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Selenium Fertilization of Pastures for Improved Forage Selenium Content

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ABSTRACT

Selenium (Se) was applied to perennial ryegrass (Lolium perenne) and subterranean clover (Trifolium subterranean) pasture as a fertilizer to determine the effect of Se form and concentration on Se accumulation in subsequent forage growth. Treatments were a no Se control, 0.6 kg/ha Se as sodium selenate, and 0.6, 1.1, and 2.2 kg/ha Se as sodium selenite, all applied to pasture plots with low soil Se concentration in southwestern Oregon (n = 3 plots per treatment). The plots were protected from grazing by use of electric fence, and total forage DM production and Se concentrations were measured after the spring growing season in yr 1. Pastures were grazed by sheep over the fall growing season, but then were protected from spring grazing to enable sampling of residual forage Se concentrations during yr 2. Application of 0.6 kg/ha selenate provided greater ($P < 0.01$) average forage Se content in yr 1 (8.44 ± 0.08 mg/kg) than all other treatments. Compared with the control (0.09 ± 0.06 mg/kg), the plots in the 0.6 and 2.2 kg/ha selenite treatments contained greater ($P < 0.01$) forage Se content (1.17 ± 0.05 and 4.24 ± 0.35 mg/kg, respectively), whereas the 1.1 kg/ha selenite treatment tended ($P = 0.06$) to increase forage Se content (3.11 ± 0.79 mg/kg). Two years after Se application, only the plots treated with 0.6 kg/ha selenate and 2.2 kg/ha selenite had forage Se concentrations (0.43 ± 0.04 mg/kg and 0.51 ± 0.06 mg/kg, respectively) that differed ($P = 0.04$ and $P = 0.01$, respectively) from the control. Fertilization with Se had no effect ($P = 0.37$) on forage yield during yr 1. These data suggest that selenite and selenate fertilization increases forage Se concentrations for up to 2 yr. This may be a cost-effective method of supplying Se for grazing livestock.

Key words: fertilization, forage, pasture, selenium

INTRODUCTION

Selenium is an essential micronutrient for livestock. However, forages grown in southwestern Oregon frequently have low Se concentrations due to the low content and availability of Se in the volcanic soils commonly found there. Deficiencies in dietary Se have detrimental effects on livestock. White muscle disease is the most commonly recognized, but other problems such as reproductive and production losses and immune system dysfunction can impact livestock (Muth et al., 1958; Gupta and Gupta, 2000).

Selenium is commonly supplemented to livestock through mineral mixes or injections. However, these strategies often do not provide adequate or sustained blood Se levels and can be expensive (Dovel and Hathaway, 1998). One main disadvantage is inconsistent consumption of mineral mixes (Tait et al., 1992; Arthington and Swenson, 2004). In addition, injections provide only short-term increases in Se blood levels (Bartle et al., 1980; McDowell et al., 2002). Mineral mixes commonly contain inorganic forms of Se that are poorly absorbed and utilized by ruminants compared with organic forms of Se (Whanger, 1989).

Another way to supply Se to livestock is through pasture plants. The enrichment of livestock feed crops with Se has been studied for many years in several countries (Gupta and MacLeod, 1994). When inorganic Se is applied as fertilizer, plants convert it to the organic form, selenomethionine. This is absorbed by the animal (Whanger, 1989) and incorporated into tissues (Whanger and Butler,

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1988) at a greater efficiency than inorganic forms.

As with many other elements, Se can be toxic if consumed or injected in excess of tolerable amounts (NRC, 1980). However, toxicity is influenced by form of Se; inorganic vs. organic and protein vs. amino acid forms (Baker et al., 1989; Panter et al., 1996). Studies on Se fertilization of pastures and hay fields in Oregon have shown that this method of Se supplementation is safe and effective (Dovel and Hathaway, 1998; Pulsipher et al., 2004). There are several properties intrinsic to the different forms of Se that may determine the efficacy of the product selected for use. For example, in contrast to the selenate form of Se, selenite is less available for plant uptake, especially under acid conditions such as those present in southwestern Oregon. In addition, the selenate form is prone to leaching and its formation is favored in alkaline soils (NRC, 1980). Thus, the purpose of the current study was to determine the rate and source of Se fertilization necessary to effectively increase forage Se concentration in western Oregon.

MATERIALS AND METHODS

Experimental Site

In the fall of the year prior to spring experimental treatment applications, Se-deficient pastures were identified by analyzing forage clippings from potential test sites. At this time, a soil sample was collected and pastures were fertilized according to soil test results (Hart et al., 2000) as soon as they were available. Pasture forage consisted primarily of perennial ryegrass (*Lolium perenne*) and subterranean clover (*Trifolium subterranean*). Livestock were excluded from the area with a temporary fence. Plots (40.5 m^2) were assigned to treatments in a randomized complete block (5 treatments, replicated 3 times).

Se Fertilization

Sodium selenate and sodium selenite were obtained from Inman and Co., Inc. (Clackamas, OR). Treatments were 0.0 (control), 0.6, 1.1, and 2.2 kg/ha Se as sodium selenite and 0.6 kg/ha Se as sodium selenate. The selenate form was only included at the lowest level (0.6 kg/ha) because of its high availability to plants (NRC, 1980) and because it has a greater ability to elevate forage Se concentrations (Archer, 1983) compared with selenite. Each Se treatment was applied in the spring season as a mixture with ammonium sulfate (**AMS**; 21%N, 24%S) and broadcast by hand in 2 passes to ensure even application of Se. Target application rate for AMS was 321 kg/ha to deliver 67 kg of N/ha (Hart et al., 2000).

Forage Sampling and Analysis

Ungrazed pasture plots were mowed with a sickle-bar mower (model 34337, Troy-Bilt, Troy, NY) at the end of the spring growing season. Forage samples, consisting of 20 subsamples per plot combined for within-plot analyses, were hand-collected randomly from the mowed residue, placed in paper bags, stored in an air-tight container, and weighed using an electronic scale (Integra 5, Pitney Bowes, Stamford, CT). Total wet forage weight for each replication was determined by hand-raking forage onto a tarp suspended from a tripod-mounted crane scale (Intercomp, model CS200, Minneapolis, MN). Samples were partially dried at 55°C for 3 h using a laboratory oven (model 05015-58, Cole-Parmer Instrument Co., Vernon Hills, IL), reweighed, and sent to the Oregon State University analytical laboratory (Corvallis) for Se and DM determinations. Sample DM content was determined after drying samples to a constant weight in a forced air oven (1380FM, VWR Scientific, West Chester, PA) at 55°C for 24 h. After acid digestion with nitric and pechloric acids, total Se concentration was determined by the semiautomatic fluorometic method (Brown and Watkinson, 1977) with an Astoria-Pacific 303 analyzer (Clackamas, OR) modified from the procedure described in Beilstein and Whanger (1986).

Statistical Analysis

Experimental units consisted of 40.5 m^2 plots. Plots were assigned to 5 treatments, each replicated 3 times. Data were analyzed by treatment, within and between years. Large differences in standard error among treatments violated the general assumptions of the ANOVA. As such, separate Kruskall-Wallis nonparametric tests (S-Plus, 2005, Insightful Corporation, Seattle, WA) were performed on the data from yr 1 and 2 to test for differences between treatments within each year. If a significant difference ($P < 0.05$) existed between treatments within year, Welch *t*-tests (2-sample *t*-test for unequal variances; S-Plus, 2005) were conducted for each 2-way comparison between the 4 active treatments and the control. The significance level was adjusted to 99% using the Bonferroni correction $\{[100 \times (1–0.05/5)] = 0.99\}$ so as to guarantee 95% confidence between comparisons.

Differences between years were analyzed using 5 separate one-sample *t*-tests (S-Plus, 2005). A Bonferonni correction (as above) was used in this analysis as well in order to guarantee 95% confidence between comparisons. In addition, a Kruskal-Wallis nonparametric test was conducted to determine if the addition of Se fertilizer had any effect on forage production in yr 1. The Bonferroni correction was used in this test as well. All analyses were conducted in S-Plus 7.0.2.

RESULTS AND DISCUSSION

Application of 0.6 kg/ha selenate provided the greatest ($P < 0.01$) average forage Se content in yr 1 (8.44 ± 0.08 mg/kg, Figure 1). This is consistent with findings by Archer (1983) who found greater Se in forage treated with selenate than with selenite. Both the 0.6 and 2.2 kg/ha selenite treatments provided significantly

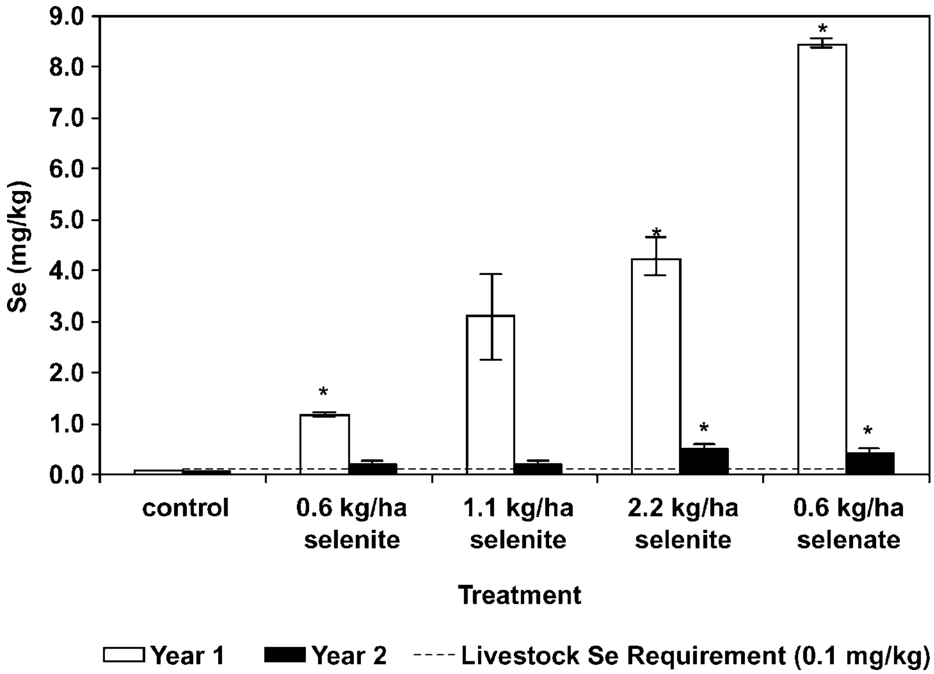

Figure 1. Comparison of Se accumulation in forage for yr 1 and 2 after fertilization with varying Se forms and concentrations (livestock Se requirement from NRC, 1996). Forage Se content values that are different (P = 0.01) from the control in a particular year are marked with an asterisk (*).

greater forage Se content (1.17 ± 0.05 and 4.24 ± 0.35 mg/kg, respectively) than the control (0.087 ± 0.06 mg/kg). In yr 1, only the 1.1 kg/ha selenite did not increase forage Se content ($P = 0.06$). However, it did tend to increase Se forage concentration (3.11 ± 0.79 mg/kg), which exceeded the nutrient requirements of livestock for Se. The plot-to-plot variation within the 1.1 kg/ha selenite treatment was too large for statistical significance. Future trials with more replication may alleviate the large spread observed for this particular treatment. Fertilization with Se had no effect ($P = 0.37$) on mean forage yield during yr 1 and was not measured in yr 2.

Two years after Se application, only the plots treated with 0.6 kg of selenate and 2.2 kg of selenite/ha had forage Se concentrations (0.43 ± 0.04 mg/kg and 0.51 ± 0.06 mg/kg, respectively; Figure 1) that were different ($P < 0.01$ and $P = 0.01$, respectively) from the control (0.06 mg/kg). All treatments exhibited a decrease ($P \leq 0.01$) in forage Se content in yr 2 when compared with yr 1, with the exception of the control ($P = 0.69$) and 1.1 kg/ha selenite ($P = 0.07$). Again, the high degree of variability in Se forage content of the plots treated with 1.1 kg/ha selenite precluded its inclusion as a treatment that displayed a statistically significant difference between years. All treatments in which plots were fertilized with Se produced forage Se content in excess of minimum dietary requirements (e.g., 0.1 mg Se/kg in beef cattle; NRC, 1996) for 2 consecutive years (Figure 1).

The rate of AMS fertilizer in this trial applied along with the Se was chosen to reflect common N applications of 67 kg/ha. However, this exceeds recommended S application rates (Hart et al., 2000). Because S and Se are chemically similar, relative amounts of these 2 elements are known to influence uptake by plants (Westerman and Robbins, 1973). It is possible that excess S from AMS may have limited plant Se uptake in this experiment and may also negatively impact uptake in other fertilizer programs. Future studies should include steps to quantify S and monitor its impact on Se uptake.

When selenate and selenite are applied as fertilizer, the plants convert these inorganic forms to the organic form, selenomethionine. It is this organic form that the grazing animals ingest through forages. Although Se is a required nutrient, it can also be toxic if consumed in excess. The NRC (1996) lists dietary Se toxicity for beef cattle as 2 mg/kg. Studies used to set the tolerance level included inorganic forms of Se (selenate and selenite) or the nonprotein, amino acid form found in Se accumulator plants (e.g., *Astragalus* species). Although the Se concentration of forages in the current study sometimes exceeded the NRC maximum tolerable level, it was presumed to be in the organic form as selenomethionine. This has a much higher margin of safety compared with the inorganic forms (Whanger and Butler, 1988; van Ryssen et al., 1989; Whanger, 1989; Panter et al., 1996; and Taylor, 2005).

A study in eastern Oregon found that cattle receiving multiple, simultaneous methods of Se supplementation, including Se-enriched hay and mineral mixes, had safe Se blood levels, indicating that the forage Se concentrations observed in that study did not harm livestock (Pulsipher et al., 2004). Recently, Davis et al. (2006) found that sheep are more tolerant of diets high in inorganic Se than was previously suggested. More research is needed to quantify maximum tolerable concentrations of the organic form found in Se-fortified pastures grazed by different livestock species.

If pastures are successfully fertilized with Se every other year and forage Se concentrations are monitored to ensure adequate levels, livestock do not need to be provided with other forms of Se. Managers should, however, continue to provide other minerals required by livestock. Additionally, Se blood levels, as well as other minerals, should be monitored during routine health examinations by a veterinarian.

Selenium supplementation via forage fertilization is a very cost effective way to provide dietary Se to livestock. A commercially available Se fertilizer product (0.01 kg/ha Se as selenate) costs about $12.50/ha, with forage sustaining adequate concentrations of Se for approximately 2 yr. In comparison, supplies of Se by injection (1 mg/ml Se as selenite) cost $0.325 per lamb, whereas mineral blocks (90 mg/kg Se as selenite) cost about $0.077 and mineral premixes (210 mg/kg Se as selenite) cost $0.05 per lamb (30-d supplies). Therefore, a 2-yr supply of Se for 100 lambs on 8 ha would cost $100 for Se fertilizer, $780 for injections, $185 for mineral blocks, and $120 for mineral premixes, based on October 2006 prices in Oregon (S. Filley, unpublished data).

The above analysis does not account for the differences in effectiveness among supplementation methods in providing Se to the animals. Placental and mammary transfer of Se to offspring is another benefit that could be factored into an economic analysis. Often, Se blood levels are deficient when livestock are supplemented through mineral block and premixes because they do not always consume the required amount of the blocks, loose mineral mixes, or premixes (Tait et al., 1992; Arthington and Swenson, 2004). Selenium-enriched forage through fertilization sustains animal blood Se levels for a significantly extended period compared with these other methods (Pulsipher et al., 2004).

IMPLICATIONS

These data suggest that fertilization with sodium selenite at 0.6 to 2.2 kg/ha may be a cost-effective method of supplying Se for grazing livestock, with Se concentrations that are moderately high in yr 1 and remain slightly above animal requirements through yr 2. However, 0.6 kg/ha Se as sodium selenate provides initial forage Se concentrations that are likely in excess of a reasonable margin of safety for livestock to consume over a 1-yr period.

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