Cadmium transfer to crops from biosolids-amended soils: implications for food quality, national regulations and international markets

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Introduction

Cadmium (Cd) contamination of agricultural soils has become increasingly important in recent years due to increased public awareness and concern for food and land quality. Cadmium residues in foods are regularly monitored by both national and international agriculture and health agencies. While the severity of risks associated with dietary intake of certain levels of Cd is a contentious issue (Ryan et al., 1982), many countries have regulations controlling permissible levels of Cd in soils and crops. Concentrations of Cd in foods in Australia are regulated at the state level, but there is a common national standard developed by Food Standards Australia New Zealand (FSANZ, 2005). Biennially, FSANZ conducts a total dietary survey of contaminants and toxicants in Australian foods. As well as the Australian Total Dietary Survey operated by FSANZ, the Australian National Residue Survey (NRS) samples and analyses a wide range of commodities for contaminants, including Cd. NRS tests residues and contaminants in animal and plant products of participating industries, and compliance with FSANZ standards for Cd, is generally excellent. In addition to government compliance testing, there has been growth in compliance testing by industry e.g. wholesalers, food processors, etc. Many companies seek market advantage in maintaining and improving product quality. Cadmium is therefore a critical food quality indicator, and addition of biosolids to agricultural soils poses a potential risk that needs to be well managed.

Concentrations of Cd in biosolids in Australia are controlled by state-based biosolid guidelines (NSW EPA, 1997; SA EPA 1997; DPIWE, 1999; WA DEP, 2002; EPA Victoria, 2004). Biosolids are graded into several quality classes depending on the concentrations of Cd (and other contaminants) (McLaughlin et al. 2000a). Furthermore, agreement has been reached with all states to decrease the amount of Cd introduced to agricultural land by biosolids to 150g Cd/ha/5 yr. This will be incorporated into state guidelines as revisions occur. Cadmium concentrations in soils are also controlled by the same state-based guidelines (Table 1).

Australia also has national guidelines for biosolid reuse (NRMMC, 2004) which specify a maximum soil Cd concentration of 1 mg/kg.

Table 1. The maximum permissible concentration of Cd in soil following the application of biosolids in the various jurisdictions within Australia.

Jurisdiction	Maximum soil Cd concentration following biosolid application (mg/kg)
New South Wales	1-11
South Australia	3.0
Victoria and Western Australia	1-3
Tasmania	0.7
National	1.0

One of the aims of the National Biosolids Research Program (NBRP) is to validate and/or improve current guidelines for maximum permissible Cd concentrations in soils receiving biosolids, to ensure the quality of crops produced on biosolid-amended soils. In order to benchmark the potential effects of Cd in the biosolids on food quality, field sites spiked with Cd salts were established in parallel with the biosolid field trials.

Materials and Methods

Twelve field sites that were established across Australia as part of the NBRP, received both biosolid and metal salt treatments. Biosolid rates applied were based on the Nitrogen Limited Biosolid Application Rate (NLBAR) which is the amount of biosolids that can be added to a soil so there is no net accumulation of nitrogen after one year (i.e. the amount of nitrogen added in the soil by the biosolids is equal to the amount used (taken up) by the crop in one year). Each trial was designed in a randomized block design, with each treatment conducted in triplicate. All biosolid field trials consisted of eight treatments – a control (un-amended soil), a fertilizer control (according to normal farmers practise), 0.25, 1, 1.5, 3 and 4.5 NLBAR as a single application in time and a 1.5 NLBAR per year repeat application.

For the Cd salt trials, a series of increasing concentrations of soluble Cd (Cl or SO_4 salt) was established with four rates designed to span a wide range of crop Cd concentrations, up to and exceeding the current food standards. Note that these rates were well below those which could lead to toxicity to plants or soil organisms. Soil pore waters were extracted using the method of Thibault and Sheppard (1992) and Cd concentrations in pore water determined by inductively-coupled plasma mass spectroscopy (ICP-MS). After acid digestion, Cd concentrations in plant shoots and grains were determined by ICP-MS.

Reactivity/availability of salt and biosolid Cd was expressed as a distribution coefficient (Kd), which describes Cd distribution between soil and soil pore water as follows:

$$Kd\ (kg/L) = \frac{Total\ soil\ Cd\ concentration\ (mg/kg)}{Soil\ pore\ water\ concentration\ (mg/L)}$$

To compare the relative plant availability of biosolid and metal-salt Cd was expressed as a bioconcentration factor as follows:

$$BCF = \frac{Crop\ Cd\ concentration\ (mg/kg)}{Soil\ Cd\ concentration\ (mg/kg)}$$

Results and Discussion

Crop accumulation of Cd was highly dependent on soil type, and on biosolid type. An example of Cd uptake by wheat at three sites in South Australia is shown in Figure 1. It is evident that soil type plays a major role in determining the availability of Cd added to soil.

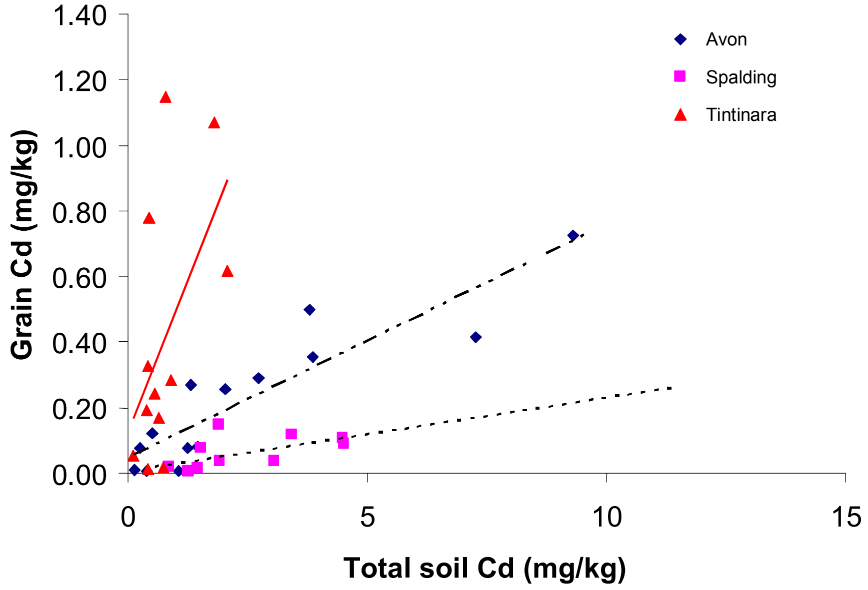

Figure 1: Wheat grain Cd concentration (mg/kg) as affected by addition of Cd salts to soil.

To compare the accumulation of Cd from biosolids compared to metal salts, the BCF of biosolid Cd was compared to metal-salt Cd across all sites (Figure 2).

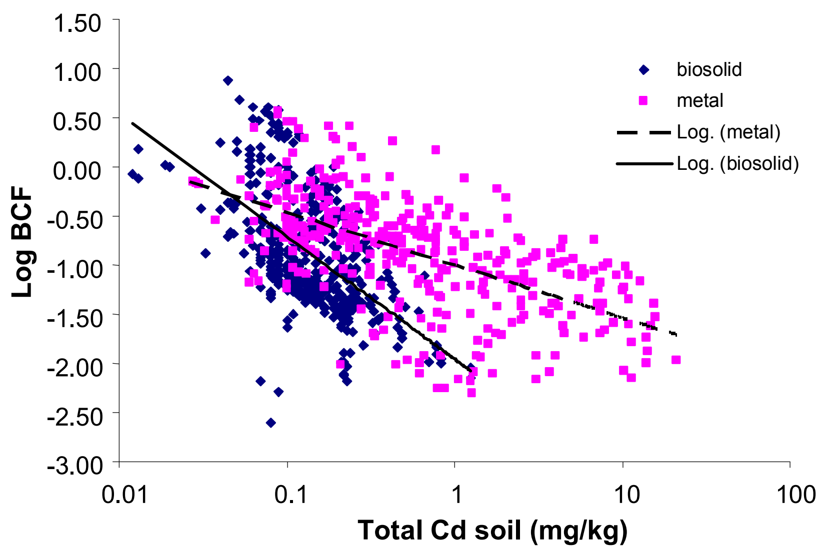

Figure 2: Bioaccumulation factor for biosolid Cd compared to metal-salt Cd across all sites for Years 1 and 2 of the NBRP.

In general, the BCF for Cd decreased with increasing soil Cd concentration, but the relationship was not as strong as for Cu and Zn reported elsewhere (Heemsbergen et al. 2006). This is likely due to the strong homeostasis exhibited by plants in terms of uptake of Cu and Zn, while Cd is much less well regulated, especially at low concentration in soils. Biosolid Cd was generally less available than Cd in soluble salts, and this tendency was stronger at higher Cd loadings. Two mechanisms may be responsible for this:

1) increased binding of Cd to biosolid surfaces thereby reducing soil pore water concentrations of Cd per unit added Cd, and hence reducing plant access to biosolid Cd; and/or
2) the addition of co-contaminants in biosolids which competitively inhibit uptake of biosolid Cd by plants e.g. zinc.

To examine which of these mechanisms was contributing to the lower bioavailability of biosolid Cd compared to metal-salt Cd, the partitioning of Cd across all the soils was examined (Figure 3). The partitioning of Cd varied markedly across soils, with some soils (e.g. Cecil Plains in Queensland) having very high Kd values (log Kd=4, Kd =10,000, indicating for every unit (weight) Cd in soil solution there were 10,000 units adsorbed to the soil surfaces).

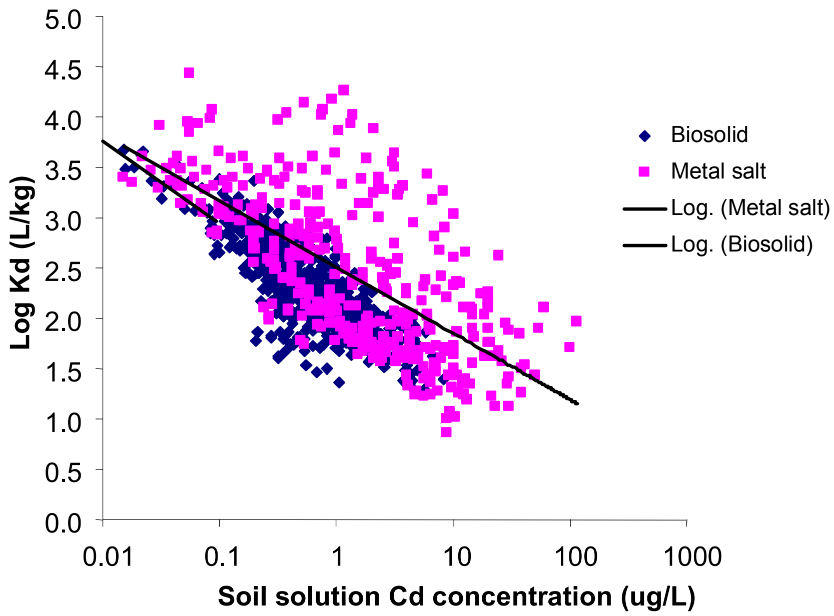

Figure 3: Partitioning coefficient (Kd) for biosolid and metal-salt Cd across all sites.

There was little difference in Cd partitioning between the biosolids and the metal-salt treatments, indicating that for each unit Cd added by these sources, soil pore water Cd concentrations would be similar. This indicates that overall, biosolid addition at the agronomic rates used had little effect on Cd retention by the soils. Hence, the reduced BCF for biosolid Cd noted in Figure 2 is more related to co-contaminants in the biosolids, or organic matter complexation of Cd, reducing the availability of biosolid Cd to crops.

Are current guidelines protective?

NBRP trial data are still rolling in, but some preliminary analysis of the Cd data can be performed. In the NBRP trials, the experimental design was established using agronomic rates of biosolid application based on the NLBAR. Thus, soil Cd concentrations were only raised to a small degree by biosolid applications and effects on crop Cd uptake were often small. However, some sites allowed significant soil-plant transfer of Cd and produced crops above

FSANZ maximum levels. For example, Cd uptake by peanuts, a Cd accumulating crop, was high even on control soils, so the practice of adding biosolids to these crops may be undesirable. Barley crops do not accumulate much Cd compared to other cereals such as wheat, and biosolids may be added with minimal risk to these crops. However, it should be remembered that Cd remains in the soils for decades or longer, so the types of crops used in rotation in the future needs to be considered.

Some soil types also allow greater soil-plant transfer of Cd than others – the BCF data shown in Figure 2 indicate that high risk soils could have BCF values as high as 0.5-1.0, meaning that if soil Cd concentrations are 0.1-0.2 mg/kg (levels only slightly elevated from typical background values), crop Cd concentrations could reach 0.1 mg/kg (the FSANZ ML for wheat, peanuts and vegetables is 0.1 mg/kg). It is important that biosolids are not used on these high risk soils, and the NBRP trials are producing data which will help to identify which soils are most sensitive to added Cd.

Initial data for crop Cd concentrations were regressed against soil Cd concentrations at several sites (see Figure 1 for an example), and critical soil Cd concentrations interpolated from the relationships. Soil pH was found to influence soil-plant transfer of Cd and the critical soil Cd concentration at which crops would exceed 0.1 mg/kg was found to increase with soil pH (Figure 4).

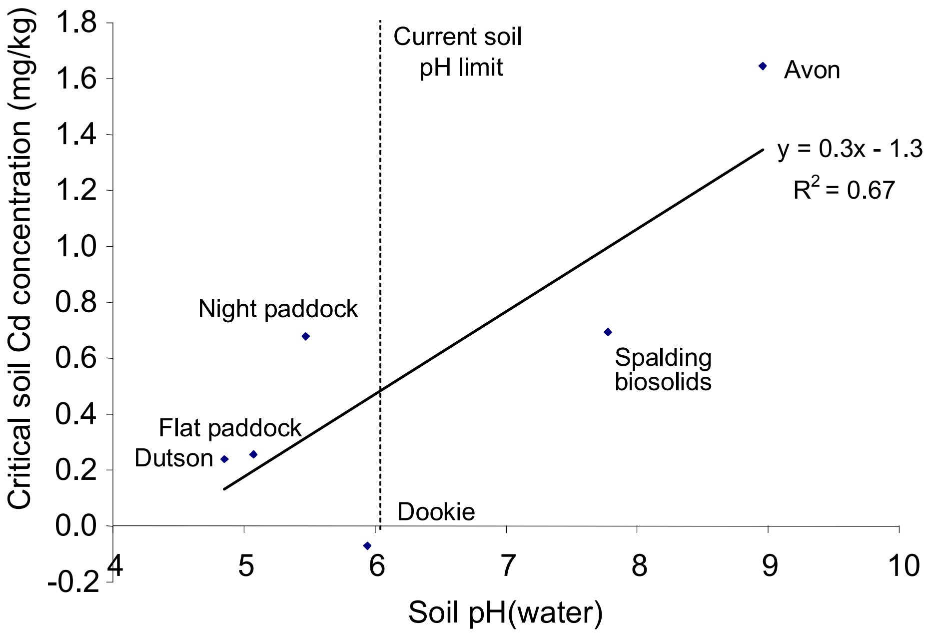

Figure 4: Relationship between soil pH and critical soil Cd concentration (mg/kg) above which crops exceed 0.1 mg/kg, based on Cd salt trreatments.

This initial analysis therefore suggests that some acidic soils may pose a potential risk from Cd uptake at soil concentrations below 1 mg/kg *when Cd is added as a highly available or soluble source*. However, it should also be remembered that the bioavailability of Cd in biosolids is lower than that in soluble metal salts, especially at higher soil concentrations approaching current limit values (on average 10-fold lower at a soil Cd concentration of 1 mg/kg – see Figure 2). Thus, combining an assessment of soil bioavailability to added Cd with an assessment of biosolid Cd bioavailability will produce an accurate measure of the risk from Cd in biosolids, and improved soil guidelines for biosolid use. This analysis only presents and uses data from the first two years of the NBRP - further data are being collated and integrated into this analysis. The NBRP will continue to integrate data from 2005 and 2006 seasons.

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