SELENIUM *is particularly important among the secondary elements in the soil because it causes the fatal sickness known as alkali disease of cattle. For 75 years the disease was a mystery. This article tells how the cause was discovered, where the disease occurs, and what is known about it today.*

Selenium in Soils

By K. T. Williams [1]

FOR MANY YEARS a disease of animals, apparently peculiar to certain portions of South Dakota and adjacent areas, has been recognized and described under the name "alkali disease." The symptoms are loss of hair and hoofs, lameness, liver lesions, and edema, and the rate of mortality among affected livestock is high.

For more than 75 years the cause of alkali disease was unrecognized. The first known written mention of it is found in a statistical report by Madison (*234*) [2] on sickness and mortality in the Army of the United States, dated September 1857. Dr. Madison described a "very fatal disease" which manifested itself among the cavalry horses at Fort Randall in the then Nebraska Territory. He gave a very satisfactory description of the symptoms and correctly ascribed the origin of the trouble to the pasturage. In later years the disease was supposed to be caused by the water of the area. Because of the frequent loss and still more frequent illness of cattle, this supposed source of the disease was investigated at the South Dakota Agricultural Experiment Station, and the harmlessness of the water in this particular respect was established.

In 1928 Kurt W. Franke, station chemist of the South Dakota Station, began a series of investigations which definitely determined that the disease in question is produced by the consumption of grain and other vegetation grown upon definite soil areas.

As a result of a conference between Franke and Henry G. Knight, Chief of the Bureau of Chemistry and Soils, a cooperative study of the problem was begun in 1931. At the suggestion of Knight, W. O. Robinson of the Bureau was asked to determine the presence or absence of selenium in a sample of toxic wheat. By a method that he devised for the detection of selenium in small amounts in vegeta-

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[2] Italic numbers in parentheses refer to Literature Cited, p. 1181.

tion, Robinson was able to show that selenium was present in the toxic wheat to the extent of 10 to 12 parts per million (*314*). He found that nontoxic wheat grown in Virginia and Maryland contained no selenium. Horn, Nelson, and Jones (*171*) found that the gluten contained nearly all the toxic principle, and Robinson found most of the selenium in the gluten. He found that the hoof of an animal that had died of alkali disease contained a relatively large amount of selenium and the hoof of a healthy animal contained none. Shales, soils, and vegetation from the toxic area contained selenium. Research on the subject rapidly expanded in the Department of Agriculture and in several State experiment stations.

Survey work has shown that certain Cretaceous geological formations are the parent material for most of the toxic soils. Soils derived from some Permian and possibly Triassic geological formations are also seleniferous (selenium-bearing). The seleniferous soils of the United States, that is, those capable of producing toxic vegetation, are apparently confined to areas of low rainfall (20 inches or less per year). It seems that in areas of high rainfall percolating water keeps available selenium below the toxic limit. Toxic areas have been located and to some extent delimited in South Dakota, Nebraska, Wyoming, Kansas, Colorado, New Mexico, and Montana (*57, 58, 59*).

In most cases the geological formations from which these toxic soils are derived contain less than 10 parts per million of selenium. Soil with 1 part per million or even less may produce vegetation containing sufficient selenium to be toxic. Tables 1 and 2 give selected data for geologic and soil profiles.

Plant species vary widely in the quantity of selenium they absorb. Table 3 gives an idea of the variations that may be expected in the selenium content of the vegetative growth on toxic soils.

Table 1.—***Selenium content of representative samples from profiles of geological formations that give rise to the majority of the seleniferous soils of the United States***

PIERRE FORMATION

Material	Thickness		Selenium content	Material	Thickness		Selenium content
	Feet	*Inches*	*Parts per million*		*Feet*	*Inches*	*Parts per million*
Shale	2	..	28	Bentonite and gypsum	--	1	22
Do	3	--	52	Gypsum streak	--	--	5
Siltstone	--	1	26	Shale	6	8	28
Ironstone and mudstone	4	--	14	Limestone and chalk	10	1	1.5
Do	3	-	4	Bentonite	--	1-2	9
Do	--	3	8	Shale	2	--	8
Ironstone and shale	1	6	10	Bentonite	--	¼	76
Do	2	6	20	Shale	2	--	103
Do	2	6	14	Limestone	1	--	12
Shale	4	6	23	Do	1	3	46
Do	4	--	14	Bentonite	--	1	26
Do	1	--	16	Shale	3	3	24
Do	3	--	3	Mudstone and shale	2	8	28
Do	3	--	14	Shale	1	--	3
Do	3	--	28	Do	2	--	7
Ironstone and mudstone	1	6	10	Bentonite	--	10	2
Shale	4	--	21				
Do	3	--	26				
Do	4	--	21				

Table 1. ***Selenium content of representative samples from profiles of geological formations that give rise to the majority of the seleniferous soils of the United States*—Continued**

UPPER PORTION NIOBRARA FORMATION

Material	Thickness		Selenium content	Material	Thickness		Selenium content
	Feet	*Inches*	*Parts per million*		*Feet*	*Inches*	*Parts per million*
Chalk	3	--	12	Chalk	4	--	20
	3	--	8		2	--	8
	6	--	20		2	--	28
	3	--	30		2	--	16
	1	--	25				

LOWER PORTION NIOBRARA FORMATION

Material	Thickness	Selenium content	Material	Thickness	Selenium content
Sandstone	(1)	0.5	Limestone	(1)	0.3

CARLILE MEMBER OF BENTON FORMATION

Material	Thickness	Selenium content	Material	Thickness	Selenium content
Yellow sandstone	(1)	0.2	Gray shale	(1)	0.7
Gray shale	(1)	1.0			

GREENHORN MEMBER OF BENTON FORMATION

Material	Feet	Inches	Selenium content	Material	Feet	Inches	Selenium content
Clay shale	25	--	3.0	Dark-gray shale (with thin seam of limonite)	--	7	2.5
Dense dark-gray shale	--	14	.8	Gray clay shale	--	8	1.0
Dense dark-gray limestone	--	7	1.0	Dense dark-gray limestone	--	9	1.0
Gray clay shale	--	13	.7	Limonite (with bentonite)	--	2	8.0
Do	--	12	.4				
Bentonite	--	7	1.0				

GRANEROS MEMBER OF BENTON FORMATION

Material	Feet	Inches	Selenium content	Material	Thickness	Selenium content
Dark-gray shale	4	--	2.5	Bentonite layer	(1)	3.0

[1] Not determined.

Table 2.—***Variation of selenium content with depth in seleniferous soil profiles***

Type and location	Depth	Selenium content	Type and location	Depth	Selenium content
	Inches	*Parts per million*		*Inches*	*Parts per million*
Fort Lyons silt loam, Prowers County, Colo.	0- 6	0.7	Pierre clay loam, Crowley County, Colo.	0- 1	2.0
	6-12	.8		1- 6	2.0
	12-24	.8		6-12	.8
	24-36	.8		12-24	1.0
	36-48	1.0		24-36	10.0
	48-60	1.0		36-48	5.0
Niobrara clay loam, Gove County, Kans.	0- 6	2.0	Boyd clay loam, Lyman County, S. Dak.	0- 8	3.5
	6-12	1.5		8-12	4.0
	12-18	1.5		12-24	5.0
	18-24	3.0		24-36	6.0
	24-60	1.0		36-48	8.0
Pierre silt loam, Mora County, N. Mex.	0- 2	4.0		48-60	12.0
	2- 6	1.0			
	6-12	.7			
	12-22	.7			
	22-30	.6			
	30-36	.7			

Table 3.—*Selenium content of various plants collected simultaneously from the vegetative growth on gritty clay loam with a selenium content of 2 parts per million, Kiowa County, Colo.*

Type of vegetation		Selenium content	Type of vegetation		Selenium content
Botanical name	Common name		Botanical name	Common name	
		Parts per million			*Parts per million*
Aplopappus fremontii	Goldenweed	320	*Helianthus annuus*	Sunflower	2
Astragalus pectinatus	Narrowleaf milk-vetch.	4,000	*Malvastrum coccineum.*	Scarlet mallow	1
Bouteloua gracilis	Blue grama	2	*Munroa squarrosa*	False buffalo grass.	4
Zea mays	Corn	10	*Salsola pestifer*	Russian-thistle	5
Euphorbia sp	Spurge	10	*Stanleya pinnata*	Stanleya	330
Gutierrezia sarothrae	Turpentine weed	70	*Xanthium* sp	Cocklebur	6

From the analysis of several thousand samples of seleniferous vegetation it appears that plant species may be grouped with reference to their relation to selenium absorption as follows: (1) Plants that absorb selenium readily and appear to be able to utilize it in their physiological activities. This group includes *Astragalus racemosus*, *A. pectinatus* (narrowleaf milkvetch), *A. bisulcatus* (two-groove poison-vetch), *A. carolinianus*, *A. grayii*, and perhaps others, but not all species; also *Stanleya pinnata* and *S. bipinnata*, *Aplopappus fremontii* (goldenweed), *Aster parryi* (woody aster), and probably others. (2) Plants that grow fairly well on seleniferous soils, though not entirely without injury, and are able to absorb moderate to large quantities of selenium. Among such plants are the common cereals and a number of native plants such as *Aster ericoides* (wreath aster), *A. fendleri* (blue aster), *Gutierrezia sarothrae* (turpentine weed), *Helianthus annuus* (sunflower), and *Salsola pestifer* (Russian-thistle). Members of a third group absorb selenium only in small quantities when growing on seleniferous soils and appear to have only a limited tolerance for it. Included in this group are grasses in general.

The selenium content of a given species has no constant ratio to the selenium content of the soil on which it grows. Table 4 gives data on this variation.

Vegetation from several irrigation projects was found to have a relatively low selenium content as compared with the vegetation on adjacent unirrigated soil of similar selenium content.

Hurd-Karrer (*174*) found that sulphates inhibit the selenium absorbed by plants on artificially selenized soils. Franke (*113*) and Beath (*26*) found that selenium absorption by vegetation grown on the seleniferous soils of South Dakota and Wyoming was not inhibited by the application of sulphur or sulphates.

Examination of several samples of soil and vegetation from different parts of the world indicates that the occurrence of selenium is widespread. In the United States the toxic soils are in arid and semiarid regions where the lands are devoted primarily to grazing and, to a less extent, to wheat growing. Native range animals normally tend to avoid the toxic plants, but shortage of forage caused by overgrazing forces them to eat vegetation they would otherwise avoid. Range animals brought from other areas into the seleniferous regions are

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especially susceptible to injury from toxic vegetation. Heavy losses of transient animals have been known to take place in a single night on limited areas where toxic vegetation was abundant.

Table 4.—*Selenium content of plants grown on soils containing different quantities of selenium*

Kind of vegetation	Selenium content of vegetation	Selenium content of soil (0–8 inches)
	Parts per million	*Parts per million*
Astragalus bisulcatus (two-groove poisonvetch)	6,530	6.0
	50	5.0
	4,300	4.0
	150	4.0
	2,050	2.0
	60	2.0
	3,030	.8
	510	.8
	130	.7
Salsola pestifer (Russian-thistle).	160	5.0
	35	4.0
	2	3.5
	12	2.0
Salsola pestifer (Russian-thistle)—Continued.	3	2.0
	40	1.0
	35	.5
	1	.5
Bouteloua curtipendula (Side-oats grama)	2	8.0
	10	6.0
	14	5.0
	2	5.0
	4	2.0
	0	.8
	2	.7
	1	.2

In certain areas farmers have long known that animals become affected when fed exclusively with grain grown on particular fields. However, when this grain is mixed with nontoxic grain from other fields, the trouble is eliminated or greatly reduced.

The effects of the food consumed by persons residing in the toxic areas are being investigated by the United States Public Health Service. It has been found that many individuals who show a definite intake and excretion of selenium have at the same time certain characteristic symptoms of disease. No definitely known acute cases of human poisoning have been discovered in the United States, but some have recently been found in Mexico. Among the reasons for the small incidence of poisoning in our seleniferous areas are the extensive use of other than home-grown foods and the fact that irrigation greatly diminishes the absorption of selenium in foodstuffs grown on seleniferous soils. Danger from flour made from toxic wheat seems remote, as ordinarily large quantities of wheat from different areas are mixed before the grain is milled. It seems probable from available data that such hazard as exists in seleniferous areas is in the consumption of meat, eggs, and milk produced in very toxic localities.