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Selenium Availability and Methods of Selenium Supplementation for Grazing Ruminants

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Introduction

White muscle disease (WMD) is a degeneration of striated muscles that occurs without neural involvement and is the major clinical sign of selenium (Se) deficiency in newborn ruminants. White muscle disease, which may develop intrauterine or extrauterine, is seen in young ruminants and characterized by generalized weakness, stiffness and muscle deterioration with affected animals having difficulty standing. Calves with WMD have chalky white striations, degeneration, and necrosis in the skeletal muscles and heart. During some years, incidence of WMD in certain world regions is sporadic, with less than 1% of the herds affected. In other areas such as Turkey and New Zealand, a 20-30% incidence of WMD may occur regularly.

In calves the tongue musculature may be affected, therefore not allowing effective suckling (NRC, 1996). Death often occurs suddenly from heart failure as a result of severe damage to heart muscle. In milder cases with calves, where the primary-clinical signs are stiffness and difficulty standing, a rapid and dramatic improvement can result from Se-vitamin E injections.

In Florida feeder calves, the condition is seen most commonly as “buckling”; calves come off the truck, or out of the processing chute with weakness of rear legs, buckling of fetlocks and frequently, generalized shaking or quivering of muscles. Many calves become progressively worse until they are unable to rise and may appear to be paralyzed. Calves with excitable temperaments appear to be most commonly affected. Post-mortem examination of affected calves reveals pale, chalky streaks in muscles of the hamstring and back. The heart, rib muscles and diaphragm may also be affected (McDowell et al., 1985; McDowell and Williams, 1991).

An additional disease condition associated with Se deficiency in Florida is referred to “shoulder lameness” or “flying scapula” (Buergelt et al., 1996). When bilateral dorsal scapular displacement occurs it is due to degenerative myopathy from nutritional deficiency. Flying scapula occurs suddenly and is associated with stiff gait and reluctance to move (Gunning and Walters, 1994). Cattle with the condition were deficient in Se; also water from the ranch was high in S which probably contributed to the Se deficiency (Buergelt et al., 1996).

The vast majority of forages from various parts of Florida are deficient in Se. Monthly mineral concentrations of bahiagrass forages over a 2-year period on a central Florida ranch indicated that 98% were low in Se (< 0.2 ppm) (Espinoza et al., 1991). In a review of 15 experiments throughout Florida, 95% of mean forage Se values were less then 0.1 ppm, and 67% were 0.05 ppm Se or less (McDowell and Tiffany, 1998).

The present paper deals with Se deficiency, availability of Se sources, methods of Se supplementation for grazing ruminants, and two recent Florida experiments dealing with Se supplementation. One experiment compares injectable Se products with free-choice supplementation and the second experiment deals with the use of fertilizer Se as a means of providing Se to cattle.

Availability of Supplemental Selenium

Previously the U.S. Food and Drug Administration (FDA) prohibited the addition of supplemental Se to livestock feeds. However, from the time period of 1974-1980, this regulatory agency gradually allowed Se supplementation for various classes of livestock. Presently, the FDA is allowing Se supplementation to equal an upper limit of 0.3 ppm for livestock diets. The regulation for free-choice mineral supplementation would currently be 120 ppm Se (not to exceed 3 mg/head/day) for cattle and 120 ppm Se (not to exceed 0.70 mg/head/day) for sheep.

Sources of supplemental Se currently in use in the U.S. are sodium selenite (Na_2SeO_3) and sodium selenate (Na_2SeO_4), with organic yeast approved for some species. The selenate form, which is less commonly used, has been considered preferable by some because the selenite form is more readily reduced to less available elemental Se which may form insoluble compounds with other metals. Other sources of supplemental Se include calcium selenite, Se dioxide, and barium selenate.

The organic yeast product has the potential to be a better supplemental source of Se for all species due to its higher bioavailability (McDowell, 1997). In pigs (Mahan, 1999; 2000) and cattle (Ortmann and Pehrson, 1999), organic Se increased milk Se content more than inorganic Se. Organic Se increased blood, milk, and liver Se concentration 2-3 time more than inorganic Se (Knowles et al., 1999). The Se yeast product resulted in a 130% increase in milk Se compared to the control, while the increase due to selenite and selenate was only 20% (Ortman and Pehrson, 1999).

Several researchers have suggested that at least 100 µg of Se/L of whole blood is associated with optimal immune capacity and optimal fertility. Pehrson et al. (1999) compared supplemental Se as selenite and Se in yeast on Se blood levels of calves. Ten of eleven calves had blood Se < 100 µg/L in the yeast group. For the selenite group, seven of nine calves were < 100 µg/L and two of nine < 50 µg/L. Liver, heart, pancreas and muscle tissues of sheep were significantly higher when fed the same level of dietary Se from wheat compared to selenite (Van Ryssen et al., 1989).

Methods of Selenium Supplementation for Grazing Ruminants

The principal methods of increasing Se intake by grazing livestock include (1) a free-choice Se mineral supplement, (2) Se fertilization, (3) injections of Se, (4) Se as an oral drench, (5) Se in water, and (6) Se in ruminal pellets (heavy boluses).

Aqueous Se solutions have been successfully used as a periodic oral drench or as an intramuscular or subcutaneous injection (NRC, 1983). Direct subcutaneous injections, usually as sodium selenite, or oral dosing with this compound in doses from 10 to 30 mg for cattle and 1 to 5 mg for sheep are common means of preventing Se-responsive diseases in grazing livestock (Underwood and Suttle, 1999). Barium selenate injections have been shown to have a long lasting effect in ruminants (Judson et al., 1991). Barium selenate as a pellet or a subcutaneous injection maintained blood Se for at least 200 weeks in ewes and their lambs (Judson et al., 1991).

Use of heavy ruminal pellets (similar to those earlier developed for Co), consisting of 95% finely divided Fe and 5% elemental Se, has prevented the occurrence of WMD in sheep and cattle grazing Se-deficient pastures (Underwood and Suttle, 1999). The use of a slow release glass bolus containing Se, in addition to Cu and Co, has been successful in preventing Se deficiencies (Kendall et al., 2001, Mackenzie et al., 2001). An intraruminal osmotic pump has been developed which actively disperses Se at a rate of 3 mg per day (Campbell et al., 1990). The use of Se-fortified salt mixtures appears to be the most promising procedure for prevention of deficiency of this element (McDowell, 1997). Free-choice mineral mixtures for grazing livestock should be formulated to provide 0.1 to 0.3 ppm Se of total dry matter.

Florida Experiment Using Injectable or Free-choice Supplemental Selenium

A number of methods for Se supplementation are available, including both short and long lasting injectable products as well as part of a free-choice mineral supplement. The objective of the two-year experiment in a beef cow-calf herd was to compare Se sources. Selenium from two injectable products was compared to the Se included in a free-choice mixture with regard to blood, liver, milk and colostrum Se concentrations.

Materials and Methods

Seventy-five Angus cows (1124 lb average weight, and 5-8 months pregnant as determined by palpation) were utilized in a two-year experiment at the Beef Demonstration Unit of the University of Florida in Chipley, Florida. The duration of the experiment was from December 1996 to December 1998. Animals were randomly allotted into five groups and treatments as follows: 1) a control (no Se supplementation), 2) subcutaneous injection of 5 ml of Mu-Se® (5 mg Se per ml sodium selenite, from label, Burns Biotech Labs, Inc. Oakland, CA 94621) every 6 mo, 3) subcutaneous injection of 9 ml of Deposel® (50 mg Se per ml as barium selenate, from label, Grampian Pharmaceuticals Ltd, Leyland, Lancashire PR5 3QN, U.K.) administered only at the initiation of the experiment, and, 4) use of mineral mix with organic Se (Se-yeast: Yea-Sacc, Alltech Biotech Center, 3031 Catnip Hill Pike, Nicholasville, KY 49356) administered to two groups as replicates. The free-choice mineral mixture contained 54.5 g/kg Se-yeast (calculated), which resulted in a Se concentration of 30 mg/kg in the mineral mixture. For both free-choice mixtures the average daily Se intake was 2.1 mg per cow per day. Each of the five groups consisted of 15 cows which remained in the experiment for the two-year study. At initiation of the experiment and every six months, blood and liver biopsy samples were collected for a total of five collections. Colostrum and milk samples from cows in both years were also collected periodically to determine Se concentrations. The cows were provided Argentine bahiagrass and Coastal bermuda pastures (0.05 mg/kg Se) in summer. They grazed ryegrass (0.045 mg/kg Se) during the winter, and were also fed bahiagrass hay (0.04 mg/kg Se) during this period.

Results and Discussion

Cow Plasma Selenium (Table 1)

Six months after initiation of the experiment, differences ($P < 0.05$) among treatments were observed, with the control animals containing numerically less Se than all groups and statistically less than the Deposel® and the two free-choice mineral treatments. The Mu-Se® treatment cows contained less ($P < 0.05$) plasma Se than the Deposel® and the two free-choice mineral mixture treatment cows. Selenium concentrations for all cows were considered adequate (Ellis et al., 1997) except for the control animals which were at a critical level (0.03 µg/ml).

After 12 months, all Se-supplemented groups had higher ($P < 0.05$) plasma Se concentrations than the control. One replicate of the free-choice supplement group was also higher ($P < 0.05$) than the other treatments. In the second summer (18 months), the same replicate of the free-choice supplementation group had higher ($P < 0.05$) plasma Se than the control and Mu-Se® treatments. All treatments were below suggested adequacy (0.07 µg/ml), with the control and Mu-Se® at a critical level (0.03 µg/ml). At the end of the experiment (24 months), there were also differences ($P < 0.05$) among treatments with all supplemented animals above those of the control. Mean Se concentrations of animals receiving Se were above the critical level of 0.03 µg/ml, while the control group was below, averaging 0.02 µg/ml.

Cows in control and Mu-Se® treatments had lower plasma Se concentrations at the end of the study than at the start two years earlier. The control group started with 0.06 µg/ml and ended with 0.02 µg/ml, suggesting that the Se was being used by the animal at a greater rate than it was being replaced, but in this case no Se was being supplemented. At the administered dose and frequency (every 6 months) the Mu-Se®

source of Se was not sufficient to raise and maintain adequate Se concentrations in cow plasma. For the two year period, the Deposel® treatment maintained the Se status in cow plasma while both free-choice mineral mixture groups resulted in higher plasma Se concentrations at the end of the study than the control and Mu-Se® groups. It has been reported (Abdelrahman and Kincaid, 1995) that cows with daily intakes of 1 mg/d Se were unable to maintain adequate Se concentrations in blood during late gestation. Awadeh et al. (1997) found that cows consuming 1.27, 3.98 and 8.57 mg Se per day had a decline in blood Se post-partum, except for cows consuming the highest level. For the present experiment, 2.1 mg Se per day for the free-choice groups was sufficient for maintaining plasma Se.

Cow Liver Selenium (Table 2)

At six months, Mu-Se® and Deposel® treatment cows were higher ($P < 0.05$) than the control but were lower ($P < 0.05$) than cattle receiving the two free-choice mineral mixtures. Liver Se concentrations for both groups of animals receiving the free-choice mineral mixtures were considered adequate for status of this element.

One year after the initiation of the experiment differences ($P < 0.05$) were observed among treatments. Liver Se (0.04 mg/kg) in control animals was lower ($P < 0.05$) than all other groups. The Mu-Se® treatment (0.61 mg/kg) animals did not differ ($P <0.05$) from the Deposel® treatment (0.83 mg/kg) and both treatments had less ($P < 0.05$) liver Se than the free-choice mineral groups (1.36 and 1.30 mg/kg). The control, Mu-Se® and Deposel® treatments were relatively low in Se, whereas the two free-choice mineral mixes were adequate (0.25 -0.50 ppm).

At 24 mo (end of experiment), the Deposel®-treated animals had the highest liver Se concentration (1.69 mg/kg) and differed from ($P < 0.05$) all other groups followed by the two free-choice mineral mixture animals (1.29 and 1.24 mg/ kg). These treatments had adequate Se concentrations whereas the control and Mu-Se® treatment did not.

Deposel® and the two free-choice mineral mixtures succeeded in raising liver Se concentrations to adequate levels after two years (1.69, 1.29 and 1.24 mg/kg, respectively), and this was also reflected by adequate plasma Se concentrations in the cows. Research with cattle and sheep has shown injectable barium selenate to be effective for one year in cattle (MacPherson et al., 1988) and 2 to 4 years in sheep (Judson et al., 1991).

Cow Colostrum Selenium (Table 3)

During the first year of the experiment there were differences ($P < 0.05$) among treatments in colostrum Se concentrations. The control treatment had the lowest concentration and was different ($P < 0.05$) from all other treatments. Mu-Se®-treated animals were similar to those treated with Deposel® but lower ($P < 0.05$) than animals receiving the free-choice mineral treatments. Abdelrahman and Kincaid (1995) reported Se concentrations in colostrum of 0.04 to 0.06 mg/L which is similar to concentrations found in the present study.

In the second year, colostrum Se concentrations declined in all treatments. The control presented the lowest Se concentration (0.024 mg/L) but was not different ($P < 0.05$) from the Mu-Se® treated group. Highest colostrum Se was found in the cows receiving Deposel® and the two free-choice mineral mixtures.

Cow Milk Selenium (Table 4)

At 60 days after calving (Year 1), the highest milk concentrations were for the free-choice mineral mixture treatments (0.03 and 0.04 mg/L) and the lowest (0.02 mg/L) were found in the Mu-Se® and Deposel® groups. At 120 days post-partum, the tendency was similar, with the highest concentrations of Se in milk coming from cows receiving the salt mineral mix treatments. The control group was numerically less than all treatments (0.01 mg/L) but not statistically different than Mu-Se® and Deposel® groups at 0.02 mg/L. At 180 days, again there was a similar trend in both years. During the three periods, milk Se concentrations were maintained in all treatments, except for the control which decreased noticeably from 0.03 to 0.01 mg/L. All milk Se concentrations were similar to and mostly above the values reported by Ammerman et al. (1980).

During the second year, milk Se concentrations at 60 days post-partum were 0.02 mg/L for all supplemented groups and higher ($P < 0.05$) than the control. At 120 days post-partum the control presented equal concentration of Se (0.01 mg/L) as the Deposel® treatment. The Mu-Se® and both free-choice mineral mixture treatments were not different ($P < 0.05$) but had a higher (0.02 mg/L) Se concentration than the Deposel® and control ($P < 0.05$). At 180 days, milk Se concentrations were highest (0.03 mg/L) for free-choice mineral mixture # 2 and lowest (0.01 mg/L) for the Mu-Se®-treated group ($P < 0.05$).

Ortman and Pehrson (1999) and Suoranta et al. (1993) have indicated that supplementing inorganic Se to the dam to alleviate Se needs in calves is not satisfactory due to the poor capacity of these compounds to increase the Se content of milk. Ortman and Pehrson (1999) also reported that organic Se in the form of a yeast product for dairy cows results in higher concentrations of Se in the milk than supplemental sodium selenite.

Calf Plasma Selenium

During year one (1997), calf plasma Se concentrations at birth were at a critical level (0.03 mg/L) for the control, but below adequacy (0.07 mg/L) for the control, Mu-Se® and Deposel® treatments. The two free-choice mineral treatments had an average Se concentration of 0.06 mg/L, which is borderline to adequate (0.07 mg/L). At 60, 120 and 180 d, the control, Mu-Se® and Deposel® treatments were below critical level Se concentrations, whereas the averages for the free-choice mineral mixtures were at or above adequacy. During year two (1998), the control was below critical level at all times, while Mu-Se® and Deposel® treatments were at critical level at birth and 60 d postpartum and below the critical level thereafter. The two free-choice mineral mixtures were higher ($P<0.05$) in Se than all other treatments with average borderline concentrations (0.055 mg/L) at birth and adequate values (0.065 mg/L) the rest of the time.

Providing Selenium as a Fertilizer

Selenium provided as a fertilizer is uniformly received by grazing livestock through forage consumption after topdressing pastures with Se. This method or practice has proven effective in preventing Se deficiency. This is a common livestock production practice in New Zealand (Watkinson, 1983) and in the high rainfall areas of Australia (Whelan, 1994) and is practically the only means of Se supplementation in Finland (Gissel-Nielsen, 1993).

Both sodium and barium selenate forms of Se, as compared with the selenite form, are the best to use in fertilization programs. A Se fertilizer, Selcote Ultra (Corp Care Holding, Ltd., 25 McPherson St., Richmond 7002, Nelson, New Zealand), incorporating a slow release formula (90% minimum sodium and barium selenate and 10% maximum sodium and barium selenite) is commercially available. Two experiments were conducted, one with bahiagrass (*Paspalum motatum*) in north central Florida (Gainesville), and the other with fescue (*Festuca spp.*) in northwest Florida (Quincy) to evaluate the Se level of the grasses after applying a slow-release Se fertilizer (Selcote Ultra).

Materials and Methods

Bahiagrass experiment – The soils from the Gainesville location had a pH of 5.7 and are classified as Millhopper sand. Forage samples were collected from previously mowed 3 x 5 m plots (12 cm high) replicated 4 times which were sprayed with Selcote Ultra at rates of 0, 5, 10, 15, and 20 g/ha Se. Samples were collected every 2 weeks starting in August for a total of six collections.

Fescue experiment – Soils in the Quincy location were classified as Orangeburg loamy fine sand (fine-loamy siliceous thermic Type Kandiudult), with a pH of 5.8. The dry-granule fertilizer was broadcast by hand at levels of 0, 5, 10, 24, and 120 g/ha on 3 x 5 m plots which had been mowed. Forage samples were collected at 2, 4, 6, 10, 16, and 22 weeks after the application of the fertilizer.

Results and Discussion

Bahiagrass experiment – Selenium concentrations of bahiagrass at different weeks after spraying with Selcote Ultra are presented in Table 6. Selenium concentrations (dry basis) were highest in the fourth and sixth week for the 5, 10, and 20 g/ha Se treatments, respectively, while the 15 g/ha treatment presented the highest value at 2 weeks after spraying, but declined thereafter. All treatments presented a marked decline in forage Se concentrations at 8 weeks after spraying and this trend continued at 12 weeks. At 8 and 12 weeks, none of the forage Se concentrations were adequate.

The decline over time of Se concentrations in bahiagrass is in agreement with Archer (1983), who found that upon applying 170 g/ha of Se as sodium selenate, grass DM samples contained up to 11.6 mg/kg Se, and clover up to 13.7 mg/kg in the first defoliation. One the other hand, when Rimmel et al. (1990) applied 10 and 20 g/ha of Se to a grass-legume pasture, they found after collecting every 2 months, concentrations of 1.9, 1.1, 0.2, 0.19, 0.14, and 0.11 for 10 g/ha and of 3.5, 2.1, 0.39, 0.41, 0.17, and 0.12 mg/kg Se for 20 g/ha fertilizer Se. These forage Se levels were adequate without reaching toxic levels and the samples came from six harvests over 21 months. In the above study, forage DM had adequate (0.1 mg/kg) Se concentrations one year after application.

Fescue experiment – Selenium concentrations in fescue DM at different weeks after topdressing with Selcote Ultra can be observed in Table 7. Selenium was highest at 2 weeks after applying Selcote Ultra, decreased from week 4 to 16, and at week 22 the levels were still declining. The control (no added Se) was below cattle requirements (NRC, 1996) at all times. The four Se treatments at all times presented adequate levels of forage Se, except for the 24 and the 120 g/ha treatments which gave toxic levels of Se, but only at 2 weeks after fertilization.

Valle et al. (1993) reported that Se concentrations in bermudagrass DM reached non-toxic levels between 6 to 12 weeks after spraying with sodium selenate, and that 24 g/ha Se is an application rate that can be used safely to provide Se to grazing livestock. Based on the levels obtained in the present study for fescue, it is possible that after one year the forage Se would still be adequate. The levels of forage Se for 10 and 24 g/ha Se are higher at 10 weeks and at 22 weeks than the one reported by Rimmel et al. (1990) at 2 and 4 months.

Conclusion – Provision of Se through pasture fertilizer has many advantages. It avoids labor costs of handling animals for individual treatments, and its easier to treat large animals such as cattle. Management of a pasture, however, can affect Se availability to animals grazing the pasture.

Spraying of Selcote Ultra fertilizer on bahiagrass during the summer is not very effective in increasing forage Se to adequate levels (> 0.1 mg/kg) beyond 8 weeks for the 5 g/ha rate whereas the 10, 15 and 20 g/ha rate treatments were still adequate at 8 weeks. However, topdressing of Selcote Ultra on fescue is an adequate method to increase forage Se, as the Se concentrations exceeded the adequate level 22 weeks after the application.

Summary and Implications

Selenium deficiency as exhibited by white muscle disease is a serious problem in many countries. Selenium is severely deficient in Florida. In a review of 15 experiments throughout Florida 95% of mean forage Se concentrations were less than 0.1 ppm and 67% were 0.05 ppm Se or less. Organic Se is more available than selenite and has resulted in higher Se levels in blood, milk and liver. Injectable barium selenate has proven effective for one year in cattle studies. Methods of Se supplementation include use of free-choice supplements, fertilization, injections, in addition to water and ruminal pellets. In a cow-calf supplementation experiment, the selenite (Mu-Se®) treatment was not effective in raising plasma Se concentrations for long periods while the barium selenate (Deposel®) maintained a constant level of Se in plasma for two years. Higher concentrations of Se in blood, liver and milk were obtained from the Se-yeast product. Deposel® was more effective in elevating calf blood Se than the other injectable product. Deposel® and the use of Se-yeast product in free-choice mineral mixture are reliable methods of providing Se to grazing cattle. Fertilizer Se (Selcote Ultra) was more effective in raising forage Se to an adequate level in fescue than in bahiagrass.

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Table 1. Plasma selenium concentration (g/ml) of Angus cows under different methods and sources of selenium supplementation (n=375 samples)[a]

	Months of Experiment				
Sources	0	6	12	18	24
Control	0.06[b]	0.03[b]	0.02[b]	0.03[b]	0.02[b]
Sodium selenite[1] (Mu-Se)	0.06[b]	0.04[b]	0.05[c]	0.03[b]	0.05[c]
Barium selenate[2] (Deposel)	0.06[b]	0.07[c]	0.06[c]	0.04[bc]	0.06[cd]
Free-choice[3] mineral #1 (Se-yeast)	0.06[b]	0.08[c]	0.06[c]	0.04[bc]	0.07[d]
Free-choice[3] mineral #2 (Se-yeast)	0.07[b]	0.10[d]	0.08[d]	0.05[c]	0.07[d]

[a]Presented are the LS means. Their standard error = 0.015.

[bcd]Means with different superscripts within a column differ ($P < 0.05$), by LSD test.

[1]Animals received a subcutaneous injection of 5 ml of Mu-Se (Burns Biotech Labs, Inc.; 5 mg Se per ml from sodium selenite) every 6 mo.

[2]Animals received a subcutaneous injection of 9 ml of Deposel (Grampian Pharmaceuticals, Ltd.; 50 mg Se per ml as barium selenate) administered once.

[3]Animals consumed a free-choice mineral mixture with organic Se (Se-yeast: Yea-Sacc, Alltech) at a rate of 54.5 g/kg of mineral mix, which resulted in 30 mg/kg Se in mineral mixture.

Table 2. Liver selenium concentration (mg/kg, dry basis) of Angus cows under different methods and sources of selenium supplementation (n=250 samples)[a]

	Months of Experiment				
Sources	0	6	12	18	24
Control	0.070[b]	0.041[b]	0.043[b]	0.034[b]	0.027[b]
Sodium selenite (Mu-Se)	0.073[b]	0.472[c]	0.612[c]	0.704[c]	0.923[c]
Barium selenate (Deposel)	0.070[b]	0.601[c]	0.826[c]	1.003[d]	1.694[e]
Free-choice mineral #1 (Se-yeast)	0.075[b]	1.611[e]	1.358[d]	0.979[d]	1.287[d]
Free-choice mineral #2 (Se-yeast)	0.063[b]	1.180[d]	1.304[d]	0.909[cd]	1.239[d]

[a]Presented are the LS means. Their standard error = 0.008.

[bcd]Means with different superscripts within a column differ ($P < 0.05$), by LSD test.

Table 3. Colostrum selenium concentrations (mg/L) of Angus cows in two years under different sources and methods of selenium supplementation (n=80 samples)[a]

	Years of Experiment	
Sources	1	2
Control	0.032^{b}	0.024^{b}
Sodium selenite (Mu-Se)	0.056^{c}	0.035^{bc}
Barium selenate (Deposel)	0.071^{c}	0.049^{c}
Free-choice mineral #1 (Se-yeast)	0.092^{d}	0.039^{c}
Free-choice mineral #2 (Se-yeast)	0.092^{d}	0.065^{d}

[a]Presented are the LS means. Their standard error = 0.007
[bcd]Means with different superscripts within a column differ (P < 0.05), by LSD test.

Table 4. Milk selenium concentrations (mg/L) of Angus cows under different methods and sources of selenium supplementation (n=240 samples)[a]

	1997			1998		
	Days post-partum			Days post-partum		
Sources	60	120	180	60	120	180
Control	0.03^{bc}	0.01^{b}	0.01^{b}	0.01^{b}	0.01^{b}	0.02^{c}
Sodium selenite (Mu-Se)	0.02^{b}	0.02^{b}	0.02^{bc}	0.02^{c}	0.02^{c}	0.01^{b}
Barium selenate (Deposel)	0.02^{b}	0.02^{b}	0.02^{bc}	0.02^{c}	0.01^{b}	0.02^{c}
Free-choice mineral #1 (Se-yeast)	0.03^{bc}	0.04^{c}	0.03^{c}	0.02^{c}	0.02^{c}	0.02^{c}
Free-choice mineral #2 (Se-yeast)	0.04^{c}	0.04^{c}	0.03^{c}	0.02^{c}	0.02^{c}	0.03^{d}

[a]Presented are the LS means. Their standard error = 0.002
[bcd]Means with different superscripts within a column differ (P < 0.05), by LSD test.

Table 5. Calf plasma selenium concentrations (mg/L) at different ages whose Angus dams were supplemented with different sources of selenium during 1997 and 1998[a].

	Intervals (d)							
	1997				1998			
Sources	0	60	120	180	0	60	120	180
Control	0.03[b]	0.02[b]	0.01[b]	0.02[b]	0.02[b]	0.02[b]	0.02[b]	0.02[b]
Sodium selenite[1] (Mu-Se)	0.04[b]	0.03[b]	0.02[bc]	0.02[b]	0.03[b]	0.03[b]	0.03[b]	0.02[b]
Barium selenate[2] (Deposel)	0.03[b]	0.02[b]	0.03[c]	0.02[b]	0.03[b]	0.03[b]	0.02[b]	0.02[b]
Free-choice mineral #1 (Se-yeast)[3]	0.05[c]	0.07[c]	0.09[d]	0.07[c]	0.05[c]	0.06[c]	0.07[c]	0.06[c]
Free-choice mineral #2 (Se-yeast)[3]	0.07[d]	0.06[c]	0.08[d]	0.07[c]	0.06[c]	0.07[c]	0.06[c]	0.07[c]

[a]Data represent LS means and standard error = 0.004

[bcd]Means with different superscripts within a column differ (P<0.05), by LSD test.

[1]Dams received a subcutaneous injection of 5 ml Mu-Se (Burns Biotech Labs, Inc.; 5 mg selenium per ml from sodium selenite) every 6 mo.

[2]Dams received a subcutaneous injection of 9 ml Deposel (Grampian Pharmaceuticals, Ltd.; 50 mg selenium per ml as barium selenate) administered once.

[3]Dams consumed a free-choice mineral mixture containing organic selenium (Se-yeast: Yea-Sacc, Alltech) which provided 54.5 g selenium yeast per kg mixture (30 mg/kg selenium in mixture).

Table 6. Average selenium concentration (mg/kg, dry basis) of bahiagrass at different weeks after spraying with Selcote Ultra fertilizer[a].

Levels of Se applied (g/ha)	Weeks after spraying				
	2	4	6	8	12
0	0.008[b]	0.026[b]	0.035[b]	0.009[b]	0.008[b]
5	0.019[b]	0.055[bc]	0.085[bc]	0.018[b]	0.008[b]
10	0.022[b]	0.246[d]	0.083[bc]	0.026[b]	0.015[b]
15	0.193[c]	0.168[cd]	0.173[cd]	0.071[b]	0.050[b]
20	0.080[b]	0.194[d]	0.235[d]	0.053[b]	0.025[b]

[a]Data represent LS means and standard error = 0.044.

[bcd]Means with different superscripts within a column differ (P<0.05), by LSD test.

Table 7. Average selenium concentration (mg/kg, dry basis) of fescue at different weeks after topdressing with Selcote Ultra fertilizer[a].

Levels of Se applied (g/ha)	Weeks after applying					
	2	4	6	10	16	22
0	0.06^{b}	0.06^{b}	0.07^{b}	0.05^{b}	0.05^{b}	0.03^{b}
5	1.90^{bc}	0.80^{bc}	0.32^{b}	0.26^{b}	0.25^{b}	0.14^{b}
10	2.42^{bc}	1.23^{bc}	0.91^{b}	0.27^{b}	0.28^{b}	0.17^{b}
24	4.04^{c}	3.14^{cd}	1.23^{b}	0.64^{b}	0.65^{b}	0.58^{b}
120	11.05^{d}	3.86^{d}	1.76^{b}	0.91^{b}	0.70^{b}	0.50^{b}

[a]Data represent LS means and standard error = 0.86.
[bcd]Means with different superscripts within a column differ (P<0.05), by LSD test.