Uptake of Available Selenium by Certain Range Plants[1]

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Plants are variable in their response to the presence of selenium in the soil. A group of plants termed "indicator plants" has never been observed, under natural conditions, growing on soil free of selenium. Their growth in a certain area has been accepted as unmistakable evidence of the presence of selenium. In contrast to other plants, these "indicator plants" possess the ability to leach or solubilize, for their own use, normally insoluble selenium occurring in numerous geological formations. When these plants decay the selenium is returned to the soil in a soluble or available form.

There are only a limited number of locations where naturally occurring soil selenium exists in an available form. In most instances, where available soil selenium occurs, it has been supplied by the leaching effect of soil water or by decay of selenium-containing vegetation. Many workers have observed that nearly all plants, growing upon soils containing selenium in a water-soluble or available form, will absorb, metabolize, and store in their tissues variable quantities of selenium. This study was carried out to determine the amount and chemical nature of the selenium in certain range plants that were grown in the greenhouse on soils containing different amounts and forms of available selenium. All of these greenhouse plants grew at a satisfactory or near normal rate.

Review of Previous Work

The presence of different chemical forms of selenium in plants was recognized by early investigators as variable toxic effects were exerted upon animals by ingestion of different selenium-containing plants. Chronic selenium poisoning of animals is of two types commonly termed "blind staggers" and "alkali disease" and is discussed in detail by Trelease and Beath (1949). The toxicants, symptoms, and pathology of the two diseases are different. The blind-staggers type is produced

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in cattle and sheep by ingestion, over a considerable period of time, of seleniferous weeds containing appreciable quantities of selenium. Alkali disease is observed in cattle, hogs, and horses that have consumed cereal grains, forage grasses, and perhaps certain other plants containing appreciable quantities of selenium. The selenium contents of wheat grain, wheat products, barley, corn, oats, and several other crops were extensively studied by Williams *et al.* (1941).

Range grasses growing in various seleniferous areas, principally in South Dakota, were studied by Moxon (1937) and by Olson *et al.* (1942). They found western wheatgrass, *(Agropyron smithii* Ryd.), to be the most efficient absorber of selenium among the grasses studied. Other grasses were reported to contain small amounts of selenium. Jones *et al.* (1937), Horn and Jones (1941), and Trelease *et al.* (1960) reported that selenium partially replaced sulfur in plant metabolism and occurred along with sulphur in the amino acid and protein components of wheat, narrow leaf milkvetch *(Astragalus pectinatus* Dougl.), and two-grooved milkvetch *(Astragalus bisulcatus* (Hook) Gray).

Plants vary widely in their ability to accumulate selenium from soils containing available selenium. The solubility and chemical nature of the accumulated selenium is quite variable according to Beath and Eppson (1947). These workers reported that plants comprising several species of *Astragalus,* and several species of *Stanleya,* alfalfa (*Medicago sativa* L.), barley, (*Hordeum vulgare* L.), corn, *(Zea mays* L.), oats, (*Avena sativa* L.), and sweetclover (*Mellilotus alba* Desr.), contained organic selenium compounds and no inorganic selenium. Most of the seleniferous plants they studied contained variable amounts of soluble selenium in the organic and selenate forms. Small amounts of selenite selenium were detected in some plant extracts.

It appears that a number of factors affect the selenium absorption of plants since Hurd-Karrer (1935) reported that alfalfa contained 560 ppm and sweetclover 645 ppm when grown in the greenhouse on soil containing five ppm selenate selenium. In our study, alfalfa grown on soil containing five ppm selenate selenium contained 41 ppm selenium and white blossom sweetclover grown on soil containing 20 ppm of selenate selenium contained 226 ppm selenium. Beath and Eppson (1947) reported values of 202, 98 and 41 ppm selenium in range grown western wheatgrass in contrast to values of 298, 154, and 71 ppm selenium in our greenhouse grown western wheatgrass.

Methods and Procedures

In nearly all instances the plants used in this study were started from seed and were grown in the greenhouse. Plants grown and analyzed were: western wheatgrass, slender wheatgrass (*Agropyron trachycaulum* Link), western aster (*Aster occidentalis* (Nutt.) T. and G.), common winter fat (*Eurotia lanata* (Pursh) Moq.) broom snakeweed (*Gutierrezia sarothrae* Pursh), Fremont goldenweed (*Haplopappus fremontii* A. Gray), summer cypress (*Kochia scoparia* (L.) Schrad), prickly lettuce (*Lactuca serriola* L.), Nuttall goldenweed (*Machaeranthera grindelioides* (Nutt.) Shinners) tansy aster *(Machaeranthera ramosa* A. Nels.), alfalfa (*Medicago sativa* L. var. Grimm), white blossom sweetclover, Indian ricegrass *(Oryzopsis hymenoides* Roem. and Schult.), common yellow oxalis *(Oxalis stricta* L.), timothy *(Phleum pratense* L.), rabbitfoot grass *(Polypogon monspeliensis* (L.) Desf.), alkali prince's plume (*Stanleya bipinnata* (Pursh) Britton), needle-and-thread (*Stipa comata* Trin. and Rupr.), common dandelion (*Taraxacum officinale* Weber), and yellow goatsbeard (*Tragopogon pratensis L.). The plants were grown on the same soil mixture containing known levels of added selenium supplied as powdered two-grooved milkvetch and Preuss milkvetch *(Astragalus preussii* Gray) plants, potassium selenate, or sodium selenite. Amounts of selenium varying from two to 30 ppm were added to the essentially selenium-free soil mixture. The soil was a mixture of one part black loam from a forest area and two parts of red soil derived from the Chugwater formation. Supplemental lighting was used as needed to increase the light period to a minimum of 14 hours daily. Insecticides, water, and fertilizer were applied when needed. The entire above-ground portions of the plants were harvested at definite stages of growth and definite amounts of the whole plant were used for analytical work. The plants reached what appeared to be normal maturity in a shorter time than would similar plants growing on the range. Moisture contents of the freshly harvested plants were determined by drying in a vacuum oven and expressed as a percentage of fresh weight. The air-dry plant material was reduced to a uniform powder. Methods of water extraction and selenium analytical methods were essentially those used by Beath and Eppson (1947). The total amounts of selenium present in the dry plant and water-soluble fraction, along with the amount of inorganic selenium found in the water extract, were determined. Amounts of water-insoluble selenium and of water-soluble organic selenium were

Table 1. Common name, stage of growth, amount and form of added soil selenium, moisture content of plant, amounts of total, water-soluble, soluble inorganic, soluble organic, and insoluble selenium in various range plants.

Common name	Stage of growth	Soil selenium Amount ppm	Soil selenium Form	Plant moisture percent (Fresh-basis)	Selenium (Oven-dry plant weight basis) ppm Total	Soluble	Soluble inorganic	Soluble organic	Insoluble
Western wheatgrass	Pre-bloom	5	Selenate	62.3	154	87	75	12	67
		10	Selenate	64.8	298	214	146	68	84
		20	Organic	62.7	71	45	20	25	26
Slender wheatgrass	Pre-bloom	20	Selenate	84.6	56	49	26	23	7
		20	Organic	82.9	53	44	20	24	9
Western aster	Bloom	20	Selenate	73.4	1,413	1,287	1,077	210	126
		10	Selenite	73.6	557	495	402	93	62
		20	Organic	73.4	304	270	215	55	34
Common winter fat	Bloom	20	Organic	70.2	114	84	41	43	30
Broom snakeweed	Bloom	10	Selenate	70.1	101	84	55	29	17
		20	Selenate	69.4	112	80	52	28	32
		20	Organic	69.0	104	69	32	37	35
Fremont goldenweed	Bloom	5	Selenate	76.8	657	597	324	273	60
Kochia, burning-bush, summer cypress	Pre-bloom	20	Selenate	84.0	191	130	82	48	61
		10	Selenite	82.5	136	102	55	47	34
		20	Organic	84.5	137	110	68	42	27
Prickly lettuce	Pre-bloom	5	Selenate	88.4	25	21	16	5	4
		10	Selenite	89.0	59	48	37	11	11
		20	Organic	87.6	94	87	31	56	7
Nuttall goldenweed	Bloom	20	Selenate	68.4	182	158	133	25	24
		20	Selenite	68.2	116	90	53	37	26
		20	Organic	67.4	199	152	87	65	47
Tansy aster	Bloom	10	Selenate	78.4	3,900	2,915	2,083	832	985
		20	Selenate	74.6	8,078	6,877	5,722	1,155	1,201
		10	Selenite	79.2	1,478	1,152	1,043	109	326
		20	Selenite	70.8	2,352	2,195	2,090	105	157
		20	Organic	77.6	720	604	458	146	116
Alfalfa	Bloom	5	Selenate	72.0	41	29	21	8	12
		10	Organic	72.0	40	29	15	14	11
White blossom sweetclover	Bloom	20	Selenate	75.8	226	201	122	79	25
		20	Selenite	79.0	200	163	129	34	37
		20	Organic	75.7	182	150	86	64	32
Indian ricegrass	Bloom	10	Selenate	77.6	546	451	413	38	95
		20	Selenite	79.0	526	435	323	112	91
		20	Organic	78.4	58	38	17	21	20
Common yellow oxalis	Bloom	30	Selenite	76.2	36	32	21	11	4
		10	Organic	77.3	23	19	9	10	4
Timothy	Bloom	3	Selenate	79.0	33	26	18	8	7
		20	Organic	78.4	39	33	21	12	6
Rabbitfoot grass	Bloom	10	Selenate	78.4	149	107	88	19	42
		20	Organic	80.3	80	56	36	20	24
Alkali prince's plume	Pre-bloom	10	Selenate	84.4	915	877	0	877	38
		30	Selenite	83.2	540	474	0	474	66
		20	Organic	83.6	724	681	0	681	43
Needle-and-thread	Pre-bloom	5	Selenate	71.4	37	27	13	14	10
		10	Organic	72.3	30	22	10	12	8
Common dandelion	Bloom	2	Selenate	79.3	67	55	38	17	12
		20	Organic	81.7	89	69	41	28	20
Yellow goatsbeard	Bloom	20	Organic	84.7	84	65	40	25	19

obtained by difference. Amounts of selenium present are expressed as ppm based on oven-dry sample weights. Considering the minimum sample weights used in some instances selenium analyses cannot be considered accurate to less than 0.5 ppm and fractional ppm selenium contents are therefore expressed only to the nearest whole number. The water-insoluble fraction is assumed to be organic selenium, Beath and Eppson (1947). No attempts were made to determine whether elemental selenium was present in the plant dregs, as has been suggested by Peterson and Butler (1962). All inorganic selenium compounds present are considered water-soluble under the extraction conditions.

Discussion of Results

The common name of the plant and the amount and form of selenium added to the soil along with the results of selenium analyses of the entire plant and certain plant fractions are given in Table 1. Most of the plants were collected at the bloom stage of growth. However, a few species were collected at the pre-bloom stage. The moisture contents of the freshly harvested plants varied from 62.3 to 89.0 percent.

The grasses tested varied widely in their ability to absorb, metabolize, and store selenium. Indian ricegrass accumulated by far the highest amount of selenium with values of 526 and 546 ppm when grown on soil containing inorganic selenium. Western wheatgrass and rabbit-foot grass samples also contained large amounts. Nearly all grasses grown on soils containing selenium, supplied by powdered indicator plants, contained a much lower level than similar plants grown on soils containing inorganic selenium. The grasses contained from 12.5 to 36.6 percent of the total selenium in an insoluble or organic form. The major portion of the water-soluble selenium present in the grasses was inorganic in nature and this amount was not markedly influenced by the form of selenium added to the soil.

White blossom sweetclover was an efficient absorber and stored a relatively large amount of selenium whether it was supplied as selenate, selenite, or organic selenium. Alfalfa contained relatively low levels of 40 and 41 ppm selenium. The second cutting contained nearly the same level of selenium as did the first cutting. Under these experimental conditions both alfalfa and white blossom sweetclover plants collected at bloom stage, contained from 37.5 to 64.5 percent of the total selenium in the inorganic form. Plants of both species, when grown on soil containing organic selenium, contained 37.5 and 47.2 percent of the total as inorganic selenium. These results are not in agreement with those reported by Beath and Eppson (1947) since, they reported that both alfalfa and yellow sweetclover contained only organic selenium. Possible explanations could be variety differences in the alfalfa, variations in selenium metabolism between white and yellow species of sweetclover, or differences in selenium metabolism and accumulation by plants grown under natural and those grown under greenhouse conditions.

Fremont goldenweed is an efficient selenium absorber since plants grown on soil containing five ppm of selenate selenium contained 657 ppm selenium of which more than 40 percent was in the organic form. Tansy aster is the most efficient absorber of selenium studied and its tissues contained 8,078 ppm selenium when grown on soil containing 20 ppm of selenate. This plant contained 2,352 ppm selenium when grown on selenite containing soil and 720 ppm when organic selenium was added to the soil. The major portion of the selenium was water soluble and inorganic. Western aster plants contained 1,413 ppm selenium when grown on soil containing 20 ppm selenate as compared with 304 ppm selenium when grown on soil containing a similar level of organic selenium.

Alkali prince's plume, a selenium-indicator plant, accumulated a comparatively high level and absorbed organic selenium more efficiently than selenite but less efficiently than selenate. This plant contains only organic compounds of selenium irrespective of the form contained in the soil.

All the plants studied absorbed, metabolized, and stored selenium. It appears that the plants vary widely in their ability to accumulate selenium in their tissues. All species studied are able to absorb inorganic selenium and convert some or all of it into organic compounds. The majority of the plants are able to convert organic selenium into inorganic compounds. The ability of plants to absorb, metabolize, and store selenium in their tissues is important, potentially dangerous, and emphasizes the need to avoid growing food plants on soils containing selenium in an available form, since consumption of plants produced on these soils can be directly harmful to humans and livestock. Livestock consuming selenium-containing plants metabolize the selenium and some of the selenium is incorporated into milk, eggs, and meat products which are consumed by humans and other animals. Precautions should be exercised to limit, insofar as possible, the intake of selenium by humans and livestock.

Summary

All plants studied, when grown on soils containing available selenium in the selenate, selenite,

and organic form accumulated selenium in varying amounts in their tissues. Grasses varied widely in selenium-absorption efficiency. Indian ricegrass was the most efficient selenium-absorbing grass, western wheatgrass was somewhat less efficient. Common winter fat, broom snakeweed, kochia or burning bush, rabbitfoot grass, common dandelion, and yellow goatsbeard exhibited a somewhat lower selenium absorption efficiency. Alkali prince's plume contained a relatively high level of selenium which was present only in organic compounds. Tansy aster plants grown on soil containing inorganic selenium contained high levels of selenium. In general, increasing the level of soil selenium resulted in increased selenium absorption by the plant. Selenate selenium was in most instances, absorbed most efficiently, selenite somewhat less efficiently, and organic selenium absorbed to a lesser extent. However, some plants readily absorbed comparatively large amounts of organic selenium from the soil. All plants changed inorganic selenium into the organic form and in most plants the reverse process operated with varying degrees of efficiency. Plants grown on soils containing selenium in an available form should not be used for human consumption. Livestock consuming plants containing appreciable quantities of selenium are capable of metabolizing the selenium, which is harmful to them. Milk, eggs, and meat obtained from selenium-fed animals will contain selenium.

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