Biosolids and forests: an overview of New Zealand trials, and the benefits and drawbacks in marrying two industries

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Introduction

Wastewater treatment processes are generally designed to ensure that most of the constituents in the liquid influent (pathogens, organics and excreta) are biologically degraded and separated into the solid fraction within the system, leaving the effluent clean and suitable for discharge to waterways. The microbiological treatment process converts raw effluent to a combination of microbial biomass and residues from this process (biosolids) that contain low levels of macro- and micronutrients, trace levels of heavy metals, pathogens and other constituents of concern. Their composition is variable and highly dependent on the influent sewage from which they are derived and the treatment process in use.

While raw excreta and sludges have long been applied to land in many parts of the world, the application of biosolids (which is produced by modern wastewater treatment plants and generally does not have the same environmental suitability issues as sludges) to land is often met with concern or hostility. The perceived potential for contamination of land and waterways has led to biosolids often being retained in landfills or incinerated, rather than used as a soil amendment. Concerns regarding the potential transmission of pathogens from biosolids to farm stock or humans has prompted reviews of land application practices involving biosolids and food chain organisms (O'Connor *et al.* 2003). Several major industries have indefinitely postponed the application of biosolids to food chain crops pending appropriate scientific results that prove the methods to be safe (NZ Dairy Board 2001). This policy has enhanced the importance of applying biosolids to forested land (Magesan and Wang 2003). It can reduce the likelihood of contaminants entering the human food chain, and may also increase tree growth and economic return (Kimberley et al. 2004).

The nutrient content of biosolids and their potential value as a fertiliser for forestry have been studied since the early 1970's, and work in New Zealand has been ongoing since the late 1980's. Forest Research has been involved in two nationally significant operational scale

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biosolids application trials, at Canterbury and Nelson. These two programmes have focussed on the technical and operational challenges to councils and forest owners/managers with respect to communication and requirements. While these two programmes have been successfully applying biosolids to forests for several years, few new programmes have been developed in the interim. The Ministry for the Environment has implemented a New Zealand Waste Strategy (MfE 2002), encouraging the target of reducing the amount of biosolids that is dumped in landfills. In addition, comprehensive guidelines have been produced outlining the issues with biosolids application (NZWWA 2003).

This paper addresses findings from the Biosolids to Forests Programme trials at Canterbury and Nelson run by our institute, looking at the major technical and social areas of study. We then examine the question of why further uptake of beneficial biosolids application to land is not being used to it's potential in New Zealand. This examination looks at the conflicting goals of the forest owner/manager and the waste manager, and the obstacles these groups will have to overcome to achieve a harmony between their industries.

An overview of the programme

The Biosolids to Forests programme, funded by the Foundation for Research, Science and Technology (FRST) in the late 1990s, was initiated to incorporate research on the topics of nutrient fate and mobility, tree growth, heavy metal mobility and leaching, pathogen attenuation, and social issues. Research trials have been established on two sites in New Zealand. While most of this work has progressed, social and cultural work were originally declined funding. This work has been funded recently through the second generation of FRST funding, in which the programme has expanded to become the new Waste to Resource (W2R) Programme, including social and cultural work. Also included in the new programme is work focussing on terrestrial and aquatic ecotoxicology of organisms potentially affected by application of municipal and industrial residuals to land.

Research overview – Canterbury

The Christchurch wastewater treatment plant serves the City's 330,000 people. Wastewater treatment plant produces anaerobically digested and dewatered biosolids, which contains low levels of contaminants, such as heavy metals and persistent organic compounds (McLaren *et al*. 1999). Christchurch City Council planned to apply biosolids to 1500 ha of radiata pine plantation forests at an application rate of 400 kg N ha^{-1} every two years. The forests are within 50 km of the wastewater treatment plant (Bourke 2001). The limiting factor for land application was the total N content, of which about a quarter is present as ammonium. In August 2000, biosolids were applied to two forests of different ages (5 and 20 years) at three rates of application (0, 400 and 800 kg N/ha). Following application, movement and the fate of biosolids constituents were assessed by measuring changes in biosolids, soil, soil solution, and plants (Clinton *et al*. 2002a).

Tree growth and nutrition

Nutrients, in particular nitrogen (N), are often considered to be the biosolids constituents of highest priority and concern due to their mobility in soil. The potential for movement of these nutrients into groundwater and waterways has led to the use of an agronomic rate of nitrogen to be considered a limiting factor when calculating application rates for biosolids in New Zealand. There has been much study of fate and mobility of nutrients from biosolids.

At the Canterbury field site, despite the high organic N content, very little N has mineralized (become mobile) when studies through a 26-week laboratory incubation of biosolids mixed with soil (Wang *et al*. 2003). Measurement during the field application (surface spreading) showed that 43-55% of the ammonium applied in biosolids was volatilized. The majority of the losses occurred within about one day of application, and represented about 12% of the total N applied (Robinson and Röper 2001). Therefore, very little of the added N could be considered immediately available for plant uptake due to rapid volatilization of ammonia. Changes in isotopic nitrogen values for foliage and forest floor, however, suggest N availability increased in these pools as a result of biosolids application. Younger trees may have shown some growth response to increasing rate of biosolids application, but this was masked by the earlier onset of moisture limitations. Trends in carbon isotope discrimination suggest that at higher rates of biosolids application, young trees that had initial growth response to the nutrients in the biosolids may become moisture stressed due to greater transpiration. This water deficiency may have limited the further growth response to N released from the biosolids (Clinton and Leckie 2002).

Concentrations or fluxes of ammonium, nitrate, dissolved organic N, total N, phosphate, were not increased above background (or control) levels in soil or leachate during the initial period after application (Clinton *et al*. 2002a). Up to 57% of the total N applied remained in residual biosolids 15 months after application (Clinton and Leckie 2002).

Phosphorus (P) generally displays less mobility than N in most soils, but in the case of sandy soils, P can be quite mobile, so it should be monitored carefully. The ratio of N:P in biosolids is much lower than the natural ratio of N:P in plants, which means that soils will retain and bind a large amount of P during application. This is not considered a serious issue as most soils have high capacity for P retention. The work at Canterbury has not shown any significant leaching of P after biosolids application.

Heavy metals

Heavy metals of concern include arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), copper (Cu), nickel (Ni) and zinc (Zn). Elevated levels of these heavy metals are known to cause symptoms of toxicity in humans and plants. Trees are able to take up, Cu, Ni, and Zn, and in fact require small amounts of these elements to function (Marschner 1997). Lead and Hg tend to remain resident in the soil, and can accumulate in the soil and in some organisms, although the levels of these that are applied with biosolids (Pb ~ 50 ppm, and Hg, ~ 1ppm) are not considered toxic, even after many applications.

Heavy metals were not increased above background (or control) levels during initial period after application at the trial site (Clinton *et al*. 2002a). Examination of leachate collected with zero-tension lysimeters at the site showed no significant migration of heavy metals into the soil profile (Bowden *et al.* 2001). Work examining the constituents of water leaching through the soil profile, as well as examination of the soil itself, will continue under the W2R programme, with the help of the Christchurch City Council.

Pathogens

Sewage sludge contains a variety of pathogens, including bacteria, viruses, helminths, protozoa, and fungi. A host of these pathogens are used as indicator organisms (such as *Escherichia coli*) or otherwise regulated in biosolids (campylobacter, salmonella, enteric viruses, helminth ova, and protozoan ocysts and oocysts (NZWWA 2003)).

Although most pathogens are destroyed in the wastewater treatment and sludge digestion processes, public access to the Christchurch land application sites had been restricted for six months after biosolids application to minimize health risks. Survival of biosolids-derived indicator bacteria *E. coli,* the pathogenic bacteria *Salmonella,* and the protozoon *Giardia* *intestinalis* were monitored after biosolids application at 800 kg N/ha. *Salmonella* sp. were not detectable, and *E. coli* and *Giardia* levels returned to background soil level after 5 and 7 weeks, respectively, after biosolids application (Horswell *et al*. 2001). The examination of biological effects of biosolids application continues at the trials, further examining not only the pathogen survival in the biosolids, but also examining the effect of biosolids on the structure of soil microbial and fungal communities.

Social perceptions

The importance of social perceptions in forestry cannot be understated. Successful contemporary forest companies are driven by a requirement to be sustainable and socially accountable through certification systems cooperatively designed by the industry, the environmental lobby, and the public. Negative social perception due to the application of biosolids to the forest could have significant impacts on the ability to apply biosolids to forests, the public image of the council and the public image of the forest company. The threat of potentially losing hard won public faith is a likely impediment to cooperation from forest managers (Langer and Killerby 1999).

Christchurch City Council has put great effort into tackling the public perception issue, with one-on-one ratepayer meetings, forums and inviting experts to verify their work. One of the ways they have worked to improve public perception is by making the land application process accessible to the public. The Christchurch Biosolids Demonstration Area is located at Bottle Lake Forest Park, and features a creatively designed interpretive trail for interested people to follow. It is set up for the public to be able to understand the biosolids production process, as well as the application regime. This demonstration site serves as one of the tour stops for the councils “Waste of a Day Out” programme for school-age children, a field trip where students learn about how the city treats its waste. Christchurch continues to have a very small group of individuals who oppose the application, but the vast majority of the population appears content.

In order to find a true sustainable solution to the growing problem of waste in New Zealand, the social issues are an integrated part of any considered “beneficial use”, alongside the environmental and economic components. The members of the W2R team that are currently working in this social area are developing ways to identify and integrate community perspectives in waste management.

The social component of the W2R programme places importance on achieving genuine and meaningful consultation, which is more interactive and prospective than reactive. There are internationally tested dialogue methods that can support a two-way and meaningful dialogue with the public. Involvement of the community where all parties contribute and share knowledge and perspectives in addressing areas of concern could provide a substantive contribution to long-term sustainable solutions for waste management.

Plans are being considered to run a scenario workshop to trial a suitable dialogue method to stimulate discussions between a variety of parties. This will allow the evaluation and development of options and opportunities to understand community perspectives and to ensure sustainable waste management.

Research overview – Nelson

The municipal wastewater treatment plant at Bell's Island, Nelson, was upgraded to treat biosolids by aerobic digestion in the mid-1990s. Since then, aerobically digested liquid biosolids with a solids content of 3% from the Bell's Island plant have been applied to a nearby 1000 ha radiata pine forest plantation growing on a low fertility sand at Rabbit Island, Nelson (Kimberley *et al*. 2004). The Bell's Island WTP treats Nelson and Richmond sewage, as well as several industrial waste streams, including an abattoir. The biosolids at Rabbit Island are applied as a liquid using a purpose built machine. The biosolids contain relatively high concentrations of nitrogen (typically about 9% N on dry weight). Concentrations of heavy metals are very low and well below the maximum concentrations defined in the Guidelines for the safe application of biosolids to land in New Zealand (NZWWA 2003). A long-term research trial was established in 1997 to investigate sustainability of the biosolids application. Biosolids were applied to the trial site in 1997 and 2000, at three application rates: 0 (control), 300 (standard) and 600 kg N ha^{-1} (high). Tree growth response and nutrition were measured along with a number of other environmental variables such as soil and groundwater quality. The objectives of trial were to describe the effects of the biosolids applications on tree nutrition, soil and ground water quality, and the forest ecosystem.

Tree growth and nutrition

Foliage analysis indicated that natural soil nitrogen supply in the Rabbit Island *P. radiata* forest was low, with nitrogen concentration in foliage from the control treatment being well below 1.5% N, a level below which *P. radiata* may benefit from nitrogen fertilisation.

Biosolids application, particularly at the high rate, significantly improved nitrogen nutrition of *P. radiata*. Nitrogen concentration in the foliage had increased with application rate five months after the first application. Four months after the second biosolids application (November 2000) at tree age 9 years, there was another significant increase in foliage nitrogen concentrations in the biosolids treatments, compared with the control.

As a result of enhanced nitrogen nutrition, application of biosolids significantly increased *P. radiata* tree growth. There was a pronounced growth response to biosolids application by diameter and correspondingly basal area and volume, and a lesser but still significant response in height growth. In 2003 the average basal area of the high treatment was 53% and the standard treatment 47% greater than the control. The live volume of the high treatment was 52% and the standard treatment 36% greater than the control treatment, indicating a substantial gain in productivity (Kimberley *et al.* 2004). These improvements have continued through 2004.

Soil chemistry

Application of biosolids had no significant effect on soil acidity, concentration of total nitrogen and other nutrients, but it increased soil available P concentration. Biosolids treatments significantly increased concentrations of Cu in the litter layer and soil. Increased Cu concentration in soil receiving biosolids application did not increase the *P. radiata* foliage Cu concentration, indicating a low bioavailability of the biosolids derived Cu. Interestingly, there were significantly lower concentrations of Cr and Zn in the subsurface soil (0.25 – 0.5 m) in the standard biosolids treatment than in the control. These small but statistically significant variations of heavy metal concentration in soil were more likely to be caused by heterogeneity of the soil, particularly when the low concentrations of heavy metals in biosolids and low loading rates were taken into account. Generally, heavy metal concentrations including Cu, with or without biosolids application, were low and well below the soil contaminants limits defined by the guidelines for the safe application of biosolids to land in New Zealand (NZWWA, 2003). Overall, biosolids application improved soil fertility and appeared to have no significant detrimental effect on soil quality at Rabbit Island.

Groundwater quality

Quarterly monitoring data indicated little change in groundwater quality after the application of biosolids. There were no differences in chemical properties of groundwater samples taken from up gradient and down gradient wells. Concentration of heavy metals in the groundwater was generally low, e.g., concentrations of Ni and Zn <0.01 g m^{-3}, As, Cr and Pb <0.005 g m^{-3}, Cd, Cu and Hg <0.001 g m^{-3}. These values are well below the Maximum Acceptable Values for inorganic determinands of health significance (Ministry of Health 2000). Since the trial was established, concentrations of NO_3-N in groundwater have always been low, and were well below drinking water standards of 11.3 g NO_3-N m^{-3} (Ministry of Health, 2000). The shallow groundwater is low in potassium and contains relatively high concentrations of Mg, which can be taken up by tree roots, and helps prevent occurrence of upper mid-crown yellowing, a common symptom of *P. radiata* grown in Mg deficient soils.

Social perceptions

The social perceptions of the Rabbit Island application scheme appear to be favourable and benign. The site is well marked with signs explaining the process and its benefits as well as its drawbacks. The system has had no major public complaints regarding its operation, apart from a series of odour complaints that resulted not from application, but from an aerator failure at the Bell's Island plant in the mid 1990s.

The reason for the strong relationship with the public appears to be the amount of consultation that the Nelson City Council and Tasman District Council went through with the public before the system was put in place. The consulting group that helped to build the system (Beca Steven Ltd) seemed to have done an excellent series of transparent public consultations, where all concerns were allayed. Similarly, the site was discussed with local iwi, and the archaeological sites of value were clearly defined as "no-go" zones on the island. The thorough approach at the start of the process has seemingly resulted in a strong, long-term relationship with the local populace.

Why would a forest company not want biosolids?

The trials in New Zealand to date have shown that biosolids can increase growth and production in radiata pine stands growing on nutrient-poor soils provided there are no other limiting factors (such as growing-season drought stress). Our work and corresponding work elsewhere work has also shown that the biosolids applied to the surface may leach small amounts of N and P, but will retain most heavy metals in the upper 10 cm of the soil. The pathogens in the biosolids have shown consistent attenuation to background levels within 6 months to 1 year.

The two examples of biosolids application to forests that Forest Research is involved in are special in that they are both forests indirectly owned by the local council that produces the biosolids. Where local councils have the ability to apply biosolids to their own land, there is less complication in setting up the procedure. In each case, the forest manager has worked with the council to ensure that the system is managed in concert with biosolids application.

Several councils are currently examining options for biosolids use, and consequently looking into a partnership approach with a local forest owner, or a manager of forests on crown land. The added complication of working with an external forestry group leads to several perceived complications. Because most forestry companies have little experience with municipal biosolids, there is a gap in mutual understanding between the two groups, both in terms of operational forestry knowledge, and in terms of knowledge of biosolids as a product. From the perspective of the forester, several questions and concerns are brought up.

- Who is liable for the biosolids application and any contamination of the site?
- Will there be an expenditure of money on the part of the forest manager?
- Additional complications in the management and harvesting schedule.
- Dealing with an unknown substance.
- Pathogens with respect to health and safety in the forest.
- The potential for land contamination and subsequent restriction to land use change.
- The resource consent processes is onerous.

These concerns, regardless of their technical validity, need to be answered before any beneficial partnership can be developed. While there is some technical validation to show that properly applied biosolids will not contaminate a site, and that current guidelines have been designed to ensure that land use change is not inhibited, these are only part of the technical and social issue at hand.

The *Guidelines for the safe application of biosolids to land in New Zealand* were developed with many aims, among them to promote the responsible use of biosolids. While the work that has gone into the *Guidelines* project has brought a sense of perspective to the use of biosolids, it is possible that not enough potential user/landowner groups were consulted in the production of the *Guidelines.* As a result, groups like the New Zealand Forest Owners Association are only just becoming officially aware that councils are interested in applying biosolids to land, and that forests are considered. These groups have not had the time to ponder the issues like the wastewater sector has, and is just beginning to adopt some of the information. One stumbling block is that some of their concerns have not been addressed in the *Guidelines* and must therefore be addressed through other means.

Large forest companies that lease the plantation management and cutting rights of crown forest land are ultimately responsible for their management of the land through liability clauses in the management contract. Uncertainty surrounding biosolids as a potential liability has only begun to be addressed between producers and forest managers. At the same time, the issue of resource consent compliance needs to be addressed by the producers and forest managers, determining who is responsible for the application.

Currently, the methods that are being used for application of biosolids to forests are land based. The long term nature of forestry means that management actions early in the rotation (such as windrowing or slash removal) can be very expensive, when discounted over the length of a harvest rotation. Additional site preparation actions for future biosolids applications diminish the profits of a site unless those costs are recovered through increased growth. There are other methods of application that remove the requirement for excess site preparation, including more robust vehicles, aerial application, and tracked vehicles. The costs involved in site preparation and application would likely rest with the producer, regardless of the impact on the trees.

The variability of biosolids, and the difficulty in knowing the complete composition, is another potential source of concern for foresters. Part of this is due to the requirement of most forest companies that the forest land be amenable to land use change, should economic conditions make it prudent to sell the rights to the estate. This requires biosolids applications to be restricted to quantities that ensure no constituent could be raised to unacceptable levels and potentially contaminate the land. Current proposals contained in the *Guidelines* suggest the method of resolving this issue is to use an auditable certification standard for production process regulation and testing. or example, the concept of the “Biosolids Quality Mark” continues to be pursued.

Summary

The Biosolids to Forests Programme, and now the Waste to Resource Programme, have produced a large quantity of technical information, which continues to suggest that biosolids application to forests is a safe sustainable way of using this product. Further work is now required to bring forest companies and biosolids producers together to make these systems work for the benefit of all New Zealanders. It is important to remove biosolids from the landfill and put them to work as fertilisers and soil conditioners.

The trials at Nelson and Canterbury both show that groundwater remains safe, that leachate is untainted by biosolids, and that the trees have the capacity to assimilate the nutrients from the biosolids and use them to grow larger and faster. Continuing technical work is aimed at the long-term impacts of biosolids throughout the rotation, and the impacts on soil fauna and flora. Pathogen issues and social perception work continue to be developed.

Acknowledgements

The Biosolids to Forests and Waste to Resource programmes are initiatives funded by the Foundation for Research, Science and Technology. They are collaborative programmes and we acknowledge our collaborators from Christchurch City Council, Nelson City Council, Tasman District Council, P.F. Olsen & Co, Landcare Research, University of Canterbry, ESR and Lincoln University. We also acknowledge the efforts of our field crews and technicians.

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