Effect of Barium Selenate Fertilizer on the Concentration of Barium in Pasture and Sheep Tissues†

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To provide a slow-release form of selenium, a barium selenate ($BaSeO_4$) fertilizer was applied to a subterranean clover pasture at two sites at Bakers Hill in Western Australia. The rate was 10 g of Se ha^{-1}; this supplies Ba at 17.4 g ha^{-1}. The uptake of Ba in pasture and the liver, kidney cortex, and muscle tissues of sheep grazing the pasture was measured. There was no significant increase in Ba concentration in either the pasture or the sheep tissues from the $BaSeO_4$ application. There was however, up to a 3-fold difference in pasture concentration of Ba between the two sites. Furthermore, dry summer pasture had a 2–3 times higher concentration of Ba than the green pasture in spring. The concentration of Ba in the kidney cortex was significanty higher from sheep at the site with the higher pasture concentration, but the concentrations of Ba in other sheep tissues samples were not different. There was no adverse effect from the Ba in the application of $BaSeO_4$ as a slow-release selenium fertilizer for pasture.

INTRODUCTION

As part of an evaluation of selenium fertilizers, a barium selenate fertilizer produced by Mintech, New Zealand (now ICI New Zealand), incorporating a slow-release technology was applied to pasture grazed by sheep. The fertilizer was designed to provide a slow release of selenium for application to selenium-deficient pasture. The selenium concentration of the pasture that received no selenium fertilizer was generally less than 0.04 mg of Se kg^{-1} of dry weight. A single application of the barium selenate fertilizer maintained the concentration of plasma selenium in sheep at more than adequate levels for at least 3 years (Whelan et al., 1993a). Sheep grazing the pasture fertilized with sodium or barium selenate had significant increases in both live weight and wool production (Whelan et al., 1993b).

Plants are known to take up barium, and the concentration varies widely both within and between species (Nielsen, 1986). Bowen and Dymond (1955) have reported a range of 0.5–400 mg of Ba kg^{-1} in different plant species growing on different soils. Mitchell (1957) compared the barium concentration of red clover and ryegrass grown together on different soils in Scotland and found that clover contained 12–134 (mean 42) mg of Ba kg^{-1} and grass 8–35 (mean 18) mg of Ba kg^{-1}.

Barium is poorly absorbed from ordinary diets and has a low toxicity when consumed orally, with little retention in the tissues or excretion in the urine (Nielsen, 1986). There is almost no documentation on concentrations of barium in sheep tissue, and there is no maximum limit for barium in food (NHMRC, 1986). Tipton and Cook (1963) reported the following mean barium concentrations (μg kg^{-1} of dry tissue) for normal adult human tissue: kidney, 100; liver, 30; and muscle, 50. There is no conclusive evidence that barium performs any essential function in living organisms (National Research Council, 1980). There is therefore no recommended minimum concentration of barium in plant tissue or animal diets in Australia. There is also very limited information on the toxic effects of barium in plant tissue. A paper by Chaudhry et al. (1977) showed that a concentration of 2000 mg of Ba kg^{-1} of dry material in barley shoots decreased barley yields by 38%.

With the prospect of regular applications of barium selenate as a slow-release selenium fertilizer, although there appeared to be no hazards associated with barium from the application of barium selenate fertilizer, it was considered necessary by the regulatory authorities to establish the effect of the fertilizer on pasture and sheep tissue concentrations of barium. In this study, the concentration of barium in pasture in spring and midsummer was measured for 3 years after a single application of barium selenate. The concentration of barium in the liver, kidney cortex, and muscle of sheep after grazing these pastures for 3.5 years was also compared to those of control animals on untreated pasture.

MATERIALS AND METHODS

The experiment was conducted on subterranean clover (*Trifolium subterraneum*) based pastures on two sites at the Yalanbee Field Station at Bakers Hill, Western Australia (31° 27′ S, 116° 27′ E). The climate is mediterranean with an average annual rainfall of 600 mm, of which 77% is received between May and September. Fertilized and unfertilized treatments were compared on duplicate 1.0-ha plots at site 1 and on single 0.6-ha plots at site 2. All plots received an annual dressing of 100 kg ha^{-1} of superphosphate. The soil at site 1 was a lateritic podzol (Stace et al., 1968) derived from the weathering of laterite on Precambian granite and gneiss. Site 2 was on a noncalcic brown soil (Stace et al., 1968) on Precambian dolerite. The soil at both sites is classified as Haploxeralf according to *Soil Taxonomy* (Soil Survey Staff, 1975). A single application of prilled barium selenate fertilizer was applied at 1 kg ha^{-1} in May 1987. One kilogram of this fertilizer contained 35.5 g of $BaSeO_4$, i.e., 10 g of Se and 17.4 g of Ba. The fertilizer was applied by hand to strips on the plots after the prills were mixed with sand.

Eight-month-old merino wether weaners were placed on the fertilized and control plots in May 1987 at a stocking rate of 10 sheep ha^{-1}. Apart from 1–2 months at the end of each summer when the sheep were removed to prevent overgrazing, the sheep remained on the plots for 3.5 years.

Pasture Samples. Random samples were collected at 7-m intervals on the two diagonal transects in each plot in the flush growth period of spring (August/September) and in the dry pasture of midsummer (January/February). The pasture samples on each transect were bulked to provide two composite samples for each plot. The samples were oven-dried and ground to pass

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Table I. Mean Concentration of Barium in Pasture in Spring and Summer over 3 Years[a]

	spring		summer	
	control	$BaSeO_4$	control	$BaSeO_4$
site 1	1.1 ± 0.2	1.1 ± 0.1	2.2 ± 0.1	2.8 ± 0.3
site 2	2.6 ± 0.1	2.7 ± 0.3	8.7 ± 1.5	8.5 ± 1.4

[a] mg of Ba kg^{-1} over dry weight ± SEM.

through a 1.0-mm sieve. Subsamples of the ground material from each transect were mixed to provide a treatment sample.

Sheep Tissue Samples. Three sheep from each plot were killed in December 1990, and samples of liver, kidney cortex and the semitendinosus muscle were taken and frozen.

Analytical Procedure. Samples of approximately 0.5 g of dry plant material and 2 g of fresh sheep tissue were digested individually in 5 mL of nitric acid. The solution, on approaching dryness, had a further 0.5 mL of nitric acid added and was made up to 10 mL with distilled–deionized water. All of the samples were analyzed by an atomic absorption spectrophotometer, with a graphite furnace being used for the sheep tissue samples. The results were corrected for blank values. The sheep tissue results are presented in terms of both dry and fresh weight as most regulatory authorities use fresh weight, while most scientific studies are presented in terms of dry weight. The soil pH was determined in 0.01 M $CaCl_2$.

Statistical Analysis. The analysis of variance was carried out with the Systat statistical program (Wilkinson, 1990) incorporating standard range tests. As there was only one pasture sample for each site at each sampling time, the data from each of the 3 years were therefore used as the error term.

RESULTS AND DISCUSSION

Pasture. There was no significant increase ($P < 0.01$) in the barium concentration of the pasture from the application of the barium selenate fertilizer (Table I). The barium concentration of the pasture was low compared with other published values. Lee and Smith (1972) recorded concentrations of 19–59 mg of Ba kg^{-1} of dry weight for 1-year-old lucerne plants (*Medicago sativa*) grown in pots under a range of environmental conditions, and Cipollini and Pickering (1986) measured a concentration of 20 mg of Ba kg^{-1} for both bean (*Phaseolus vulgaris*) and barley (*Hordeum vulgare*) plants grown in soil in pots that received only tap water.

Over the 3 years of the experiment, the concentrations of barium in the pasture were consistently 2–3 times higher in the summer than in the spring. There was also a 2–3-fold increase in the concentration of barium from site 1 to site 2 that was consistent over the 3 years of the experiment. A significant interaction ($P < 0.01$) was measured between season and site that resulted from a different proportional increase in the concentration of barium from spring to summer between sites.

Lawrey (1979) also found a significant 6-fold difference in the concentration of barium in the same species between different sites. He attributed this to differences in soil pH, but in this instance, the sites had similar pHs of 5.0 for site 1 and 5.4 for site 2. The difference in the barium concentration between the two sites probably reflected the different parent material and the difference in weathering of the two soils.

At site 1, the pasture barium concentration in summer was approximately twice as high as the spring concentrations, and at site 2 there was a 3-fold increase. There are several possible explanations: the supply of barium was limited, and the rapidly growing pasture in spring diluted the barium content of the pasture; the summer pasture experienced differential leaching or decomposition and thereby increased the relative barium content; or the dry summer pasture was contaminated by dust from the dry soil, increasing the barium concentration. Results from Lawrey (1979) showed litter from five species of trees also appeared to accumulate barium during leaching and decomposition. He attributed this to the low mobility of barium in the decomposing leaf litter compared with the relatively high mobility of Mn, Fe, Al, Cu, Zn, and Mo.

Table II. Mean[c] Concentration of Barium in Various Sheep Tissues Expressed on Dry and Fresh Weight Bases

	µg of Ba kg^{-1}		
	muscle	liver	kidney cortex
		Dry Weight	
control	232	159	1483
$BaSeO_4$	274	157	1086
site 1	257	142	1056[a]
site 2	245	193	1776[a]
		Fresh Weight	
control	63	53	332
$BaSeO_4$	71	50	245
site 1	68	46	237[b]
site 2	64	64	401[b]

[a,b] Data with the same letter are significantly different ($P < 0.05$) from each other. [c] Mean concentration in the nine sheep on each treatment.

Sheep Tissue. There was no significant increase ($P < 0.05$) in the barium concentration of tissues from sheep grazing $BaSeO_4$-fertilized pasture compared with sheep grazing the unfertilized controls (Table II). Furthermore, although the concentration of barium in the pasture at site 2 was consistently 2–3 times higher than that in the pasture at site 1, there was no significant difference ($P < 0.05$) between the concentrations of barium in the muscle and liver from the two sites. However, the concentration of barium in the cortex of the kidney was not only 4–5 times higher than in the muscle and liver but also significantly higher ($P < 0.05$) at site 2 compared with site 1 (Table II). Although these barium concentrations are higher than those given for healthy adult humans, the kidney concentrations are only a sixth of the 8.3 mg of Ba kg^{-1} of dry weight concentration for Dorset and Hampshire sheep that were fed a commercial pelleted ration that contained 12 mg of Ba kg^{-1} (Heffron et al., 1977). In the same experiment, Heffron et al. (1977) substituted 23% of the ration with colored magazines and newsprint and measured a maximum Ba concentration of 23.8 mg of Ba kg^{-1} in the kidney with no ill effects. This is consistent with the National Research Council (1980) that considered the uptake of barium by plants, even from soils high in barium, was so low that there was little chance of toxicity from animals grazing the plants.

As a divalent cation competing with the more prevalent calcium and magnesium ions in a soil cation-exchange complex, it is not surprising that the addition of only 17.4 g of Ba ha^{-1} did not significantly affect the concentration of barium in either the plant or animal tissue. In conclusion, the application of $BaSeO_4$ fertilizer to pasture to provide a slow-release form of selenium had no significant effect on the barium concentration of the pasture or the tissues of the sheep.

(The commercial selenium fertilizer released in Australia by ICI is known as Agsel and contains 1% selenium. Fifty percent of the selenium is in the $BaSeO_4$ form and the balance in the $NaSeO_4$ form.)

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