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Effects of cadmium in herbage on the apparent absorption of elements by sheep in comparison with inorganic cadmium added to their diet

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Abstract

A meta-analysis of existing scientific literature recently suggested that Cd is absorbed more efficiently by sheep if it is in the organic form in grass, than if it is added as an inorganic supplement to the diet. We tested this experimentally by feeding sheep grass from contaminated soil, compared with uncontaminated grass and with Cd added to the diet. To produce contaminated herbage, Cd nitrate was added to soil in 11 lysimeters sown with perennial ryegrass, with a further 11 lysimeters receiving no Cd to produce uncontaminated herbage. In the Cd-treated lysimeters, soil had increased exchangeable K, Mg, and Ca, leachate had increased K, Mg, Ca, Na, and P, grass had increased Cd and reduced Mg, Na, P, Mn, Fe, Cr, Al, and Ni, and there was some reduction in grass yield compared with untreated lysimeters. Grass from Cd-treated or untreated lysimeters was fed to groups of 12 ewes for 2 days, with Cd intake equated by adding Cd nitrate to the concentrate feed of ewes receiving the uncontaminated grass. The apparent absorption of Cd, Zn, Mo, Cr, and Al was increased for ewes receiving Cd-enriched grass, and apparent absorption of Cu was reduced, compared to those receiving supplementary inorganic Cd. Most of the unabsorbed Cd was excreted in feces within 4 days of feeding. The ewes consuming Cd in grass had increased B concentrations in their urine, possibly due to adverse effects of Cd on kidney function. Finally, the ewes were offered a choice of the two herbages and they ate significantly more of the uncontaminated grass. It is concluded that the apparent absorption of Cd and other heavy metals by sheep in a short-term experiment was greater when Cd was in the grass than when the Cd was added in in an inorganic form and that sheep partially avoided herbage with a high Cd concentration.

Keywords: Cd; Grass; Herbage; Sheep; Absorption; Element

1. Introduction

Cadmium (Cd) is a nonessential toxic heavy metal which accumulates in mammals. It occurs mostly as an impurity of zinc ores and phosphate fertilizers and is widely used in electroplating, pigments, plastic stabilizers and nickel–cadmium batteries, eventually ending up in sewage sludge or in municipal incinerators after product disposal. Sewage sludge is a major source of Cd on grassland (Wilkinson et al., 2003). In many industrialized countries the Cd content of sewage sludge has decreased in recent years (Smith, 1996), but even applying sewage sludge with low Cd concentrations increases the adsorption of organic ligands to the soil and thereby increases heavy metal retention (Petruzzelli et al., 1992). Leaching of Cd is slow in most soils, amounting to only approximately 0.1% of the total soil content per year (Holm et al., 1998). Phosphate

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fertilizers also add major quantities of Cd to grassland, although some countries now limit fertilizer Cd concentrations.

Accumulated Cd in the offal of ruminants that consumed contaminated herbage represents a significant source of intake for some consumers (Ministry of Agriculture and Fisheries and Food (MAFF), 1997; Prankel et al., 2005). Recently, Prankel et al. (2003) reported that a meta-analysis of the existing scientific literature describing Cd accumulation trials indicated that when Cd was consumed in an organic form, principally following incorporation into plant material, it was accumulated into liver and kidney faster than if it was consumed in an inorganic form. The majority of Cd in plants is organically bound (Pickering et al., 1999), but most accumulation experiments with ruminants have added inorganic Cd artificially to the diet.

The uptake of Cd from the intestine is assisted by metallothioneins, which are low-molecular-weight, cysteine-rich compounds present in moderate quantities in sheep (Henry et al., 1994). They compete with large ligands such as serum albumin (Foulkes and Voner, 1981) or those in fiber (Cherian, 1979) that render the metal unable to be absorbed, at least in nonruminant animals. Ruminal bacteria can dissociate some large ligands, such as phytic acid which binds to zinc (Zn) (Oberleas et al., 1966), and there is evidence for increased absorption of organically bound Zn in ruminants (Spears, 1996). However, organically bound Cd, chelated by the carboxyl and amino group of amino acids, is probably protected from rumen degradation in sheep (Lee et al., 1999). There is no clear evidence of increased absorption of other organically bound heavy metals, compared with inorganic forms, and it is possible that they interact less with antagonists in the intestine (Bailey et al., 2001). In mice, Turecki et al. (1998) has found reduced absorption of Cd in yeast compared with $CdCl_2$.

This experiment compared the absorption of elements by sheep from herbage grown either in high- or low-Cd soil, with inorganic Cd added to the herbage grown in low-Cd soil to approximately equate Cd intakes. The ability of the sheep to avoid high Cd herbage was also tested.

2. Material and methods

Research to investigate the effects of low levels of Cd application on accumulation of Cd and other elements in sheep, taking into account associated element changes in herbage, soil, and leachate, was conducted.

2.1. Herbage production and sample analysis

Twenty-two concrete lysimeters of dimensions 1.3 m long × 1.1 m wide × 1 m deep were filled with sand to 80 cm depth. A 6-cm layer of brown earth with gleying loam of the Sannan series (Soil Survey—England and Wales (SSEW) and 1967–69, 1969), which had previously been used for growing a wheat crop, was added on top of the sand. The lysimeters were sown on 14 June with perennial ryegrass (*Lolium perenne*), and a phosphorus (P) and potassium (K) fertilizer[1] was applied. Each lysimeter was then covered with a further 1 cm depth of soil, and nitrogen (N) fertilizer[2] was applied on 11 and 21 July following germination. Soil samples were taken to a depth of 15 cm on 17 July before the treatments were applied, dried for 5 days and then passed through a 2-mm sieve. Mean OM concentration was 47 (SE 3.4) $g\,kg^{-1}$ and mean C.E.C. was 8.7 (SE 0.37) meq $100\,g^{-1}$ (for analytical methods see Ministry of Agriculture and Fisheries and Food/Agricultural Development and Advisory Service (MAFF/ADAS), 1986). Element concentrations (Table 1) were measured by atomic emission spectrometry (AES) (all elements except Cd and lead [Pb]) and by atomic absorption spectrophotometry (AAS) (Cd and Pb) (Chiy et al., 1998) by the methods outlined below under sample analysis.

One half of the lysimeters, selected at random, were treated with Cd at a rate of $727\,g\,ha^{-1}$. There were no significant differences in soil element concentrations in the lysimeters allocated to the two treatments before the Cd was applied ($P>0.25$). The Cd was applied as a solution of $Cd(NO_3)_2 \cdot 4H_2O$, diluted to $17\,mg\,L^{-1}$, and split into three applications on 28, 29, and 30 July to avoid foliar scorch. All lysimeters were watered before and after Cd application to aid uptake and minimize the risk of foliar damage, which was not observed. A second set of soil samples was taken on 30 September, these were prepared and analyzed for total element concentrations and for concentrations of exchangeable Ca, Cd, Mg, and K as described under sample analysis.

Each lysimeter drained into a plastic pipe, which conveyed leachate into plastic containers for total collection. Samples were taken up to first harvest on three occasions when there had been sufficient rainfall to produce leachate, which was analyzed for element concentrations by atomic absorption spectroscopy (Chiy et al., 1998).

The grass in each lysimeter was harvested to 1 cm using electronic sheep shears with stainless steel blades and stainless steel scissors on 20 September and 29 December. On 1 March the roots, stems and leaves from a 50 × 50-cm area of each lysimeter were harvested and soaked in distilled water to remove soil contamination. The three fractions were weighed, dried, and analyzed

[1] 240 g P and 240 g K kg^{-1} compound fertilizer, Champion Fertilizers Ltd. at 40 $kg\,ha^{-1}$.

[2] Nitram, 345 g N kg^{-1} (as ammonium nitrate), ICI Fertilizers Ltd., Billingham, UK, at 40 $kg\,ha^{-1}$.