CAST
COUNCIL FOR AGRICULTURAL SCIENCE AND TECHNOLOGY

ISSUE PAPER

NUMBER 3 JUNE 1994

RISKS AND BENEFITS OF SELENIUM IN AGRICULTURE

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Summary

The appropriateness of the legally approved levels of selenium (Se) supplementation of livestock in the United States has been challenged. The most recent challenge called into question the appropriateness of increasing the allowable level of supplemental Se, not in terms of animal response but in terms of environmental safety.

The levels of dietary Se supplementation initially approved (0.1 part per million [ppm] for swine and growing chickens, 0.2 ppm for turkeys) were inadequate. Although a number of factors influence Se requirements, 0.3 ppm Se clearly is near the minimum required to support health and optimal performance of food-producing animals. The seven amendments to the original 1974 U.S. Food and Drug Administration (FDA) regulation recognized this fact, as did the 1993 stay of the 1987 amendment. But the 1987 amendment was challenged on the basis of environmental concerns. Instances have been reported where toxic levels of selenium have been identified in specific locales; however, these relate to excess levels of Se in local environments and have no association with animal supplementation practices. The 1987 amendment to the FDA regulation of Se thus appears justified, both in terms of supplying animal requirements for Se and in maintaining environmental safety.

Introduction and History

Selenium belongs to the group of micronutrient elements required in very small quantities by animals and humans. The same properties allowing Se to function metabolically at levels of less than 1 ppm in the diet dry matter make it toxic at excessive concentrations. This circumstance is not unusual—indeed, it exists for all nutrients; nor is the range of Se tolerances especially narrow. For example, the range of nutritional functionality for Se is about a hundred-fold, i.e., from 0.04 to 4.0 ppm, but that of copper only about four-fold in sheep (an especially sensitive species), i.e., from 6 to 25 ppm (McDowell, 1992). It is noteworthy that many wild aquatic birds regularly consume fish containing 1 to 3 ppm Se (dry basis) without evidence of harm.

In 1957, the nutritional essentiality of Se was established through controlled experiments with laboratory animals (Schwarz and Foltz, 1957). Shortly thereafter, Se was found preventive in domestic animals against a variety of metabolic aberrations described as *selenium responsive*. As these conditions were investigated, it became clear that Se was involved in basic life processes including growth, reproduction, and resistance to infectious disease.

Concurrently, the Se status of vast areas of the world was studied, and regions of soil deficiency, nutritional adequacy, and toxicity of forages and other feeds were mapped. In the widespread regions of deficiency, Se supplementation of domestic animals became established as a production practice. Supplements have been used for more than 20 years in the United States and in some other countries and have proved both effective and safe when given at approved levels.

Various means are available to improve the Se status of animals when low-Se soil or low soil-Se availability result in low feed levels. Selenium can be given by injection or perhaps most effectively by mouth as a feed supplement or, for ruminants, in the form of heavy boluses that lodge in the reticulo-rumen and release the nutrient slowly over a long period of time.

Moreover, Se applied as a fertilizer amendment to deficient soils will raise Se levels in forages and other feeds to concentrations sufficient to prevent Se deficiency in animals. New Zealand and Finland, both small countries with extensive areas of low-Se soils, have adopted Se augmentation of fertilizers as a routine commercial practice. Whereas Se is a necessity for animal life, it is not required by higher plants although certain high-Se range plants grow only on seleniferous soils (Rosenfeld and Beath, 1964). Various forms of Se have been used as supplements. Elemental Se is preferred in the heavy boluses; sodium selenite is preferred in other oral and parenteral applications. Sodium selenate is used as a fertilizer amendment although use of barium selenate for this purpose is increasing.

Soil status map for selenium in the United States (Council for Agricultural Science and Technology, 1986).

Long before its essential nutrient properties were known, Se was recognized as being toxic to livestock. In 1937, Moxon (1937) observed that in the semiarid Great Plains of the United States a livestock problem named *alkali disease* was due to Se toxicity. A high incidence of this problem in the Dakotas and adjoining areas was related to the accumulation of Se by certain range plants, including members of the vetch genus, *Astragalus*. Alkali disease involved loss of hair from the manes and tails of cattle and horses, pus formation at the juncture of hooves and skin, and sometimes death. Problems of Se poisoning have been recognized worldwide, but affected areas are relatively small and generally are associated with semiarid, alkaline soils with high concentrations of Se available to plants. The most severely affected areas have been removed from agriculture because of the problem and because these areas have otherwise low productivity.

Supplementary use of Se for domestic animals in regions of Se-deficient soil has been practiced widely in various parts of the world since the early 1960s. At first this practice was prohibited in the United States by the FDA because of concern that Se might be carcinogenic. This hypothesis was investigated thoroughly and found to be unsupported. In 1973, scientists at the National Cancer Institute and the FDA issued a joint statement that “judicious administration of Se derivatives to domestic animals would not constitute a carcinogenic risk." (U.S. Food and Drug Administration, 1973b). Subsequently, federally sponsored programs to examine the anticarcinogenic potential of Se have been initiated. The FDA felt it was necessary to regulate this element, however, because it did not have GRAS (generally recognized as safe) status.

Wetland once in the Kesterson Reservoir in the San Joaquin Valley, California. This was fed by irrigation runoff, which contained excessive levels of Se originating in high-Se rocks and soils in hills adjoining the valley. Photograph courtesy of J. E. Oldfield, Corvallis, Oregon.

The Issue

An intense research effort was launched by university and government scientists to establish the biochemical functions of Se, to define the quantitative dietary requirements for this element, to ensure the safety of animals that might receive Se supplements and of humans that consume animal products, and to determine the impact of Se supplementation on the environment. In 1974, the FDA approved the addition of 0.1 or 0.2 ppm of Se to the diets of certain domestic animals and, through a series of regulatory amendments, increased supplementary levels to 0.3 ppm for all major food-producing animals by 1987.

In 1993, however, the FDA issued a stay order of the 1987 amendments of the regulation because of concerns expressed about the effect of Se supplementation upon the environment, and solicited further information on amounts and forms, the effects of those forms on various ecosystems, and predictive models capable of integrating this information. Thus, Se supplementation was legally limited to 0.1 ppm in diets for cattle, sheep, chickens, ducks, growing/finishing pigs, and breeding swine. Turkey diets could be supplemented with 0.2 ppm Se and swine prestarter and starter diets with 0.3 ppm Se.

Environmental Concerns

The concern that induced the FDA to lower approved levels of Se supplementation of livestock diets stemmed from problems noted in wildlife in the San Joaquin Valley of California in the 1980s. Loss of much of California's wetland habitat for wildlife had prompted the recycling of subsurface agricultural drainage water for the creation and management of marshlands. The Kesterson Reservoir in Merced County consisted of 12 shallow ponds, which received water from subsurface agricultural drains originating in the highly productive irrigated areas of Fresno County, to the south.

- **Waterfowl Losses.** An extensive survey in 1983 to 1985 of nesting waterfowl in the Kesterson Reservoir area revealed reproductive defects and high mortality rates among the young. Analyses of pond water, indigenous plants, invertebrates, and small vertebrates revealed higher than usual concentrations of a number of elements, including Se, and excess Se was proposed as a cause of these abnormalities (Ohlendorf et al., 1986a, 1993; Engberg and Cappellucci, 1993).
- **Selenium Source.** Further studies identified the source of Se as soils and rocks in the Panoche hills, on the west side of the San Joaquin Valley, from which the element had leached, over time, to the valley floor. There it was transferred by irrigation through subsurface water to the San Luis drain and thence to Kesterson, where Se and other elements and organic compounds were accumulated (Saiki and Lowe, 1987).
- **Selenium Toxicity Threshold.** There was no evidence that livestock Se supplementation practices were a factor in the problems at Kesterson. Nevertheless, it has been proposed that, on the basis of studies conducted in laboratory simulations at the Kesterson Reservoir and elsewhere, the toxicity threshold for Se in water is 1 part per billion (ppb).

Objections to Se supplementation of animal diets derive from the assumption that diet supplementation will increase the environmental burden of Se and lead to waterborne Se concentrations producing adverse effects. In part, this concern assumes that Se will biomagnify or bioaccumulate at progressively higher concentrations as it moves through the food chain from lower to higher trophic levels. Such increases have been noted when Se was present in food or water at levels in excess of an organism's ability to regulate this element homeostatically. But Se is an essential nutrient and as such is accumulated or excreted in relation to need over a broad range of intakes, which approximates the range of nutritional functionality. Se may bioaccumulate in some aquatic organisms at higher exposure levels, and limited information has been available to allow regulatory agencies to assess the environmental safety of animal feed supplementation. Data addressing this issue are presented herein.

Se deficiency in range areas causes white muscle disease. It may affect leg muscles causing lameness, as in this calf, or the heart muscle causing death. Photograph courtesy of J. E. Oldfield, Corvallis, Oregon.

Sources and Uses of Selenium

In soil and in water, base concentrations of Se have been reported against which elevated levels may be compared. Extreme variation of Se in soil makes the use of average figures inappropriate. "Normal" soils in the United States contain from below 0.1 to 4.4 ppm Se (Shacklette and Boerngen, 1984; Tidball, 1984); seleniferous soils, from 1 to 80 ppm (Trelease, 1945), although in some instances levels are much higher (Fleming, 1962). Naturally existing Se in ground water reflects soil or rock levels, although in the absence of particulates water Se usually is low. Nevertheless, in a random survey of 1,080 samples of well and surface water in South Dakota (a high-Se area), over 60% contained 1 or more ppb Se (Stach et al., 1990). A small study by Ullrey et al. (pers. com., 1993) of Se in pond and stream water in central lower Michigan (a low-Se area) found 0.8–1.4 ppb. Reported Se concentrations in snow and rainfall are 0.03–1.1 ppb (Cutter, 1989; Mosher and Duce, 1989).

In 1989, commercial production of Se in the United States was estimated at 250 metric tons (t) and imports at 450 t (Oldfield, 1990). By far, most of this 700 t of Se was used in electronic and photocopier components, glass manufacturing, chemicals and pigments, catalysts, metallurgy, and selenium sulfide shampoos. About 47.5 t (less than 7%) were used in veterinary products and feed supplements. Approximately 60% of supplemental Se, fed as sodium selenite, is excreted in feces and urine. If all livestock diets in the United States were supplemented with 0.3 ppm Se, 28.5 t or less of Se would be introduced into the environment in animal waste. By contrast, Se released in the United States annually from identified natural and anthropogenic sources is 9,340 t or more. Thus, the contribution of supplemental dietary Se is less than 0.3% of the total (Ullrey, 1992).

In addition to the relatively small amount of Se introduced into the environment by waste from supplemented animals, the bioavailability of supplemental Se is reduced as it passes through the digestive tract. Highly insoluble forms, such as elemental Se and metal selenides, predominate in feces. Poorly available methylated selenonium ions predominate in the urine.

Bioaccumulation and Biomagnification

It is evident that *bioaccumulation* and *biomagnification* of Se occur, as noted by research at Kesterson and other sites. Selenium concentrations in aquatic plants, invertebrates, and fish from uncontaminated areas typically are lower than 4 to 5 ppm, dry weight, whereas concentrations in habitats receiving seleniferous agricultural drainage water may be 100 times that range. Direct efforts have been made to measure the impact of dietary Se supplements upon the environment.

- **Supplemental Se and Pastured Cattle.** In a California study, no significant differences in Se concentration were found in stream water above and below for ranches at which Se supplements were provided to beef cattle (Norman et al., 1992).
- **Supplemental Se and Feedlot Cattle.** A potentially more serious situation may exist if waste from an intensively managed feedlot is applied to a limited land area. In a Michigan study, Stowe (pers. com., 1992) found an average Se concentration of 62 ppb in waste under slatted, concrete-floored pens filled with beef cattle fed 0.1–0.2 ppm supplemental Se. When applied to soil at 4,000 gal./a. (consistent with agronomic practice designed to provide nutrients for 150 bushels/a. of shelled corn), only 0.9 grams (g)/a. Se would be added.
- **Supplemental Se and Feedlot Swine.** Similar measurements by Stowe (pers. com., 1992) were made on waste under a swine feedlot filled with swine fed 0.3 ppm supplemental Se. The swine waste contained 85–133 ppb Se and when applied to soil in conformity with the above agronomic practice provided 1.2–1.9 g Se/a. The safety of these Se-bearing wastes can be assessed by comparison with government-sanctioned fertilizer amendments in New Zealand, where 4 g Se/a. (from highly soluble sodium selenate) has been applied to 10 to 13 million acres of Se-deficient soil for more than 10 years with no evidence of environmental harm (Watkinson, pers. com., 1992).

Regulatory Summation

The initially approved levels of dietary Se supplementation (0.1 ppm for swine and growing chickens, 0.2 ppm for turkeys) were inadequate. Although a number of factors influence Se requirements, 0.3 ppm Se clearly is near the minimum required to support health and optimal performance of food-producing animals. The seven amendments to the original 1974 FDA regulation recognized this fact, as did the 1993 stay of the 1987 amendment. But the 1987 amendment was challenged on the basis of environmental concerns. Instances have been reported where toxic levels of Se have been identified in specific locales; however, these relate to excess levels of Se in local environments and have no association with animal supplementation practices. The 1987 amendment to the FDA regulation of Se thus appears justified, both in terms of supplying animal requirements for Se and in maintaining environmental safety.

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ISSN 1070-0021

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This issue paper is a summary of a well-referenced document submitted to the U.S. Food and Drug Administration. Additional copies of the issue paper are available for $3.00 from CAST.

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