Review of selenium in soils, plants, and animals in Nevada

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REVIEW OF SELENIUM IN SOILS, PLANTS, AND ANIMALS IN NEVADA

Stephen C. Poole¹, Verle R. Bohman², and James A. Young³

ABSTRACT.—Selenium is critical in livestock nutrition; forage can be either potentially deficient or toxic in this element. Selenium is accumulated in excessive amounts by a relatively few species of plants. Several of these plants, termed indicator species, occur in the western Great Basin; however, selenium toxicity is not a problem in Nevada for domestic livestock. The detection of marginal dietary deficiencies of selenium is of much greater economic importance to the livestock industry than an excess of this element.

Selenium occurs as a trace element in the composition of various minerals. Selenium levels are very low in volcanic rocks of recent origin. Accumulations of this element require concentration through secondary dispersion and subsequent sedimentation. Therefore, excesses of selenium are usually associated with siltstone, sandstone, or other sedimentary rocks.

Selenium is usually found in soils as selenate, a water-soluble mineral. The selenium concentration of plants is directly related to the selenate concentration in soil. In soils low in selenate, the ability of plants to accumulate selenium is similar. In soils with high levels of selenate, indicator species accumulate 10 times as much selenium as other species. The foliage of most indicator plants is generally avoided by grazing animals. Deficiencies in dietary selenium are associated with the occurrence of white muscle disease, retained placentas, and general unthriftness of animals. Insufficient dietary selenium can be overcome through injection, intraruminal pellets, or supplementation with salt mixtures.

The biological significance of selenium in animal nutrition was not recognized until 1934, when it was identified as a toxic element that caused lameness and death in livestock grazing certain range plants in the Dakotas and Wyoming (Franke 1934). Although toxic levels of selenium for livestock were first described, deficiencies of dietary selenium are much more widespread. The geographical areas of selenium-responsive diseases have been described in the United States in general (Fig. 1), but specific information on Nevada conditions is fragmentary. Because the geology of Nevada is complex, the relationships between critical plant selenium levels and various geological formations are difficult to define.

GEOBOTANY OF SELENIUM

Selenium can be found in minute amounts in virtually all materials of the earth's crust. Shales, which are sedimentary rocks, have been associated with the majority of selenium-toxic soils, whereas igneous rocks are inherently low in selenium and thus produce selenium-deficient soils. Among the shales, those containing organic matter are the richest in selenium. Selenium can also occur in limestones or sandstones (Fleming 1980). The concentration of selenium in basaltic, granitic, and sandstone rocks averages 0.05 ppm; shales, 0.6 ppm; and carbonate sedimentary rocks, 0.08 ppm (Tarekian and Wedepohl 1961).

Selenium in Rock Formations

Seleniferous geological formations in North America belong to seven different geological periods of time. They include the Tertiary, Cretaceous, Jurassic, Triassic, Pennsylvanian, and Mississippian periods (Rosenfeld and Beath 1964). The oldest rocks associated with accumulations of selenium are mainly marine limestones, sandstones, and shales from the Mississippian and Pennsylvanian periods of the Paleozoic era. In Nevada, isolated blocks of these very old strata occur in the Schell Creek and Fish Creek ranges of central and eastern Nevada. Sedimentary rocks in these formations derived from sediments with high organic matter content give the highest levels of selenium (Desborough et al. 1979).

Rocks of Triassic age in most parts of the western United States are characterized by

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their red and brown colors. They are mainly of continental origin and include conglomerates, sandstones, sandy shales, limestones, evaporites, and volcanic or pyroclastic rocks. Triassic strata are identified from New Mexico, Texas, Arizona, Utah, southeastern Idaho, Wyoming, Montana, Colorado, and Nevada (Table 1). The Moenkopi Formation, a lower Triassic formation, is exposed in southeastern Nevada, southern Utah, northern Arizona, and southwestern Colorado. This formation is known to support a variety of seleniferous plants. In fact, most vegetation on the Moenkopi is considered to be high in selenium and hazardous to livestock. The Chinle Formation, an upper Triassic formation, is exposed in northern Arizona, southern Utah, northwestern Colorado, northern New Mexico, and southeastern Nevada. Extensive and varied selenium indicator plants grow on the Chinle Formation. Although plants found on this formation generally contain less selenium than plants from the Moenkopi Formation, their widespread distribution makes them a serious hazard to livestock (Rosenfeld and Beath 1964).

Fig. 1. Selenium content of forages and grains in the United States and Canada as related to mineral nutritional needs of animals. Map from NRC (1983).
Table 1. Selenium-bearing formations in Nevada.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Period or era</th>
<th>Millions of years ago (approx.)</th>
<th>Nevada location (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humboldt</td>
<td>Miocene</td>
<td>2.5–6.8</td>
<td>North of Wells</td>
</tr>
<tr>
<td>Chinle</td>
<td>Triassic</td>
<td>205–230</td>
<td>Near Las Vegas</td>
</tr>
<tr>
<td>Moenkopi</td>
<td>Triassic</td>
<td>205–230</td>
<td>Near Las Vegas</td>
</tr>
<tr>
<td>Phosphoria</td>
<td>Permian</td>
<td>230–285</td>
<td>N.E. Nevada</td>
</tr>
<tr>
<td>Unknown</td>
<td>Carboniferous</td>
<td>250</td>
<td>Goose Creek</td>
</tr>
<tr>
<td>Unknown</td>
<td>Carboniferous</td>
<td>250</td>
<td>Taylor Canyon</td>
</tr>
<tr>
<td>Unknown</td>
<td>Pennsylvanian</td>
<td>255–325</td>
<td>Near Las Vegas</td>
</tr>
<tr>
<td>Unknown</td>
<td>Mississippian</td>
<td>325–350</td>
<td>Round Mountain</td>
</tr>
<tr>
<td>Unknown</td>
<td>Mississippian</td>
<td>325–350</td>
<td>Near Ely</td>
</tr>
<tr>
<td>Woodruff</td>
<td>Devonian</td>
<td>350–410</td>
<td>Near Ely</td>
</tr>
<tr>
<td>Conus</td>
<td>Ordovician</td>
<td>430–500</td>
<td>Near Winnemucca</td>
</tr>
<tr>
<td>Unnamed</td>
<td>Paleozoic era</td>
<td>230–600</td>
<td>Near Eureka</td>
</tr>
<tr>
<td>Vinini</td>
<td>Ordovician</td>
<td>430–500</td>
<td>Near Eureka</td>
</tr>
</tbody>
</table>

*Compiled from Beath et al. (1939), Davidson and Lakin (1961), Bosenfield and Beath (1964), Tagg (1964), Desborough et al. (1979), Poole et al. (1979), and USGS (1975).

Rocks of Pennsylvanian age in the western interior of the United States that contain selenium are mainly marine limestones, sandstones, and shales. Several species of Astragalus were collected in southeastern Nevada from an unknown detritus limestone mass believed to be of Pennsylvanian age (Beath et al. 1939).

Tertiary rocks are widely distributed in the western interior of the United States. They are nonmarine, somewhat consolidated deposits of reworked debris from older rocks plus volcanic rocks such as tuffs and lava flows. The Humboldt Formation (Tertiary) is known to support seleniferous Stanleya. The Humboldt Formation extends in patches from the west base of the Wasatch Mountains in Utah to the Humboldt River and Humboldt Mountains in northern Nevada (Beath et al. 1939). This formation was originally cited as being of the Pliocene epoch. However, later correlation of the stratigraphic units in the Great Basin assigns the Humboldt Formation to the Miocene epoch (Sharp 1939, Allen 1973).

In the Schell Creek Range in eastern Nevada, samples of the Chainman shale (Mississippian) are relatively high in selenium. Samples from an unnamed Paleozoic formation exposed in the Fish Creek Range near Eureka were also high in selenium (Davidson and Lakin 1961). The Woodruff Formation (Devonian) in the southern Fish Creek Range in Eureka County has been evaluated for several constituents including selenium. The organic matter in this formation was found to contain selenium (Desborough et al. 1979) (Fig. 2).

Phosphate rock samples from the western phosphate field, which covers western Wyoming, northern Utah, northeastern Nevada, southeastern and south central Idaho, and southwestern Montana, contained 1.4–178 ppm selenium (Robbins and Carter 1970). In the West, the rock occurs as marine sedimentary deposits that are considered to be lateral equivalents of the Phosphoria Formation (Tagg 1964).

Other Ordovician and Devonian age marine strata sampled in Nevada have been found to contain anomalously high concentrations of selenium, ranging from 0.2 to 360 ppm, with an average of 32 ppm (Poole et al. 1979). Generally, old rocks of sedimentary origin produce higher concentrations of selenium, and, consequently, selenium indicator plants are generally present. Conversely, rocks of relatively recent origin (Tertiary period), such as the extensive basalt flows of the Pacific Northwest extending into northwestern Nevada, are relatively low in selenium.

Selenium is also concentrated in deposits of minerals left by geothermal water. Selenium is common in epithermal silver-gold, vanadium, and antimony deposits but less common in gold-silver and mercury deposits and is reported to be present in at least 22 ore deposits in Nevada (Luttrell 1959, Davidson 1960, 1964).

Selenium in Soil

The presence or absence of selenium in any soil is dependent upon the interaction of several factors: (1) the presence of selenium in the
Selenium in soil can be found as selenides, selenates, selenites, organic selenium compounds, and, rarely, elemental selenium. The forms and concentration of selenium in a soil solution are determined by various physical-chemical factors expressed as pH, dissociation constants, solubility products, and redox potentials (Geering et al. 1968, National Research Council 1983).

Elemental selenium in soil is readily formed by reduction of selenites in an acid solution. Hydrous oxide complexes of selenites have been recognized as an important form of selenium in acidic soils. The low solubility of selenite complexes may be responsible for the nontoxic levels of selenium in plants growing on acid ferruginous soils high in total selenium. Insoluble selenides associated with sulfides may be present in some soils. The low solubility of the metal selenides, particularly copper selenides, may be responsible for the persistence of selenides in agricultural soils. In well-aerated alkaline soils, other forms of selenium will be oxidized to selenites. Selenates are the primary watersoluble form of selenium in the soil. The selenium content of crop and indicator plants is directly related to the selenate concentration in the soil solution (van Doorst and Peterson 1984).

Recent volcanic deposits, which are inherently low in selenium, constitute the principal soil-forming materials in western Washington, Oregon, northern California, and extreme western Nevada. Parent materials for the soils in extreme northwestern Nevada include igneous and metamorphic rocks along with volcanic ash and sand (USDA 1983). The low-selenium soils are apparently responsible for the low selenium content of the plants grown in this area and therefore the selenium-deficiency symptoms in livestock raised on native forage crops (Allaway et al. 1967, National Research Council 1983). This area of low selenium has as its southern boundary a line extending from the Carson River valley in Nevada northwest across the Sierras and the Sacramento River valley to the Pacific Ocean near Eureka, California. From the Carson Valley, the eastern boundary of the low-selenium area extends north to Lakeview, Oregon, northwest to the Deschutes River valley of Oregon, and then northward parallel with the eastern border of the Cascade Mountains (Kubota et al. 1967). Soils from low-selenium areas in the United States contain less than 0.5 ppm selenium (National Research Council 1983).

On Quaternary period or very recent landscapes where there is a mixture of old sedimentary and recent igneous rocks exposed, the distribution of selenium can be quite complex. Northern Nevada illustrates one of these selenium-variable areas.

Selenium-variable areas within Nevada include many closed basins filled with alluvium and lacustrine sediments interspersed with mountain ranges of volcanic, granitic, and sedimentary rocks. Most of the soils are neutral.
or alkaline, but some acid soils are present in the mountainous areas. The distribution of selenium has several origins: (1) Eocene- and Miocene-aged sediments high in selenium are exposed in scattered areas. (2) Ancient Lakes Bonneville and Lahontan, which once covered much of the intermountain basin area, may have been the recipients of runoff waters from seleniferous areas near their eastern boundaries. (3) Erosion of seleniferous epithermal deposits, scattered throughout Nevada, has contributed selenium to nearby soil materials (Kubota et al. 1967).

A limited survey of Nevada soils as part of a trace element survey of soils throughout the United States revealed a variety of selenium levels (Shacklette et al. 1974) (Fig. 3). Samples were taken at depth of 20 cm below the surface of the deposit to include parts of the zone of alluviation below the plow zone (Shacklette et al. 1971).

Selected trace elements, including selenium, were evaluated in a recently formed alluvial soil (Aquic Xerofluvent) sampled in Nevada. Total selenium levels decreased with increased depth. A total selenium concentration of 0.32 ppm was found in the soil at a depth of 0–61 cm, 0.28 ppm at 64–79 cm, and 0.23 ppm at 79–104 cm (Kubota 1972). Soil samples from central Nevada, along the border of Eureka/Lander counties have been found to contain 0.23–0.28 ppm extractable selenium, primarily as selenate. Soils were of a silt to gravelly loam texture. These soils supported crested wheatgrass (Agropyron desertorum) that contained 0.13–0.17 ppm selenium (dry basis) (Poole 1988).

**Selenium in Plants**

Selenium is not known to be essential for plant growth; however, nearly all plants growing on soils containing selenium in a watersoluble available form will absorb, metabolize, and store variable quantities of selenium in their tissues (Hamilton and Beath 1963). The type of plant, its geographical location, and the presence and availability of the element in the soil will influence the selenium content of the plant.

The selenium content in different parts of the plant will vary with the stage of development, the species, and the regrowth of certain species. The differences among plant species in their ability to accumulate selenium from soils low in selenium are relatively small. This is in contrast to selenium accumulation from soils high in selenium in which species differences of tenfold or more are common (Ehlig et al. 1968).

For herbivores, the concentrations of selenium in grazed plants is a useful measure of the nutritional adequacy of their diets. The requirement for selenium is listed as 0.1 mg/kg (ppm) for most domestic animals (Maynard et al. 1979) that subsist almost exclusively on grazed forage.

**Forage Plants**

Forage plants usually absorb too little selenium to be considered toxic. The levels of selenium in grasses have been found to be only a few parts per million (Shrift 1973). In the United States, extensive areas exist where nearly all plants contain low levels of selenium, such as in the Pacific Northwest, the Northeast, and the Southeastern Seaboard.
Selenium in Nevada Forage

![Diagram of Selenium in Nevada Forage]

**Fig. 4.** Selenium in Nevada forage. Map from Kubota et al. (1967).

Soil and plant surveys have indicated a variety of selenium levels across Nevada. Alfalfa (*Medicago sativa*) has been used as the key plant for sampling. Kubota et al. (1967) found that the selenium concentration in crops was adequate in southern Nevada along the western edge of the Colorado River watershed. In this area over 80% of the plant samples collected contained more than 0.1 ppm selenium and would provide animals with adequate amounts of this element (Fig. 4). A selenium-deficient area may exist in high mountain elevations such as those adjacent to the Humboldt River valley (Kubota et al. 1967) in northern Nevada. This may be the result of acid soils at higher elevations.

Very low concentrations of selenium were found in plant samples along the northwestern border of Nevada, extending from the Carson River valley across the Sierra Nevada and northward toward Oregon. This corresponds to the areas with low selenium in the soil and parent material. More than 80% of the forage samples collected in the low-selenium area contained less than 0.05 ppm selenium and would not provide animals with adequate amounts of this element (Kubota et al. 1967).

In general, most of the high northwestern U.S. rangelands produce forage low in selenium. Carter et al. (1968) sampled primarily alfalfa and, where alfalfa was not available, grasses, other legumes, and grass-legume mixtures in the Pacific Northwest, including Nevada. Selenium concentration was variable, with less than 0.10 ppm selenium in 50% of the samples in the northern portion of Nevada. Plants in the extreme northeast corner and the southern part of the state contained adequate selenium, that is, 90% or more of the samples contained more than 0.1 ppm selenium. In a more detailed study (Carter et al. 1970), samples of mixed forage from high-elevation rangelands of extreme northeastern Nevada contained selenium levels below the dietary requirement of livestock. Forages were growing on Idavada volcanics and silicic rocks of volcanic origin. In contrast, lower elevation range forage and hay produced in the same vicinity contained adequate levels of selenium for livestock.

Alfalfa samples collected near Fallon, Nevada, were highly variable but adequate enough in selenium to prevent white muscle disease (0.05–0.17 ppm) (Allaway and Hodgson 1964). Hay samples from the Yerington, Nevada, area contained 0.12 ppm selenium, thus providing animals with adequate amounts of selenium (T. Erquiaga, unpublished data). Crested wheatgrass collected in central Nevada contained 0.13–0.17 ppm selenium (S. C. Poole and V. R. Bohman, unpublished data).

The selenium intake of cattle grazing northern Nevada rangelands could vary greatly during a single year. If indicator plants were grazed on salt desert ranges, plants with potentially toxic levels of selenium would be consumed. Adequate but nontoxic amounts of selenium would be ingested later while grazing big sagebrush (*Artemisia tridentata*)/bunchgrass ranges, and plants deficient in selenium would be the major part of the diet when mountain brush and meadow ranges were grazed in the summer. Gough and Erdman (1983) have established elemental baseline concentrations for big sagebrush (*Artemisia sp.*) in the western United States, including the Great Basin province. Selenium concentrations ranged from 0.1 to 1.1 ppm.
Selenium Indicator and Accumulator Plants

When selenium was implicated as a toxic agent in western range plants, a survey was undertaken during the 1930s and into the 1940s to determine the extent to which range plants would absorb selenium, their geological distribution, and their geological associations. It became apparent that certain plant species were more reliable than others as indicators of selenium toxic regions. Species from four genera of plants, representing three different families, will accumulate high concentrations of selenium when grown on seleniferous soils or seleniferous geological formations. These plants have been classified as primary indicators. The primary indicator plants are milkvetch (Astragalus), of the family Leguminosae; woody aster (Xylorhiza), of the family Compositae; goldenweed (Haplopappus), of the family Compositae; and prince’s plume (Stanleya), of the family Cruciferae. Other plants will also absorb toxic levels of selenium from seleniferous soils or seleniferous geological formations; however, they are usually found growing on nonseleniferous soil. These plants include 10 genera representing five different families. They are Aster, Grindelia, Gutierrezia, Haplopappus, and Machaeranthera of the family Compositae; Atriplex and Graya of the family Chenopodiaceae; Castilleja and Penstemon of the family Scrophulariaceae; and Comandra of the family Santalaceae. They are classified as secondary indicators (Table 2) (Kingsbury 1964, Shrift 1973).

All selenium indicator plants are perennials with well-developed root systems that absorb selenium continually throughout the life of the plant. Seasonal changes in the selenium content of indicator plants have been reported (Beath et al. 1937, Olson and Moxon 1939, Rosenfeld and Beath 1964). The absorption of selenium by indicator plants will vary widely depending on the genetic capabilities of the species of plant and the chemical environment in the soil. The effect of one ion on the absorption of other ions by higher plants has been demonstrated. A favorable growing season and an abundance of soil moisture are conducive to high selenium absorption by deep-rooted indicator plants (Rosenfeld and Beath 1964).

Selenium indicator plants are quite unpalatable, and as their selenium content increases they may become even less palatable (Olson 1967). Acute selenium intoxication usually occurs as a result of hungry animals grazing indicator plants, particularly the Astragalus species. Consumption of selenium indicator plants in limited amounts over periods of weeks or months can result in chronic selenium poisoning of the blind staggers type (James et al. 1983).

Of the 500 species of Astragalus in North America, only about 25 appear to be definite

<table>
<thead>
<tr>
<th>Genus</th>
<th>Common name</th>
<th>Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary indicators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Astragalus</td>
<td>Poisonvetch</td>
<td>Leguminosae</td>
</tr>
<tr>
<td>Stanleya</td>
<td>Prince’s plume</td>
<td>Cruciferae</td>
</tr>
<tr>
<td>Haplopappus</td>
<td>Goldenweed</td>
<td>Compositae</td>
</tr>
<tr>
<td>Xylorhiza</td>
<td>Woody aster</td>
<td>Compositae</td>
</tr>
<tr>
<td>Secondary indicators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atriplex spp.</td>
<td>Aster</td>
<td>Compositae</td>
</tr>
<tr>
<td>Atriplex spp.</td>
<td>Saltbrush</td>
<td>Chenopodiaceae</td>
</tr>
<tr>
<td>Castilleja spp.</td>
<td>Paintbrush</td>
<td>Scrophulariaceae</td>
</tr>
<tr>
<td>Comandra pallida</td>
<td>Bastard toadflax</td>
<td>Santalaceae</td>
</tr>
<tr>
<td>Graya spp.</td>
<td>Hopsage</td>
<td>Chenopodiaceae</td>
</tr>
<tr>
<td>Grindelia spp.</td>
<td>Gumweed</td>
<td>Compositae</td>
</tr>
<tr>
<td>Gutierrezia spp.</td>
<td>Snakeweed</td>
<td>Compositae</td>
</tr>
<tr>
<td>Machaeranthera sp.</td>
<td>Tansy aster</td>
<td>Compositae</td>
</tr>
<tr>
<td>Penstemon spp.</td>
<td>Beardtongue</td>
<td>Scrophulariaceae</td>
</tr>
<tr>
<td>Haplopappus spp.</td>
<td>Ironweed</td>
<td>Compositae</td>
</tr>
</tbody>
</table>

*Compiled from Kingsbury (1964) and Shrift (1973).*
selenium indicators that grow only on seleniferous soils (Shrift 1973). Even when growing on soils in proximity to selenium-accumulating species, these other species are free from selenium or contain very low levels (Trelease and Trelease 1939).

Seleniferous Astragalus species have been collected in Elko and White Pine counties in Nevada. Samples from these plants showed relatively high selenium levels (Beath et al. 1939, Beath et al. 1941, Lakin and Byers 1948). Astragalus artemisiarum was collected in areas between Indian Springs, Nevada, and Boulder Dam (Lakin and Hermann 1940). Astragalus species collected in the vicinity of the Toano Mountain Range in Elko County and the Schell Creek Range in White Pine County, Nevada, were relatively high in selenium. Seleniferous Astragalus toanus was sampled near Wendover, Nevada, on carboniferous shale (Beath et al. 1939) (Table 3).

Astragalus toanus is a woody, sparsely leaved plant found on barren, calcareous clay banks, sandy shales, or clay bluffs. Its occurrence is scattered, but extensive colonies are found where selenium-rich soils are available. It is plentiful in northeast and east central Nevada, especially in the upper Humboldt Valley and extending east into northwest Utah, and occasionally westward in Nevada to the Humboldt Sink, the Quinn River, and the lower Walker River and south to the White River in northeast Nye County. Astragalus preussii is a coarse, ill-scented plant and is found on alkaline clay flats, talus in canyons, or gravelly or sandy washes. It is confined to selenium-bearing soils derived from sandstone or limestone. It is locally plentiful but rather scattered in southern Nevada. Astragalus artemisiarum (A. beckwithii) grows on dry hillsides in alkaline gravelly soils of various origins but prefers limestone and is often among big sagebrush or bud sage. It is commonly abundant in northeast Nevada, extending south and becoming rarer (Barney 1964).

Three species of *Stanleya* occur widely throughout Nevada. In general, they are low in selenium. Whether this is due to low soil selenium, genetic characteristics, or environmental factors is not known. In northern Nevada a sample of seleniferous *Stanleya pinnata* was found on rocks assigned to the Humboldt Formation (Tertiary age) (Beath et al. 1939). Seleniferous *Stanleya pinnata* have also been observed growing on alluvium near Mina, in the vicinity of Indian Springs, and on limestone near Las Vegas (Beath et al. 1939, Lakin and Hermann 1940). *Stanleya pinnata* occurs in diverse numbers of habitats in the upper salt desert and lower Artemisia zones in the Lahontan Basin, though it may not be obligatorily bound to seleniferous soils. Other *Stanleya* species have been sampled in the Clark County, Nevada, area and were found to be relatively low in selenium. It would appear that the distribution of seleniferous plants in Clark County is restricted to localized areas (Lakin and Byers 1948).

Extensive and varied species of selenium indicator plants can be found in the southeastern part of Nevada on rock formations of the Upper Triassic period. Seleniferous vegetation has been found near Reno and areas extending south (Rosenfeld and Beath 1964) (Fig. 5).
the more readily diagnosed diseases of white muscle disease and retained placentas.

High levels of dietary selenium are toxic to most animals. Acute selenium poisoning in the grazing animal is usually caused by the ingestion of large quantities of selenium accumulator plants in a brief period of time. This type of poisoning is infrequent since animals will usually avoid such plants (National Academy of Science 1980, National Research Council 1983). Clinical symptoms of selenium poisoning include liver cirrhosis, loss of long hair, soreness of feet, elongated hoof growth, stiffness and lameness due to erosion of the joints, atrophy of the heart, hemorrhaging, and emaciation (National Academy of Science 1980, McDowell 1983).

The biochemical role of selenium is complementary with that of vitamin E. Vitamin E has been implicated as a lipid antioxidant, scavenging free radicals and possibly singlet oxygen before they attack cellular and intracellular membranes. Inorganic selenium, as selenite, is an effective catalyst in vitro in the oxidation of thiol groups. Selenium, as a component of glutathione peroxidase (GSHPx), protects membrane lipids against peroxidation either by removing the oxidant or by acting as a preventive antioxidant and removing radical-producing hydroperoxides. About 75–80% of the selenium in bovine erythrocytes is associated with glutathione peroxidase. Lipid peroxidation is therefore minimized by vitamin E and dietary selenium (Fraser 1985, National Research Council 1983).

Leinfelder et al. (1987) found that selenocysteine, the selenium analog of the sulfur-containing amino acid cysteine, is inserted into growing peptide chains as are the standard 20 amino acids. Selenocysteine may, therefore, be considered the 21st amino acid.

Similarities in the chemistry of selenium and sulfur led to investigations of possible biological interactions (Hill 1975). Biological interactions between selenium and arsenic, mercury, cadmium, and copper render selenium much less toxic than it is when present alone. Selenium has also been shown to reduce the toxicity of mercury and cadmium.

Selenium levels in blood and other tissues are indicative of a dietary intake of selenium up to the nutritional requirement of 0.1 ppm. As dietary selenium levels further increase in

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**Nutritional Significance of Selenium in Animals**

Selenium occurs normally in very small amounts in all of the cells and tissues of the animal body and is organically bound (Schwartz 1961, Underwood 1977). Minute amounts of selenium in the diet will prevent exudative diathesis of chicks (*Gallus gallus*), liver necrosis in pigs (*Sus scrofa*) and rats (*Rattus* sp.), retained placentas in adult bovines, and white muscle disease in ruminants (National Research Council 1983). Although white muscle disease and retained placentas are the most typical symptoms of selenium deficiency in the bovine, other selenium-responsive diseases characterized by general unthriftiness, poor growth, and low tissue selenium also occur (National Research Council 1983). Probably the correction of these nonacute symptoms of selenium deficiency may be more economically critical than

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**Fig. 5. Selenium indicator plants in Nevada.** Map compiled from Beath et al. (1939), Lakin and Byers (1941), Lakin and Hermann (1940), Lakin and Byers (1948), and Rosenfeld and Beath (1964).
poultry, blood levels plateau and are no longer a reliable indicator of selenium levels (Scott 1973). Above the range of dietary adequacy of 0.1–0.3 ppm selenium for most species, the plasma or serum levels may plateau and then continue to rise slowly. Plasma or serum selenium concentrations rise rapidly with an excess of 0.3–0.5 ppm dietary inorganic selenium (Ullrey 1987). Possibly the same reaction takes place in ruminants. Measurement of the activity of GSH-Px is also used as an indicator of selenium levels in animals. The critical plasma selenium level used in the diagnosis of selenium deficiency in animals is 0.03 \( \mu g/ml \) (ppm) (McDowell et al. 1983). Williams (1980), using nonparametric classification of selenium data from cattle in northern California, specified 0.04 ppm whole blood selenium as the critical level in the diagnosis of selenium deficiency. Herds that were low in GSH-Px enzyme activity and had a whole blood selenium level below 0.04 ppm were compared with herds high in GSH-Px activity and with whole blood selenium levels above 0.04 ppm. Canadian workers (Puls 1981) feel that 0.09 ppm selenium in whole blood is critical (a level corresponding to 0.03 ppm selenium in serum or plasma). Maas and Koller (1985) indicate that levels of less than 0.3 ppm selenium (dry basis) in liver suggest selenium deficiency. These levels are less than those suggested by Puls (1981).

Dietary intake of 0.1 mg/kg (ppm) selenium will provide a satisfactory margin of safety against any dietary variables likely to be encountered by grazing cattle and sheep. Exact requirements may vary according to the form of selenium ingested and other dietary factors (McDowell et al. 1983). Selenium in plants ingested by animals is returned to the soil mainly in feces or urine, while some may be exhaled in the breath (Olson 1967).

In the United States, observations of selenium deficiency in ruminants have been somewhat limited to congenital and delayed white muscle disease in lambs and calves (Scott 1973).

In Carson Valley, Nevada, and adjoining areas inherently low in selenium, white muscle disease has been recognized (Vawter and Records 1947, Kuttler and Marble 1958). Alfalfa samples collected from Carson Valley were found to be below (< 0.05 ppm) the dietary requirement of 0.1 ppm selenium (Allaway and Hodgson 1964).

Poole et al. (1986) found that plasma selenium levels differed between northeastern (Elko County) and central (Lander/Eureka counties) Nevada. Animals grazing in Elko County had plasma selenium levels of 0.020 ppm, which were below the critical plasma selenium level (0.030 ppm) (McDowell et al. 1983), whereas animals grazing in central Nevada were found to be marginally adequate (0.029 ppm) in selenium. Animals in central Nevada were grazing crested wheatgrass (Aegilops desertorum or A. cristatum), which contained 0.13–0.17 ppm selenium (S. C. Poole and V. R. Bohman, unpublished data). Cattle raised in the Reno, Nevada, area on grass forage (pasture and haylage) containing 0.09 ppm selenium are deficient in selenium. Plasma selenium levels averaged 0.019 ppm selenium (S. C. Poole and V. R. Bohman, unpublished data).

Selenium can be supplemented by: (1) injection, (2) intraruminal pellets, or (3) salt or mineral mixtures (Nader et al. 1986). Results of supplementation are somewhat inconsistent (Hathaway et al. 1980, McDowell et al. 1983). Subcutaneous injections of selenium have been found to raise the blood selenium level but only for a period of about 90 days. Animals have responded favorably to injectable selenium supplementation in a study conducted in northern California (Mayland et al. 1985), an area similar to extreme northwestern Nevada in its selenium status. Cows receiving two intraruminal selenium boluses had blood selenium levels raised from deficient to adequate levels (< 0.02 to > 0.08 ppm selenium). Calves that were born to the supplemented cows had elevated blood selenium levels and gained faster from birth to weaning (Nelson and Miller 1987). Salt or mineral mixtures can be used to provide supplemental selenium to animals, although intake is variable. In Fallon, Nevada, whole blood selenium of cattle raised on native hay increased from 0.034 ppm selenium to 0.081 ppm selenium after the animals received a selenium-containing mineral mix for three months (T. Erquiaga, unpublished data).

Other cattle herds in Nevada have been evaluated for selenium. Cattle in White Pine County (eastern Nevada) that were raised on desert forage in the summer, followed by alfalfa in the fall, had average whole blood selenium levels of 0.51 ppm (0.41–0.62 ppm).
Blood selenium from cattle in western Nevada was much lower. Three cattle herds in the Fallon area had an average of 0.09 ppm blood selenium (0.05–0.14 ppm), while cattle from Yerington that grazed on forage from an alkali flat high in molybdenum had 0.048 ppm (0.03–0.08 ppm) selenium. None of the herds had a reported history of white muscle disease (H. Mayland, unpublished data).

Summary

Selenium deficiency problems occur in western Nevada, extending from the Carson River valley northward toward Oregon. Forage is deficient in selenium in this area due to low selenium soils derived from recent volcanic deposits that are inherently low in selenium. Cattle raised in the Reno area are deficient in selenium. White muscle disease, a degenerative disease of the muscle in ruminants caused by insufficient selenium in the diet, has been reported in animals raised in the Carson River valley, south of Reno. Cattle low in tissue selenium have responded favorably to selenium supplementation in the Fallon area.

Variable amounts of selenium are found in forage in the north and central portions of the state, extending south to the western border of the Colorado River watershed. The areas of variable selenium include closed basins filled with alluvium and lacustrine sediments interspersed with mountain ranges of volcanic rocks, granites, and sediments. Cattle in northeastern Nevada had low tissue selenium, whereas animals grazing in the central part of the state were marginally adequate in this element. Differences between locations reflect the geological distribution of selenium. Forages grown on the high rangelands (above 2,300 m) of the selenium-variable area of the state are usually low in selenium. Forage produced at lower elevations is usually adequate. Forage sampled in southeastern Nevada contains adequate amounts of selenium for the grazing animal.

Selenium accumulator plants, which are usually considered toxic to animals, grow throughout Nevada on seleniferous geological formations. Although they can cause large losses of livestock, selenium indicator plants and subsequent livestock losses because of consumption of these plants are not recognized problems in Nevada.

Because selenium is variable in Nevada's rocks, soils, and forages, additional research should be conducted to locate and define areas of selenium adequacies and deficiencies for forage-fed animals. The status of animals that graze both selenium-deficient and selenium-adequate areas during the year needs evaluation. If selenium stores (i.e., liver stores) are adequate to meet the needs of animals during periods of inadequate intake, the problem is simplified. Tissue sampling (blood and liver) at critical intervals could be used to provide answers to this problem. Some areas of low selenium forage may be large enough that animals may spend their lives in these areas, with correspondingly lower growth and reproductive performance than desirable. If the seasonal status of selenium for animals is delineated, corrective measure could be initiated to minimize this problem when it exists.

Literature Cited


