MINERAL CONCENTRATIONS IN SOIL EXTRACTS, FORAGES, AND BLOOD SERA OF CATTLE GRAZING ON RECLAIMED URANIUM-MINED LAND IN SOUTHEASTERN WYOMING[1]

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Abstract. The Pathfinder Uranium Mine which is located in southeastern Wyoming, was actively mined during the 1960's-1980's. Upon closure of the mine; the spoil overburden was returned and regraded and the salvaged top soil replaced.. The area was revegetated in 1974-1977, but was not grazed until 1980-85. A grazing experiment was then conducted to determine solubility of soil mineral elements and uptake by plants and grazing animals. Blood sera were collected at 28-30 day intervals during the three grazing/growing seasons in 1980-1982. Blood sera samples were frozen and later analyzed by ICP. When compared to published data, plants on the reclaimed site contained lower concentrations of Ca, Mg, Mn, P, and Zn; but higher concentrations of Cd, Cr and Ni than plants on adjacent native sites. When compared to expected blood sera data, animals grazing on the reclaimed site had lower concentrations of B, Ca, Cu, Mg, and Na; but higher concentrations of Cr and Fe than would be expected for most grazing animals. Livestock producers are advised to provide supplements of Ca, Mg, Mn, P, and Zn to minimize deficiency of these elements in livestock nutrition when grazing these rangelands.

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Introduction

Uranium surface mining activities occurred on semiarid rangelands of several western states. The common practice was to remove and stockpile the overburden, and retrieve and process the U bearing ore. The reclamation process consisted of returning the overburden and covering it with top soil that had been temporarily stockpiled. The area was then seeded to a mixture of plant species deemed suitable for the area. This study examined the availability of some minerals from the reclaimed soil, subsequent uptake by vegetation, and ultimately absorbed by the grazing ruminant.

Site Description and Methods

The experiment was conducted on reclaimed uranium-mined lands at the 'Pathfinder Mine' at Shirley Basin, Wyoming (106E12' W and 42E20'N). The mine was located about 75km (45miles) southeast of Casper, Wyoming. The site lies at about 2200 m (7200 ft) elevation and receives an average of 228 mm (9 inches) precipitation annually. The average frost-free period is 88 days.

This area was actively mined during the 1960-1980's. After removal of the uranium ore, the White River spoil was returned and covered with 20-25 cm (8-10 inches) of topsoil. During the period of 1974-1977, the area was revegetated by seeding a mixture of western wheatgrass [*Pascopyrum smithii* (Rybd.) A. Love], green needlegrass [*Stipa viridula* Trin.], thickspike wheatgrass [*Elymus lanceolatus* (Scriber and J.G. Smith) Gould], beardless wheatgrass [*Pseudoroegneria spicata* subsp, *inermis* (Scribner and J.G. Smith) A. Love], Indian ricegrass [Oryzopsis hymenoides (Roem. And Schult.) Ricker], yellow sweetclover [*Melilotus officinalis* (L.) Lam.], four wing saltbush [*Atriplex canescens* (Pursh) Nutt.] and sainfoin [*Onobrychis viciaefolia* Scop.]. The revegetated area was not grazed by domestic livestock prior to the initiation of this grazing study in 1980.

Yearling steers were grazed, during the summer on four, 12 hectare (30 acre) pastures. Two pastures were each grazed by 3 yearling steers and the other 2 pastures were each grazed by 6 yearling steers. Eighteen steers were included in the study each year (1980-1982). Blood data were obtained during 1980, '81, and '82. In early June of each of the 3-years of this experiment, a local rancher provided 18 yearling Hereford steers selected for uniform initial weight (219, 227, and 232 kg) and temperment. Three steers were randomly assigned to each of two 12 ha (30 acres) pastures and 6 steers to each of two 12 ha pastures resulting in a low (0.25 steers ha^{-1}) or high stocking rate (0.5 steers ha^{-1}). Steer distribution and forage use within the pasture was aided by placing water and salt blocks (NaCl) at opposite ends of each of the pastures.

Sampling and Analysis

Steers were weighed and bled every 28-30 days. Grazing began during the first week of June and lasted through the first week of October, except in 1980 when steers were removed on August 29. Steers were bled by jugular puncture, blood allowed to clot, and serum decanted, frozen, and stored frozen until analyzed by ICP. Thawed serum was quantitatively transferred to silicon crucibles, evaporated on hotplate to thick gel, and combusted in muffle furnace at 485EC for 10 h. Three ml HNO_2 were added to any incompletely digested samples (residual black carbon), and these were again heated. Analyses were completed by the University of Minnesota, Department of Soil Science, Research and Analytical Laboratory using an Applied Research Laboratory model 3560, Inductively Coupled Plasma Emmission spectrograph (ICP, ARL 3560, Fisons, Sunland, CA). Four reference samples were analyzed intermittently with the unknowns. Minerals analyzed were: P, K, Ca, Mg, Al, Fe, Na, Mn, Zn, Cu, B, Pb, Ni, Cr, and Cd.. The Mn, Pb, Ni, and Cd concentrations were often below levels of detection by this instrument. Analyses were completed within 2 years of sampling.

Forage samples were clipped at each weigh day for dry matter yield and N, P, Ca, Mg, K, and Na composition (Schuman et al. 1990). Soil samples were taken in October 2001 to characterize the chemical constituents of the existing topsoil after two decades of weathering following reclamation. The blood mineral data were analyzed as a randomized block design using analysis of variance techniques, with repeated observations over time. Means were separated (P<0.10) using least significant-differences (LSD's) when F tests were significant at P< 0.05.

Results

Soil Characterization

Selected soil chemical and physical parameters are shown in Table 1. The topsoil returned to this site contained nearly twice the proportion of silt as the White River subsoil (spoil) placed underneath, but the texture of each was classified as sandy loam. The pH of both soils was similar (7.2 vs 6.9), but the top soil contained more salt (3.5 vs. 0.4). The top soil also had higher concentrations of bicarbonate extractable P (4.4 vs 0.7 mg/kg) which may have been adequate for plant growth on this rangeland where moisture and temperature are the primary growth limiting factors. In high producing systems, a bicarbonate extractable P of about 7 mg/kg would be needed. Nitrate and total nitrogen values in the topsoil suggest moderate nitrogen concentrations for this rangeland area. Water and temperature may be greater limiting factors for plant growth at this site than available P and N.

Plant Mineral Composition

Western wheatgrass was the dominant forage species present during this study period. Elemental composition of the wheatgrass growing on the reclaimed pastures is compared to composition of the same specie growing on adjacent undisturbed rangeland (Table 2).

Mineral concentrations in forage growing on the reclaimed pasture cannot be tested statistically but the mean values of the several samples taken from each of the native and reclaimed pastures were similar for most of the tested elements (Table 2). Western wheatgrass growing on the reclaimed pastures contained lower concentrations of Ca, Mg, but similar concentrations of K. The grass tetany risk in grazing cows increases exponentially when the ratio of K/(Ca+Mg) in the forage, exceeds 2.2 (Horn, 1983) computed on an equivalent basis. Average plant P concentrations of 1100 mg/kg were low, when compared to the 2300 mg/kg in forage grown on undisturbed sites, and may have restricted plant growth. Mineral concentrations evaluated in this study often showed similar values to those reported by others (Mayland et al.,1974; Murray et al., 1978; Rauzi and Tresler, 1978). Other elements quantified in this forage were quite similar on both native and reclaimed sites.

Table 1. Topsoil and White River subsoil characteristics of materials used in reclamation of the Pathfinder uranium mine in southeastern Wyoming.		
	Topsoil	White River Subsoil
pH	7.2	6.9
EC, dS/m	3.5	0.4
BiCarb-P, mg/kg	4.4	0.7
Nitrate-N, mg/kg	19.3	2.0
Kjeldahl-N, mg/kg	900	180
Sand, g/kg	570	760
Silt, g/kg	300	150
Clay, g/kg	130	90

<u>Sera Macro Minerals</u>

Mineral concentrations in semiarid rangeland plants and in ruminant animals grazing these rangelands have been considered in assessing the values reported here (Hidiroglou, 1979; Kincaid, 1999; Mayland, et al., 1974; Puls, 1994; and Selinus et al., 2004). Mineral concentrations in animal sera were not different (Table 3) for animals at the two stocking rates (0.25 and 0.5 steers ha^{-1}) therefore data were combined. Bleeding date by year interaction was significant at < 0.01 and thus most of the mineral concentrations by sampling date and year are graphically illustrated in Fig 1 - 13). For simplicty sake, the mean mineral concentrations in sera of experimental animals in shown in Table 2.

Table 2. Mineral element concentrations as water extractable from top and White River sub soil, and as total in Western Wheatgrass and blood sera of cattle grazing forages grown on the reclaimed uranium mined Pathfinder area in southeastern Wyoming. Normal sera values and some values for forages are those provided by Puls (1994). All units are mg/kg in soil or plant tissue or mg/L for sera unless noted otherwise.

Element	Symbol	Topsoil	White River Subsoil	Western Wheatgrass, Pascopyrum smithii, Clipped 16 June 1978		Blood Sera	
				Native	Reclaimed Pastures	Experimental Animals	Normal Values
Aluminum	Al					0.32 ∀ 0.1	0.009- 0.02
Boron	B	0.16	0.16	18	15	0.12 ∀ 0.06	0.5 - 4.0[A]
Cadmium	Cd	<0.01	<0.01	0.16	1.5	0.016 ∀ 0.015	0.001-0.04[C]
Calcium	Ca	230	620	6200	3000	54 ∀ 11	80 - 110
Chromium	Cr	0.05	0.01	0.6	0.8	0.03 ∀ 0.05	0.0003
Copper	Cu	0.13	0.03	18	20	0.16 ∀ .07	0.8 - 1.5
Iron	Fe	60	4.2	150	85	4.8 ∀ 11[B]	1.3 - 2.5
Lead	Pb	0.09	0.09	-	-	0.11 ∀ 0.14	0.01 - 0.2
Magnesium	Mg	72	88	710	650	10 ∀ 3	18 - 30
Manganese	Mn	1.36	0.29	48	16	0.006 ∀ 0.03	0.006 - 0.07
Nickel	Ni	<0.05	0.01	1.1	1.6	0.028 ∀ .06-	0.001- 0.006
Phosphorus	P	13	0.3	2300	1100	55 ∀ 16	45 - 60
Potassium	K	55	14	15000	16000	160 ∀ 54	160 - 200
Sodium	Na	6	45	520	410	1500 ∀ 310	3100 - 3400
Zinc	Zn	0.20	<0.02	17	14	0.74 ∀ 0.4	0.8 - 1.4

K/Mg	-	-	-	21	25	16 ∀ 5.4	-
K/(Ca+Mg)	-	-	-	2.2	4.6	2.5 ∀0.8	-
Ca/P	-	-	-	2.8	2.8	1.03 ∀ 0/3	-

[A]Value given is for plasma.

[B]Iron data for 8-29-00 and 6-11-81 were omitted from this computation because they were elevated by 5 and 20 X respectively, suggesting hemolysis or red cells during clotting.

[C]Value given for blood.

Five macro elements were quantified in the serum dawn from steers grazing on these pastures over three consecutive years. These included Ca, Mg, P, K, and Na. Serum Ca values ranged from 35 to 65 mg/L (Fig. 1) and averaged 54 mg/L (Table 3) across the entire study. These values were less than the 80 to 110 mg/L range normally noted for cattle (Puls, 1994). Serum Mg values ranged from 6 to 12 mg/L; being higher in early than late season. However. these values were considerably below the range of 18 to 35 mg/L normally expected. Serum K values (Fig. 3) averaged 160 mg/L across the three years, peaking in early season (241 mg/L). Unlike Ca and Mg; serum K values of 160 mg/L were considered to fall within the range (152 to 227 mg/L) considered adequate.

The relative concentrations of Ca, Mg, and K in the forage reflect the availability of forage Mg to the ruminant. As the ratio of K/(Ca + Mg) in forage, computed as moles of charge in the forage, increases above a value of 2.2, there is a reduced availability of Mg and, to a lesser extent, the Ca to the animal. The steers were likely to tolerate these levels of K, Ca, and Mg, but lactating cows, having a big demand for both Ca and Mg in milk, likely would have encountered a Mg deficiency known as grass tetany or hypomagnesaemia. Horn (1983) noted that cows grazing wheat pasture and diagnosed with severe grass tetany often had less than 10 mg/L of Mg. in their blood sera.. It is likely that nursing cows would have had increased risk of grass tetany when grazing these sites, especially the reclaimed sites.

Using the commonly accepted formula of K/(Ca + Mg) in forage, yields a hypothetical grass tetany risk value (Mayland and Grunes, 1979) of 0.83 for cattle grazing the native site and 2.03 when grazing the reclaimed site. The risk is logarithmically related to the ratio of K/(Ca+Mg) {calculated as moles of charge) in the forage. A value of 2.2 yields a predicted animal death loss of 5 %.

Forage growing on the reclaimed pastures had lower concentrations of P than forage growing on the native areas. But this concentration appeared adequate for acceptable P levels in blood sera (Table 3). Forage Na values are approximately 3 to 4 times greater than those values reported by Murray et al. (1978). The Na values in blood sera of cattle grazing this forage are less than desirable (Puls, 1994) and it would appear advisable to provide some form of supplemental Na salt to these animals.

Table3. Summary of fixed effects tests of main variables and their interactions for the blood sera mineral data of cattle grazing reclaimed Shirley Basin Uranium mine in Southeastern Wyoming.

Element	Year	Stocking Rate (SR)	Yr*SR	Bled date (Yr)	Bled date*SR(yr)
Al	0.04	0.96	0.84	<0.01	0.33
B	<0.01	0.49	0.80	<0.01	0.29
Ca	<0.01	0.34	0.48	<0.01	0.50
Cu	<0.01	0.43	0.05	<0.01	0.75
Mg	<0.01	0.19	0.84	<0.01	0.24
P	0.03	0.66	0.30	<0.01	0.56
K	<0.01	0.77	0.13	<0.01	0.50
Na	<0.01	0.30	0.62	<0.01	0.69
Zn	<0.01	0.44	0.87	<0.01	<0.01
K/Mg	<0.01	0.30	0.28	<0.01	0.82
K/(Ca+Mg)	<0.01	0.23	0.56	<0.01	0.88
Ca/P	0.01	0.19	0.61	<0.01	0.20

Essential Trace Elements

Four trace elements: Cu, Fe, Mn, and Zn were quantified in forage and the animal sera. Plants harvested from this area contained 18 to 20 mg/kg Cu which exceeded the 6 mg/kg considered as adequate for nutrition of cattle (Grace, 1983) in situations where Mo and S are adequate but not excessive for animal nutrition. Copper, Mo and S are integrally involved in animal nutrition, but high concentrations of Mo and S increase the concentration of Cu required for adequate nutrition. The mean Cu value of 0.16 in sera is low, but may be sufficient to meet animal requirements for the time they were on these pastures.

It was not possible to quantify the Mo and S with the methodology used in this study and so we are unable to identify the potential interference that these interfering ions might have had on Cu absorption by these animals. Serum Cu values as measured in this study (0.16 mg/kg) were less than the concentration often encountered (0.8 - 1.5 mg/L; Puls, 1994). But serum Cu values do not reflect the active status of Cu metabolism in the animal. The real Cu status is best determined by the concentration of the protein called ferroxidase (Ceruloplasmin; Grace, 1983). Elevated concentrations of Mo and S in forage may reduce absorption and availability of Cu (Grace, 1983; Hidiroglou, 1979).

Other Trace Elements

Forage Cr concentrations were similar for forage growing on both native and reclaimed pastures. However, sera Cr concentrations were many times higher in cattle grazing this site than anticipated for cattle in general. Ramirez, et al., (1995) found similarly high concentrations of Cr in body tissues of aquatic birds residing in Pathfinder reservoir area which is 75 km to the west of our site. This suggests that soil Cr values may be higher in this watershed than in others, or that the combination of mineral interactions has made the Cr much more available to these animals.

Dickerson et al. (2002) also reported higher than normal concentrations of both Cr and Se (not analyzed in this study) in this general area.. They found Hg (not analyzed in this study) concentrations to be below detection limits. In a South Texas uranium district the nratio was found to be very high (Henry and Kapadia, 1980) suggesting that Mo values are minimal and may have little effect on Cu availability status for ruminant.

Geophagia, or soil ingestion, can be another source of minerals for both birds and grazing animals. Mayland et al. (1977) reported that cattle grazing a semiarid rangeland in south central Idaho ingested sufficient to effect absorption Zn and other mineral.

Summary

Water and growing temperature are greater limiting factors for plant growth at this site, than is soil nutrient availability and subsequent uptake at this site. However; Ca, Mn, and especially P concentrations are less in plants grown on the reclaimed pastures than on the native sites. Like temperate forage grown elsewhere, there is a concern about the animal death risk associated with the low concentrations of Ca and Mg and relative high concentrations of K in the forage. Zinc values are low in both forage and blood sera (Mayland et al., 1980) and supplementation is recommended for animal growth. Sera Cu values are low and suggest the need to obtain a better measure of Cu availability by analyzing for ceruloplasmin Cu.

Acknowledgments

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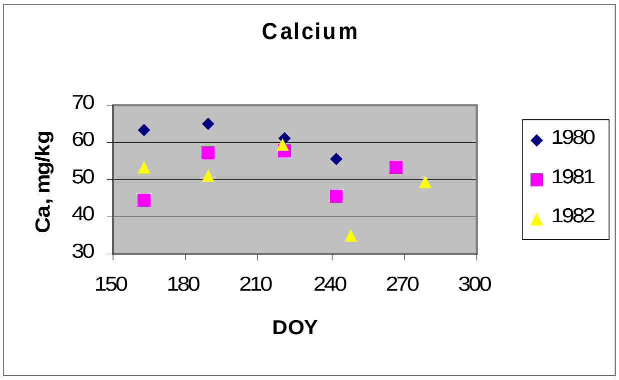

Figure 1. Calcium concentrations in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

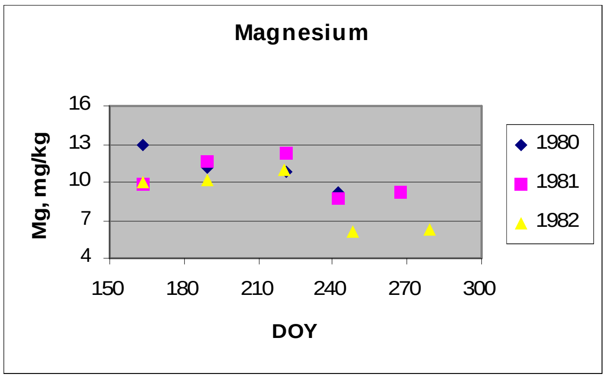

Figure 2. Magnesium concentrations in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

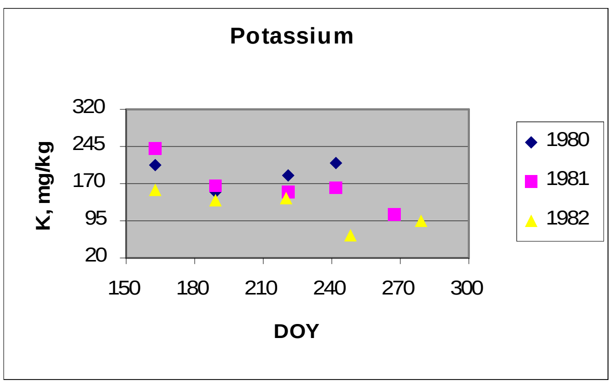

Figure 3. Potassium concentrations in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

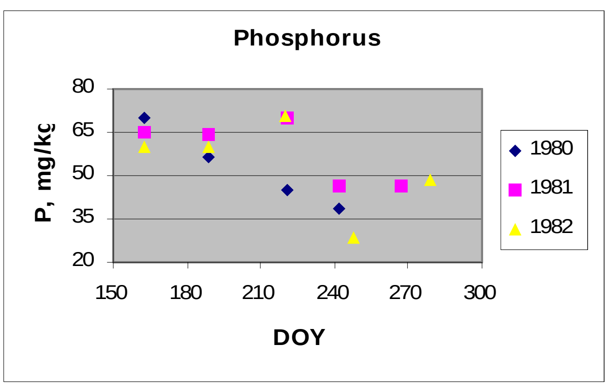

Figure 4. Phosphorus concentrations in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

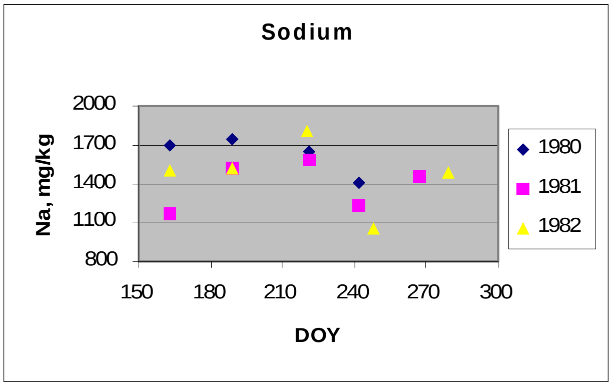

Figure 5. Sodium concentrations in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

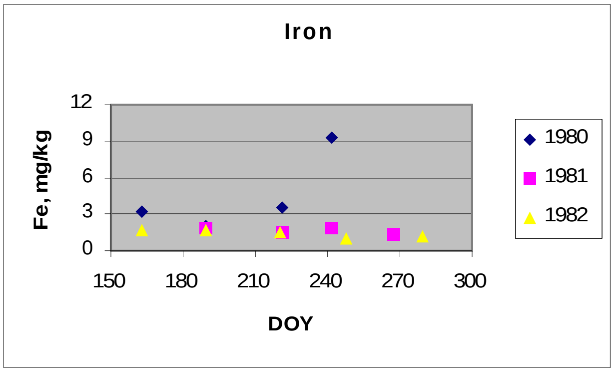

Figure 6. Iron concentrations in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

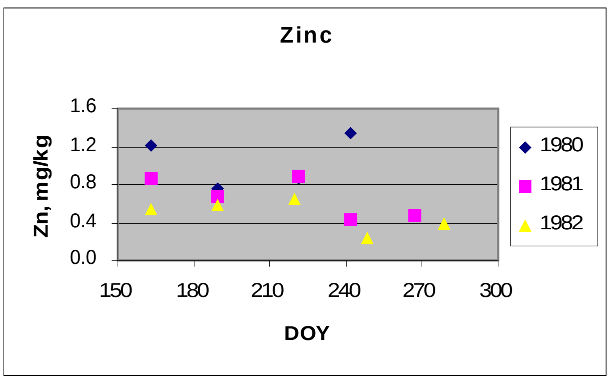

Figure 7. Zinc concentrations in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

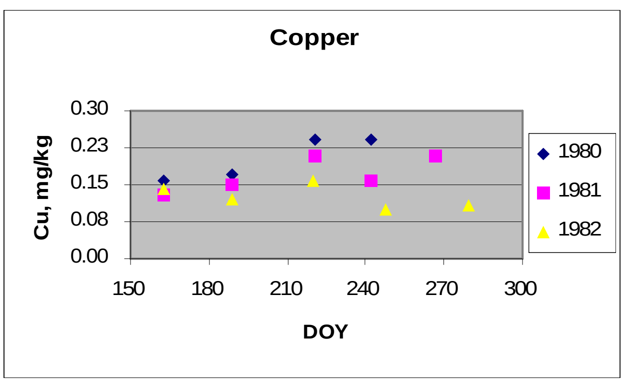

Figure 8. Copper concentrations in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

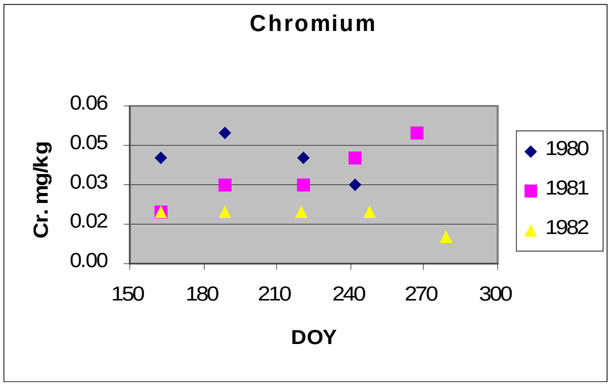

Figure 9. The Chromium in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

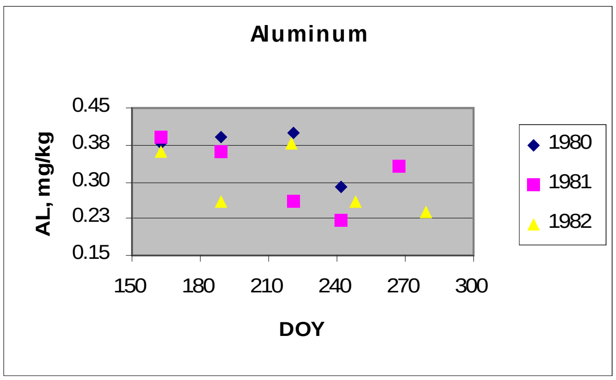

Figure 10. Aluminum concentrations in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

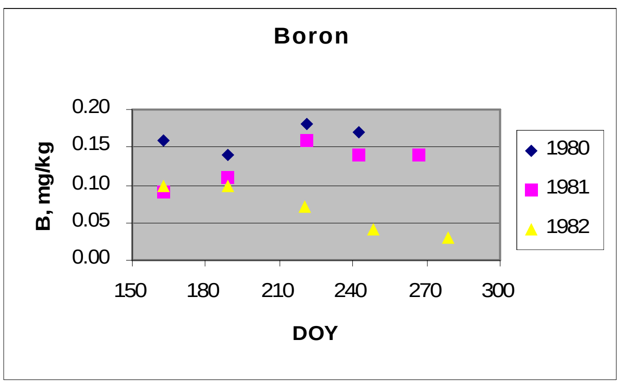

Figure 11. Boron concentrations in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming

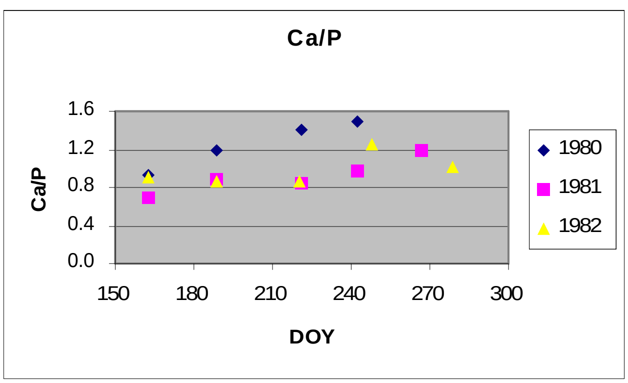

Figure 12. The ratio of Ca/P in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.

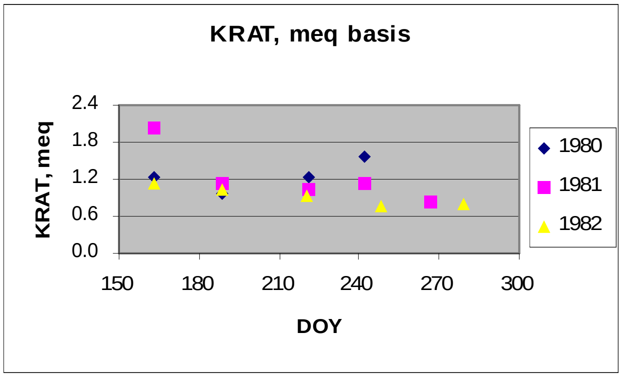

Figure 13. Potassium to Calcium plus Magnesium ratio computed as moles of charge in blood serum of cattle grazing forage on revegetated rangeland in the Shirley Basin of southeastern Wyoming.