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Assessing Aspects of the Effectiveness of Biosolids Application and Soil Incorporation

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Abstract

Today's world is facing a range of environmental challenges. It is becoming clear that along with clean air, the planet also requires enhanced supplies of clean water. Wastewater treatment is a key component of the water supply chain, and the resulting biosolids need to be managed in a more sustainable and focused manner on a global scale. In Australia, hundreds of thousands of tonnes of biosolids are produced each year with a majority of these biosolids being used in land application for agricultural purposes. Benefits of biosolids land application range from improving soil quality for crop production, through the addition on organic matter, vital trace elements for plant growth and increased nutrient levels to reductions in erosion and economic incentives for various stakeholders. Land application of biosolids presents some environmental risks if not managed effectively. Risks range from contamination of surface and groundwater supplies, pathogens, odour, vector borne disease and ingestion by animals. Many of these issues are minimised through the soil incorporation of land applied biosolids which forms a physical barrier between biosolids and potential risk causing agents while also decreasing ingestion by animals. Currently there is a lack of documentation surrounding what is considered adequate levels or specific percentages of incorporation which are required to reduce these potential risks to those acceptable by industry regulators. To develop a process of assessing adequate levels of incorporation a number of techniques were trialled to assess surface coverage of biosolids pre and post-incorporation and relate this to potential risks. Using a technique developed through this study it was found that incorporation of biosolids lead to statistically significant reductions in biosolids surface coverage for two different ploughing techniques used. The biosolids surface coverage post-incorporation was found to have little to no potential for causing environmental risks, when compared with other studies of surface applied biosolids. This study highlights a need for biosolids and industry regulators to develop a technique, such as, those used in this study for assessing adequate levels of biosolids soil incorporation. Making this information readily available to biosolids practioners and regulators will minimise confusion surrounding what represents adequate levels of incorporation.

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Abstract

Today's world is facing a range of environmental challenges. It is becoming clear that along with clean air, the planet also requires enhanced supplies of clean water. Wastewater treatment is a key component of the water supply chain, and the resulting biosolids need to be managed in a more sustainable and focused manner on a global scale. In Australia, hundreds of thousands of tonnes of biosolids are produced each year with a majority of these biosolids being used in land application for agricultural purposes. Benefits of biosolids land application range from improving soil quality for crop production, through the addition on organic matter, vital trace elements for plant growth and increased nutrient levels to reductions in erosion and economic incentives for various stakeholders. Land application of biosolids presents some environmental risks if not managed effectively. Risks range from contamination of surface and groundwater supplies, pathogens, odour, vector borne disease and ingestion by animals. Many of these issues are minimised through the soil incorporation of land applied biosolids which forms a physical barrier between biosolids and potential risk causing agents while also decreasing ingestion by animals. Currently there is a lack of documentation surrounding what is considered adequate levels or specific percentages of incorporation which are required to reduce these potential risks to those acceptable by industry regulators. To develop a process of assessing adequate levels of incorporation a number of techniques were trialled to assess surface coverage of biosolids pre and post-incorporation and relate this to potential risks. Using a technique developed through this study it was found that incorporation of biosolids lead to statistically significant reductions in biosolids surface coverage for two different ploughing techniques used. The biosolids surface coverage post-incorporation was found to have little to no potential for causing environmental risks, when compared with other studies of surface applied biosolids. This study highlights a need for biosolids and industry regulators to develop a technique, such as, those used in this study for assessing adequate levels of biosolids soil incorporation. Making this information readily available to biosolids practioners and regulators will minimise confusion surrounding what represents adequate levels of incorporation.

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1 Introduction

Today's world is facing a range of environmental challenges. It is becoming clear that along with clean air, the planet also requires enhanced supplies of clean water. Wastewater treatment is a key component of the water supply chain, and the resulting biosolids need to be managed in a more sustainable and focused manner on a global scale. The issues of wastewater treatment and management of the solids produced are global concerns with growing challenges for all stakeholders (Beecher et al., 2008, LeBlanc et al., 2008). These stakeholders range from the facilities producing the biosolids, users of the products, regulators, politicians, the scientific community, tax payers and the general public.

On a global scale, the conventional means of dealing with wastewater is for processing to occur at a centralised treatment facility; such facilities generally require large amounts of infrastructure and are expensive to establish. While centralised treatment facilities work well in some circumstances, such as, large towns or cities, they are impractical in others. In industrialised countries it is common practice for the collection and treatment of wastewater at a central facility, utilising a combination of physical and biological processes to help remove large solids and decrease biological and pollutant levels in the resulting waste water. These processes may be followed by further sophisticated tertiary treatment if a greater level of sanitisation is required, keeping in mind that the higher the level of treatment achieved, the greater the amount of wastewater solids being created and greater costs incurred (LeBlanc et al., 2008).

Although industrialised countries have more sophisticated wastewater treatment, a large percentage of the world's population (41%) currently live without proper sanitation facilities (LeBlanc et al., 2008). Increasing the effectiveness of the management and sanitation of these excreta poses one of the largest challenges in developing countries but, if successful, will also provide some of the largest health benefits to communities.

The end use of the wastewater and sludge can vary greatly depending on where in the world it is produced, with disposal methods ranging from landfill, use as an energy source and being treated and used as a soil conditioner or fertilizer (Petroff and Brashear, 2005). With methods of ocean disposal now being banned in many countries throughout the world (Beecher et al., 2008) and issues of decreasing space in landfill, other disposal options must be considered. Incineration is a commonly used practice (DeWolf, 2009) but has very high costs and also air pollution issues, and also does not remove the need to dispose of remaining wastes (e.g. ash) in landfill. Technological

advances in the future may see options for better use for biosolids in energy recovery resources, but currently these have their own pollution issues and focus has shifted to methods of land application.

The wastewater sludge which is treated and used on land in the practice of "land application" is known as "biosolids". This is not strictly the only end use for biosolids but is the focus of this review. Although there is much evidence as to the benefits of recycling and use of biosolids as a fertilizer or soil conditioner, it is not a global practice and has often met with public opposition. Within the global context, with concerns of climate change, disease, environmental pollution and diminishing global resources, it is important that beneficial use of biosolids becomes a more accepted practice rather than considering the wastewater by-products as 'waste' (LeBlanc et al., 2008, Beecher et al., 2008, Synagro, 2002).

The issues posed by wastewater sludge at a global level need to be properly managed at national and even local levels in order to overcome some of the challenges present in this area. Australia, much like Europe, North America and New Zealand, possesses infrastructure which meets the sanitation needs for a vast majority of the population that allows them to focus on the improvement of management in the wastewater sludge and biosolids arena. With a range of engineers, scientists, agricultural experts and government regulators all involved in efforts to increase management efficiency, beneficial use options and reduce potential impacts of biosolids use, Australia is well aware of the many challenges associated with wastewater management (AWA, 2011, Joshua et al., 1998, Eamens et al., 2006, Pritchard et al., 2010).

In Australia, over 300,000 dry tonnes of biosolids were produced in 2010 alone making it a significant amount of material to manage sustainably (AWA, 2011) . With a range of methods used in beneficial use from forestry, composting, landfill, stockpiling and sea disposal, agricultural use was by far the most widely practiced with over half of biosolids produced being used for this purpose. This Australian trend is mirrored worldwide with many developed countries choosing to recycle and land apply biosolids rather than opt for other methods, such as, incineration or landfill (LeBlanc et al., 2008, Petroff and Brashear, 2005, Spicer, 2002). With such vast qualities of biosolids being used in agriculture, there is a great need for legislation to govern how, when and where biosolids can be used, not only in Australia but globally.

Australian legislation regarding biosolids is similar to that of other developed countries which also use biosolids for agricultural purposes, including the European Union (EU) and the United States of America (USA). Due to the fact that much research has been conducted in the EU and USA over recent decades, advanced analyses have been developed of both the risks and benefits of the

different beneficial use options for biosolids (Cotching and Coad, 2011, Evans et al., 2004, Kuchenrither et al., 2002). A significant amount of research has also been conducted within Australia by the CSIRO and NSW Department of Primary Industries over recent decades, developing our understanding of biosolids within the Australian context (AWA, 2011). Working with this foundation knowledge, many countries, including Australia, have developed guidelines, policy and legislation which reflect the EU and USA approach whilst also incorporating local needs and conditions.

Within Australia, each state is responsible for its own water management and with this brings different structures for this management. In New South Wales (NSW), the majority of the population is serviced by Sydney Water Corporation and Hunter Water, while the remaining population is serviced by local government councils administering the water supply and dealing with wastewater. This is very different to other states such as Western Australia where a single water corporation is responsible for the supply of all retail water services (LeBlanc et al., 2008) across the state. With all states being responsible for their own water management and the possibility of many suppliers, it is understandable that each state will have different biosolids guidelines. Although there are many similarities between each state's guidelines, there are some fundamental differences, including heavy metal limits, which create confusion for the general community.

In NSW, where over 80, 000 dry tonnes of biosolids are produced each year (AWA, 2011), the *Environmental guidelines: Use and disposal of biosolids products 1997* (EPA, 1997) are the current biosolids guidelines in use. The focus of these guidelines is to promote the sustainable use of wastewater products whilst also providing maximum protection for the environment and public health.

There are many potential advantages in the beneficial use of biosolids products. Benefits range from direct agricultural aspects of improving soil quality for crop production, through the addition of organic matter, vital trace elements for plant growth and increased nutrient levels (Rigby et al., 2009, Tsadilas et al., 2005, Vu Tran, 2008). The benefits also extend to reductions in soil erosion, reclamation of lands with poor soils and enrichment of forestry land. Environmental benefits which are not directly linked to agriculture include conserving landfill space and reductions in greenhouse gases which can are emitted through processes of incineration. Economic benefits also exist for companies who provide land application services, with many water corporations aiming for most, if not all biosolids products produced to be beneficially used.

Although land application of biosolids appears to be one of the most commonly used methods of beneficial use within Australia and NSW, there are still difficulties and environmental risks to

consider. Some of the main concerns related to biosolids are the potential impacts they can have on human health due to pathogens (e.g. *Escherichia coli*, *Clostridium perfringens* and *Salmonella* (Eamens et al., 2006)) which may remain after the treatment process and risks of environmental pollution. Pathogens remaining after various levels of biosolids treatment are of high concern as they can be harmful to not only the people handling biosolids but also the general public. Also of high concern are matters of environmental pollution from the use of biosolids products on the land. Issues of heavy metals and other chemical contaminants are of concern not only from an environmental pollution standpoint but also as they can be toxic to humans if quantities are sufficient. Other environmental issues arise from land application of biosolids in agriculture including potential for runoff of nutrient rich materials ending up in local waterways and groundwater resources (Aguilar and Loftin, 1991, Aguilar et al., 1994, Joshua et al., 1998). Of high concern are the nitrogen and phosphorus compounds which when in high quantities can cause undesirable growth in marine ecosystems and eutrophication in freshwater ecosystems, resulting in reduction of dissolved oxygen which is required by aquatic species (LeBlanc et al., 2008, Vu Tran, 2008).

Although the issues around environmental pollution and public health are matters for concern, current regulations, guidelines and research are aimed at regulating and reducing their impacts. Of greater concern is the public opposition to the use of biosolids in land application. Most of the public opposition is linked to the fact that many people do not believe it is safe to use human waste in land application where other humans may be at risk of exposure (Goven and Langer, 2009). It has also been found that public opposition can be linked to issues of trace metals and chemicals, pathogens, odours, air quality, ground and surface water quality, transportation and trucking, oversight and enforcement and issues of soil/food crop quality (Goven and Langer, 2009). A need to educate and begin a change in public opinion of biosolids land application is necessary for the future development and sustainability of this practice. It is also important that the treatment and management of biosolids keep up with increasingly higher public standards and community expectations.

On a more local level, issues including transport of biosolids are of some importance. As most treatment and processing of wastewater is performed in a single location (generally nearby the population producing the waste), there is a growing issue of the need for transport from these point sources to the areas of land application. With increased cost of fossil fuels, green house gas production, impacts on roads and increased traffic flow, the potential impact of transport issues may become more noticeable as biosolids land application becomes a more widely used method of beneficial use. In the rural areas where biosolids are applied, issues needing to be addressed are

odours associated with biosolids, dust and noise on biosolids sites, and compaction of farm soil by trucks and equipment used in the spreading and incorporation processes.

With the many concerns outlined above relating to biosolids land application, a combined effort from regulators, environmental protection agencies, biosolids producers and biosolids managers/practitioners has developed actions to attempt to reduce these possible issues. One of the strategies employed in reducing environmental risks caused by runoff, vector born disease, odour and potential contact with humans and animals, is to incorporate land applied biosolids into the soils shortly after they are spread. This not only helps reduce risk but also aims to improve the soil uptake of nutrients held in the biosolids. The process of incorporation is defined in NSW *Environmental guidelines: Use and disposal of biosolids products 1997* as being a single pass with a disc plough. No specifications are given as to the depth of incorporation required or the percentage of biosolids needing to be incorporated with the soil, in order to reduce potential risks posed by biosolids and to meet the requirements of the regulations. Issues also arise with the increasing farmer movement to no or low till agricultural practices aimed at preserving soil structure and organic carbon. New methods of incorporation may be just as satisfactory without the use of a disc plough, which is known to be detrimental to soil structure (Lal et al., 2007). Development of a technique which can be used by regulators and biosolids practioners to assess the adequacy of incorporation levels, in order to reduce potential environmental risks, will prove useful in future studies and developments in this field.

1.1 Aims and Objectives

This study along with a review of relevant literature surrounding biosolids and land application aims to:

1. Identify if incorporation techniques currently outlined in NSW biosolids guidelines have an effect on reducing the environmental risks posed by biosolids land application;
2. Determine if there is an acceptable level of biosolids soil incorporation which may be achieved in order to reduce environmental and other potential risks to a level which is acceptable to regulators in regard to current guidelines and legislation;
3. Examine techniques used to determine the extent of soil incorporation of land applied biosolids and
4. Identify effective practices for the management and incorporation of land applied biosolids.

1.2 Outline of Thesis

Background information on the issues currently being faced by the stakeholders involved in wastewater recycling from the global level to local level, has been provided at the beginning of this introduction along with issues pertaining to the beneficial use of biosolids products. Following in this report is a review of literature surrounding issues relating to biosolids beneficial use options and the challenges faced with land application of biosolids in New South Wales, including legal requirements and environmental risks. This is required to place this study within the broader context of surrounding literature and also identify why this research is being conducted. The methods used in the development of a technique for assessing subsurface incorporation of land applied biosolids will be outlined followed by the presentation and discussion of results. The discussion includes an analysis of the various factors which affect the land application and subsequent subsurface incorporation of biosolids, including how these factors affected the development of a technique for assessing biosolids surface coverage in relation to potential environmental risks posed by land applied biosolids. The potential for the findings of this thesis to assist an agreement to be reached between regulators and biosolids practitioners on the issue of; what represents adequate biosolids incorporation to reduce potential environmental risks will be discussed. Finally the implications and limitations of this study will be discussed followed by the conclusions and recommendations.

2. Literature Review

2.1 Introduction

Land application of biosolids is increasing globally which is consistent with worldwide efforts to use biosolids for beneficial purposes whilst still providing maximum environmental and public health protection (Sidhu and Toze, 2009). The need to beneficially use biosolids has been highlighted in data from the US EPA (1999) where it was estimated that by the year 2010 approximately 7.4 million dry tonnes of biosolids will be generated annually in the USA alone. Many options exist for the disposal of biosolids including incineration, landfill and land application. However, with incineration being costly (and having some environmental concerns) and space in landfill becoming limited, attention has shifted to the beneficial use of biosolids, in particular land application (Moffet et al., 2005).

For a better understanding of what biosolids are and examples of beneficial use options the following definitions are provided:

Biosolids are the primary organic materials which are produced during the wastewater treatment process. Biosolids differ from sewage sludges as they have been treated to meet regulatory pollution and pathogen requirements for land application and surface disposal (USEPA, 2011).

The beneficial use of biosolids is a term used to refer to processes including land application whereby the biosolids are applied to the soil at or below agronomic loading rates to supply nutrients and replenish soil organic matter, without harming or threatening public health and safety or the environment (AWA, 2011).

While the beneficial use of biosolids products is increasing worldwide, there are many issues which are raised in the literature in relation to this subject area. Issues range from:
What are the reasons for land application of biosolids and what are the benefits?
Legal requirements which need to be followed for biosolids land application and guidance given for biosolids practitioners;
What are common methods for biosolids land application?
Issues regarding some of the potential environmental concerns and risks associated with biosolids land application and subsurface incorporation;
Various aspects which challenge and impact on biosolids land application and incorporation;

The nature of Australian soils with reference to how and why biosolids application can impact soils;
Information on soils and runoff data after biosolids land application and how this relates to possible environmental risks such as surface/groundwater contamination;
Finally are there any techniques for assessing incorporation levels to alleviate potential environmental risks following biosolids land application?
While this is a wide spanning list of issues, this review will demonstrate how they are all integral in understanding, why there is a need to develop a technique for the assessment of adequate levels of incorporation of land applied biosolids. This will not only be useful for regulators but also biosolids practioners to manage potential environmental risks.

2.2 Why apply biosolids and what are the benefits?

Biosolids are fast becoming a significant environmental challenge being faced by many communities and water authorities throughout the world (LeBlanc et al., 2008). With increasing population worldwide and the resulting stresses which are placed on finite natural resources, a need to beneficially use and recycle waste and waste products has been a top priority for many countries over recent decades (Riggle, 1996). Human/animal excreta and waste products have been used throughout history as a form of fertilizer as they were known to increase soil fertility. In recent times human waste has become more highly treated and refined into what we now call biosolids (US EPA, 2011). With increased quantities of waste being produced there is a growing need to dispose of it in an environmentally friendly manner. Countries are turning away from conventional methods of disposal including incineration, sea disposal and landfill as these are not only costly but also environmentally unsustainable (Beecher et al., 2008). Focus has shifted to beneficial use options including land application, composting, land reclamation and other agronomic purposes. The largest proportion of biosolids for beneficial use within countries such as Australia, New Zealand and the United States of America is for agricultural land application purposes (Beecher et al., 2008, AWA, 2011).

There are many reasons for the use of biosolids including; improving soil quality for crop production, reducing soil erosion, reclamation of lands with poor soils, enriching forestry land, conserving landfill space and economic incentives for companies who provide land application services, biosolids derived compost, etc. Economic incentives for companies are provided by biosolids producers setting targets to beneficially use high percentages of their biosolids, and having to pay for land

application services. Sydney Water for example has beneficially used 100% of its biosolids each year since 2003 (Sydney Water, 2011). The history and benefits of biosolids for activities of mine reclamation (Toffey et al., 1998) and forestry are significant but are not the focus of this review. A more generalised review of benefits will be assessed with a focus on benefits in agricultural practices.

The benefits of land applying biosolids are related to biological and organic matter which is provided to the soil. Biosolids are a source of organic carbon, nitrogen, phosphorus, micro/macronutrients and other trace elements including zinc, copper and iron and many others which add to soil properties (Rigby et al., 2009, Tsadilas et al., 2005, Vu Tran, 2008) some typical composition data is provided in Table 1 (NSW DPI, 2009). With increasing availability of biosolids, it has become an effective low cost source of essential plant nutrients and an effective soil conditioning agent. This has been known for many years throughout the world with biosolids providing the essential nutrients for the growth of various crops and pastures (Petroff and Brashear, 2005). The organic matter present in biosolids not only nourishes plant growth but also increases soil condition, helping increase bacterial activity, enhancing soil structure and improving consistency of poor soils (Synagro, 2002). This in turn allows for higher levels of root development and access to other nutrients provided by biosolids application.

Nutrient	%
Total Nitrogen (N)	2.9–5.1
Total Phosphorous (P)	1.05–4.26
Potassium (K)	.034–0.74
Calcium (Ca)	0.9–2.4
Magnesium (Mg)	0.1–0.5
Sulphur (S)	0.5–2
Zinc (Zn)	.03–0.1
Organic Matter	40–60

Table 1: Typical nutrient concentrations found in dewatered biosolids (mg/kg) in NSW (NSW DPI, 2009).

The benefits of biosolids are not only limited to the chemical matter which is provided to the soil; the application of biosolids has also been found to improve the soil's water retention, water infiltration, bulk density and porosity, e.g., see (Moffet et al., 2005, Spicer, 2002). In studies of surface applied biosolids effects on erosion, infiltration and surface runoff, Aguilar and Loftin (1991) and Aguilar et al. (1994) found that using simulated and natural rainfall events lead to a significant difference in infiltration rate and less surface runoff from sites amended with biosolids compared to

those which were not. These findings were also supported by Moffet et al. (2005), who attributed decreases in erosion and surface runoff on sites which received surface applied biosolids to an increase in surface roughness and also the ability of biosolids to absorb water in rainfall events. Many of these studies have focused on surface applied biosolids with very few focusing on the effect biosolids have on soils after subsurface incorporation. Sepúlveda-Varas et al. (2011) concluded that degraded soils respond positively to biosolids incorporation to improve quality, but noted a loss of surface structure due to physical incorporation technique negatively affecting water infiltration rate. While there are many studies pertaining to surface applied biosolids it seems more research needs to be done in relation to the effects incorporation has on the potential benefits offered by biosolids.

2.3 Requirements (including legal) and guidance for biosolids incorporation

The beneficial use of biosolids is a contentious issue in the eyes of some stakeholders such as the general public and the media. Many issues arise due to preconceived notions of pollution and disease which have been associated with wastewater sludges, primarily due to poor education of the general public on the matter. While there are issues surrounding environmental pollution and public health risks, many of these are dealt with by biosolids guidelines and legislation which are generally specific to a single country or states/territories (LeBlanc et al., 2008).

Australia has adopted a regulatory framework similar to that developed in the North America, Europe and New Zealand, where the regulatory systems are complex and biosolids technologies are advanced. With many trained professionals working in wastewater treatment and management fields within these countries, more emphasis is placed on improving the management of biosolids practices than on development of technologies (LeBlanc et al., 2008). Within Australia, each state and territory is responsible for the management of its own water and wastewater resources and regulations but adhere to a national framework (NRMMC, 2004). This is then overseen by state based regulatory agencies such as an Environmental Protection Agency (EPA), which ensure compliance with the relevant guidelines developed by that state (Pritchard et al., 2010).

The *Environmental Guidelines: Use and Disposal of Biosolids Products* (EPA, 1997) is the document which details the various rules and regulations which must be followed when land applying biosolids within New South Wales (NSW). These guidelines outline various requirements which must be followed including buffer distances, soil contaminant concentrations, lands which are suitable or

unsuitable to receive biosolids application, various biosolids contamination grades and management practices which need to be followed. These guidelines may seem comprehensive for NSW, but difficulty arises when applying biosolids in more than one state as each has their own set of guidelines which often differ slightly (LeBlanc et al., 2008). This can be a source of confusion especially for concerned members of the public who may do some research to find different regulations apply in each state and worry about public safety. The development of an up to date nationwide set of guidelines would help remove confusion and potentially enhance biosolids management systems and public acceptance as a whole.

According to the current NSW guidelines (EPA, 1997) incorporation of land applied biosolids must be completed within 36 hours of land application. The method of incorporation is a single pass with a disc plough. The guidelines do not state, however, the depth to which incorporation must be completed and the percentage of biosolids which need to be incorporated beneath the soils surface. This has arisen as a contentious issue amongst stakeholders, while biosolids practitioners attempt the maximum incorporation at the lowest cost, environmental and water authorities seek that incorporation be significant enough to reduce any potential environmental risks as discussed later in this review. Amongst other issues, the need to develop an understanding between authorities and practitioners as to what is considered adequate levels of biosolids incorporation is essential in moving forward with the development of biosolids guidelines which provide maximum environmental protection, whilst not making the process of beneficial use more problematic.

2.4 Common methods for biosolids application

Land applied biosolids typically come in two forms, either as a liquid with relatively low solids content (3-6 %) or as more processed dewatered cake generally with solids content up to 30% (USEPA, 2000). Liquid biosolids can either be injected into the soil using specialised machines or be surface applied using various spraying apparati. Dewatered biosolids can be surface applied using conventional agricultural equipment, such as manure spreaders pulled by tractor (Figure 1). The varying forms of biosolids are used throughout the world, although dewatered biosolids are more common due to the ease of transport (higher solids content reducing transport costs) and storage at potential land application sites.

Figure 1: Rear discharge manure spreader used in biosolids land application.

Land application of liquid biosolids was assessed by Lapen et al.(2008) using two methods of application; tillage of the soil before surface application and surface application followed by standard incorporation. In an assessment of these varying techniques on groundwater quality it was found that the tillage before biosolids application lead to significantly less contamination of groundwater than post application incorporation. While this study only focused on liquid biosolids it highlighted a point of interest in regard to surface application and potential runoff issues which arise when surface applying any biosolids product.

Of greater importance to the present study are the instances of land application of dewatered biosolids as these are most commonly used due to ease of transport and potential storage at both treatment plants and potential land application sites. Many studies in this area often refer to surface applied biosolids, but these are generally not incorporated into the soil as is expected in practice under NSW biosolids guidelines (Beecher et al., 2008, Moffet et al., 2005, Pritchard et al., 2010, Spicer, 2002, Vu Tran, 2008). Due to the fact that the studies mentioned above focus on surface applied but not incorporated biosolids makes interpretation of the results and potential impacts for incorporated biosolids difficult but does give valuable information concerning many of the environmental risks posed by biosolids and outlined in following sections.

An Australian study by Eamens et al.(2006) did focus on surface applied and incorporated biosolids in regard to survival of pathogenic and indicator bacteria in biosolids applied to agricultural soils. This study provides interesting insights into potential human and animal health risks which may still be present even after biosolids incorporation. With many studies only focusing on surface applied biosolids and very few on how incorporation effects biosolids application and the potential risks to the environmental, people and animals, more work is needed to establish standards for safe levels of application and incorporation in relation to these issues.

2.5 Potential environmental concerns/risks with regard to biosolids incorporation

Biosolids have faced much opposition in gaining a general acceptance and support towards their beneficial use in NSW for the last 20 years. Much of this opposition has come from what people believe to be the potential environmental and human health risks associated with the use of biosolids products. A number of potential environmental concerns are commonly outlined in the literature; these include: potential for surface water/groundwater contamination (with microbial and chemical agents), human related health risks, pathogens, heavy metal accumulation, ingestion by animals and potential for vector borne disease.

The environmental risk of the potential for surface/groundwater contamination has been an area of much biosolids related research over recent years. Research in this area tends to be split, focusing either on surface water contamination and runoff, or leaching of contaminants into groundwater. Aguilar and Loftin (1991) and Hansen et al. (2007) examined runoff water quality from sites amended with biosolids products and concluded that runoff from biosolids sites was well below recommended standards for groundwater and stream water supplies in relation to nitrate, heavy metals and phosphorus levels. Hansen et al. (2007) also found that dissolved phosphorus loss in runoff water was also decreased by incorporation of biosolids into the soil onsite when compared to similar non-incorporated application rates. This information provides evidence that the incorporation of land applied biosolids aids in decreasing potential surface water runoff contaminants; although other findings suggest that concentrations in runoff from surface applied non-incorporated biosolids sites are within environmental limits regardless.

Similar results have been obtained when studying the effect of biosolids application to potential groundwater contamination (Esteller et al., 2009, Rigby et al., 2009, Vogeler et al., 2006, Brenton et

al., 2007). Potential leaching of nitrate, phosphate and heavy metals into groundwater was found to be insignificant for sites that were suitable for biosolids application and at standard application rates as outlined by relevant biosolids guidelines. In most cases, all potential contaminant levels were below those of safe drinking water guidelines within the studies respective countries. These studies support the findings of potential surface water contamination studies and conclude that, with proper enforcement and practice within biosolids guidelines, potential for water contamination should not be of high environmental concern.

Another major concern in regard to biosolids is the potential for human health risks due to pathogens, viruses and vector borne diseases which can originate from application sites. Varying arrays of pathogens exist within biosolids from *E. coli* and *Salmonella* to *hepatitis*. Most of these pathogens are reduced to safe levels through the treatment process (Sidhu and Toze, 2009), but the remnant populations have the potential to pose a risk to those exposed to biosolids. There is much evidence of the pathogens and health risks associated with biosolids, some of these issues are dealt with in relevant guidelines such as Occupational Health and Safety controls, control on crop production, land withholding periods etc. Wu and Smith (1999) in their review of the regulatory update of the Part 503 rule from the U.S. EPA give reference to potentially useful methods of reducing the risks associated with biosolids pathogens. Application of biosolids to the ground surface exposes pathogens to desiccation, radiation from the sun and other environmental effects which aid in reducing their effect (Wu and Smith, 1999). These benefits are short lived, however, due to biosolids requiring incorporation within 36 hours of application which can greatly affect pathogen survival rates. This is supported by the results of Eamens et al. (2006) noting the survival of pathogens (*E. Coli* and S*almonella*) within clumps of biosolids for up to 12 months after biosolids application and a slightly higher survival rate in incorporated biosolids. While the incorporation of biosolids is done to reduce risks including those associated with pathogens and vector borne disease by creating a physical barrier between the biosolids and external sources, perhaps the effectiveness of this incorporation may be further assessed to establish if incorporation does play a significant role in reducing risks (Eamens et al., 2006).

Hill et al. (1998) examined the potential risks associated with the ingestion of biosolids by grazing animals and the potential build-up of toxic elements within body tissues. Feeding a mixed diet of soils, varying biosolids concentrations and grazed herbage to lambs, an assessment was made on the effect on body tissues. Results yielded that for most potentially toxic elements, build-up in body tissues was below the levels set for food standards with the exception of the liver and kidneys. There

was little margin for potentially toxic chemical levels for human food safety in the liver and kidneys of lambs, with caution recommended to be taken. This study provides important data for biosolids applied paddocks with quantitative assessment of how much biosolids ingestion can lead to toxic element build-up. With levels of ingestion in lambs of up to 300 g/kg of biosolids in total diet dry matter leading to highest levels of toxic element build-up, assessment of how this can related to incorporated biosolids can be made. This proves useful as incorporation helps reduce surface exposure of biosolids and can therefore reduce the potential intake of biosolids by grazing animals. Just how effective incorporation is at decreasing surface exposure of biosolids will be important for farmers wanting to graze animals on paddocks previously applied with biosolids.

For the benefit of the physical barrier provided by incorporating biosolids, the potential for the reduction in contaminated runoff water and reduction of animal ingestion, further assessment needs to be conducted on the effectiveness of incorporation or degree of incorporation and the potential this could have in reducing these risks.

2.6 Aspects which challenge and impact on biosolids land application and incorporation

There are many factors which have the potential to challenge and limit biosolids application and incorporation ranging from issues of public acceptance, odour, farmers moving towards no-till practices, the physical conditions of the soils themselves and prevailing weather conditions.

Issues of odour and public acceptance of the use of biosolids products have been some of the major inhibitors of the increased beneficial use of this product. Rynk and Goldstein (2003) and Tanto and Magette (2010) conducted studies which dealt with the issues of odour and public acceptance with results showing that, with best field practice utilising incorporation and increased community education and awareness campaigns, this issue currently inhibiting biosolids acceptance may slowly change. With increased use of biosolids products in agriculture, it is important to have community support and input to build-up a positive attitude toward the use and recycling of what is becoming a major waste issue. The role of incorporation in this context is that as it provides a physical barrier to help decrease odours and removes the biosolids from plain sight, this helps increase the positive awareness and acceptance by communities towards the use of biosolids (with a general attitude of out of sight out of mind).

Another major contributing factor which is having an effect on the use of biosolids is the move from traditional tillage methods to minimum or no-till farming practices. Lal et al (2007) discuss the gradual move towards no-till farming and highlight environmental aspects including reductions in erosion, organic carbon and nutrient losses as some of the main reasons for the shift. While conventional methods of farm tillage, including discing (Figure 2), have negative effects of breaking down soil structure and increasing potential for erosion and other losses, they still remain the required form of incorporation under current NSW biosolids land application guidelines. The use of disc ploughs for incorporation is advantageous as it allows for almost complete turnover of the soil to varying depths and provides good biosolids cover and mixing. However, with more farmers becoming aware of the issues related to this practice it may be time for regulators to look into new forms of incorporation (less soil destructive plough types) or other potential alternatives to help reduce environmental risks. As disc plough is still currently the incorporation method outlined in the guidelines, an assessment of its effectiveness of incorporation and potential reduction in environmental risks, may prove useful for development of future guidelines.

Figure 2: Conventional 2-way disc plough used for soil incorporation of biosolids as outlined in NSW guidelines.

Soil physical conditions are a contributing factor which can challenge effective biosolids soil incorporation. Dedousis and Bartzanas (2010) outline a number of soil conditions which may affect tillage, ranging from soil type, texture, organic matter content, state of compaction, soil moisture and soil structure. Soil moisture is the most commonly studied of these conditions and can greatly affect the level of soil fragmentation and therefore degree of incorporation of any surface applied solids. If these mentioned soil conditions have the potential to affect tillage, this will also affect the incorporation of biosolids into soils with varying conditions. To gain the best outcome for incorporation of biosolids, tillage should be performed at optimal soil moisture content levels (typically 12-18%); however this is not practical in real world situations as biosolids are constantly applied year round in a variety of climatic conditions, which would inevitably affect soil moisture and therefore incorporation effectiveness.

With a range of factors which challenge and impact biosolids land application and incorporation the development of strategies to deal with these challenges is extremely important. The development of an assessment technique for adequate incorporation levels which will help biosolids practitioners reduce problems of odour and environmental risk will be useful in dealing with some of these challenges in the future.

2.7 Nature of Australian soils with reference to biosolids application

Australian is a very old continent which is mirrored by the quality of our soils. Being exposed to many environmental conditions throughout geological history has lead to Australian soils which are often affected by salt and are lacking in both nutrients and organic matter making them relatively infertile (CSIRO, 1983). When compared to soils in the Northern Hemisphere, Australian soils tend to have less organic matter and are poorly structured, with many soils containing a highly clayey layer just below the surface which restricts drainage and effects root growth (ANRA, 2009). With the knowledge that Australian soils are lacking in nutrients, organic matter and are relatively infertile, the application of biosolids to these soils may help increase the potential for continued or new agricultural practices.

Due to the properties of biosolids which are outlined above they have the potential to make good soil conditioners, adding valuable micro/macronutrients, trace elements and organic matter to help replenish levels which are lacking within many Australian soil types. The incorporation of surface

applied biosolids aids in the delivery of these nutrients into the soil but care needs to be taken as to not cause overworking of the soil and increase potential for erosion. The addition of biosolids and in particular the organic matter contained within the biosolids provides a secondary effect of increasing the available water content within soils (FIFA, 2006). This has the potential to enrich areas within the Australian soil landscape which suffer from low water availability; this would therefore help increase the fertility of these areas.

If possible issues outlined above surrounding biosolids land application and incorporation can be addressed, in a cost effective and environmentally safe manner the potential benefits of biosolids for infertile Australian soils can be increased.

2.8 Soil and runoff data after biosolids land application

Many studies have been conducted overseas to assess soil and runoff data after biosolids application including those by Aguilar and Loftin, 1991, Aguilar et al., 1994, Esteller et al., 2009, Lapen et al., 2008, Moffet et al., 2005, Vogeler et al., 2006, Vu Tran, 2008. These studies have generally been conducted in the USA which has regulatory and guideline systems on which Australian guidelines were originally based. The difficulty in applying some of these studies in the Australian context is, as mentioned, because of the difference in Australian soils compared to those in the Northern Hemisphere. Therefore, it is important for similar studies to be carried out in the Australian context. Michalk and Curtis (1998) and Joshua et al. (1998) studied the effects of surface applied and incorporated biosolids respectively on soils and runoff water from field sites within NSW. Both studies concluded that the application of biosolids at rates within current NSW biosolids regulation guidelines have low potential for the pollution of soil or water resources. Levels of potential contaminants measured in runoff and soil samples were well below limits established in the NSW EPA biosolids guidelines (EPA, 1997). These results for both incorporated and surface applied biosolids provide evidence contrary to the common perception, with these forms of biosolids land application resulting in no substantial movement of contaminants which are of concern from an environmental risk standpoint. These studies were of limited duration and covered only a few soils, so studies similar to those above need to be conducted in conjunction with regulating authorities to determine what levels of environmental risk are acceptable when it comes to biosolids land application. The results of the present study will help regulating authorities, such as, the NSW EPA, biosolids practitioners and biosolids producers, to reach agreement of what is an acceptable level of

biosolids incorporation to help reduce environmental risks associated with biosolids land application.

2.9 Techniques for assessing incorporation levels to alleviate potential environmental risks following biosolids application

Outlined in previous sections of this review have been studies conducted mainly overseas and with a small number in Australia, regarding what are considered the potential environmental risks associated with biosolids application. Risks associated with soil contamination, surface and groundwater contamination have been the focus of such studies. These issues may be considered some of the major environmental concerns not relating directly to human health, but having the potential to impact upon it. The studies outlined above employ commonly used techniques for assessing surface runoff levels and contaminants concentrations within these tests sites. This, coupled with soil sampling and testing, has lead to our understanding of the effects biosolids have on soil and water resources. Many of these methods are quite expensive to establish and do not produce readily attainable measures of potential environmental impacts. While these studies have found biosolids application rates within those set by current regulatory authorities pose little to no risk to the environment, a technique for assessing the adequacy of biosolids incorporation to reduce environmental risk is yet to be developed.

Previous studies have focused on application rates of biosolids by dry/wet tonnes per hectare, applied either on the surface or incorporated into the soil (Aguilar and Loftin, 1991, Aguilar et al., 1994, Eamens G.J et al., 2006, Hansen et al., 2007, Joshua et al., 1998, Lapen et al., 2008, Michalk and Curtis, 1998, Moffet et al., 2005, Pritchard et al., 2010, Vu Tran, 2008). Regulations require land application of biosolids in NSW be incorporated into the soil by method of a single pass with a disc plough. A technique for assessing the surface coverage of biosolids after incorporation would allow for assessment of potential environmental risks and prove useful in making comparisons with previous studies. The development of such a technique will also allow biosolids practitioners and regulating authorities to work together in producing new methods and guidelines for the safe management of land applied biosolids. With no easy to use technique yet developed relating surface coverage of biosolids after incorporation to environmental risks, current knowledge can be further advanced by a study in this area.

2.10 Conclusion

Currently there is a lack of a well developed technique for quickly and easily assessing surface coverage of biosolids after soil incorporation. The development of such a technique would be an integral step towards better management of land applied biosolids allowing regulatory authorities and biosolids practitioners to understand - what is an adequate level of incorporation to reduce potential environmental risks? The benefits of land application of biosolids are well known, although common perceptions of the associated environmental risks have inhibited the acceptance and wider scale implementation of biosolids land application. Evidence suggests environmental risks are minimal under current biosolids regulations and a need to develop and educate people of this knowledge is integral to future development in biosolids use acceptance. It is hoped that the outcomes of this project will increase current understanding of environmental risks associated with land application of biosolids and soil incorporation for better use by regulating authorities and biosolids practitioners.

3 Materials and Methods

3.1 Introduction

Land application for agricultural purposes is currently a well established method for the beneficial use of biosolids products. In NSW, land applied biosolids must be incorporated into the soil within a fixed timeframe following application. This process is employed in order to reduce potential environmental risks including contamination of soil and water resources, also reduce odour and limit risks posed by potential vectors coming in contact with biosolids and spreading pathogens. Currently there is no technique for assessing whether the incorporation of biosolids has been achieved to a level which is adequate in reducing potential risks. The development of such a technique will be useful not only to regulating authorities which aim to reduce environmental impacts but also biosolids practitioners attempting to manage effective land application programs and meet regulatory requirements. A technique which can be understood and used by all stakeholders involved in biosolids management and regulation, will allow a collaborative approach to further developments in this industry.

In order to develop a technique for assessing if incorporation of biosolids has been achieved to a level which helps minimise potential environmental risks, a range of methods was trialled. Field studies were conducted in order to develop a technique which could be used to assess the surface coverage of land applied biosolids, both after initial spreading and subsurface incorporation. Subsequent sections will outline details of biosolids application sites and the techniques used to assess surface coverage of biosolids in each trial.

3.2 Biosolids surface coverage assessment technique development

3.2.1 Trial site 1 technique 1

Trial site 1 was located in the Shoalhaven region on the NSW South Coast (Figure 3). The site was situated in flat terrain with sandy clay loam soils with the paddock being 10 ha in size. The spreading and incorporation at this site occurred during the summer months of November and December 2011; over this period a variety of weather extremes were experienced and the effects this may have had on results will be discussed in Section 4. The site had light grass coverage as animals had

been used to graze the paddock prior to biosolids application. Biosolids were obtained from various Wastewater Treatment Plants around the Shoalhaven area and were applied at a rate of 150 wet tonnes/ha (30 dry tonnes/ha) with a rear discharge manure spreader.

Figure 3: Location of trial sites 1 and 2 in the Shoalhaven region (Google Earth, 2012).

An assessment of the percentage surface cover of biosolids was performed using randomly placed quadrats (1 metre x 1 metre) along a V and inverted V shape across a 1 ha area of the paddock on the ground surface. Ten samples were taken along each arm of the V's (1 arm = 1 block) to give a total of 40 samples per 1 ha site (see Figure 4 for visual detail) and a percentage of biosolids cover given (Note: during this trial a subjective assessment was given by the observer based on the percentage cover in each of the 10 cm x 10 cm cells within the quadrat (Figure 5), i.e., if a cell was more than half covered it was deemed to be a positive result for the cell). The method of taking 40 samples per 1 ha site in the pattern described was kept constant throughout all trial sites and techniques used; only the assessment technique itself was varied.

Assessment and data gathering occurred over a two day period with each sample requiring time to be accurately counted to avoid introducing unwanted error. Pre-incorporation samples were the most time intensive to gather data for, with large volumes of biosolids covering the surface having to be added together with a degree of accuracy for the entire 40 samples. This process generally took a number of hours to complete sampling and data logging. Assessment of post-incorporation samples

generally occurred after a second visit to the field site after ploughing had taken place (usually within 36 hours of biosolids application). Post-incorporation samples were assessed quicker due to the reduction in the amount of visible biosolids covering the paddocks surface. However, this process still took a considerable amount of time to gather data for all 40 samples in the paddock.

Results were recorded for the pre-incorporation and the process was repeated after incorporation had occurred. The biosolids were incorporated using a chisel plough (Note: disc ploughs are commonly used for biosolids incorporation as this is the method stated in the NSW biosolids guidelines). The post-incorporation assessment was undertaken noting that weather conditions and plough type may have affected the outcome of the incorporation. The effectiveness, limitations and difficulties encountered using the technique outlined above will be discussed further in Section 4.1.1.

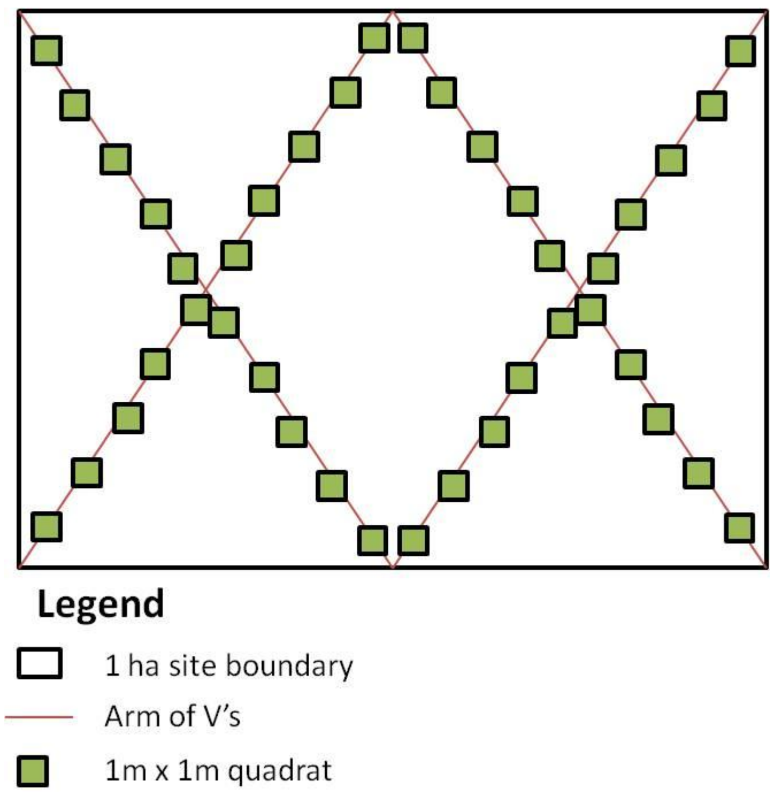

Figure 4: Layout of site assessment for a single 1 ha paddock.

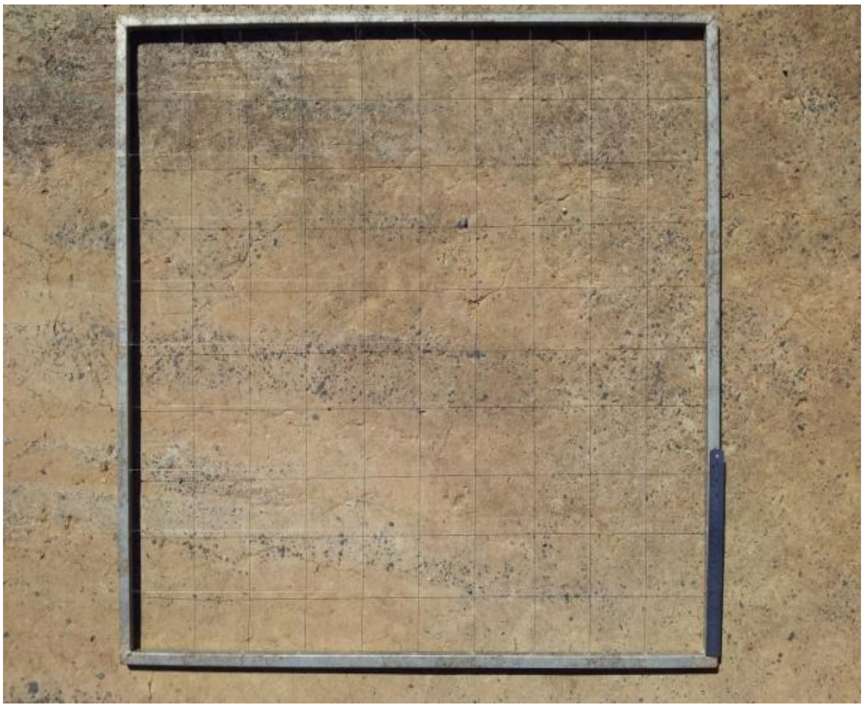

Figure 5: Quadrat used in sampling biosolids surface coverage. Metal frame dimensions 1m x 1m, with 100 10cm x 10cm cells.

3.2.2 Trial site 2 technique 2

The second trial site was also in the Shoalhaven Region a few kilometres distance from *Trial site 1*. Again the terrain was flat with sandy clay loam soils with the 2 paddocks being a combined 6 ha in size. The spreading and incorporation occurred during the same time period as *Trial site 1* using the same application rate, spreading equipments and biosolids source. The incorporation of biosolids at this site was achieved with a single pass of a disc plough as outlined in the NSW biosolids guidelines. *Trial site 2* allowed for a new surface coverage assessment technique to be examined. For the assessment of these two paddocks, a more objective approach was used. This differed to the previously described subjective approach whereby the observer made a value judgement on the percentage of biosolids surface coverage. Assessment technique 2 employed the methodology that if there were any biosolids visible in a given 10 cm x 10 cm cell then that cell would be counted as a positive result and therefore deemed to be 1% coverage. This new assessment technique introduced a number of difficulties which needed to be overcome; this will be discussed further in Section 4.

3.2.3 Image Analysis

In conjunction with the new assessment technique a number of photographs were taken from directly above each quadrat (both pre and post-incorporation), in an attempt to use image processing and analysis software to gain more accurate results. The photographs were taken using a standard 8 megapixel digital camera, in full daylight over the period of an hour and at the same time each day in order to minimise environmental variables affecting image quality. Images were cropped to the extent of the 1 m x 1 m quadrat for use in the analysis process to prevent biosolids outside the quadrat being included in any results.

Cropped images then needed to be imported into the ENVI software where Regions of Interest (ROI) were created. ROI are a grouping of pixels which represent a specific object of interest for analysis. In the case of biosolids surface coverage analysis ROI needed to be created for areas covered with biosolids and areas which were free from biosolids i.e. dirt/grass. The process of creating these ROI is time consuming as pixels selected for each ROI type have to be of that specific area with minimal to no overlap with other ROI . If pixels cross boundaries the auto classification tool will incorrectly classify areas of biosolids as grass and vice-versa. The process of creating ROI had to be completed for each image captured pre/post-incorporation for a total of 80 images analysed per paddock. This proved to be extremely time intensive work for results which are comparably not as accurate as the two visual assessment techniques for post-incorporated samples (discussed further in Section 4). The ability to batch process groups of images would have been more time effective but due to the image type this was not possible.

The process of image analysis generally requires a multispectral data set to obtain the most accurate results from analysis; this is not the same as an image from a standard digital camera. Multispectral data would allow for ROI to be created based on the spectral properties of the various objects being studied, i.e., biosolids. These spectral properties do not change greatly amongst similar objects so would eliminate the need to produce new ROI for each image. These and other issues encountered with using this assessment technique will be discussed further in Section 4.1.3.

3.2.4 Trial site 2 technique 3

Issues with developing a successful assessment technique which could be used to accurately and rapidly assess the surface coverage of biosolids pre/post-incorporation lead to a further change in methodology. Using the 1 m x 1 m quadrat and sampling method outlined previously, the assessment technique was adjusted to use visual assessment by the observer backed up with more accurate measurements using a ruler. Visual assessment was based on the coverage of biosolids in each 10 cm x 10 cm cell of the quadrat to within 0.25% of the entire area. Addition of each cell within the quadrat gave a percentage of biosolids surface coverage out of 100% for each quadrat. This was repeated for each of the 40 samples taken within a 1 ha block. To maintain experimental validity, 3 out of every 10 samples along each arm of the V's was measured more accurately for biosolids coverage using a 30 cm ruler. Biosolids clumps were measured in rectangular blocks for ease of field calculation. The result was a biosolids surface coverage measured in cm^2 out of a possible 10,000 cm^2 for each 1 m x 1 m quadrat, which was then converted to a percentage. Cross checking rapid visual assessment results with the more detailed measurements allowed comparison of how accurately rapid assessment was being performed.

The post-incorporation assessment using this new technique was performed at *Trial site 2* in the Shoalhaven, with further use needed to determine if this technique is adequate in assessing surface coverage of biosolids pre/post-incorporation.

3.2.5 Trial site 3 technique 3

The application of the rapid assessment in conjunction with more detailed measurements was trialled in a number of field situations. Site 3 was located approximately 40 kilometres south west of Orange, on the Canowindra Road, NSW (Figure 6). The terrain was slightly undulating on fine sandy clay loam soils comprised of red and brown chromosols, with an approximate paddock size of 22 ha. Biosolids were obtained from various Water Treatment Plants within the Sydney region, with land application conducted using a rear discharge manure spreader at a rate of approximately 70 wet tonnes/ha (16 dry tonnes/ha). Biosolids were incorporated using a single pass with a disc plough. Light residual crop stubble was covering the ground but had been flattened using a set of pasture harrows to allow for more even application of biosolids and to assist in visual assessment. A total of four (4) 1 ha blocks were assessed using the refined assessment techniques and same sampling methodology outlined previously. Issues using the more detailed assessment process were

discovered for measuring the pre-incorporated biosolids samples (these will be discussed further in the Section 4), with pre-incorporation only receiving rapid assessment. The post-incorporation assessments received both rapid and accurate assessment techniques for comparison of the accuracy of techniques.

3.2.6 Trial site 4 technique 3

The final site of land application was located within 7 kilometres from *Trial site 3* with terrain which was of a similar topography. The soils were also fine sandy clay loam soils comprised of red and brown chromosols and the approximate paddock size was 23 ha. Biosolids were again obtained from various Water Treatment Plants around the Sydney region, with land application conducted using a rear discharge manure spreader at a rate of approximately 50 wet tonnes/ha (9 dry tonnes/ha). Incorporation of biosolids was achieved through use of a chisel plough trailed by prickle harrows which differs from the *Trial site 3* where only a disc plough was used. The effects of the various ploughing techniques will be reviewed in the Section 4. Similarly with this site, four (4) 1 ha blocks were sampled using the same techniques and methodologies as at *Trial site 3*.

Figure 6: Location of trial sites 3 and 4 Canowindra Road, NSW (Google earth, 2012)

3.2.7. Summary of techniques

A summary of the techniques tested for biosolids surface coverage assessment is given in Table 2.

Technique 1	Subjective visual assessment of biosolids surface coverage pre/post-incorporation based on premise that, if a 10 cm x 10 cm cell was deemed to be more than half covered in biosolids it is counted as a positive result i.e. 1% of total out of 100% (for further detail refer to Figure 7). Addition of positive results for cells in quadrat added to give total coverage for each sample, repeated as described in Section 3.2.1.
Technique 2	Objective visual assessment of biosolids surface coverage pre/post-incorporation based on the premise that, if any biosolids are visible within a 10 cm x 10 cm cell (regardless of size) that cell is then counted as a positive result i.e. 1% of total out of 100%. Addition of cells with visible biosolids coverage within the quadrat gives result for each sample, with replication as described in Section 3.2.2.
Technique 3	Visual assessment based on biosolids surface coverage in each 10 cm x 10 cm cell of the quadrat to within 0.25%. Addition of result for each cell added to give total out of 100% (repeated for all 40 samples pre/post-incorporation). Three out of every 10 samples along each arm of the V's measured more accurately for biosolids coverage using a 30 cm ruler. Biosolids clumps measured in rectangular blocks to produce combined surface coverage measured in cm^2, then converted to a percentage (Detailed measurement only done for post-incorporated samples as explained in Section 4.1.5).

Table 2: Summary of biosolids surface coverage analysis techniques, all techniques employed the same sampling methodology as described in Section 3.2.1.

3.3 Statistical analysis

Biosolids surface coverage pre/post-incorporation was statistically analysed using JMP 10 (SAS Institute, 2012). A range of independent and paired t-tests was used to determine if there was a statistically significant difference between; plough types used, biosolids surface coverage pre/post-incorporation and differences between the rapid and more detailed assessment techniques. Mean biosolids surface coverage for each 1 ha paddock was obtained by taking the means of samples within each block (arm of Vs) and averaging this for each paddock.

4 Results and Discussion

This Section will present and discuss the results of the biosolids surface coverage analysis assessment technique development. Each of the techniques outlined above will be presented in order of development to establish why changes were made to existing techniques and how these changes lead to different results being obtained. The final stage of technique development (technique 3), was used to gather data in 2 field trials, the data was statistically analysed to show that a significant reduction of biosolids had occurred between pre/post-incorporation assessment. Finally an assessment of the Rapid versus Detailed assessment techniques will be presented to determine if there was a statistically significant difference in the results gained from the two techniques for post-incorporated samples. This will be followed by a discussion of the limitations of techniques used, the effectiveness of current incorporation techniques outlined in NSW biosolids guidelines and a discussion of the acceptable levels of biosolids incorporation which may be achieved in order to reduce environmental and other potential risks.

4.1 Biosolids surface coverage assessment technique development

4.1.1 Trial site 1 technique 1

Trial site 1 technique 1 provided an opportunity to test and develop ideas which may be used in assessing biosolids surface coverage. The use of the quadrat and sampling methodology mentioned previously were chosen, as they are commonly used methods for soil and geological sampling (Chiprés et al., 2009, Millán et al., 2009) and would provide a reasonable spread and range across the paddocks surface and therefore a reasonable estimate of surface coverage. The spreading of biosolids took place over a week, with incorporating taking 2 days to complete within the 36 hour period after spreading had finished. Data gathering took place over a period of 2 full days, with pre-incorporation data taking a day to gather immediately after spreading had finished. Post-incorporation data was gathered in a day of field work, after paddocks had been ploughed. During this time the area received a substantial amount of rainfall which is likely to have caused biosolids to be washed into the grass and may have caused clumps to become more spread out. Both of these issues could have affected the post-incorporation results by influencing visible distribution of biosolids in the paddocks.

A number of issues were encountered with the initial technique used including observer bias, different ploughing technique used (not discing) and issues of residual grass cover affecting data gathering. In order to gather data which minimised bias from the observer, a technique was employed whereby: any cell which was more than half covered with biosolids was marked as a positive result for that cell i.e. 1% of the total area of the quadrat. This lead to some variation from what was actually being observed and the data being recorded for each sample (illustrated in Figure 7). This subjective approach required modification in following trials to gain more accurate nonbiased results.

Figure 7: The two 10 cm x 10 cm cells on the right (yellow ticks) are marked as positive results (1% each to total) because they appear to be more than half covered with biosolids. The two cells on the left (red crosses) are marked as negative results because they appear to be less than half covered with biosolids, therefore are not counted towards the surface coverage estimate. Using this method introduced error as there is obviously biosolids cover in the two cells on the left but not enough to be counted as a positive result.

Another issue was the ploughing technique used on the paddocks. Chisel agricultural ploughs do not turn the soil as effectively as a disc plough which should be used in accordance with NSW biosolids guidelines. This lead to a greater amount of biosolids remaining on the surface after incorporation than would be expected after disc ploughing. Another issue encountered was the amount of grass remaining on the paddocks prior to biosolids application. In areas which were highly grass covered, biosolids would fall down between grass patches, or be covered by grass laying flat over the top after being weighed down by other biosolids or being compacted by the tractor tyres (an example of this can be seen in Figure 8). These issues lead to problems with visual assessment. Due to the fact assessments were made from directly above the quadrat, it was difficult to see what was laying deeper down in the grass without physically moving biosolids and therefore affecting results. While this was only an initial technique development stage, conditions which most closely resemble those commonly used would provide the best results to help develop a strong biosolids surface coverage technique.

In order to further develop assessment techniques, the issues outlined above were taken into consideration and the technique modified for use in a second field trial.

Figure 8: Evidence of biosolids being covered by grass which made visual assessment techniques difficult to apply.

4.1.2 Trial site 2 technique 2

This new technique was developed from data gathering issues and limitations which needing to be resolved from technique 1. With the subjective approach of technique 1 varying results may have been obtained depending on the observers opinions of what constituted a cell which was half covered and therefore deemed a positive result. In an attempt to eliminate this issue with the assessment process a more objective approach was developed as mentioned in Section 3.2.2. Technique 2 was developed in order to subjectively analyse biosolids surface coverage; with a positive results being recorded for a cell if any biosolids were present in that cell regardless of biosolids amount. This process allowed for more rapid results to be obtained by a simple yes/no assessment process for each cell to give an overall percentage, but also introduced a new suite of issues. These issues included difficulty in separating samples which were visibly more densely covered then others, but due to the method of assessing any visible biosolids present in a cell regardless of size as a positive result, similar counts around 90-100 % were recorded (Figure 9). To further explain this issue an example would be if a sample quadrat contained a piece of biosolids measuring only 1 cm^2 in area found in each of the cells, a count of 100% would be recorded. If this is compared with a sample quadrat where nearly the entire surface is covered in biosolids also receiving a surface coverage of 100%, there would visibly be a large difference between the two samples, but due to the technique used they would be recorded as having the same biosolids surface coverage. This problem was also carried through into the post-incorporation assessment where much less of the biosolids were as visible compared with the pre-incorporation but high percentages were still being recorded due to single small pieces of biosolids being counted as a positive result.

Trial site 2 was ploughed using a single pass with a disc plough and resulted in observed marked reductions of visible biosolids surface coverage. Although it was clear after visual inspection that biosolids coverage had significantly decreased, the issues which were faced for pre-incorporated sample assessments were having a marked affect on the results of post-incorporated samples. Results around and above 50% were not uncommon in post-incorporation samples, but if all the visible biosolids were brought together the total of the quadrat surface area covered would possibly have been between the 5-20% range, not the high values recorded. This led to a need of adjusting the methodology in a way which will yield more reliable and accurate results than those obtained by this process but also eliminate as much bias from the observer as possible.

Figure 9: Two examples of pre-incorporation samples which received similar biosolids surface cover percentages using technique 2, but clearly have a large difference in biosolids cover.

In an attempt to attain these improvements, image processing and analysis software was employed. This was done in an effort to make the results of the entire experiment more objective and less subjective and therefore more statistically reliable. Another advantage hoping to be gained through image analysis was a reduction in the time required to assess each individual sample, by the observer in the field. While field observations can be necessary they are extremely time consuming, weather dependant and also require that the person taking observations knows how to properly

perform the assessment to gain accurate results. The use of image analysis would allow for rapid data gathering with the observer required to be as knowledgeable about assessment technique, as analysis can be performed by someone other than the observer. Images can then be analysed at any time after the field visit and also stored digitally if cross checking needed to be done. With these potential benefits in mind image analysis was trialled as a technique for assessing biosolids surface coverage for pre/post-incorporated samples.

4.1.3 Image Analysis

A number of photographs pre/post-incorporation were analysed using the ENVI (Exelis, 2012) image processing and analysis software to determine if surface coverage could be assessed digitally. A trial of the image analysis technique was undertaken on images obtained of samples taken from trial sites 1 and 2 to determine if it was possible to separate areas of biosolids cover from other areas of grass/dirt. Preliminary results from trial images indicated that a distinction could be made between biosolids and surrounding features (Figure 10), but the accuracy of the analysis could not be tested in full due to not having a full set of accurate field observation to make comparisons with. Therefore another test of the accuracy of image analysis process was achieved with images obtained from trial site 3 where assessment technique 3 was used as outlined in Section 3.2.5.

A total of 40 images were captured (20 pre-incorporation, 20 post-incorporation) which related to the visual assessments made of samples using the rapid and detailed visual assessment technique to allow for comparison of the accuracy of the output of digital analysis. A comparison of results obtained from visual assessment (both rapid and detailed where possible) and those obtained using the ENVI software (refer to Appendix A for table of results) found that generally much larger surface coverage estimates were being produced using the image processing software than those obtained using by visual inspection. Post-incorporation samples gave the most obvious results for comparison, as they were visually assessed using two techniques while also being run through the ENVI software.

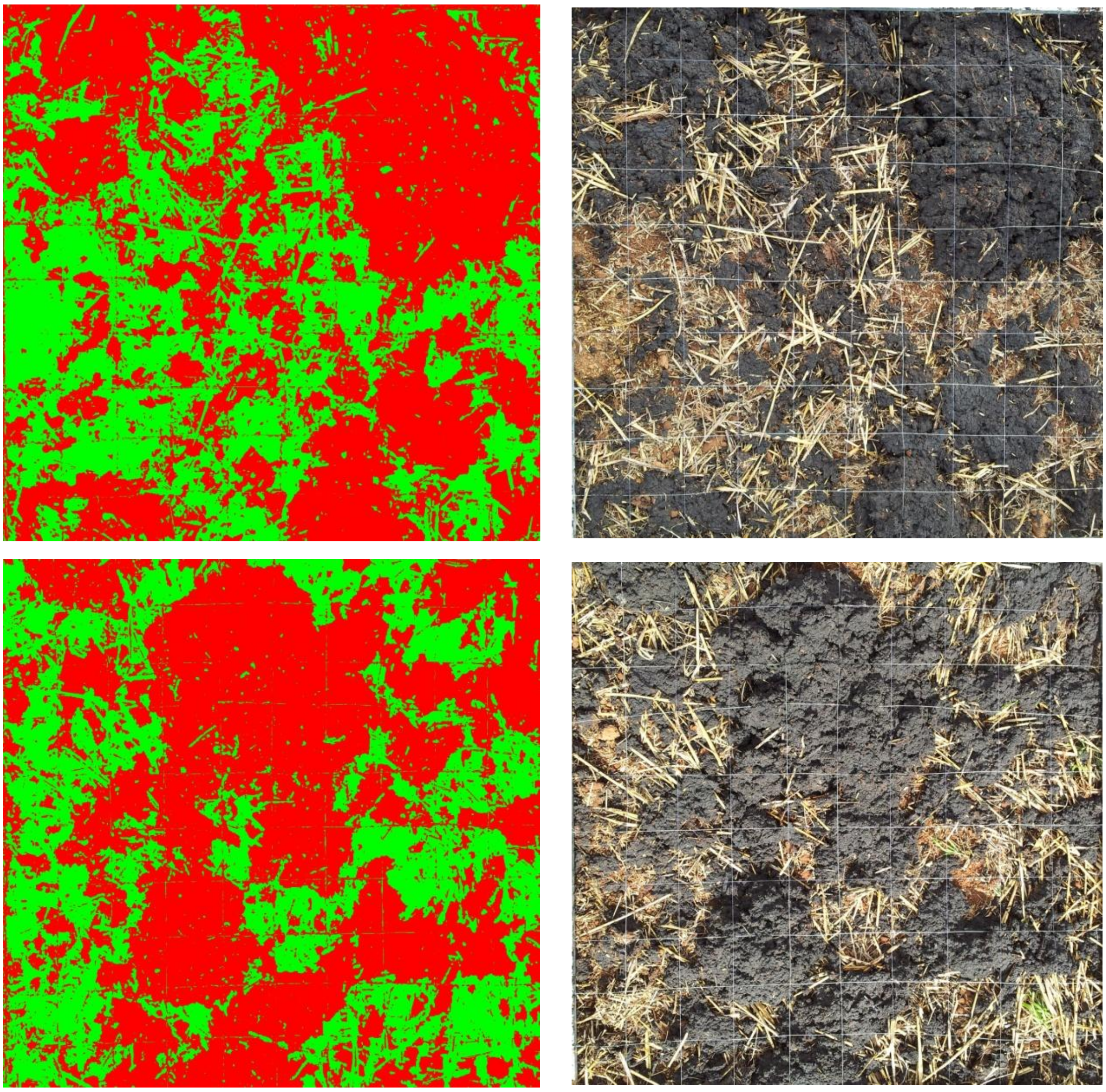

Figure 10: Trial results of ENVI image analysis to determine if biosolids could be distinguished from surround materials including grass and dirt. ENVI output (left) corresponds with the original image (right), major biosolids areas indicated in red appear to represent those areas covered in biosolids in the original images.

An example of the results obtained from the analysis of a post-incorporation sample with ENVI gave a biosolids surface coverage of 23.4% (Table 3 and Figure 11), this was compared to the visual assessment results of rapid assessment 3.5% and detailed assessment 2.8% (Figure 12). Distinguishing these large differences was simpler with post-incorporated samples as biosolids cover was more accurately assessed, however, pre-incorporated samples did not receive the detailed assessment technique and comparisons between results became more difficult. The consistent major discrepancies between the results for the post-incorporation samples and the harder to

distinguish differences found in pre-incorporated samples, led to the decision to not use the ENVI image processing and analysis software, but to modify existing visual assessment techniques, whilst still taking photographs as an added backup measure if extra analysis was needed to be performed.

As outlined in Section 3.2.3, the creation of ROI for each of the images used was a time consuming process. This had to be done, however, because the images could not be placed through a batch processing technique using standard images from a digital camera. The use of multispectral data, however, would have allowed for ROI training areas to be produced for each type of ground cover. Each image could then be quickly analysed using the predetermined ROI and a maximum likelihood classifier to separate the various types of ground cover as done in many other scenarios (Belluco et al., 2006). The lack of easily accessible multispectral data for image processing lead to this not being a possibility, but remains a potential area for further investigation.

Another possibility for digital image analysis for biosolids surface coverage employs methods used by Karcher et al., (2001) whereby turf grass cover was assessed using standard digital photographs to a high level of accuracy in predefined trial plots. This image analysis technique used SigmaScan Pro (v. 5.0, SPSS, Inc., Chicago, IL 60611) software, which has the capability to search an image for a certain colour or range of colour tones to develop a fingerprint. This fingerprint is then used to analyse the entire image for other corresponding colours on a pixels by pixel basis, with an output as a percentage of the image covered by that defined fingerprint. The application of such software could have been used to select pixels which represented biosolids (generally dark in colour) from images taken in the field to a produce similar results to those outlined by Karcher et al., (2001). The use of this software may have made the image analysis method of assessing biosolids surface coverage a feasible option, but due to the cost of the package it was not used, although this remains an option for further research.

Dims: Full Scene (4,745,850 points)

Basic Stats	**Min**	**Max**	**Mean**	**Stdev**	
Band 1	1	2	1.765865	0.423457	
Histogram	**DN**	**Npts**	**Total**	**Percent**	**Acc %**
Band 1	1	1111169	1111169	23.4135	23.4135
	2	3634681	4745850	76.5865	100

Table 3: Output from ENVI software giving analytical breakdown of various bands represented in the output in Figure 11. DN 1 represents biosolids cover at 23.4%, DN 2 represents dirt cover at 76.6%.

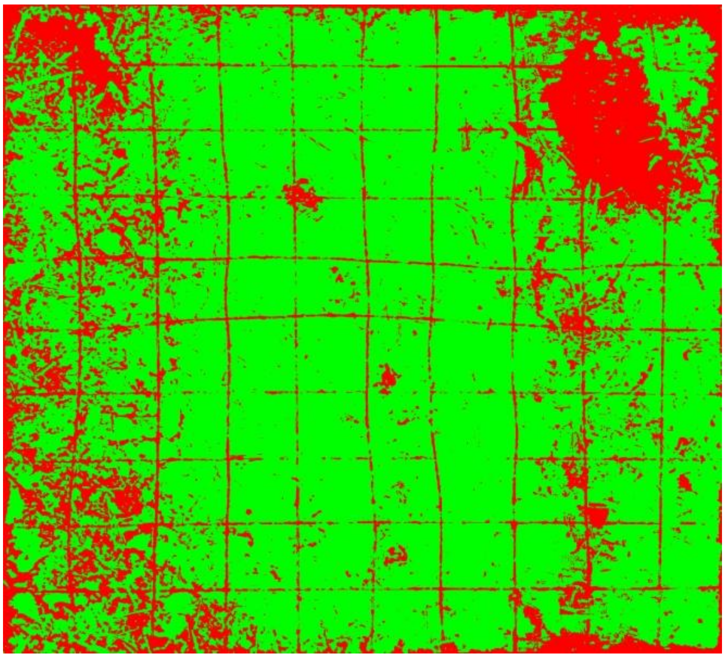

Figure 11: ENVI image output 23.4% biosolids surface coverage. Biosolids coverage represented by red areas.

Figure 12: Cropped digital photograph used in ENVI analysis. Biosolids surface coverage 3.5% (rapid assessment), 2.8% (detailed assessment).

4.1.4 Trial site 2 technique 3

Post-incorporation biosolids surface coverage was reassessed at trial site 2 using technique 3 (see Table 2 for summary of techniques), to determine if changes in technique would give results which

were representative of actual biosolids coverage compared to the previous techniques used. The outcome of using the rapid visual assessment, backed up with the detailed measurement of biosolids areas proved to be giving more accurate results of surface coverage (Appendix B). Further field trials needed to be conducted using assessment technique 3 to ensure results were not just a chance event.

4.1.5 Trial sites 3 and 4 technique 3

Assessment of biosolids surface coverage at sites 3 and 4 using assessment technique 3 revealed an issue with detailed assessment of pre-incorporated samples. Due to the high percentage of biosolids surface cover in these samples, it was proving extremely time consuming to accurately measure percentage surface cover. Each pre-incorporated sample being measured in detail was taking approximately half an hour or more at a time, with 80 rapid and 12 detailed assessments spread between pre and post-incorporation over each paddock (4 in total at each site) this was simply not possible given the time and resources available. An example of data collected is presented in Table 4 with the remaining results tables presented in Appendix C. If more resources had have been available, such as, extra people to help do visual and detailed assessments for pre-incorporated samples this option may have been feasible. This led to an on-the-spot refinement in technique with only post-incorporated samples receiving both rapid and detailed assessment, while pre-incorporated samples only received rapid assessment.

With the two sites receiving different incorporation techniques (disc vs. chisel plough) a two-tailed independent t test was used, to determine if the method of incorporation led to a significant difference in the reduction of biosolids surface coverage when ploughed using different techniques. The difference in the pre/post-incorporation biosolids surface coverage was calculated for each sample for the two ploughing techniques and analysed. The t test was significant ($t=6.39$, 267df $P<.001$) indicating that the ploughing technique led to statistically significant different reductions in biosolids surface coverage. With a mean reduction in biosolids of 68.4% it appears that the chisel plough followed by harrows produced a larger reduction in biosolids surface coverage, than the single pass with a disc plough which achieved a mean of only 61.1% reduction. The significance of this result and potential for other ploughing techniques to be used for incorporation purposes will be discussed further in Section 4.3.

		Rapid Assessment	Rapid Assessment		Detailed Assessment	%
Blocking	Sample	Pre-incorporation (%)	Post-incorporation (%)		Surface Coverage (cm^2)	
1	1	78	1.25			
1	2	69	3			
1	3	65	2.5		250	2.5
1	4	80	1			
1	5	84	6			
1	6	83	3		280	2.8
1	7	73	2.75			
1	8	81	4			
1	9	77	4.5		410	4.1
1	10	75	5.75			
2	11	82	4			
2	12	79	3			
2	13	73	1.5		160	1.6
2	14	65	2			
2	15	75	3.5			
2	16	68	4		450	4.5
2	17	70	6			
2	18	64	7			
2	19	67	5		480	4.8
2	20	77	5			
3	21	66	4			
3	22	71	3.5			
3	23	68	2		180	1.8
3	24	55	1.75			
3	25	70	2.5			
3	26	71	6.5		600	6
3	27	83	5			
3	28	72	5.5			
3	29	65	2.75		250	2.5
3	30	84	3.5			
4	31	78	1			
4	32	66	2.5			
4	33	71	3		330	3.3
4	34	87	3.25			
4	35	74	2.5			
4	36	78	3		275	2.75
4	37	68	2			
4	38	81	4			
4	39	84	1		90	0.9
4	40	77	2.75			

Table 4: Results of biosolids coverage in a single paddock assessment from *trial site 4* paddock 2.

Although there was a significant difference in biosolids reductions for different plough types, all eight (8) paddocks were analysed together as the aim of this experiment was: to determine if there is a significant reduction in biosolids surface coverage between pre and post-incorporation treatments. To assess this hypothesis the unit of analysis was the paddock. Within each paddock 4 blocks of 10 samples were measured pre and post ploughing. To account for the block design the analysis used was a two tailed paired t test (JMP version 10) comparing the average of the samples within blocks by paddock pre and post, that is the means of the paddocks were calculated by taking the means of the blocks within each paddock which were the means of the samples within each block (Figure 13). The t test was significant (t=30.03, 7df P<0.001) indicating a statistically significant reduction in biosolids exposed on the paddock surface.

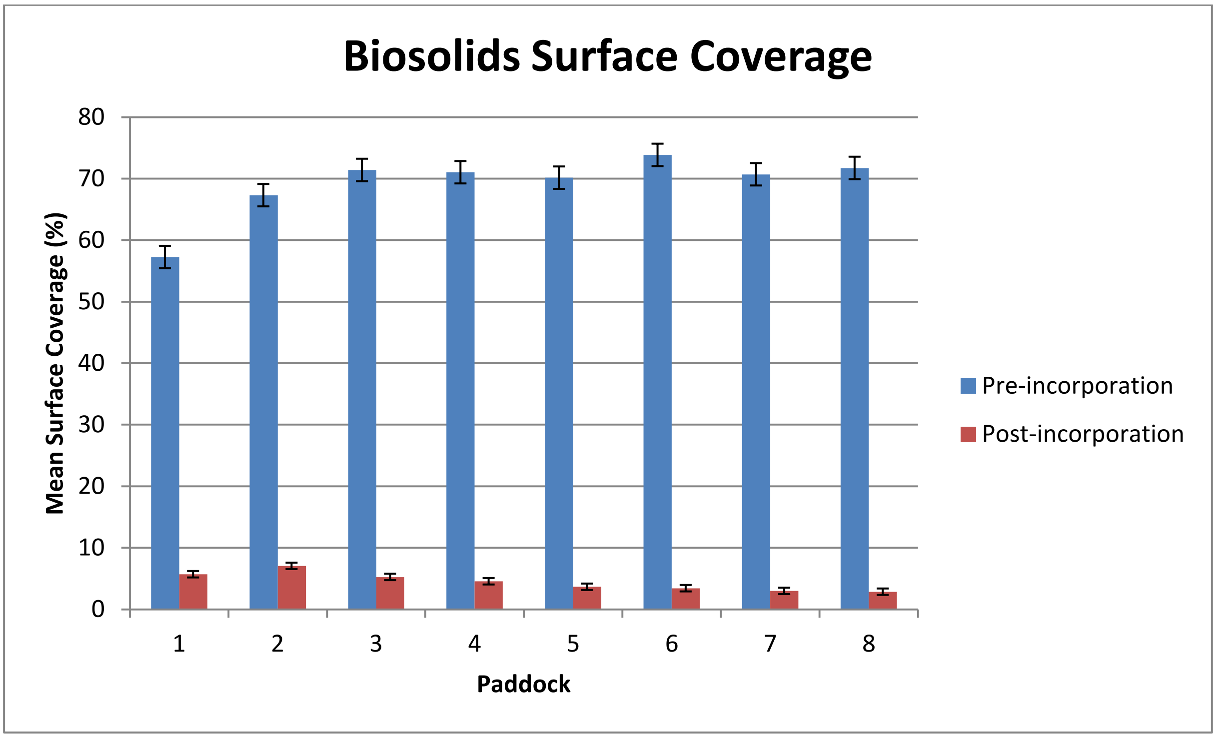

Figure 13: Mean surface coverage of biosolids pre/post-incorporation for the paddocks sampled. Error bars represent standard error for each paddocks mean biosolids cover.

The mean of the pre-incorporated samples was 69.2% with a high variance of 26.5%; this indicated the differences which were observed between samples taken within each paddock. These differences are clearly visible when looking at a selection of photos which were taken from the same paddock and noting the changes in biosolids surface coverage pre-incorporation (Figure 14).

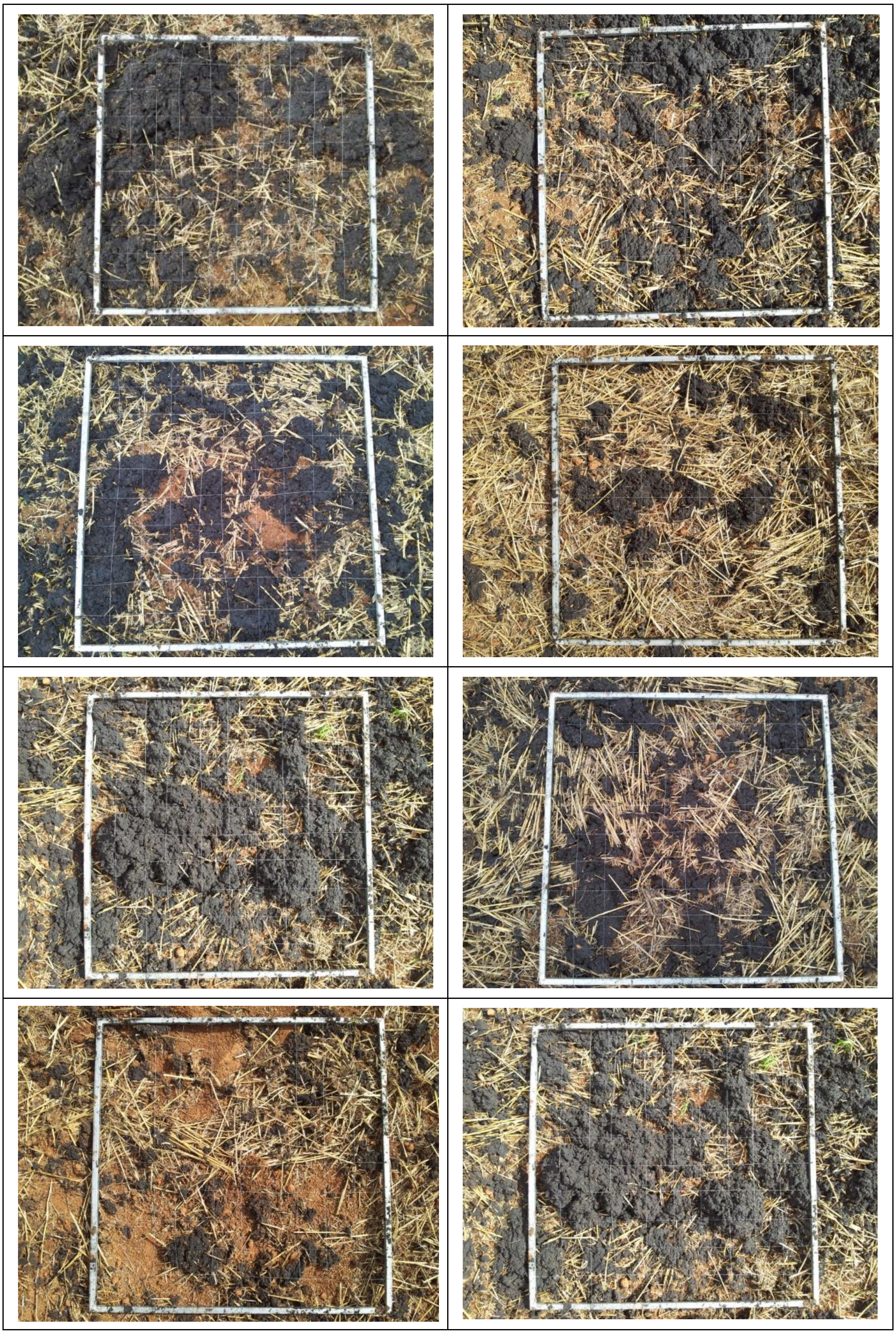

Figure 14: Variation is clearly visible within biosolids surface coverage for pre-incorporated samples in a single paddock.

The use of the rapid and detailed visual assessment techniques was also tested to determine if there is a significant difference between the results gained from the two assessment techniques for post-incorporation results. Similarly to the test performed for the reduction in biosolids surface cover, the unit of analysis was the paddock. Within each paddock, 4 blocks of 3 samples were measured with rapid and detailed assessment techniques. To account for the block design, the analysis used was a two tailed paired t test (JMP version 10) comparing the average of the samples within blocks by paddock for rapid and detailed assessment techniques, that is the, means of the paddocks were calculated by taking the means of the blocks within each paddock which were the means of the samples within each block (Figure 15). The t test was not significant (t=1.003, 7df P<0.349) indicating that there was no statistically significant difference in the results obtained from the rapid assessment technique and the detailed assessment technique. With means of biosolids surface coverage 4.3% and 4.4% respectively, it can be inferred that for the post-incorporation samples, the rapid assessment technique gives results which are quite similar to those achieved by the more time consuming detailed assessment.

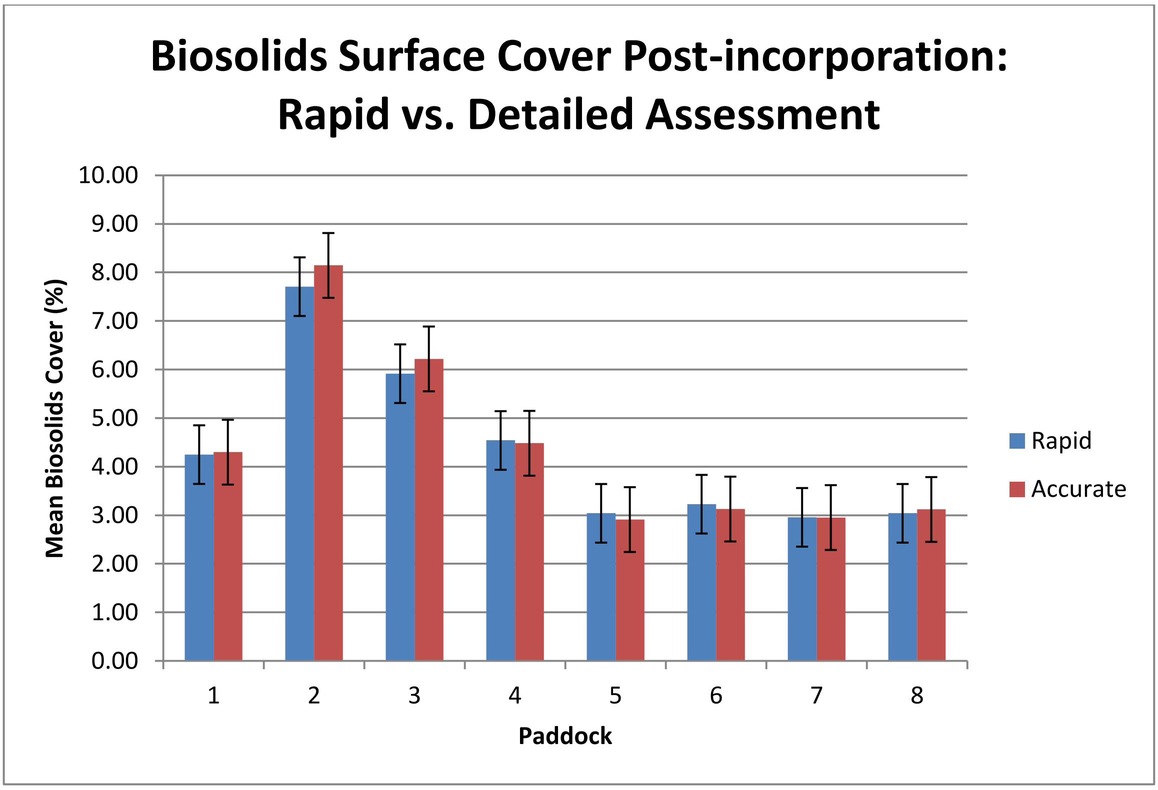

Figure 15: Mean surface coverage of biosolids post-incorporation for the paddocks sampled using rapid and detailed assessment techniques. Error bars represent standard error for each paddocks mean biosolids cover.

The correlation between the two sets of results gained was high, Pearson Correlation = 0.998 (Figure 16). This indicates that the two assessment techniques produced results which were very similar indicating that if time was a constraint in analysis, rapid assessment of post-incorporated samples could be substituted for detailed assessment with a high confidence of achieving accurate results.

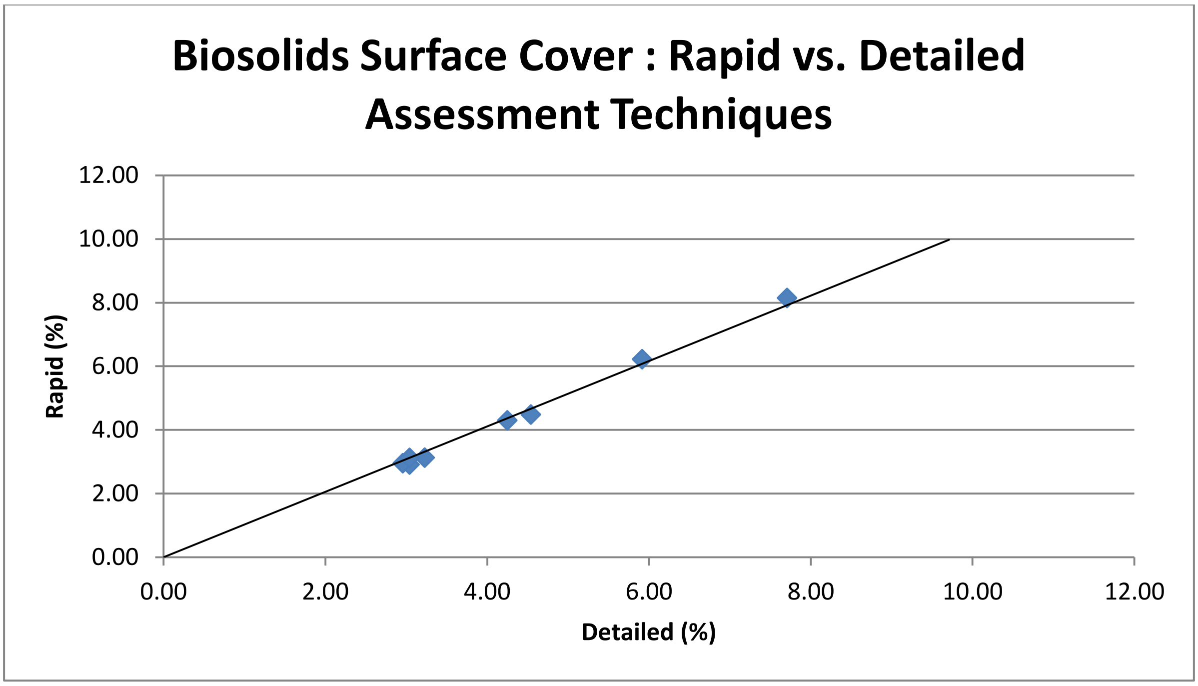

Figure 16: Biosolids surface coverage assessment using rapid and detailed assessment techniques for post-incorporation samples.

4.2 Limitations of assessment techniques

Limitations to the techniques presented in this study have been outlined in general throughout previous sections of this report but will be discussed here in more detail. Many issues that were found focused on the time intensive nature of carrying out multiple repetitions of large scale sampling, especially when more in-depth analysis needed to be performed such as was the case for detailed analysis of biosolids surface coverage. With biosolids land application operations occurring over a number of days, and incorporation required to be achieved within 36 hours, a need to be onsite at the time these operations were occurring is paramount to gather data pre/post-incorporation. With over 736 samples taken in 8 paddocks using sample technique 3 alone, many hours needed to be spent in the data gathering phase of the study. While a greater resource base such as having more individuals to help in data acquisition may reduce time spent in the field, it may

have also introduced variations in results between observers. This, however, was not an issue in this study as all data was gathered by a single observer to ensure no new bias was brought into results.

An issue encountered with the visual assessment techniques themselves was that they made no allowance for the 3-dimensional volume of biosolids clods. The visual assessment only employed a 2-dimensional view of the quadrat (directly overhead) for the calculation surface area coverage. This gave results which were easier to analyse as simple percentages, but did not fully describe the amount of biosolids present. Some biosolids remained in larger clods (as seen in Figure 17) and were not entirely broken up and evenly dispersed by the spreader. A completely even spread would be the ideal result of biosolids land application, but this is not operationally achievable. Some of these larger biosolids clods are simply an effect of the equipment used to spread the biosolids, in conjunction with the sticky nature of the biosolids themselves, due to the addition of dewatering polymers at Sewerage Treatment Plants. While dewatered biosolids are spread with rear discharge manure spreaders, problems like this will still remain and may need to be taken into consideration in the spreading process. If these larger clods are allowed to stay on the surface for some time to be affected by the sun, subject to desiccation and other environmental factors, this may aid in their breakdown and also potentially reduce pathogenic bacteria (Eamens et al., 2006, Wu and Smith, 1999).

Figure 17: A large biosolids clod which was only measure in 2-dimensional space but clearly if spread thinner would have covered much greater surface area.

Another limitation which was encountered in the field was the effect of crop residual creating a mat for biosolids to stick to and sometimes inhibiting proper incorporation (Figure 18). While leaving residual crop stubble is an effective method for controlling various forms of erosion (Jia et al., 2010, Russell, 1992), it prevented proper incorporation especially on paddocks which were ploughed using the disc plough. With the disc plough only turning the soil over it did not adequately breakdown some of the larger, mat like, structures which influenced the results for post-incorporated samples in these paddocks, leading to slightly higher surface coverage percentages.

Figure 18: Residual crop stubble has formed a mat which biosolids have stuck to, therefore leading to them not being incorporated fully. The clump being pointed to is a large mat of biosolids encompassing approximately 4 cells.

A range of other limitations were also encountered due to the nature of field operations and biosolids land application in general. As the trial sites were located on different farms, slightly different biosolids application rates were used (as per the requirements of the specific paddocks see *Environmental Guidelines: Use and Disposal of Biosolids Products* (EPA, 1997) for determination of biosolids application rates). This may have slightly influenced results for biosolids surface coverage between trial sites. With the aim to determine if the incorporation process lead to reductions in biosolids coverage, varied application rates were deemed to be a negligible variable, as all paddocks

showed a significant reduction in biosolids surface coverage pre/-post-incorporation. Other variables which may affect results but very not assessed in the current study (due to its limited timeframe of 37 weeks) include; the use of different biosolids spreading machinery, variations in biosolids e.g. solids content, different soil types, levels of residual crop cover etc. Future studies could examine the effects these variables have on assessing adequate levels of incorporation of land applied biosolids.

4.3 Effectiveness of current incorporation techniques

In NSW, the current version of biosolids guidelines is the *Environmental Guidelines: Use and Disposal of Biosolids Products* (EPA, 1997). Within this document incorporation for land applied biosolids is defined as "the use of one pass of a disc plough under favourable moisture conditions"; this was the method of incorporation used at *trial site 3* for all paddocks assessed. As outlined previously, this incorporation technique produced a significant reduction in biosolids surface coverage over all paddocks with a mean post-incorporation surface coverage of approximately 5.6%. The results were affected by some of the limitations outlined previously including the effects of residual crop stubble causing incorporation issues. Overall this incorporation technique was successful in significantly reducing the amount of biosolids visible on the paddock surfaces.

When disc ploughing is compared with the chisel plough followed with harrows (Figure 19), which achieved a mean post-incorporation surface coverage of approximately 3.1% over all paddocks, the latter of the two techniques provides the greatest soil covering of surface applied biosolids. This result raises the issue of why the current guidelines have not considered different incorporation methods as acceptable for land applied biosolids. With many farmers moving towards no-till and minimum till practices on their land to help fight issues such as erosion (Lal et al., 2007), perhaps less destructive ploughing techniques should be considered for biosolids incorporation if they achieve equal if not more acceptable results. With this being the case, there may be an issue in the future, of farmers refusing to take biosolids if they are forced to use disc ploughing as a means of incorporation. As these results are only from the comparison of two incorporation techniques, more research is needed, into the performance of various incorporation techniques at providing adequate biosolids incorporation under varying environmental conditions e.g. soil type and moisture, in regards to regulations and the biosolids guidelines.

Figure 19: Chisel plough and harrow incorporation method used at *trial site 4*.

4.4 Acceptable level of biosolids soil incorporation which may be achieved in order to reduce environmental and other potential risks

Biosolids soil incorporation as outlined throughout Section 2 helps in reducing the potential for a number of environmental risks and other issues. These range from issues of odour, vector attraction reduction, providing a physical barrier against pathogens, reducing potential for surface and groundwater contamination and also to prevent animals from ingesting biosolids. The level of incorporation achieved in this experiment resulted in significant reductions in biosolids surface cover between pre and post-incorporation, to mean levels of below 6% (Figure 20). If this 6% is converted to actual tonnes of biosolids, using the biosolids application rate outlined in Section 3.2.5 for *Trial site 3* of 70 wet tonnes/ha, approximately 1.09 dry tonnes/ha of biosolids remained on the ground surface after incorporation (Figure 21). These values are calculated using the highest application rate for the two paddocks and above average levels of post-incorporated biosolids exposure. This was done to show that even at these levels of incorporation only a small amount of biosolids is left on the surface. It is important to mention that in all of the samples taken there was not a single one which achieved 100% incorporation i.e. No biosolids visible on the surface. This indicates that achieving such a high level of incorporation is simply not feasible with current land application techniques and incorporation methods

Figure 20: Visual representation of less than 6% biosolids surface coverage for post-incorporated samples.

Assuming biosolids bulk density of <u>1000 kg/m³</u>
Average solids content of biosolids applied <u>26%</u>

70 wet tonnes/ha x (26/100) = 18.2 dry tonnes/ha

18.2 dry tonnes/ha x (6/100) = 1.09 dry tonnes/ha remaining on surface.

Figure 21: Equations used to determine dry tonnes/ha remaining of paddock surface after biosolids incorporation.

Many of the studies which focus on the environmental impacts associated with biosolids particularly runoff and contamination issues apply biosolids at rates of between 0-120 dry tonnes/ha in controlled experiments (Aguilar and Loftin, 1991, Brenton et al., 2007, Esteller et al., 2009, Hansen et al., 2007, Rigby et al., 2009, Vogeler et al., 2006). With the conversion outlined (Figure 20) from wet tonnes/ha to dry tonnes/ha using average solids content of applied biosolids of 26%, finally converting this to the amount of dry tonnes/ha remaining on the paddocks surface after incorporation of approximately 1.09 dry tonnes/ha. This is very low compared to levels applied in

most of these experiments, where it has been established by many that biosolids applications at agronomic rates pose little to no risk to surface and groundwater contamination and also lead to low risks of ingestion by animals (Hill et al., 1998). It is also well established that the physical barrier provided by biosolids soil incorporation helps reduce risks associated with pathogens, by decreasing the chance of physical contact (Eamens et al., 2006), it is also noted that those biosolids remaining at the soil surface may benefit from solar radiation, desiccation and other environmental effects which aid in pathogen reduction. If the amount of biosolids remaining on the ground surface after incorporation is at levels below those which studies have found pose little to no environmental risks and minimise other issues, it can therefore be assumed that adequate levels of incorporation have been attained.

The requirements outlined by the EPA in current NSW biosolids guidelines aim to manage those issues mentioned above; however, after extensive investigation no literature has been found for determining how the adequate incorporation of biosolids is actually measured or what specific percentages of biosolids incorporation are required. The present study has provided techniques and data which suggest ways of determining if incorporation has been achieved to an adequate level in regard to environmental risks and other issues. If biosolids incorporation can be achieved so that it meets levels of surface biosolids exposure which are below those found to have little to no risks in previous studies, this could potentially provide a method for the assessment of adequate levels of biosolids incorporation. An established method of determining adequate biosolids incorporation, which can be made easily accessible and understandable by regulators and biosolids practioners alike, will help eliminate the confusion which is generally faced at present by both stakeholders on this issue.

5 Conclusions and Recommendations

5.1 Conclusions

The environmental challenge of the effective management of wastewater treatment and the biosolids produced is an issue of global concern for all stakeholders. Within Australia a large proportion of biosolids produced is used in the practice of land application for agricultural purposes. With this practice being highly regulated due to potential environmental contamination concerns and other issues, the need to assess aspects of the effectiveness of biosolids land application and soil incorporation within NSW has become an important focus point.

Currently under the NSW biosolids guidelines, the incorporation of land applied biosolids is to be achieved through a single pass with a disc plough. The effectiveness of this incorporation technique at reducing biosolids surface coverage and therefore potential environmental risks has been found to be significant. A large reduction in biosolids surface coverage between initial land application and post-incorporation was recorded. Placing the results obtained for biosolids incorporated using the disc plough within the context of previous studies, little to no potential for environmental risks were found after biosolids soil incorporation.

An issue which has been highlighted by biosolids practioners in regards to current NSW biosolids guidelines is that, although it is documented that biosolids need to be adequately incorporated into the soil, there is no documentation to be found from regulators on the issues of what constitutes measures of adequate levels of incorporation, or specific percentages of incorporation required under current regulatory framework. The current study has extensively examined incorporation of land applied biosolids, observing that levels of less than 6% surface coverage were repeatedly found for post-incorporated paddocks. Little or no environmental risk is posed by this level of biosolids remaining on the surface of the ground following incorporation. The development of a technique for assessing adequate levels of biosolids incorporation such as those outlined in the current study, needs to be documented and made accessible by biosolids industry regulators. This would allow for regulators and biosolids practioners to know and understand what is expected in order to achieve adequate biosolids incorporation in relation to guidelines and surrounding legislation.

Currently there is a lack of literature surrounding techniques which can be used for assessing biosolids soil incorporation, therefore it was essential to develop in the current study a range of techniques for such measurements. Although a number of the techniques developed were modified due to their limitations, an initial platform for further development of assessment techniques for determining adequate levels of biosolids incorporation has been produced. The final technique

which was used in the current study for assessing biosolids surface coverage and the extent of soil incorporation, has been noted to have limitations of its own, but due to the 37 week timeframe of this study and a need to gather results it was considered the best available technique for use. The statistical comparison of rapid visual assessment and detailed measurement indicated that for, post-incorporated samples, results obtained using both rapid and detailed measures had no statistically significant difference. As it is the post-incorporated sample which will give a measure of adequate levels of soil incorporation, the current technique (technique 3) gave accurate results for coverage and could therefore be used as a basis for further development in this area.

The effective management and incorporation of land applied biosolids can be enhanced by taking into consideration issues of potential environmental impacts and the other issues related to biosolids land application as outlined throughout this report. It has been identified that the incorporation of land applied biosolids using methods outlined in the NSW biosolids guidelines are effective at achieving adequate levels of incorporation. With this being the case it was also found using a chisel plough followed with harrows provided slightly better levels of incorporation resulting in less biosolids visible on the paddock surface than disc ploughing. This use of the chisel plough has benefits of helping reduce risks of erosion by not adversely affecting soil structure as much as disc ploughing. With many farmers becoming more aware of issues related to tillage it is likely more farmers will be moving towards less soil destructive forms of agriculture. This is something which needs to be kept in mind by regulators for this industry to continue growing; biosolids management practices and legislation need to reflect changes in agricultural techniques which are moving towards minimum/no till farming.

Understanding the factors which affect biosolids land application management and achieving adequate levels of biosolids soil incorporation in order to reduce environmental and other risks, is critical in recommending areas of research which will further promote understanding and collaboration between industry regulators and biosolids practioners.

5.2 Recommendations

In order to better understand if levels of biosolids soil incorporation achieved in this study are adequate in reducing potential environmental risks such as surface and groundwater contamination (without relying on results achieved in other studies), it is recommended that research be focused on assessing runoff from sites applied using various biosolids application rates and different

incorporation methods. Assessing surface coverage post-incorporation in these trials using techniques outlined in the current study would allow for comparisons of results and a better understanding of potential environmental risks to be assessed.

It is also recommended that the results of this study be shared with regulatory authorities in order to develop a method for assessing adequate levels of biosolids incorporation from a regulatory and legislative perspective. Any resulting document detailing methodology for assessing adequate levels of incorporation should be made available to all stakeholders and would ensure the confusion between what is and is not considered adequate incorporation is minimised. The development of a method of assessing adequate levels of incorporation which can be easily used and understood, would allow for practioners or regulators to assess any biosolids land application site and be confident they are following relevant guidelines and legislation.

The techniques developed throughout the current study provide an initial platform for further development of assessment techniques for determining adequate levels of biosolids incorporation. A range of other techniques have been noted throughout this report but due to limitations of time restraints and funding they have not been explored. Further research and field trials of techniques may provide for more accurate and time effective assessment of biosolids surface coverage and relating this to environmental risks.

It is recommended that more field trials be undertaken using a range of incorporation methods/ ploughing techniques suggested by farmers using minimum till agricultural practices on their farms. If incorporation techniques can be identified which lead to adequate incorporation levels but are more sustainable then disc ploughing, perhaps these can be accepted incorporation practices under any revised editions of biosolids guidelines. A need to make the most use of available agricultural land for biosolids application in a sustainable manner will maintain the future of agricultural and biosolids industries alike.

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7 Appendices

A. Comparisons of visual assessment results with ENVI output results.

Pre-incorporation Surface Coverage (%)

Rapid Assessment	ENVI Analysis
75	63
82	72
79	88
73	89
65	57
75	62
54	68
80	71
57	70
71	60
53	62
61	68
68	75
55	81
74	82
70	65
75	83
68	81
79	89
82	93

Post-incorporation Surface Coverage (%)

Rapid Assessment	Detailed Analysis	ENVI Analysis
1.5	1.45	13
1	0.95	10
2	2.1	15
4.5	4.1	22
4.5	4.75	19
2	2.2	14
2.5	2.6	9
5.5	4.9	13
2.5	2.45	16
1.5	1.4	7
0.75	0.7	15
1	1.1	12
6	6.4	28
4	4.2	21
8	8.5	19
5.5	6	17
3	3.3	11
6	5.45	16
5	5.25	24
2	1.9	18

B. Results of initial trials of technique 3 at *Trial site 2* for post incorporation samples.

		Rapid Assessment		Detailed Assessment	%
Blocking	Sample	Post-incorporation (%)		Surface Coverage (cm^2)	
1	1	6			
1	2	7.5			
1	3	7		701	7.01
1	4	3.5			
1	5	11			
1	6	13			
1	7	0.5		56	0.56
1	8	5			
1	9	3.5		280	2.8
1	10	6.5			
2	11	6			
2	12	2.5			
2	13	2		236	2.36
2	14	3			
2	15	2		180	1.8
2	16	6			
2	17	5			
2	18	4.5		498	4.98
2	19	3			
2	20	9			
3	21	1			
3	22	4			
3	23	4.5		505	5.05
3	24	8			
3	25	1		96	0.96
3	26	8.5			
3	27	1.5			
3	28	5		532	5.32
3	29	3			
3	30	4.5			
4	31	7			
4	32	8			
4	33	6.5		615	6.15
4	34	1.5			
4	35	3		313	3.13
4	36	2			
4	37	3			
4	38	7		675	6.75
4	39	5.5			
4	40	7			

C. Results obtained from assessment technique 3 from T*rial site 3 and 4*.

<u>**Trial site 3 paddock 1.**</u>

		Rapid Assessment	Rapid Assessment		Detailed Assessment	%
Blocking	**Sample**	**Pre-incorporation (%)**	**Post-incorporation (%)**		**Surface Coverage (cm²)**	
1	1	60	3			
1	2	55	4.5			
1	3	45	1.5		145	1.45
1	4	75	3.5			
1	5	65	5.5			
1	6	70	3.5		335	3.35
1	7	55	4			
1	8	78	6			
1	9	80	5		520	5.2
1	10	56	6			
2	11	63	3.5			
2	12	55	7			
2	13	61	6.5		645	6.45
2	14	82	4.5			
2	15	87	8			
2	16	80	3		275	2.75
2	17	78	4.5			
2	18	69	9			
2	19	65	4		420	4.2
2	20	68	3.5			
3	21	80	10			
3	22	72	5			
3	23	83	2		215	2.15
3	24	69	12			
3	25	88	6			
3	26	82	4		370	3.7
3	27	65	7			
3	28	79	5			
3	29	73	3		280	2.8
3	30	65	8			
4	31	79	5			
4	32	82	2			
4	33	83	7		730	7.3
4	34	77	3			
4	35	90	4.5			
4	36	63	4.5		475	4.75
4	37	58	9			
4	38	62	8			
4	39	80	7		750	7.5
4	40	79	2			

Trial site 3 paddock 2.

		Rapid Assessment	Rapid Assessment		Detailed Assessment	%
Blocking	Sample	Pre-incorporation (%)	Post-incorporation (%)		Surface Coverage (cm²)	
1	1	50	5			
1	2	67	4.5			
1	3	64	8		770	7.7
1	4	80	7			
1	5	73	10			
1	6	72	6		640	6.4
1	7	75	8			
1	8	65	9			
1	9	66	4		420	4.2
1	10	60	5			
2	11	55	6			
2	12	58	7.5			
2	13	80	8		850	8.5
2	14	85	9			
2	15	78	3.5			
2	16	73	5.5		600	6
2	17	70	7			
2	18	50	5			
2	19	55	8		775	7.75
2	20	51	6			
3	21	80	5.5			
3	22	77	5			
3	23	91	12		1280	12.8
3	24	79	11			
3	25	76	10			
3	26	80	3		330	3.3
3	27	45	6			
3	28	49	8			
3	29	80	15		1600	16
3	30	60	9			
4	31	59	8			
4	32	53	7			
4	33	80	11		1200	12
4	34	69	3			
4	35	65	6.5			
4	36	82	9		990	9.9
4	37	73	5			
4	38	50	6			
4	39	57	3		320	3.2
4	40	60	7			

Trial site 3 paddock 3.

		Rapid Assessment	Rapid Assessment		Detailed Assessment	%
Blocking	Sample	Pre-incorporation (%)	Post-incorporation (%)		Surface Coverage (cm²)	
1	1	60	4			
1	2	78	6			
1	3	51	9		980	9.8
1	4	55	3.5			
1	5	62	7			
1	6	47	5.5		580	5.8
1	7	58	7			
1	8	61	4			
1	9	72	3		290	2.9
1	10	58	2			
2	11	54	8			
2	12	80	6			
2	13	57	10		1120	11.2
2	14	71	9			
2	15	53	5			
2	16	61	4		420	4.2
2	17	73	6			
2	18	65	7			
2	19	55	3.5		370	3.7
2	20	51	6.5			
3	21	49	5			
3	22	70	9			
3	23	55	8.5		900	9
3	24	61	7			
3	25	45	4			
3	26	40	5.5		585	5.85
3	27	45	6			
3	28	52	3			
3	29	75	3		290	2.9
3	30	35	2			
4	31	53	4			
4	32	38	8			
4	33	42	11		1050	10.5
4	34	57	7			
4	35	40	5			
4	36	64	5		530	5.3
4	37	55	6.5			
4	38	50	7			
4	39	70	3		350	3.5
4	40	72	2			

Trial site 3 paddock 4.

		Rapid Assessment	Rapid Assessment		Detailed Assessment	%
Blocking	Sample	Pre-incorporation (%)	Post-incorporation (%)		Surface Coverage (cm²)	
1	1	72	5			
1	2	69	2.5			
1	3	81	4		430	4.3
1	4	58	3.5			
1	5	63	7			
1	6	71	6		545	5.45
1	7	70	3.75			
1	8	75	4.5			
1	9	68	5.5		530	5.3
1	10	65	3			
2	11	86	2.5			
2	12	82	7			
2	13	74	6.75		615	6.15
2	14	76	3			
2	15	66	3			
2	16	58	5		525	5.25
2	17	75	2			
2	18	72	4.5			
2	19	66	6		550	5.5
2	20	69	8			
3	21	71	5.5			
3	22	59	3.75			
3	23	83	4		370	3.7
3	24	72	5			
3	25	76	2.5			
3	26	67	2		190	1.9
3	27	65	4			
3	28	74	4.5			
3	29	79	5		480	4.8
3	30	55	6.5			
4	31	64	9			
4	32	69	3.75			
4	33	77	4		460	4.6
4	34	73	6			
4	35	79	5.25			
4	36	68	2		210	2.1
4	37	82	4			
4	38	64	3.5			
4	39	66	4.25		475	4.75
4	40	82	5			

Trial site 4 paddock 1.

		Rapid Assessment	Rapid Assessment		Detailed Assessment	%
Blocking	Sample	Pre-incorporation (%)	Post-incorporation (%)		Surface Coverage (cm²)	
1	1	80	1			
1	2	72	2.5			
1	3	60	2		210	2.1
1	4	75	4			
1	5	78	5			
1	6	83	4		380	3.8
1	7	60	5.5			
1	8	79	3.5			
1	9	72	5		465	4.65
1	10	65	3			
2	11	73	6			
2	12	81	5			
2	13	70	4.5		470	4.7
2	14	65	7			
2	15	55	1.5			
2	16	73	4.5		410	4.1
2	17	70	1			
2	18	93	8			
2	19	75	2.75		245	2.45
2	20	68	3			
3	21	63	1.5			
3	22	75	3.5			
3	23	68	2.5		260	2.6
3	24	64	1.75			
3	25	88	4.5			
3	26	65	5.5		490	4.9
3	27	70	3			
3	28	68	2.75			
3	29	70	2.5		245	2.45
3	30	65	6			
4	31	63	5.5			
4	32	69	1.75			
4	33	77	1.5		140	1.4
4	34	60	3.75			
4	35	75	2.5			
4	36	55	0.75		70	0.7
4	37	68	6			
4	38	59	9			
4	39	60	1		110	1.1
4	40	77	2			

Trial site 4 paddock 3.

		Rapid Assessment	Rapid Assessment		Detailed Assessment	%
Blocking	Sample	Pre-incorporation (%)	Post-incorporation (%)		Surface Coverage (cm^2)	
1	1	76	2			
1	2	73	4			
1	3	68	1.5		145	1.45
1	4	71	6			
1	5	65	3.5			
1	6	69	2		210	2.1
1	7	73	2.5			
1	8	62	1.5			
1	9	60	1		95	0.95
1	10	79	1.25			
2	11	82	2			
2	12	77	1.5			
2	13	66	4.5		475	4.75
2	14	70	3.5			
2	15	65	1.25			
2	16	59	5		455	4.55
2	17	83	3			
2	18	78	1			
2	19	77	4.5		410	4.1
2	20	75	5			
3	21	68	0.75			
3	22	55	3.5			
3	23	74	2		220	2.2
3	24	70	2.25			
3	25	75	3			
3	26	68	4.5		550	5.5
3	27	63	1.5			
3	28	81	1			
3	29	77	5		460	4.6
3	30	71	2.5			
4	31	66	7			
4	32	69	2			
4	33	75	1		115	1.15
4	34	61	3			
4	35	82	4.5			
4	36	58	2.5		220	2.2
4	37	71	1.5			
4	38	76	5.25			
4	39	67	2		190	1.9
4	40	73	7.75			

Trial site 4 paddock 4.

		Rapid Assessment	Rapid Assessment		Detailed Assessment	%
Blocking	Sample	Pre-incorporation (%)	Post-incorporation (%)		Surface Coverage (cm²)	
1	1	73	3			
1	2	69	1.25			
1	3	77	4		425	4.25
1	4	65	2.75			
1	5	68	1.25			
1	6	69	3		310	3.1
1	7	78	4			
1	8	74	3.5			
1	9	81	6		720	7.2
1	10	66	2.5			
2	11	67	1			
2	12	59	3			
2	13	83	1		95	0.95
2	14	76	2			
2	15	74	3.75			
2	16	79	4		380	3.8
2	17	63	6.25			
2	18	68	1.5			
2	19	78	2		185	1.85
2	20	57	1			
3	21	71	3.25			
3	22	73	1			
3	23	66	2.75		235	2.35
3	24	69	2			
3	25	77	4			
3	26	84	4.5		475	4.75
3	27	65	3			
3	28	73	3.75			
3	29	78	2		210	2.1
3	30	66	1			
4	31	64	1			
4	32	76	1.5			
4	33	68	4.25		400	4
4	34	77	5			
4	35	78	2.5			
4	36	81	1		115	1.15
4	37	68	4.5			
4	38	54	3.25			
4	39	82	2		195	1.95
4	40	75	5			

D. Results obtained using technique 1.

Blocking	Sample	Pre-incorporation (%)		Post-incorporation (%)
1	1	82		15
1	2	92		26
1	3	98		19
1	4	80		23
1	5	88		20
1	6	80		21
1	7	86		12
1	8	78		26
1	9	82		32
1	10	80		16
2	11	60		15
2	12	65		25
2	13	60		9
2	14	80		16
2	15	78		13
2	16	80		15
2	17	95		20
2	18	85		16
2	19	88		16
2	20	77		24
3	21	78		22
3	22	85		18
3	23	65		13
3	24	82		8
3	25	75		18
3	26	90		19
3	27	68		25
3	28	75		32
3	29	73		15
3	30	85		14
4	31	82		18
4	32	90		16
4	33	88		17
4	34	82		19
4	35	90		22
4	36	70		23
4	37	75		25
4	38	77		16
4	39	80		15
4	40	68		10

E. Results obtained using technique 2.

Paddock 1.

Blocking	Sample	Pre-incorporation (%)		Post-incorporation (%)
1	1	98		40
1	2	97		70
1	3	100		58
1	4	92		60
1	5	100		45
1	6	98		60
1	7	95		23
1	8	98		40
1	9	99		39
1	10	99		56
2	11	97		42
2	12	100		51
2	13	98		60
2	14	99		32
2	15	95		29
2	16	100		51
2	17	100		26
2	18	98		54
2	19	95		43
2	20	97		40
3	21	96		38
3	22	93		52
3	23	99		35
3	24	94		36
3	25	100		29
3	26	94		41
3	27	96		53
3	28	98		29
3	29	100		38
3	30	92		41
4	31	98		58
4	32	95		28
4	33	96		37
4	34	89		46
4	35	98		38
4	36	96		72
4	37	100		56
4	38	99		39
4	39	92		45
4	40	97		38

Paddock 2.

Blocking	Sample	Pre-incorporation (%)		Post-incorporation (%)
1	1	80		53
1	2	95		47
1	3	75		36
1	4	95		39
1	5	93		54
1	6	88		46
1	7	100		39
1	8	99		29
1	9	98		36
1	10	96		48
2	11	95		47
2	12	100		38
2	13	98		65
2	14	96		68
2	15	87		52
2	16	92		49
2	17	90		65
2	18	88		54
2	19	91		57
2	20	100		32
3	21	94		54
3	22	89		48
3	23	96		45
3	24	100		39
3	25	98		36
3	26	96		42
3	27	95		51
3	28	99		48
3	29	100		49
3	30	98		30
4	31	90		45
4	32	97		56
4	33	100		50
4	34	99		49
4	35	95		58
4	36	96		60
4	37	88		37
4	38	96		48
4	39	99		49
4	40	94		56