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Growth and Selenium Content of Wheat as Affected by Applications of Salts to Soils

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GROWTH AND SELENIUM CONTENT OF WHEAT AS AFFECTED BY APPLICATIONS OF SALTS TO SOILS

By

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This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION AND PURPOSE

For many years livestock in some areas have been subject to a certain sickness. The external symptoms of this sickness are a rough hair coat, loss of hair from the mane and tail of horses, loss of hair from the tail of cattle, and sore feet. In some extreme cases, an animal's hooves have been known to drop off. This sickness has been called "Alkali Disease", because it was believed to be caused by alkali or mineral salts in the soil or water. Later, it became known that forages and grain crops grown in those areas caused this sickness, when fed to animals. The presence of toxic amounts of selenium in the forage or grain has been determined to be the direct cause of this sickness.

The purpose of this study was to ascertain the effects of applications of sea salt and various other chemical salts to the soil on selenium uptake and yields of grain and straw of Rushmore wheat. This is one of several studies concerned with the prevention of selenium poisoning by restricting selenium uptake by plants. This author and others are searching for material which can be practically applied to the soil and which will prevent or inhibit selenium uptake in the plants to such an extent as to render the forages and grains non-toxic. This work was conducted over a period of almost two years. The work includes two phases: field experiments on naturally seleniferous Pierre clay soil at Reeds Ranch, Presho, South Dakota, and greenhouse experiments on naturally seleniferous Pierre clay soil and artificially selenized Barnes loam soil. The chemical analyses for selenium were made in the selenium laboratory at Station Biochemistry, South Dakota State College.

REVIEW OF LITERATURE

The history and review of the literature on selenium poisoning has been presented by Moxon and Rhian (21) and Trelease and Beath (30). A thorough discussion of the selenium research which had been done at South Dakota State College was prepared by Moxon (20).

In 1929, K. W. Franke (5) began a series of investigations on toxic foodstuffs which were thought to cause "Alkali Disease". His work, published in 1934, demonstrated that grain, i.e. corn, wheat, barley, or emmer, raised in certain areas of South Dakota was highly toxic to animals.

In 1931, H. G. Knight suggested that selenium might be the cause of the toxicity (30). W. O. Robinson was then furnished with samples of toxic wheat from South Dakota to be analyzed for selenium. His report (26) in 1933 stated that one sample contained 10 to 20 parts per million (ppm) of selenium, and another sample contained 5 to 6 ppm of selenium. He also found that the gluten of the toxic wheat contained 90 ppm of selenium. Franke and Painter (7) found that concentrations of less than 5 ppm of selenium in a rat's diet prevented normal growth. Byers (4) suggested a selenium tolerance of not more than 3 ppm in foodstuffs for human consumption, and Franke and Moxon (6) agreed with this suggestion.

The amount of selenium which accumulates in a plant (30) depends on the chemical form and concentration of selenium in the soil, the forms and concentrations of other substances in the soil solution (i.e. sulfates, proteins, and amino acids from plant decay), the species of plant, the stage of growth, and the physiological condition of the plant.

Olson et al. (24) found that most of the selenium occurring in the soil solution was in the selenate form, but selenite was also present. The selenium content varied considerably in plants growing relatively short distances from each other on soils derived from the same parent materials. The soluble selenium content in the soil profile usually increased from the first to the second and third foot in depth. Generally, the plants containing the higher amounts of selenium were found growing in soil where concentrations of selenium increased with depth. This work indicated that the second and third foot soil depths were more important as sources of selenium than the surface soil.

Olson and Moxon (23) presented data which indicated that the availability of selenium to plants depended largely upon the form in which it existed in the soil. Plants (wheat, corn, barley, oats, sorghum, and mustard) grown on soils with higher amounts of water-soluble selenium accumulated more selenium than the same species of plants grown on soils containing low amounts of water-soluble selenium. Water-soluble selenium appeared to be dependent on the amount of organic selenium in the soil.

Various converter plants (2) may accumulate several thousand ppm of selenium in their tissues from as little as 1 to 5 ppm of inorganic selenium in the soil. When the plant residue is returned to the soil, the selenium is returned in various forms, depending upon the species and genus of the plant. Beath and Eppson have determined the chemical forms of selenium in many plants. They found that some species of selenium converter plants (*Astragalus bisulcatus*, *A. confertiflorus*, *A. grayi*, *A. osterhouti*, *A. pattersoni*, *A. pectinatus*, *A. preussii*, *A. sabulosus*, *Stanleya bipinnata*, *S. integrifolia*, and *S. pinnata*) contained only organic selenium, about 80 percent of which was soluble in water.

Some selenium indicator plants, (Aster caerulescens, A. commutatis, A. occidentalis, Atriplex canescens, A. confertifolia, A. nuttallii, Hymenoxys floribunda, Machaeranthera ramosa, Xylorrhiza, and X. venusta), in which most of the selenium was water soluble, contained 70 percent or more of selenate selenium. Cereal grains and forages examined (barley, corn, oats, wheat, alfalfa, and sweet clover) contained only organic selenium. Several species of native grasses contained both organic and selenate selenium. The selenate selenium made up 60 percent or less of the selenium in these plants.

Hurd-Karrer (9, 10) found that selenium as sodium selenate was more toxic and available to wheat than as sodium selenite. Trelease, Greenfield, and Di Somma (32) found that corn seedlings accumulated more selenium from an Astragalus extract than from sodium selenite solutions when the selenium concentrations were equal. Also, selenium from an Astragalus extract, per unit of selenium accumulated, was less toxic than sodium selenite to corn seedlings. Trelease and Greenfield (31) demonstrated that corn seedlings grown in culture solutions accumulated much more selenium when the element was supplied as an organic extract of Astragalus bisulcatus than when supplied from a sodium selenite solution.

Beath and Eppson (2) have also shown that organic selenium from an Astragalus extract caused no injury to crop plants (barley, corn, oats, wheat, alfalfa, and sweet clover), while crop plants showed toxic effects and died when grown on the same soil with an identical selenium content added as selenate selenium.

Hurd-Karrer (15) found that Dixie winter wheat, grown on soil selenized by adding 2 ppm of selenium as sodium selenate, had a lower selenium content when grown on plots which received large applications of sulfur (1500 pounds/acre) or gypsum (7500 pounds/acre) than when grown on plots which received no treatments of sulfur or gypsum. When checked the second year for carry over effect, the reduction of selenium uptake was even more pronounced in the treated soils than during the first year.

Hurd-Karrer (9), working with wheat in culture solutions, found that sulfates reduced selenate uptake, but did not significantly reduce uptake of selenite selenium. However, with selenite, high sulfate concentrations increased the amount of selenium that accumulated in the roots as compared to the selenate form.

Hurd-Karrer (12) grew wheat in nutrient solutions containing various amounts of selenate as sodium selenate and sulfate as magnesium sulfate. She found that the selenium content of the plants increased with increasing concentrations of selenate in the nutrient solutions, at constant sulfate levels. With constant levels of selenate, the selenium content of the plants decreased with increasing concentrations of sulfate. She also grew wheat in Keyport clay loam soil, selenized by adding sodium selenate at rates of 10, 20, and 30 ppm of selenium. Additions of sulfate as gypsum, elemental sulfur, and ammonium sulfate decreased the selenium uptake by the plants.

Martin and Trelease (18), working with tobacco and soybeans grown in sand cultures and fed by nutrient solutions containing sodium selenite, found that the presence of sulfur as sulfate tended to decrease the toxic effects of the sodium selenite in the tobacco and soybeans. The amount of selenium absorbed was directly related to the selenite concentration of the nutrient solution. The sulfate in the nutrient solution tended to decrease accumulations of selenium in the plants. However, the reduction was not sufficient to prevent possible toxicity to animals.

Beath (1) fertilized soil plots heavily with green *Astragalus bisulcatus.* One plot was treated with 1.0 percent of sulfur, and wheat was then sown. The whole, mature wheat plants on soil without sulfur had 484 ppm of selenium, while the whole, mature wheat plants on soil treated with sulfur contained 845 ppm of selenium. Neither treatment showed evidence of stunting or chlorosis. Beath, Eppson, and Gilbert (3) also found that sulfates tended to increase the uptake of organic selenium by the crop.

Based on greenhouse studies using soil obtained from six seleniferous farms, Olson and Moxon (23) found no apparent relationship between the total sulfates or soluble sulfates of the soils studied and the availability of selenium to the plants grown on them.

To determine whether salts other than sulfates affect selenium absorption, Hurd-Karrer (12) grew wheat plants in soil containing 20 ppm of selenium as sodium selenate and treated with sulfate, phosphate, or nitrate salts of ammonium, calcium, potassium, or magnesium in equivalent amounts. The plants grown with the sulfates in the soil showed no apparent injury as compared to the plants grown on the control soil. All the other plants were chlorotic and stunted, with yields of grain reduced at least fifty percent. (Whether or not these treatments affected the selenium uptake is not known, since the selenium content was not published).

Trelease and Di Somma (28) found that corn seedlings grown in culture solution showed a marked increase in the accumulation of selenium from a sodium selenite solution when a water soluble extract of dried non-seleniferous string beans was added to the culture solution.

Trelease, Greenfield, and Di Somma (32) reported that the addition of proteins, protein derivatives, and amino acids to culture solutions nearly doubled the accumulation of selenium in corn seedlings. They suggested that crop plants and native grasses may accumulate more selenium when grown on soils naturally high in organic, nitrogenous substances than on soils low in such substances. Legumes plowed under in seleniferous areas in preparation of grain fields might result in a substantial increase in selenium uptake by the grain.

Beath, Eppson, and Gilbert (3) found that seleniferous weeds are sources of selenium for farm crops and may produce very toxic grains. Wheat grown on raw Steele shale, to which was added coarsely-cut green Astragalus bisulcatus, contained approximately 100 ppm of selenium in stems and leaves, heads, and roots.

Several workers have shown that selenium accumulation in a plant varies with the species of plant. Miller and Byers (19) have shown that Astragalus bisulcatus and A. racemosus contained over 1,000 ppm of selenium, while Astragalus missouriensis growing in the same area contained only 3 ppm. Williams (33) analyzed specimens of twelve different species of plants growing in the same area in a clay loam soil containing 2 ppm of selenium in Kiowa County, Colorado. The plants analyzed and their selenium content were as follows: Aplopappus fremontii (goldenweed), 320 ppm; Astragalus pectinatus, (narrowleaf milk vetch), 4,000 ppm; Bouteloua gracilis (blue grama), 2 ppm; Zea mays (corn), 10 ppm; Euphorbia sp (spurge), 10 ppm; Gutierrezia sarothrae (turpentine weed), 70 ppm; Helianthus annuus (sunflower), 2 ppm; Malvastrum coccineum (scarlet mallow), 1 ppm; Munroa squarrosa (false buffalo grass), 4 ppm; Salsola pestifer (Russian thistle), 5 ppm; Stanleya pinnata (princes plume), 330 ppm; and Xanthium sp (cocklebur), 6 ppm. These analyses demonstrated that plant species vary widely in the quantity of selenium they absorb. Olson et al. (25) found that Agropyron smithii generally had a higher selenium content than Stipa viridula when grown in the same area.

Trelease and Trelease (29) showed that Astragalus racemosus was stimulated by selenite selenium, while A. crassicarpus was injured by it.

Wide differences (14) in the absorption of selenium from sodium selenate by 19 different crop plants grown in Keyport clay loam, untreated with respect to sulfur, were directly correlated with corresponding differences in their respective sulfur absorbing capacities. Members of Cruciferae, i.e. cabbage, cauliflower, mustard, rape, and kale, had the highest percentages of both sulfur and selenium. Flax, sunflower, and legumes, except soybeans, were intermediate, while the cereals and soybeans had low percentages of sulfur and selenium. This work led Hurd-Karrer to suggest that the sulfur requirement of the plant determined its tendency to absorb selenium.

Olson et al. (25) and Moxon and Olson (22) found that the stage of growth of some plants affected their selenium content. Analysis of Agropyron smithii, Stipa comata, S. viridula, Boutelous gracilis, and B. curtipendula showed a relatively high content of selenium in young plants, which decreased slowly until the plant reached maturity, after which the decrease was quite rapid. Heliantthus sp. (sunflower) showed a relatively stable selenium content through maturity, but showed a rapid loss of selenium on drying. It was suggested that this rapid loss of selenium after maturity was due to the combined effects of leaching, volatilization, and the shedding of seeds. Beath, Eppson, and Gilbert (3) found that selenium in farm crops such as wheat, corn, oats, barley, grasses, and vegetables did not volatilize on drying. This was thought to be due to a synthesis of selenium into the proteins of these crops. These workers were also of the opinion that, as a general rule, a favorable growing season with an abundance of moisture favored selenium uptake.

MATERIALS AND METHODS

GREENHOUSE EXPERIMENTS

Soils Used

Two different soils were used. One was a naturally seleniferous Pierre clay. The other was a Barnes loam which is used in most of the greenhouse work by the Agronomy Department at South Dakota State College. The naturally seleniferous Pierre clay was obtained at Reeds Ranch, Presho, South Dakota. It was taken from the top 8 inches of the surface soil. When air dry, it was seived through a 1/4 inch mesh screen. The soil was then thoroughly mixed and sacked until it was used in the various experiments. The Barnes loam soil was also seived through a 1/4 inch mesh screen, thoroughly mixed, and sacked until ready to use. The Barnes loam soil for the final experiment, however, was taken directly from the soil bin in the greenhouse. It was nearly the same as the soil used previously, since it was obtained from the same area in the field.

Greenhouse Procedure

The experimental design of all the greenhouse experiments was a randomized block replicated four times.

All soil weights were calculated on the oven dry basis, and all treatments were calculated on an acre plow layer weight basis of 2,000,000 pounds per acre.

Selenium was added in solution to the soil. One gram each of sodium selenite and potassium selenate was accurately weighed out and dissolved in 100 milliliters (ml.) of distilled water. One ml. of the stock solution was diluted to 100 ml. A 3 ml. aliquot of the dilute solution was analyzed for selenium by the Klein (16) method. These analyses were run in duplicate, an average taken, and calculations were made to determine the amount of selenium in the stock solution. Sodium selenite was then added to some of the soil to give a concentration of 4 parts per million (ppm) of selenium. The soil to which potassium selenate was added contained 2 ppm of selenium as selenate.

The total amount (360 pounds) of soil needed for each selenium treatment was weighed out. Most of the soil was spread evenly on a large tarpaulin. Selenium in solution was accurately measured by pipette and added to approximately one half gallon of the soil. This was thoroughly mixed, added to a larger amount of soil in a corrugated metal bushel basket, and again thoroughly mixed, care being taken to crush out any lumps. This selenized soil was spread evenly over the soil on the tarpaulin and thoroughly mixed by pulling the tarpaulin back and forth, subjecting the soil to a rolling action. The soil was then divided into 45-pound lots.

The chemical compounds, except for sodium chloride and sea salt, were dissolved in distilled water and mixed into the 45-pound lots of soil by the method described above. Since considerably larger amounts of sodium chloride and sea salt were used, it was felt that thorough mixing could be obtained without putting the salt in solution. Equal amounts of the treated 45-pound lots of soil were placed in four one-gallon, glazed pots (four replications); each pot was provided with a one-half inch hole in the side near the bottom for drainage. The filled pots were moved to the greenhouse bench, and randomized according to a table of random numbers.

When all pots were filled, Rushmore wheat was planted by removing the top 1 1/2 inches of soil, placing the seed, and replacing the soil. When all pots were planted, approximately equal amounts of distilled water were applied on consecutive days until the soil at the drain holes became moist. Care was taken to prevent puddling of the soil. The plants were watered only with distilled water. Over-watering was avoided, yet care was taken that the plants did not wilt excessively. The plants were thinned to the desired number when they reached 3 to 4 inches in height, selection being made to leave the most vigorous, healthy plants. All thinned plants and weeds were returned to the top of the pot. To prevent positional effects, the pots were moved periodically.

The plants were harvested at maturity by clipping at ground level, placed in paper bags, dried in a forced draft oven at 60 degrees C. for five hours, and weighed. A hand threshing board and a seed cleaner were used to separate out the grain. The straw and chaff were combined and finely ground in a semi-micro Wiley mill and analyzed for selenium by the Klein (16) method. The unground grain was also analyzed for selenium.

FIELD EXPERIMENTS

Procedure

The experimental designs used in the two field experiments were randomized split plot designs replicated six times.

A preliminary selenium survey was made over the general area where the field experiments were intended to be put out. An area was chosen which was as uniform as possible in both selenium content and topography. This area supported a heavy growth of predominantly green needlegrass and western wheatgrass. The entire area was plowed in late September and left rough over winter. As soon as possible in the spring (April 14, 1955), the soil was disked both lengthwise and crosswise with a double disk. The salts and chemical treatments were applied on April 15 and double-disked into the soil. On April 16 Rushmore wheat was planted with a drill. The drill was set to seed 4 pecks per acre, but because of the small seed size, it was estimated that the number of seed planted approximated a planting rate of 5 pecks per acre. The wheat was harvested August 2, 1955 by mowing a strip 26 inches wide and 16 feet long from each plot.

RESULTS AND DISCUSSION

GREENHOUSE EXPERIMENTS

All plants on non-seleniferous Barnes loam soils were analyzed for selenium and some were found to contain small amounts of selenium. It was felt that these amounts would fall within the error of titration, so no selenium content is listed for plants grown on the non-seleniferous soils.

Set I: Greenhouse Experiments With Sea Salt Applications on Soils Containing Different Forms of Selenium.

These were preliminary experiments to determine what effect, if any, various amounts of sea salt applied to the soil would have on the selenium content of grain and straw of Rushmore wheat, and also to determine what level of sea salt might be applied without seriously affecting the yields. With respect to the form and the amount of selenium, essentially 4 soils were used: Barnes loam with no selenium (as a control), Barnes loam containing 2 ppm selenate selenium, Barnes loam containing 4 ppm selenite selenium, and naturally selenized Pierre clay containing 3.75 ppm of selenium. Where Barnes loam soil was used, each pot contained 4,848 grams of soil. Because the bulk density of the Pierre clay soil was less than the bulk density of the Barnes loam, only 4,210 grams of naturally selenized Pierre clay soil was used. Each soil was treated with four levels of sea salt and replicated four times. The sea salt levels were as follows: no salt as control, 0.1 percent, 0.3 percent, and 0.6 percent by weight. Calculated on the basis of 2,000,000 pounds of soil per acre, these treatments are 0, 1, 3, and 6 tons per acre, respectively. The sea salt was mixed with the soil, and the mixture was potted; the wheat was then planted and cared for by the method previously described. The wheat plants were thinned to 15 plants per pot, 7 of which were harvested at the flowering stage, while the remaining 8 were permitted to mature.

These experiments were conducted in the greenhouse in the fall of 1954. They were planted September 21, 1954 and harvested December 7, 1954. The last one-half to one-third of the growth of the plants was made under conditions of relatively low temperature and low intensity of light as compared to plants grown during a regular growing season in the field.

Yields of Grain and Straw

Yields were taken of plants harvested at the flowering stage, and of the mature straw and grain (Table 1). The general effect of applications of sea salt to the soil was to progressively decrease the yield at the 3 ton and the 6 ton per acre applications, as compared to the check (Figure 1). The decrease in yield at the higher sea salt levels was severe enough to indicate that further applications at these high salt levels would be very impractical. It was observed that plants growing in the 3 and 6 tons per acre concentrations were small, spindly, and wiry. Sodium chloride had accumulated in the mature straw to such an extent that the straw was briny to the taste.

No observable differences were noted between the control plants and plants grown with one ton per acre of sea salt; however, application of sea salt at the one ton per acre level tended to decrease yields in

Table 1. **Effect of Sea Salt on Yield and Selenium Content of Grain and Straw of Wheat Grown in the Greenhouse on Soils Containing Different Forms of Selenium.**

Soil and form of selenium	Sea Salt in tons/acre	Yield in grams/pot			Selenium content					
					ppm			ppm coded•		
		Flowering stage	Grain	Mature Straw	Flowering stage	Grain	Straw	Flowering stage	Grain	Straw
Barnes loam:	0	2.76	3.35	4.46						
No selenium	1	2.53	3.26	3.72						
	3	1.79	2.06	2.71						
	6	1.16	1.18	1.73						
F value for treatments		42.20**	30.79**	62.78**						
LSD+ at 5% level		.36	.61	.47						
Barnes loam	0	2.28	2.05	3.64	18.63	26.02	19.45	4.32	5.08	4.39
plus 2 ppm	1	2.36	2.77	3.65	23.20	25.78	20.30	4.86	5.12	4.55
selenium as	3	1.71	1.85	2.79	18.89	22.97	28.57	4.38	4.84	5.35
selenate	6	1.12	.84	1.51	25.91	33.26	28.72	5.13	5.77	5.36
F value for treatments		26.40**	127.00**	101.75**				NS[a]	NS	NS
LSD at 5% level		.36	.23	.32						
Barnes loam	0	2.41	3.29	4.35	8.11	13.18	6.19	2.94	3.68	2.59
plus 4 ppm	1	2.41	3.31	3.88	3.90	8.43	6.46	2.22	2.99	2.63
selenium as	3	1.91	2.80	3.29	6.84	7.37	6.43	2.67	2.81	2.62
selenite	6	1.17	1.05	1.66	5.59	6.68	4.36	2.46	2.68	2.21
F value for treatments		34.50**	91.40**	78.71**				NS	11.43**	NS
LSD at 5% level		.32	.36	.43					.43	
Naturally	0	1.04	1.00	1.88	.64	1.41	3.87	1.02	1.33	2.00
seleniferous	1	1.14	.99	1.82	5.24	.47	1.70	2.19	.98	1.41
Pierre clay	3	.94	.60	1.32	.62	.87	1.88	1.00	1.12	1.48
3.75 ppm selenium	6	.78	.29	1.04	2.08	1.00	2.24	1.44	1.23	1.53
F value for treatments		4.50*	23.00**	22.00**				NS	NS	NS
LSD at 5% level		.23	.23	.27						

• ppm coded by the following formula: $\sqrt{.5 + ppm}$. (This method of coding is recommended by Goulden, C. H., Methods of Statistical Analysis, John Wiley and Sons, Inc., New York, 2nd Ed., pg. 98, 1952.)

+ Least Significant Difference

a Not Significant

* Significant at the 5% level

** Significant at the 1% level

Figure 1. Growth Response of Wheat Grown in the Greenhouse on Barnes Loam Soil Treated with 0, 1, 3, and 6 tons of Sea Salt per Acre.

the non-seleniferous soil. In the selenate soil, the application of one ton of sea salt per acre increased the yield of grain, but did not affect the yield of straw, while the same treatment in the selenite soil effected a significant decrease in the yield of straw, but did not affect the yield of grain. The application of sea salt at the one ton per acre level did not appear to affect the yields on the naturally seleniferous Pierre clay. The yields of both the grain and the straw of wheat grown on naturally selenized Pierre clay were less than half the yields obtained from wheat plants grown on Barnes loam soil.

Selenium Content

The application of sea salt to the soil produced a highly significant decrease in selenium content of the grain of Rushmore wheat grown on Barnes loam soil selenized with 4 ppm of selenite selenium. The application of sea salt produced no significant differences in the selenium content of plants grown on either naturally seleniferous Pierre clay or Barnes loam containing 2 ppm of selenate selenium; but the trend, however, was for sea salt to decrease the selenium content slighly in the naturally selenized Pierre clay soil, and to increase the selenium content slightly in the selenate soil.

Set II: Greenhouse Experiment Using Commercial Fertilizers on Naturally Selenized Pierre Clay Soil.

It seemed desirable to determine the effect of commercial fertilizers, at recommended rates of application, on the yield and selenium content of straw and grain of Rushmore wheat grown on naturally selenized Pierre clay soil. The treatments were:

O = control,

N = 80 lbs. of nitrogen per acre as ammonium nitrate,

P = 80 lbs. of phosphorus pentoxide per acre as treble superphosphate, and

NP = 80 lbs. of phosphorus pentoxide as treble superphosphate plus 80 lbs. of nitrogen per acre as ammonium nitrate.

Approximately 50 seeds were planted in 8,800 grams of soil in three-gallon, glazed, porcelain pots. The plants were later thinned to 36 plants per pot. This experiment was started in the greenhouse February 8, 1955 and harvested May 15, 1955. The last half of the growing period was characterized by bright, sunny days and temperatures in the greenhouse which approached 100 degrees F. during the sunny part of the day.

Yield of Grain and Straw

The application of fertilizers gave highly significant differences in the yield of both the grain and the straw (Table 2). The application of either 80 lbs. of nitrogen or 80 lbs. of phosphorus pentoxide per acre increased the yield of both the grain and the straw by approximately 30 percent, while the application of 80 lbs. of nitrogen plus 80 lbs. of phosphorus pentoxide increased the yield of both the grain and the straw approximately 100 percent as compared to the control (Figure 2).

Selenium Content

The application of fertilizers gave differences in selenium content which were highly significant in the grain, and significant at the 5 percent level in the straw. The selenium content of the grain was decreased by approximately 65 percent with nitrogen, 25 percent with phosphorus, and

Table 2. Effect of Commercial Fertilizers on the Yield and Selenium Content of Rushmore Wheat Grown in the Greenhouse on Naturally Seleniferous Pierre Clay Soil.

Treatment	Yield in grams		Selenium content			
			ppm		ppm coded=	
	Grain	Straw	Grain	Straw	Grain	Straw
0-0-0β	10.68	15.64	4.44	1.31	2.22	1.34
80-0-0	13.75	20.85	1.63	.50	1.45	.98
0-80-0	13.40	20.71	3.28	.85	1.94	1.16
80-80-0	20.99	31.52	2.23	.54	1.66	1.02
F value for treatments	119.58**	113.75**			45.00**	5.5 *
LSD+ at 5% level	1.29	2.01			.16	.23

+ Least Significant Difference at the 5% level
* Significant at the 5% level
** Significant at the 1% level
= Refer to Table 1.
β Pounds per acre of nitrogen, phosphorus pentoxide, and potassium oxide, respectively.

50 percent with nitrogen plus phosphorus. The selenium content of the straw was decreased by approximately 60 percent with nitrogen and 60 percent with nitrogen plus phosphorus; the trend with phosphorus alone was to decrease the selenium content, but the difference was not significant as evaluated by the LSD at the 5 percent level.

Since the yields increased and the selenium content in ppm decreased with the application of fertilizer, the question arose as to whether fertilizer affected the total uptake of selenium in the wheat plants. The total selenium content in micrograms per pot was calculated by multiplying the ppm of selenium by the total weight in grams of the sample (Table 3). Since the soil in each pot contained equal amounts of selenium, it was possible that there would be as much selenium in plants

Figure 2. Response of Rushmore Wheat to Fertilizers When Grown in the Greenhouse on Naturally Seleniferous Pierre Clay Soil.
Nitrogen (N) and phospherus pentoxide (P) were each applied at the rate of 80 pounds per acre.

grown in one pot as in another. Also, if the rate of selenium uptake was constant, it would be expected that there would be a corresponding increase in the total selenium content as the yield increased. This was not the case. The application of ammonium nitrate gave a definite

Table 3. Yield and Total Selenium Content of Grain and Straw of Rushmore Wheat Grown in the Greenhouse on Naturally Selenized Pierre Clay Soil with Applications of Ammonium Nitrate and Treble Superphosphate Fertilizers.

Treatment	Yield in grams		Selenium content			
			ppm		Micrograms/pot	
	Grain	Straw	Grain	Straw	Grain	Straw
0-0-0[β]	10.68	15.64	4.44	1.31	47.42	20.49
80-0-0	13.75	20.85	1.63	.50	22.41	10.43
0-80-0	13.40	20.71	3.28	.85	43.95	17.60
80-80-0	20.99	31.52	2.23	.54	46.81	17.02

β Pounds per acre of nitrogen, phosphorus pentoxide, and potassium oxide, respectively.

reduction in total selenium content of the plants. In fact, the total uptake of selenium decreased even though the actual yield increased. When the pots treated with nitrogen were compared to the check, the total yield of grain was increased by 3.07 grams, while the total selenium in the grain decreased by 25.01 micrograms. The same general relationship held true for the straw.

Set III: Greenhouse Experiments with Applications of Chemical Salts on Artificially Selenized Barnes Loam.

The soils in this set of experiments, with respect to selenium, contained no selenium (as control), 2 ppm selenate selenium, and 4 ppm of selenite selenium. From the previous experiments, it was found desirable to have larger samples for analysis, so enough wheat seeds were planted to insure twenty plants per pot after thinning. The compounds used as treatments in the experiments were compounds containing elements which occur in sea salt in most abundance (Table 4). One ton of sea salt per acre was used as the basis for calculating the amounts of the various compounds to apply, since previous greenhouse studies showed little or no decrease in yield at that level. Nitrogen and phosphorus were applied at recommended fertilizer rates. The treatments for the three experiments were as follows:

Control — no treatment,

Sodium nitrate — 80 lbs. of nitrogen per acre,

Monobasic calcium phosphate — 80 lbs. of phosphorus pentoxide per acre,

Sodium chloride — 0.1 percent by weight (1 ton per acre),

Sea salt — 0.1 percent by weight (1 ton per acre),

Sodium sulfate — sulfur equivalent to the amount of sulfur in one ton of sea salt per acre,

Magnesium chloride — magnesium equivalent to the amount of magnesium in one ton of sea salt per acre, and

Magnesium sulfate — magnesium equivalent to the amount of magnesium in one ton of sea salt per acre.

These experiments were conducted in the greenhouse in the spring, at the same time as the experiment (Set II) using fertilizers on naturally selenized Pierre clay soil. The environmental conditions of these two experiments, as far as light and temperature are concerned, more nearly

Table 4. Elemental Analyses of Sea Salt*

ELEMENT	PARTS PER MILLION	PERCENTAGE	AMT. PER 2200 LBS. SEA SALT
Chlorine	18,980	54.23	1193.03 lbs.
Sodium	10,561	30.17	663.83 lbs.
Magnesium	1,272	3.63	79.95 lbs.
Sulfur	884	2.53	55.57 lbs.
Calcium	400	1.14	25.14 lbs.
Potassium	380	1.09	23.89 lbs.
Bromine	65	0.19	4.09 lbs.
Carbon	28	0.08	28.16 oz.
Strontium	13	0.04	13.07 oz.
Boron	4.6		4.63 oz.
Silicon	0.02 - 4.0		568.80 mg. to 4.02 oz.
Fluorine	1.4		39916.10 mg.
Nitrogen	0.01 - 0.7		279.41 mg. to 19958.05 mg.
Aluminum	0.5		13970.63 mg.
Phosphorus	0.001 - 0.10		27.94 mg. to 2794.13 mg.
Iodine	0.05	.0000015	1397.06 mg.
Arsenic	0.01 - 0.02		279.41 mg. to 568.80 mg.
Selenium	.004	0.000011	109.77 mg.

* These analytical figures were obtained from tables supplied by Dr. Maynard Murray, Loyola University, School of Medicine, 706 South Wolcott Avenue, Chicago, Illinois.

represented field conditions than the other greenhouse experiments presented in this study. The wheat was grown to maturity, and the selenium content was determined for the mature straw and grain. The data for these experiments are presented in Table 5.

Yield of Grain and Straw of Wheat Grown on Non-seleniferous Barnes Loam

The yield of grain grown on non-seleniferous Barnes loam was increased by the application of sodium chloride and sodium nitrate. All other treatments tended to increase the yield of grain as well, but the increases were not significant. The yield of straw was increased by the application of sodium nitrate and monobasic calcium phosphate. Sodium sulfate, magnesium sulfate, and magnesium chloride applications tended to increase the yield slightly, while sodium chloride and sea salt tended to produce no change and a slight decrease, respectively.

Yield and Selenium Content of Wheat Grown on Barnes Loam Containing 2 ppm of Selenate Selenium

The yield of grain grown on Barnes loam soil containing 2 ppm of selenate selenium was increased by the application of sodium chloride, sea salt, magnesium chloride, magnesium sulfate, sodium nitrate, or monobasic calcium phosphate. Sodium sulfate also tended to increase the yield of grain. The yield of straw was increased by sodium sulfate and sodium nitrate. Magnesium chloride, monobasic calcium phosphate, and magnesium sulfate tended to increase the yield of straw slightly, while sodium chloride and sea salt effected a slight decrease and no change, respectively.

The selenium content of both the grain and the straw of wheat plants

Table 5. Effect of Chemical Salts on Yield and Selenium Content of Rushmore Wheat Grown in the Greenhouse on Artificially Selenized Barnes Loam Soil.

Soil and form of selenium	Treatment	Yield in grams		Selenium content			
				ppm		ppm coded"	
		Grain	Straw	Grain	Straw	Grain	Straw
Barnes loam. No selenium	Check	10.26	13.32				
	NaCl	11.51	13.24				
	Sea salt	11.07	12.85				
	$MgCl_2$	10.75	13.93				
	Na_2SO_4	10.76	13.79				
	$MgSO_4 \cdot 7H_2O$	11.08	14.28				
	$NaNO_3$	13.01	16.28				
	$Ca(H_2PO_4)_2$	10.93	15.53				
F value for treatments		8.00**	5.94**				
LSD+ at 5% level		.85	1.44				
Barnes loam plus 2 ppm selenium as selenate	Check	10.24	13.34	32.72	31.40	5.75	5.63
	NaCl	11.34	13.04	72.50	68.27	8.54	8.28
	Sea salt	11.35	13.28	79.38	67.20	8.93	8.22
	$MgCl_2$	11.28	13.48	74.19	62.67	8.63	7.93
	Na_2SO_4	10.81	14.94	26.68	18.95	5.20	4.40
	$MgSO_4 \cdot 7H_2O$	11.16	14.52	20.18	12.08	4.54	3.53
	$NaNO_3$	11.90	15.26	67.09	56.27	8.22	7.53
	$Ca(H_2PO_4)_2$	11.14	13.94	71.45	63.01	8.48	7.96
F value for treatments		3.96**	3.67**			86.13**	75.47**
LSD at 5% level		.71	1.29			.54	.64
Barnes loam plus 4 ppm selenium as selenite	Check	10.20	14.01	19.33	6.69	4.45	2.67
	NaCl	11.37	13.42	11.18	3.05	3.41	1.63
	Sea salt	11.38	13.64	13.95	3.94	3.79	2.11
	$MgCl_2$	10.43	14.01	20.25	6.28	4.55	2.60
	Na_2SO_4	10.90	13.91	20.25	6.02	4.55	2.55
	$MgSO_4 \cdot 7H_2O$	10.43	14.20	16.57	5.19	4.13	2.38
	$NaNO_3$	12.29	16.78	25.60	8.95	5.11	3.07
	$Ca(H_2PO_4)_2$	10.70	14.77	18.90	6.34	4.40	2.61
F value for treatments		8.26**	8.22**			18.17**	2.74*
LSD at 5% level		.71	1.10			.35	.77

+ Least Significant Difference
* Significant at the 5% confidence level
** Significant at the 1% confidence level
" Refer to Table 1.

grown on selenate soil was decidedly decreased by the application of sodium and magnesium sulfate. Magnesium sulfate, for instance, depressed the uptake of selenium in the grain by 12.64 ppm when compared to the check. The addition of sodium chloride, sea salt, magnesium chloride, sodium nitrate, or monobasic calcium phosphate definitely increased the selenium uptake. A similar increase, however, did not occur in a later experiment.

Yield and Selenium Content of Wheat Grown on Barnes Loam Containing 4 ppm of Selenite Selenium

The yield of grain of wheat plants grown on Barnes loam containing 4 ppm of selenite selenium was increased by the application of sodium chloride, sea salt, and sodium nitrate; the other salts tended to increase the yields of grain slightly. The addition of sodium nitrate produced a definite increase in the yield of both grain and straw, while monobasic calcium phosphate tended to increase the yield of the straw but not the grain. Sodium chloride and sea salt had a tendency to decrease straw yields, while magnesium chloride, sodium sulfate, and magnesium sulfate treatments were essentially comparable to the check.

The selenium content of grain grown on selenite soil was decreased approximately 7 ppm by sodium chloride or sea salt, while sodium nitrate increased the selenium content by approximately the same amount when compared to the check. Sodium chloride and sea salt tended to reduce the selenium content of straw, while sodium nitrate tended to increase the selenium content. Magnesium sulfate tended to decrease the selenium content of both the grain and the straw. Little or no difference was caused by the other salts.

Set IV: Greenhouse Experiments with Applications of Chemical Salts and Commercial Fertilizers on Artificially Selenized Barnes Loam Soil.

Several of the most promising treatments affecting selenium uptake in Rushmore wheat in previous experiments were included in this greenhouse study. The effect of certain fertilizers on the selenium content of plants grown on artificially selenized Barnes loam soil was also investigated. The soils used in these experiments were: Barnes loam with no selenium (as a control), Barnes loam containing 2 ppm of selenate selenium, and Barnes loam containing 4 ppm of selenite selenium. The treatments for each soil were as follows:

Control — no treatment,

Ammonium nitrate — 80 lbs. of nitrogen per acre,

Sodium nitrate — 80 lbs. of nitrogen per acre,

Monobasic calcium phosphate — 80 lbs. of phosphorus pentoxide per acre,

Monobasic calcium phosphate plus ammonium nitrate — 80 lbs. per acre each of phosphorus pentoxide and nitrogen,

Magnesium sulfate — magnesium equivalent to the amount of magnesium in one ton of sea salt per acre,

Sodium sulfate — sulfur equivalent to the amount of sulfur in one ton of sea salt per acre, and

Sodium chloride — one ton per acre.

These experiments were started in the greenhouse in late fall. Rushmore wheat was planted October 1, 1955, but a very poor stand was obtained. Subsequently, the surface soil was thoroughly loosened to a depth of three inches, incorporating the existing vegetation into the soil. A new source of seed of Rushmore wheat was obtained and the pots were replanted on October 9, 1955. The plants were later thinned to 16 per pot, grown to maturity, and harvested January 16, 1956. Most of the growth of the plants was made under conditions of cool temperatures, cloudy days, and relatively high humidity. A variable seed set was obtained; many of the heads appeared to be sterile or were only partly filled. This condition was not consistent with any particular soil or treatment, but occurred as frequently in one soil or treatment as in any other.

Yields of Grain and Straw Grown on Non-seleniferous, Selenate, and Selenite Soils

Differences in the yield of grain in the three experiments were not significant (Table 6). This was probably due to the very poor, inconsistent seed set. The general trends, however, appeared to be a decrease in the yield of grain due to sodium chloride, and an increase with all the other treatments in the non-seleniferous and the selenate soil. Sodium chloride, magnesium sulfate, and sodium sulfate tended to decrease the yield of grain in the selenite soil, while the other treatments appeared to effect no change.

Selenium Content of Grain and Straw Grown on Selenate Soil

Magnesium and sodium sulfate decreased the selenium content of both the grain and the straw from approximately 85 to 20 ppm. This reduction in the uptake of selenate selenium due to sulfates is consistent throughout this study, and agrees with the work of Hurd-Karrer (9, 12, 15).

The selenium content of both the grain and straw was decreased

Table 6. Effects of Chemical Salts on Yield and Selenium Content of Rushmore Wheat Grown in the Greenhouse on Artificially Selenized Barnes Loam Soil.

Soil and form of selenium	Treatment	Yield in grams		Selenium content			
				ppm		ppm coded[=]	
		Grain	Straw	Grain	Straw	Grain	Straw
Barnes loam. No selenium	Check	4.77	12.24				
	NH_4NO_3	5.50	12.66				
	$Ca(H_2PO_4)_2$	4.53	12.04				
	NH_4NO_3 + $Ca(H_2PO_4)_2$	5.06	12.17				
	$NaNO_3$	4.64	11.78				
	$MgSO_4 \cdot 7H_2O$	5.65	11.61				
	Na_2SO_4	5.46	12.16				
	NaCl	4.97	10.56				
F value for treatments		NS[a]	5.45**				
LSD[+] at 5% level			.79				
Barnes loam plus 2 ppm selenium as selenate	Check	4.53	12.11	83.27	88.47	9.14	9.43
	NH_4NO_3	4.91	12.41	69.80	78.13	8.38	8.86
	$Ca(H_2PO_4)_2$	5.14	12.46	64.89	75.83	8.08	8.73
	NH_4NO_3 + $Ca(H_2PO_4)_2$	4.91	12.19	64.41	69.34	8.05	8.43
	$NaNO_3$	4.61	12.30	73.52	82.47	8.59	9.10
	$MgSO_4 \cdot 7H_2O$	5.44	11.82	17.75	16.81	4.26	4.14
	Na_2SO_4	5.12	12.46	23.39	20.95	4.88	4.62
	NaCl	4.22	10.25	63.94	79.24	8.02	8.92
F value for treatments		NS	4.87**			186.86**	149.75**
LSD at 5% level			.98			.40	.52
Barnes loam plus 4 ppm selenium as selenite	Check	5.05	11.83	19.14	11.56	4.43	3.47
	NH_4NO_3	4.92	12.15	17.19	9.48	4.20	3.16
	$Ca(H_2PO_4)_2$	5.04	12.43	15.87	10.18	4.03	3.27
	NH_4NO_3 + $Ca(H_2PO_4)_2$	5.05	11.61	17.78	9.92	4.27	3.22
	$NaNO_3$	4.97	11.86	18.22	10.63	4.32	3.33
	$MgSO_4 \cdot 7H_2O$	3.91	11.50	16.94	9.43	4.17	3.16
	Na_2SO_4	4.53	11.60	18.16	10.75	4.31	3.35
	NaCl	3.92	9.67	13.37	8.47	3.72	2.99
F value for treatments		NS	27.60**			6.67**	4.00**
LSD at 5% level			.46			.25	.21

a Not Significant
** Significant at the 1% level
+ Least Significant Difference
= Refer to Table 1.

slightly by applications of ammonium nitrate, monobasic calcium phosphate, and ammonium nitrate plus monobasic calcium phosphate. Applications of sodium nitrate and sodium chloride gave slight decreases in the selenium content of the grain, but did not give significant decreases in the straw. The trend, however, was to decrease the selenium content of the straw as compared to the check. The decreases obtained from applications of sodium chloride, sodium nitrate, and monobasic calcium phosphate in this experiment are not in accordance with the results obtained from the selenate soil in the preceding set of experiments. In fact, the results were exactly the opposite, these salts showing a decided increase in the uptake of selenate selenium by the plants in the earlier greenhouse experiment.

Selenium Content of Grain and Straw of Wheat Grown on Selenite Soil

Monobasic calcium phosphate, magnesium sulfate, and sodium chloride decreased the selenium content of the grain, while the selenium content of the straw was decreased by applications of ammonium nitrate, ammonium nitrate plus monobasic calcium phosphate, magnesium sulfate, and sodium chloride. The reduction in the uptake of selenite selenium by sodium chloride agrees with the results of the previous experiments. Other treatments tended to reduce the selenium content of the grain and the straw, but the reductions were not significant.

FIELD EXPERIMENTS

A preliminary selenium survey was made over the general area where the field experiments were to be put out. Soil samples were taken at the first, second, and third foot depths. Soil samples at sample location 6C were taken to the fifth foot in depth. Samples of green western wheatgrass were taken from an area of approximately 10 feet in diameter around the soil sample locations. The selenium content of the soil and western wheatgrass samples is presented in Table 7. The selenium content of the soil tended to increase with depth. The selenium content of the soil and the western wheatgrass varied considerably over relatively small areas. These findings agreed with work done by Olson et al. (24). The field experiment using applications of sea salt and fertilizers was placed in the vicinity of sample locations 4B and 4C. The field experiment using chemical salts and fertilizers was placed at the extreme west end of the surveyed area in the vicinity of sample locations 6A and 6B.

The weather outlook in the spring of 1955 appeared to be favorable for the growth of spring wheat. There seemed to be a fair amount of moisture in the soil from the melted snow, and a heavy rain fell the day after the wheat was planted. (According to the ranch manager and neighboring ranchers, it was estimated that about 5 inches of rain fell over a 2-day period, with the major portion falling in the relatively short time of 2 to 3 hours.) However, official precipitation records at Pierre, Vivian, and Kennebec, South Dakota for that month averaged approximately 2 inches of rain. These same 3 weather stations recorded below normal precipitation for April and July, and above normal for May and June, 1955. After a light shower about May 1, there was no rain at all until late in May when another 2 to 3 inches of rain, accompanied by a heavy hail, fell in a very short time. On May 31, just a few days after the storm, it was estimated that at least 50 percent hail damage

Table 7. Sample locations at Reeds Ranch, Presho, South Dakota

	1	2	3	4	5	6
A+	5.86*1.43	5.70* .79	7.60* .08	6.80* .75	5.62*2.06	6.02*1.98
	2.02	1.50	.55	.91	1.82	2.61
	4.63	3.21	3.48	3.41	1.78	4.32
B	7.44* .51	5.07* .00	6.49* .63	5.07*2.42	13.46*3.05	3.48*4.08
	2.81	.24	.91	3.17	3.88	4.32
	7.37	4.04	3.84	5.27	6.22	5.15
C	11.16*2.38	9.82*1.82	9.26*1.90	4.91*2.14	6.10*1.90	9.50*2.65
	2.97	1.70	3.01	3.05	2.53	2.61
	7.21	3.45	3.01	1.27	6.06	4.04
						7.76
						7.37

* Sample taken here. The number to the left of the sample area is selenium content of western wheatgrass in ppm. The number to the right indicates the ppm of selenium in the soil at the 1, 2, and 3 foot depths respectively.

\+ Each sample site was approximately 150 feet apart.

had occurred to the wheat on the experiment. There was another long, dry period until about June 20, when another very heavy rain fell, accompanied by hail. A large portion of the vegetation harvested appeared to be second growth, or shoots put out after the hail storms. About 20 counts were made before harvesting to determine the extent of hail damage. Damage was found to vary from 25 to 45 percent. The amount of damage did not appear to be consistent in plots receiving the same treatments.

The yield results and the selenium contents of the grain and straw of Rushmore wheat grown in the field on naturally selenized Pierre clay soil are recorded in Tables 8 and 9. An analysis of variance was run on the results of the experiment. The F values and the least significant differences are included in the tables. It will be noted that both the average yield and selenium content of the wheat were quite low. This was probably due to unfavorable growing conditions.

Field Experiment I: Effect of Sea Salt and Fertilizers on Yield and Selenium Content of Rushmore Wheat Grown on Pierre Clay Soil at Reeds Ranch, Presho, South Dakota.

The main plot treatments were 3 levels of sea salt which were as follows: no salt (as a control), 0.1 percent, and 0.3 percent by weight. Figured on the basis of 2,000,000 pounds of soil per acre, these treatments were 0, 1, and 3 tons of sea salt per acre, respectively. Within each sea salt treatment there were 3 fertility levels; they were: no fertilizer (as a control), 80 pounds of nitrogen as ammonium nitrate, and 80 pounds of nitrogen as ammonium nitrate plus 80 pounds of phosphorus pentoxide as treble superphosphate.

Most of the significance in the experiment, as is indicated by the F values in Table 6, occurred because no vegetation was produced on the plots treated with 3 tons of sea salt per acre. Early in the season, while there was an abundance of moisture available, no difference was observable between the 3-ton treatment, and the check or the one ton per acre treatments. After the first period of drouth, however, the soil which received the 3-ton per acre treatment was bare of vegetation except for one or two sunflower plants. The application of one ton of sea salt per acre also tended to decrease the yields of grain and straw (Figure 3), while the application of fertilizers tended to increase the yields. The greatest increase occurred when nitrogen and phosphorus were applied together.

The application of either sea salt or fertilizers, or both, had no significant effect on the selenium content of either the grain or the straw, although there was a trend toward a slight decrease due to the application of sea salt.

Field Experiment II: Effect of Chemical Salts and Fertilizers on Yield and Selenium Content of Rushmore Wheat Grown on Naturally Seleniferous Pierre Clay Soil at Reeds Ranch, Presho, South Dakota, 1955.

The treatments of the major plots were as follows:

Control -- no treatment,

Sodium sulfate -- sulfur equivalent to the amount of sulfur in one ton of sea salt per acre,

Magnesium sulfate -- magnesium equivalent to the amount of magnesium in one ton of sea salt per acre,

Table 8. Effect of Sea Salt and Fertilizer on Yield and Selenium Content of Rushmore Wheat Grown on Naturally Seleniferous Pierre Clay Soil at Reeds Ranch, Presho, South Dakota in 1955.

Salt Treatment	Fertilizer	Yield[β] Grain in bu./A	Yield[β] Straw in lbs./A	Selenium content ppm Grain	Selenium content ppm Straw	Selenium content ppm coded[=] Grain	Selenium content ppm coded[=] Straw
Control	0-0-0["]	2.99	929	4.15	2.40	2.13	1.69
	80-0-0	6.78	1616	4.50	2.55	2.22	1.74
	80-80-0	7.29	1675	4.07	2.24	2.13	1.65
	Average	5.69	1407	4.24	2.40	2.16	1.69
1 ton/A	0-0-0	2.69	896	3.12	1.80	1.97	1.50
	80-0-0	3.53	1095	3.73	2.21	2.04	1.62
	80-80-0	5.04	1387	3.69	2.21	2.04	1.64
	Average	3.75	1126	3.51	2.07	2.02	1.59
3 ton/A	0-0-0	.10	1.0				
	80-0-0	.10	1.0	NO	STAND	NO	STAND
	80-80-0	.10	1.0				
	Average	.10	1.0				
Averages of fertilizer levels	0-0-0	1.93	609	3.64	2.10	2.05	1.60
	80-0-0	3.47	904	4.12	2.38	2.13	1.68
	80-80-0	4.14	1021	3.88	2.23	2.09	1.65
F value for fertilizer levels x treatments		11.21**	11.68**			NS[α]	NS
F value for salt treatments		101.26**	134.61**			NS	NS
LSD[+] at 5% level		1.54	350				
F value for fertilizer levels		28.30**	32.43**			NS	NS
LSD at 5% level		1.06	186				

+ Least Significant Difference
** Significant at the 1% level
β Grain yield coded by adding 0.1, and straw yield coded by adding 1.0 to each entry.
α Not Significant
= Refer to Table 1.
" Pounds per acre of nitrogen, phosphorus pentoxide, and potassium oxide, respectively.

Figure 3. Growth Response of Wheat to Treatments of 0, 1, and 3 tons of Sea Salt per Acre, Field Experiment I at Reeds Ranch, Presho, South Dakota, 1955.
The denuded area in the background represents the three ton per acre application.

Sodium chloride — one ton per acre,

Sea salt — one ton per acre, and

Phosphate — 80 pounds of phosphorus pentoxide per acre as treble superphosphate.

Within each major treatment there were three fertility levels; these were: no fertilizer (as a control), 80 pounds of nitrogen as ammonium nitrate, and 80 pounds of phosphorus pentoxide as treble superphosphate.

The application of 80 pounds of nitrogen per acre had no effect on the yield of grain in this experiment (Table 9), but 80 pounds of nitrogen in combination with 80 or 160 pounds of phosphorus pentoxide per acre tended to increase the yields of both grain and straw (Figure 4), although the increases were not significant. Nitrogen alone tended to increase the yield of the straw. Sodium sulfate or magnesium sulfate had little or no effect on the yield of grain or straw, while sodium chloride and sea salt tended to decrease yields.

The application of fertilizers had no definite effect on selenium uptake. There was, however, a trend toward a very slight decrease from the use of sodium sulfate, magnesium sulfate, sodium chloride, or sea salt. Phosphate applications tended to cause very slight increases as compared to the controls. The greatest reduction in selenium uptake in grain occurred in plots which had applications of sodium or magnesium sulfate used in combination with both nitrogen and phosphate. The greatest decrease in selenium content of the straw occurred in plots with applications of sodium sulfate plus nitrogen, and magnesium sulfate plus nitrogen and phosphate.

The results of the field experiments are perhaps somewhat un-

Table 9. Effect of Various Chemical Salts and Fertilizers on Yield and Selenium Content of Rushmore Wheat Grown on Naturally Seleniferous Pierre Clay Soil at Reeds Ranch, Presho, South Dakota in 1955.

Treatment	Fertilizer	Yield		Selenium content			
		Grain in	Straw in	ppm		ppm coded=	
		bu./A	lbs./A	Grain	Straw	Grain	Straw
Control	0-0-0"	5.53	1219	2.50	1.36	1.72	1.41
	80-0-0	4.97	1204	2.31	1.02	1.66	1.24
	80-80-0	6.86	1554	2.00	1.23	1.57	1.31
	Average	5.79	1326	2.27	1.20	1.65	1.32
Sodium sulfate	0-0-0	5.73	1161	1.96	1.16	1.56	1.29
	80-0-0	5.04	1155	2.02	.63	1.49	1.05
	80-80-0	7.07	1535	1.09	1.28	1.26	1.28
	Average	5.95	1284	1.69	1.02	1.44	1.21
Magnesium sulfate	0-0-0	6.01	1189	1.62	.88	1.43	1.17
	80-0-0	5.69	1397	1.87	.80	1.49	1.14
	80-80-0	6.65	1481	.84	.67	1.15	1.08
	Average	6.12	1356	1.44	.78	1.36	1.13
Sodium chloride	0-0-0	4.57	933	2.31	1.14	1.65	1.29
	80-0-0	4.59	1160	1.91	1.11	1.52	1.28
	80-80-0	5.20	1150	2.07	1.20	1.58	1.31
	Average	4.79	1081	2.10	1.15	1.58	1.29
Sea salt	0-0-0	4.17	936	1.67	.91	1.44	1.18
	80-0-0	4.21	1019	1.62	.91	1.44	1.19
	80-80-0	4.61	1198	1.70	1.03	1.48	1.23
	Average	4.33	1051	1.66	.95	1.45	1.20
Phosphate as T.S.P.β	0-0-0	6.12	1348	3.62	1.38	2.01	1.35
	80-0-0	7.27	1622	2.38	2.52	1.69	1.62
	80-80-0	7.52	1636	2.55	1.70	1.72	1.46
	Average	6.97	1535	2.85	1.87	1.81	1.48
Averages of fertilizer levels	0-0-0	5.36	1131	2.28	1.14	1.64	1.28
	80-0-0	5.30	1260	2.02	1.17	1.55	1.25
	80-80-0	6.32	1426	1.71	1.19	1.46	1.28
F value for fertilizer levels x treatments		NS	NS			NS	NS
F value for treatments		11.54**	12.10**			3.77*	4.00**
LSD+ at 5% level		1.42	264			.41	.31
F value for fertilizer levels		11.99**	20.58**			5.40*	NSα
LSD at 5% level		1.15	226			.28	

" Pounds per acre of nitrogen, phosphorus pentoxide, and potassium oxide, respectively.

β 80 pounds of phosphorus pentoxide per acre as treble superphosphate.

* Significant at the 5% level

** Significant at the 1% level

\+ Least Significant Difference

= Refer to Table 1.

α Not Significant

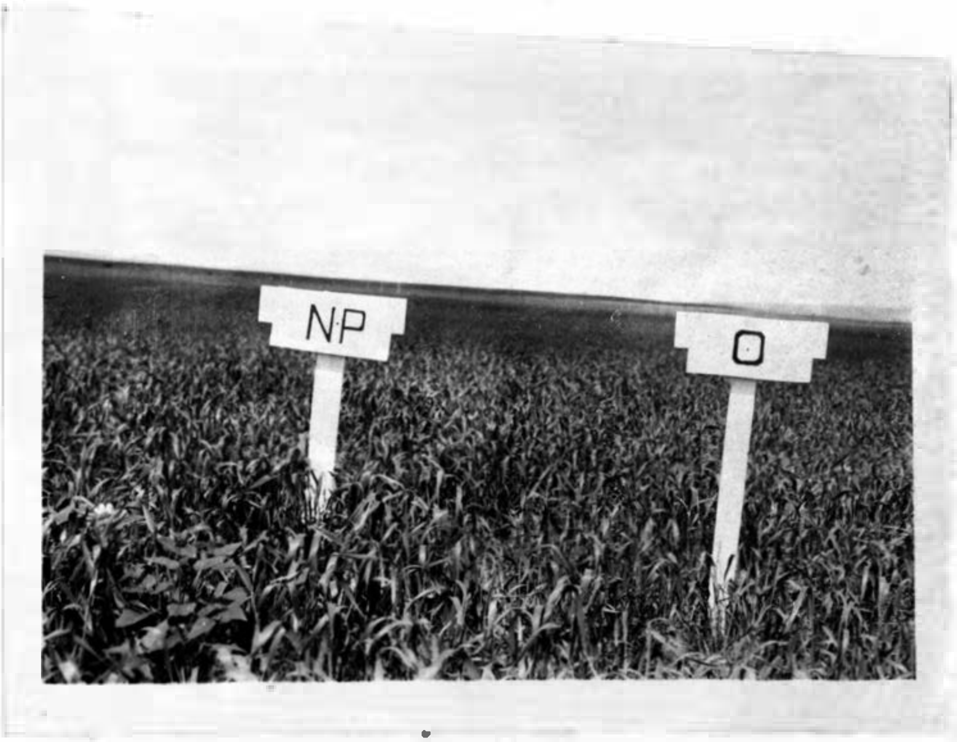

Figure 4. Response of Wheat to 80 lbs. of Nitrogen plus 80 lbs. of phosphorus Pentoxide per acre, Field Experiment II at Reeds Ranch, Presho, South Dakota, 1955.

reliable due to the very unfavorable growing season this past year (1955), and to the variations in selenium content of the soil over very short distances within the experimental area.

DISCUSSION

The form of selenium, at the concentrations used in this study, i.e. 2 ppm as selenate and 4 ppm as selenite, appeared to have little or no effect on the yield of grain or straw. The concentrations of selenium in the soil were low and no visible traces of stunting or chlorosis, as described by Hurd-Karrer (13), were apparent. The form of selenium in the soil, however, did have a very definite effect on the amount of selenium taken up by the plant. In the greenhouse study, Rushmore wheat plants grown on soil containing 2 ppm of selenate selenium accumulated approximately twice as much selenium as wheat plants grown on soil containing 4 ppm of selenite selenium. These results agree with the work of Hurd-Karrer (9, 10, 13), who found that selenate selenium was more toxic and available to wheat than was selenite selenium.

The application of sodium and magnesium sulfate only tended to reduce the amount of selenium accumulated by wheat grown in the field on naturally seleniferous Pierre clay soil, but in the greenhouse studies, the application of these same sulfates caused a significant reduction in the amount of selenium accumulated by wheat grown on Barnes loam soil containing 2 ppm of selenate selenium. Magnesium sulfate consistently reduced the selenium content of wheat plants grown on selenate soil more than did sodium sulfate. This difference was very likely due to the fact that approximately twice as much sulfur was applied as magnesium sulfate than was applied as sodium sulfate. The soil contained approximately 25 ppm of sulfur as sodium sulfate as compared to approximately 48 ppm of sulfur as magnesium sulfate. Neither sodium nor magnesium sulfate had more than a slight effect, if any, on the amount of selenium accumulated in the wheat plants grown on selenite soil. These results are also in agreement with the results obtained by Hurd-Karrer (9, 12, 15). She found that wheat grown on a soil containing selenate selenium had a lower selenium content when the soil was treated with large applications of sulfur, gypsum, or ammonium sulfate than when the soil was untreated. When working with wheat in culture solutions, Hurd-Karrer found that sulfates reduced the uptake of selenate, but not of selenite selenium. She also found that with constant levels of selenate, the selenium content of wheat plants decreased with increasing concentrations of sulfate.

The application of sodium or magnesium sulfate had little or no effect, however, on the yields of wheat grown in the greenhouse or in the field.

In the greenhouse, sea salt and sodium chloride at the 0.3 and the 0.6 percent concentrations inhibited the growth of the wheat, thereby reducing the yields of both grain and straw. There was little or no difference between the yield of wheat grown on the control soil and the yield of wheat grown on soil treated with either sea salt or sodium chloride at the 0.1 percent level. According to Sir E. J. Russell (27), a 1.0 percent concentration of salt will prevent growth of most crop plants, and a 0.5 percent concentration will inhibit plant growth. In the field experiments where quite lengthy periods without rain were prevalent, the yields of wheat were reduced severely at the 0.1 percent level, and all vegetation, except a few sunflower plants, was completely killed off at the 0.3 percent concentration of sea salt.

The application of either sea salt or sodium chloride to the soil containing 4 ppm of selenite selenium resulted in a substantial reduction in the amount of selenium accumulated by the plants. This reduction was consistent in all of the greenhouse experiments. Sea salt and sodium chloride also tended to reduce the selenium uptake in the field experiments.

There appears to be an inconsistency in the results of the action of sodium chloride, sodium nitrate, and monobasic calcium phosphate on the uptake of selenate selenium in Sets III and IV of the greenhouse experiments. In Set III these salts gave a definite increase in selenium content, while a significant decrease resulted in Set IV. The selenium content of the control plants grown on the selenate soil in Set IV was approximately 85 ppm, while the control plants in Set III contained only approximately 30 ppm. The value for the selenium content of the selenate control in Set III corresponds very closely to the selenate control value in Set I. The selenium content of plants grown with treatments of sodium chloride, sodium nitrate, monobasic calcium phosphate, sodium sulfate, and magnesium sulfate correlated very closely in both experiments. It should be noted, however, that the decrease due to sulfates in the selenate soil in Set III was not nearly so pronounced as was the decrease in Set IV. The increase or decrease in selenium content of the wheat plants in response to the treatments apparently was caused by the differences in the selenium content of the controls of the two experiments (Set III and Set IV).

These differences may have been due to the soil used, variation in growing conditions in the greenhouse, or some bacteriological factor, or a combination of various things. The soil used in the experiments in Sets

I and III was the same. It was taken from the soil bin the same day, screened, sacked, and stored until used. The soil used in Set IV was taken from the soil bin a year later, just after a new supply had been brought in. The experiments in Set III were grown in the greenhouse during the spring. The growing conditions were characterized by warm temperatures and bright, sunny days as compared to cool temperatures, dark, dreary days, and high humidity of the fall growing conditions of Set IV. Oral communications with Dr. E. C. Berry, Professor of Bacteriology at South Dakota State College, suggest that the difference in the selenate controls may be caused by some form of bacteria which has the ability to make selenate selenium more available in one environment as compared to another.

Fertilizer salts tended to increase yields in both the greenhouse and field studies. The greatest response to fertilizer occurred in the greenhouse on naturally selenized Pierre clay soil. Both ammonium nitrate and treble superphosphate gave substantial increases in yield, but the two used in combination with each other approximately doubled the yield.

The application of ammonium nitrate to naturally seleniferous Pierre clay soil resulted in a substantial reduction in the amount of selenium accumulated by wheat plants grown in the greenhouse. Ammonium nitrate, however, had little or no effect on the amount of selenium accumulated by wheat grown in the field on naturally seleniferous Pierre clay soil. This lack of response in selenium uptake may have been due to the form (inorganic selenate and selenite, and organic complexes) of selenium present in the soil, or to the very poor growing conditions in the field this past summer (1955). Also, since the roots of the wheat plants extend considerably deeper than the surface soil, and the selenium content of the soil increases with depth in the root zone, it is possible that greater effects due to treatments and fertilizers may occur within the next few years, after the treatments have leached to lower depths in the profile.

In all experiments, except the experiments with selenate soil, the grain consistently accumulated more selenium than the straw. Approximately equal amounts of selenium were accumulated in the grain and straw of mature wheat plants grown on Barnes loam selenized with 2 ppm of selenate selenium.

SUMMARY AND CONCLUSIONS

Experiments were conducted in the greenhouse in 1954 and 1955, and in the field in the summer of 1955, to determine what effects, if any, the application of sea salt and various chemical salts to the soil would have on the selenium content and the yield of Rushmore wheat plants grown on this soil. The soils used were naturally seleniferous Pierre clay obtained from Reeds Ranch, Presho, South Dakota, and Barnes loam obtained at Brookings, South Dakota. Experiments were conducted with Barnes loam containing no selenium (as a control), Barnes loam with 2 ppm of selenium added as potassium selenate, and Barnes loam with 4 ppm of selenium added as sodium selenite.

Applications of sea salt and sodium chloride depressed yields of wheat. They had little or no effect on the uptake of selenium by plants, except in Barnes loam soil containing 4 ppm of selenite selenium, where both sea salt and sodium chloride significantly decreased the selenium content.

The use of commercial fertilizers tended to increase the yields of wheat grown in the field and in the greenhouse. Fertilizers had little or no effect on the uptake of selenium by wheat, except in wheat grown in the greenhouse on naturally seleniferous Pierre clay soil. On this soil, applications of ammonium nitrate resulted in a decided reduction in selenium content of the grain and straw of wheat.

Sodium and magnesium sulfate decreased the amount of selenium accumulated by plants grown on selenate soil, but had little or no effect on the amount of selenium accumulated by plants grown on selenite soil.

The application of sulfates appeared to have little or no effect on the yield of wheat.

The grain of wheat, grown on naturally selenized Pierre clay in both the field and the greenhouse, and grown in the greenhouse on Barnes loam containing 4 ppm of selenite selenium, contained higher concentrations of selenium than did the straw. The grain and straw of wheat grown in the greenhouse on Barnes loam containing 2 ppm of selenate selenium accumulated approximately equal amounts of selenium in ppm.

Rushmore wheat plants accumulated higher concentrations of selenium when grown on Barnes loam containing 2 ppm of selenate selenium than when grown on Barnes loam containing 4 ppm of selenite selenium.

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