosolids application, with a number of years of research data available to support this. Tree volume growth in pine plantations has increased significantly following biosolids application. The agricultural land application rates are being fine tuned to ensure biosolids loading rates consider both the nutrient needs of the crop and the environmental risks associated with the specific product (i.e. dewatered biosolids cake, lime-amended biosolids, alum sludge). Continuing research is being conducted into the risk of pathogens to ensure the safety of public health. Techniques are being developed to better monitor the presence of faecal matter in waterways using PCR methods. The fly breeding program has highlighted solutions to prevent the breeding of flies in biosolids and influenced the design of the Centralised Biosolids Storage Facility. The land application of biosolids is constantly subject to public scrutiny and therefore it is essential to have a sound research program to be scientifically accountable to ensure that the environment and public health are not being compromised by real or perceived risks.

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