UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

UPTAKE AND PHYSIOLOGICAL ANTAGONISM OF SELENIUM AND SULFUR IN ALFALFA AND WHEAT UNDER FIELD CONDITIONS, SAN JOAQUIN VALLEY, CALIFORNIA

By

R.C. Severson,* L.P. Gough,* J.G. Crock,*
D.L. Fey,* P.L. Hageman,* A.H. Love,* and T.R. Peacock*

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*U.S. Geological Survey, DFC, Box 25046, MS 973, Denver, CO 80225

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INTRODUCTION

The San Joaquin Valley (SJV) in California (fig. 1) is a highly productive irrigated agricultural area. Irrigation drain water from part of the valley was transported to Kesterson Reservoir via the San Luis Drain. Evaporative concentration at Kesterson Reservoir resulted in the accumulation of selenium in biota which resulted in deformities of wildfowl using the area (Ohlendorf, 1989). The distribution of selenium and other elements in soils of the SJV (Tidball and others, 1989b), in ground water (Deverel and Gallanthine, 1989), and in wildlife (Ohlendorf, 1989) has been documented.

The naturally high levels of Se in some soils of the SJV is of agricultural interest because of its possible uptake by vegetation and introduction into grazing animals and the human food chain. Several studies have been published based on laboratory and field-plot evaluations of sulfur-selenium antagonisms in agricultural crops (Hurd-Warner, 1934; Mikkelsen and others, 1988; Wan and others, 1988; and Westermann and Robbins, 1974). These studies show, in general, that by increasing the plant uptake of sulfur selenium uptake by plants is decreased. Little work has been done in the SJV to evaluate this potential antagonism between selenium and sulfur uptake in agricultural crops under field conditions.

The soils of the SJV are derived from sediments from two main sources. The soils on the east side of the valley represent sediments derived mostly from the granitic Sierra Nevada Mountains, and tend to be low in soluble salts and trace elements as compared to soils on the west side of the valley. The soils on the west side of the valley are derived from marine and non-marine Tertiary and Cretaceous sediments from the Diablo Range. These western soils tend to be enriched in selenium, soluble salts, and trace elements. Tidball and others (1989b) have prepared maps showing the distribution of selenium, mercury, arsenic, and sulfur for soils of the entire SJV and at a more refined scale for the Panoche Fan, which is located in the west-central part of the valley (fig. 1). Interpretative maps, based on factor analysis of geochemical data for soils, are presented for the Panoche Fan by Tidball and others (1989a).

METHODS

Field Methods

Study Site Selection

Using multivariate analysis of total element concentrations in Panoche Fan soils, Tidball and others (1989a) identified five element associations (factors) that describe the soil geochemistry. The five factors are summarized as follows: Factor-1, elements representing a felsic source material; Factor-2, elements derived from serpentine rocks; Factor-3, selenium and sulfur negatively associated with sodium; Factor-4, alkaline-earth elements associated with carbon and sulfur; and Factor-5, carbon associated with mercury. Maps showing the landscape distribution of scores for Factor-3 and Factor-4 (figs. 9-5 and 9-6 in Tidball and others, 1989a) were used to define the sampling locations for the present study. Areas with high factor scores (95-100th percentile), moderate scores (50-70th percentile), and low scores (0-10th percentile) were identified

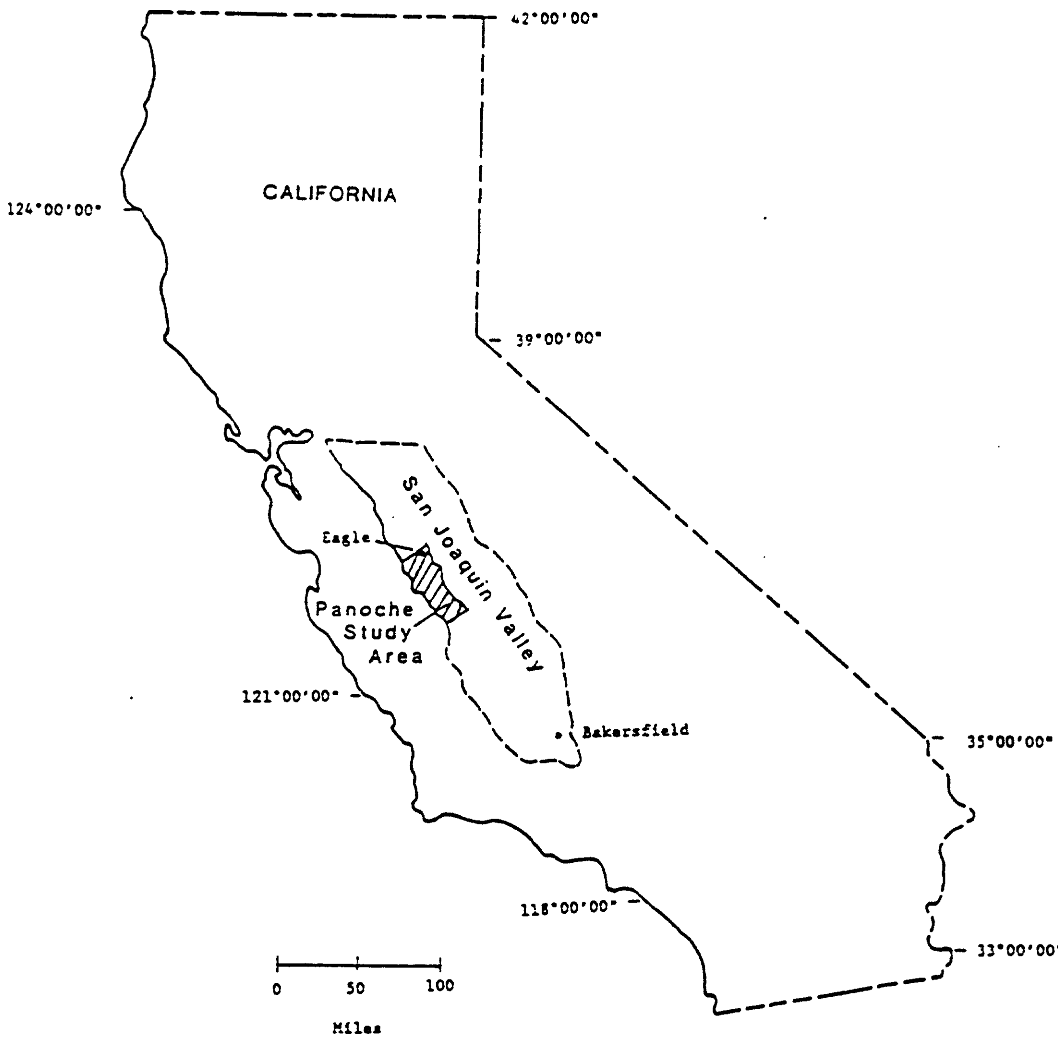

Figure 1. The location of the study area.

for both Factor-3 and Factor-4. Areas were considered for sampling where all possible combinations of high, moderate, and low scores overlapped for Factor-3 and Factor-4. Areas with each of the nine possible combinations were visited, and potential sampling sites were fields planted in either alfalfa (*Medicago sativa* L.) or wheat (*Triticum aestivum* L.). Wheat was located at five of the nine, and alfalfa at eight of the nine areas representing all possible combinations of factor scores (fig. 2).

Figure 2. The presence of wheat and (or) alfalfa fields at areas with various combinations of soil geochemistry factor levels.

		Factor 4		
		Low	Moderate	High
Factor 3	High	--- Alfalfa	Wheat Alfalfa	Wheat Alfalfa
	Moderate	Wheat Alfalfa	Wheat Alfalfa	--- ---
	Low	--- Alfalfa	Wheat Alfalfa	--- Alfalfa

At each of the sampling sites (fig. 3) a traverse was made along one edge of the field and samples of soils and plants were collected from five locations spaced equidistant apart, depending on the length of the field. Plant and soil samples were collected in close proximity to each other at each of the five locations. All sampling was done between June 15 and June 24, 1987.

Soil Sampling

Soil samples were collected using a hand-powered, stainless-steel auger with a 3.5-inch diameter barrel. The soil sample at each location consisted of a 1-kg composite of soil material from the soil surface to a depth of 100 cm. The soils ranged in texture from sandy loam to clay loam and all samples were estimated to contain less than one percent coarse (>2 cm) fragments.

Plant Sampling

Samples of both alfalfa and wheat were collected using stainless-steel shears. Samples of alfalfa consisted of the terminal 20-30 cm of green stems and leaves from plants at five positions within 1.5 meters of the soil sampling location. Two seed-alfalfa and six forage-alfalfa fields were sampled. Seed-alfalfa fields, unlike forage alfalfa, are allowed to grow and flower extensively before harvest. Samples of seed alfalfa, therefore, consisted of many flower heads and care was taken in the laboratory to remove the flower heads before

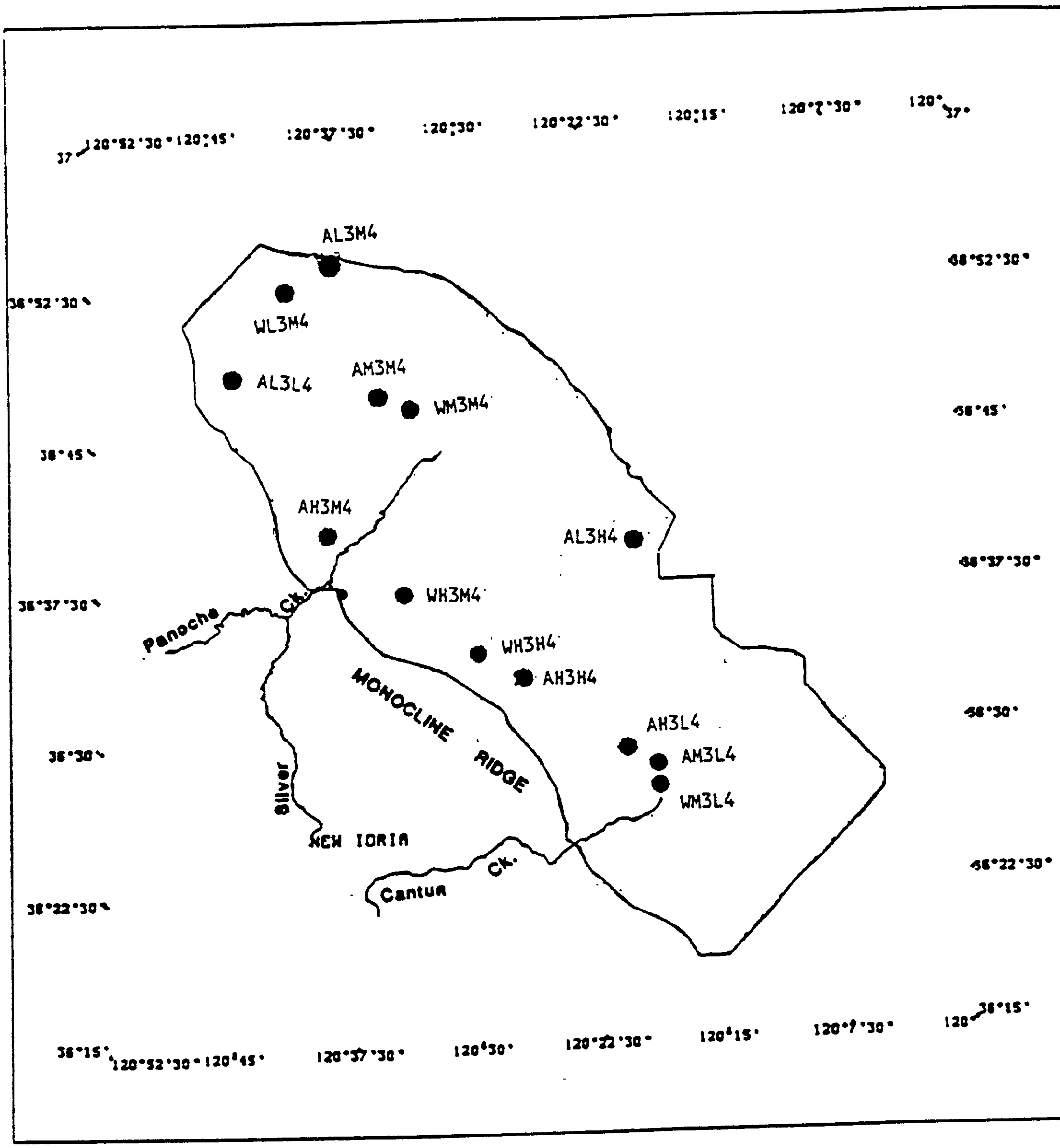

Figure 3. Sampling sites in the Panoche Fan area of the San Joaquin Valley, California.

grinding. All samples were placed in cloth Hubco bags and allowed to air-dry in order to prevent the development of mildew. Although only a few alfalfa varieties are preferentially planted, there was no attempt to identify them, which, according to J. Steiner (Agronomist, California State University-Fresno, Fresno, California) is very difficult to do in the field.

Wheat-grain samples were collected along transects with the same sampling interval as for alfalfa and soil. At all sampling locations the wheat heads were thrashed by hand rubbing and a rough separation of grain from chaff was made. One representative sample of wheat straw was taken at each sampling location; these consisted of a composite of dry culms and leaves clipped 10 cm above the ground with the grain heads removed. Samples of wheat were collected within about 3 m of the soil sampling site. All samples were placed in Hubco cloth bags.

Most wheat planted in the SJV is hard-red wheat, either Yecora Rojo or Anza varieties. The wheat is planted in the same manner as a winter wheat but these varieties are technically spring wheats because the seeds do not require vernalization in order to germinate. Varietal selection is based on resistance to aphid susceptibility, which is the most serious pest problem.

Laboratory Methods

Soil Sample Preparation for Analysis

Soil samples were dried under forced air at ambient temperature. The air-dry samples were disaggregated in a mechanical mortar and pestle and the minus 2-mm fraction saved. A split of the minus 2-mm material was ground to minus 80 mesh in a ceramic plate grinder and this material was used for total chemical analysis. The unground, minus 2-mm material was used for water-extractable chemical analysis.

Plant Sample Preparation for Analysis

Alfalfa was removed from the bags, placed in Teflon beakers, submerged and rinsed in deionized water, and drained. This process was repeated three times. The material was then placed on stainless steel colanders, rinsed briefly with deionized water, and allowed to drip drain. Colanders were then placed directly into ovens and the material was dried for 24 hrs at about 40 °C. In the laboratory, the wheat chaff was removed from the grain sample using a dockage separator. Both alfalfa and wheat grain samples were ground in a Wiley mill to pass a 2-mm sieve. Reagent blanks, soil and plant reference materials (using both U.S. Geological Survey and National Institute for Standards and Technology reference materials), and sample replicates were all digested by the same procedure and analyzed at the same time as the samples.

Inductively Coupled Plasma Spectrometry

Samples were analyzed for 39 elements using inductively coupled plasma-atomic emission spectrometry (ICP-AES). Each soil sample (0.200 g) and plant sample (0.100 g of plant ash) was dissolved using a low-temperature (<150 °C) digestion with concentrated hydrochloric, hydrofluoric, nitric, and perchloric acids (Crock and others, 1983). The acidic sample solution was taken to dryness and the residue was dissolved with 1 mL of aqua regia and then diluted to 10.0 g with 1% v/v HNO_3. The elements determined and their determination limits are shown in table 1. The elements Ag, Au, Bi, Cd, Eu, Ho, Sn, Ta, and U were below detection in all soil samples; elements below detection in all alfalfa and wheat samples were Ag, Au, Be, Bi, Cd, Cd, Eu, Ga, Ho, Nd, Pb, Sn, Ta, Th, Ti, U, Y, and Yb. In addition, Hg, La, Sc, and V were below detection in all wheat samples. The relative standard deviation (RSD) for replicate determinations of the samples for most elements is five percent or less.

Continuous Flow Hydride Generation Atomic Absorption Spectroscopy

Selenium in soils and plants was determined by continuous flow hydride generation atomic absorption spectroscopy (HGAAS) (Briggs and Crock, 1986; Sanzolone and Chao, 1987). A 0.25 gram of soil sample was digested with nitric, perchloric, and hydrofluoric acids. After digestion, the sample was diluted to 50 mL with 6<u>N</u> HCl. Selenium was determined independently using specifically designed continuous flow systems. In the procedure, the sample solution was reacted with sodium borohydride in order to generate the gaseous hydrides which were swept into the heated quartz furnace of an atomic absorption spectrometer. Selenium was determined using an aqueous standard calibration curve. Determination limits for selenium is shown in table 1. The RSD for the determination of Se was about ten percent.

The determination of selenium in vegetation by HGAAS also followed Briggs and Crock (1986), and Sanzolone and Chao (1987). A 1.00 gram plant sample was digested with nitric and perchloric acids and 30 percent hydrogen peroxide. After digestion, the clear solution was diluted to 50 mL with 6 <u>N</u> HCL. Selenium was then determined in the same fashion as for soil. An in-house standard alfalfa sample and a National Institute for Standards and Technology standard Citrus Leaves were carried through the entire procedure. Unfortunately, both the standards and the majority of the samples were below the detection limit of 0.05 parts per million.

Miscellaneous Determinations

Total carbon in soils and total sulfur in both soil and dry plant material was determined by combustion infrared photometry (Jackson and others, 1988). Carbonate C was determined by coulometric titration of acid-evolved CO_2 (Engleman and others, 1985). Organic C was determined as the difference between total and carbonate C.

Percent ash yield for plant samples was determined gravimetically following ashing at 450 °C.

Mercury in soil was determined using an automated continuous flow cold vapor atomic absorption spectroscopic method (Kennedy and Crock, 1987). A 0.100 g sample was digested with nitric acid and sodium dichromate in a closed teflon bottle and then diluted to 12 mL with deionized water. The solution was reduced with a sulfuric acid-hydroxylamine hydrochloride solution and stannous chloride

Table 1.--Approximate limits of determination for pH and elements reported

Analytical method	Medium	Determination limit	Variables
Continuous flow hydride generation	Soil	0.1 ppm	Se
		3.0 ppb	Extractable Se
	Plant	0.05 ppm	Se
Induction coupled plasma	Soil and Plant[1,2]	2.0 ppm	Ag, Cd, Eu, La, Li, Mo, Ni, Sc, Sr, V, Y, Zn
		0.005 %	Al, Ca, Fe, Mg, Na, P, Ti
		0.05%	K
		1.0 ppm	Ba, Be, Co, Cr, Cu, Yb
		4.0 ppm	Ce, Ga, Ho, Mn, Nb, Nd, Pb, Th,
		8.0 ppm	Au
		10 ppm	Bi
		10 ppm	Sn
		40 ppm	Ta
		100 ppm	U
		0.1 ppm	Extractable B
Gravimetric	Plant	0.01 %	Ash
Continuous flow cold vapor	Soil and Plant	0.02 ppm	Hg
Infrared detection	Soil	0.01 %	Total C, Total S
	Plant	0.01 %	Total S
Titration	Soil	0.01 %	Carbonate C
By difference	Soil	0.01 %	Organic C
Electrode	Soil	0.1 units	pH
Ion chromatograph	Soil	0.01 me/L	Extractable Cl
		1.0 me/L	Extractable SO_4
Conductivity cell	Soil	10 umhos/cm	Specific conductance

[1] Determined on plant ash.

[2] Sample mass for plants was one-half that for soils, so determination limits are twice those listed for soils.

solution in a continuous flow system. The gaseous mercury was separated in a phase separator and swept into a quartz cell of an atomic absorption spectrometer. Mercury was determined using an aqueous standard calibration curve.

A standard 1:1 (20 g soil to 20 g demineralized-deionized water) slurry was made and the solution pH measured using a standard pH meter calibrated with pH 7 and pH 10 buffer solutions (Crock and Severson, 1980).

Water-extractable Se, SO_4, Cl, B, and specific conductance in soils were obtained using a 1:5 soil:water suspension. Soil (5 gm) and deionized water (25 gm) were shaken in a 2 ounce polypropylene bottle for 4 hours. The sample solution was separated from the soil by centrifuging at 15,000 rpm for 10 minutes. Selenium was determined by HGAAS as described above. Chloride and SO_4 were determined using an ion chromatograph. Boron was determined by ICP-AES as described above. Specific conductance was determined by a conductivity cell.

All laboratory data for soil, alfalfa tissue, wheat grain, and wheat straw are reported in appendix tables A1-A5.

Statistical Techniques

A precaution was taken to convert any systematic error, which might occur in either sampling or analysis, into random error. This was accomplished by analyzing all samples (original and duplicate samples) in a randomized sequence so that samples collected in the field to represent some geographic progression would not be analyzed in that same progression.

Statistical analyses require completely numeric data sets. Some elements were reported as being below the limit of determination (censored) of the analytical method (table 1). These elements are identified in tables 2 through 5 as having detection ratios of <1:1. Where more than 20 percent of the determinations were below detection, summary statistics are presented but the element is omitted from any further interpretation. When some, but less than 20 percent, of the reported values were below determination the censored values were replaced with arbitrary values equal to 70 percent of their determination limit. The replacement values are justified because their small number neither alters the statistical tests nor affects the interpretation of the data. For the elements with censored distributions, the geometric means and deviations were estimated by the technique of Cohen (1959) for singly truncated distributions.

Data reported by the analyst for plant material on an ash-weight basis were converted to dry-weight equivalents and then transformed to logarithms prior to statistical analysis. Because ash yield varies (Appendix tables A3 and A4), the conversion from an ash-weight base to a dry-weight base produces variable lower limit of determination (LLD) values for elements with censoring. The mean and deviation estimation of Cohen (1959), however, can not handle variable LLD values. A single LLD was created using a procedure that adjusts the variable LLD values to a common value based on a procedure that produces the fewest overall changes in the data in order to make that adjustment.

Table 2. Summary statistics for the concentration of elements in soil samples collected from alfalfa fields in the San Joaquin Valley

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Variable, unit of measure	Detection ratio	Geometric mean	Geometric deviation	Observed range
pH, std.[1]	49:49	7.8[2]	0.194[2]	7.5 - 8.3
Al, %	49:49	7.6	1.11	5.9 - 9.0
B-extr., ppm	49:49	5.0	4.17	0.8 - 68
Ba, ppm	49:49	900	1.27	440 - 1700
Be, ppm	49:49	1.4	1.42	1.0 - 2.0
C-carbonate, %	49:49	0.13	1.79	0.03 - 0.31
C-organic, %	49:49	0.52	1.46	0.26 - 0.95
C-total, %	49:49	0.67	1.39	0.4 - 1.19
Ca, %	49:49	2.0	1.27	1.4 - 3.3
Ce, ppm	49:49	45	1.12	33 52
Cl-extr., me/L	49:49	18	3.68	3.0 - 180
Co, ppm	49:49	15	1.21	10 - 19
Cond., umhos/cm	49:49	1200	3.78	170 - 7800
Cr, ppm	49:49	130	1.47	52 - 300
Cu, ppm	49:49	35	1.25	19 - 50
Fe, %	49:49	3.6	1.16	2.7 - 4.6
Ga, ppm	49:49	17	1.14	13 - 21
Hg, ppm	34:49	0.025	2.00	<0.02 - 0.18
K, %	49:49	1.9	1.12	1.5 - 2.3
La, ppm	49:49	26	1.10	20 - 30
Li, ppm	49:49	58	1.35	31 - 81
Mg, %	49:49	1.6	1.45	0.92 - 3.0
Mn, ppm	49:49	550	1.25	310 - 710
Mo, ppm	14:49	1.5	1.62	<2.0 - 4.0
Na, %	49:49	1.3	1.17	0.96 - 1.7
Nb, ppm	47:49	7.1	1.34	<4 - 16
Nd, ppm	49:49	22	1.11	16 - 26
Ni, ppm	49:49	80	1.62	30 - 180
P, %	49:49	0.073	1.35	0.04 - 0.12
Pb, ppm	49:49	16	1.18	11 - 23
S-total, %	36:49	0.17	5.27	<0.05 - 1.5
Sc, ppm	49:49	13	1.20	8 - 17
Se-total, ppm	49:49	0.87	1.95	0.2 - 2.5
Se-extr., ppb	48:49	12	2.64	<3.0 - 110
SO_4, me/L	49:49	350	12.0	9.0 - 4700
Sr, ppm	49:49	250	1.21	190 - 430
Th, ppm	49:49	11	1.23	7 - 15
Ti, %	49:49	0.33	1.12	0.25 - 0.39
V, ppm	49:49	120	1.25	67 - 160
Y, ppm	49:49	16	1.10	12 - 19
Yb, ppm	49:49	1.9	1.15	1 - 2
Zn, ppm	49:49	100	1.19	65 - 130

[1] Measured in standard units

[2] Arithmetic mean and standard deviation

Table 3. Summary statistics for the concentration of elements in soil samples collected from wheat fields in the San Joaquin Valley

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed]

Variable, unit of measure	Detection ratio	Geometric mean	Geometric deviation	Observed range
pH, std.[1]	33:33	7.8[2]	0.216[2]	7.5 - 8.1
Al, %	33:33	7.4	1.10	6.3 - 9.0
B-extr., ppm	33:33	2.2	1.57	1.2 - 9.2
Ba, ppm	33:33	820	1.36	250 - 1400
Be, ppm	33:33	1.2	1.38	1.0 - 2.0
C-carbonate, %	33:33	0.16	1.41	0.09 - 0.30
C-organic, %	33:33	0.47	1.36	0.28 - 0.86
C-total, %	33:33	0.64	1.32	0.4 - 1.19
Ca, %	33:33	1.9	1.25	1.3 - 3.6
Ce, ppm	33:33	41	1.13	33 - 53
Cl-extr., me/L	33:33	7.2	1.95	2.0 - 23
Co, ppm	33:33	14	1.26	9.0 - 19
Cond., umhos/cm	33:33	530	2.94	170 - 2800
Cr, ppm	33:33	130	1.31	70 - 170
Cu, ppm	33:33	33	1.31	21 - 51
Fe, %	33:33	3.5	1.19	2.6 - 4.6
Ga, ppm	33:33	17	1.14	13 - 21
Hg, ppm	20:33	0.024	2.19	<0.02 - 0.08
K, %	33:33	1.9	1.12	1.5 - 2.3
La, ppm	33:33	25	1.11	20 - 31
Li, ppm	33:33	51	1.24	36 - 79
Mg, %	33:33	1.3	1.33	0.8 - 1.8
Mn, ppm	33:33	500	1.33	330 - 740
Mo, ppm	8:33	1.5	1.61	<2.0 - 3.0
Na, %	33:33	1.2	1.20	0.91 - 1.5
Nb, ppm	33:33	6.6	1.23	4 - 13
Nd, ppm	33:33	21	1.12	17 - 26
Ni, ppm	33:33	76	1.49	37 - 140
P, %	33:33	0.069	1.33	0.04 - 0.12
Pb, ppm	33:33	15	1.16	11 - 19
S-total, %	21:33	0.79	4.77	<0.05 - 1.4
Sc, ppm	33:33	12	1.25	9 - 17
Se-total, ppm	33:33	1.1	2.00	0.3 - 2.5
Se-extr., ppb	33:33	11	2.41	3.0 - 58
SO_4, me/L	33:33	110	8.43	10 - 2700
Sr, ppm	33:33	230	1.13	190 - 300
Th, ppm	33:33	9.9	1.24	6 - 15
Ti, %	33:33	0.31	1.15	0.23 - 0.43
V, ppm	33:33	120	1.24	77 - 160
Y, ppm	33:33	16	1.16	11 - 19
Yb, ppm	33:33	1.8	1.29	1 - 2
Zn, ppm	33:33	100	1.20	75 - 140

[1] Measured in standard units

[2] Arithmetic mean and standard deviation

Table 4. Summary statistics for the concentration of elements in alfalfa tissue collected from fields in the San Joaquin Valley

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed; -.-, Not determined]

Variable, unit of measure	Detection ratio	Geometric mean	Geometric deviation	Observed range
Ash, %	49:49	11.5	1.24	8.2 - 16.9
Al, %	49:49	0.016	1.55	0.008 - 0.043
Ba, ppm	49:49	19	2.55	3.1 - 63
Ca, %	49:49	1.1	1.25	1.1 - 2.7
Co, ppm	49:49	0.52	1.55	0.25 - 1.6
Cr, ppm	49:49	0.61	1.43	0.28 - 1.4
Cu, ppm	49:49	13	1.24	8.7 - 22
Fe, %	49:49	0.017	1.34	0.011 - 0.031
Hg, ppm	47:49	0.031	1.63	<0.01 - 0.14
K, %	49:49	3.5	1.36	2.1 - 5.5
La, ppm	46:49	0.67	1.29	0.45 - 1.0
Li, ppm	49:49	2.4	1.28	1.5 - 4.7
Mg, %	49:49	0.33	1.21	0.23 - 0.46
Mn, ppm	49:49	44	1.27	28 - 69
Mo, ppm	49:49	4.2	1.63	0.87 - 9.6
Na, %	49:49	0.089	2.24	0.21 - 0.34
Ni, ppm	49:49	2.9	1.652	0.98 - 6.8
P, %	49:49	0.47	1.29	0.27 - 0.82
S-total, %	49:49	0.50	1.23	0.37 - 1.5
Sc, ppm	4:49	-.-	-.-	<0.62 - 0.73
Se, ppm	49:49	0.37	2.05	0.04 - 1.1
Sr, ppm	49:49	130	1.42	64 - 260
V, ppm	3:49	-.-	-.-	<0.68 - 0.85
Zn, ppm	49:49	38	1.27	21 - 65

Table 5. Summary statistics for the concentration of elements in wheat grain collected from fields in the San Joaquin Valley

[Detection ratio, number of samples in which the element was found in measurable concentrations relative to the number of samples analyzed; -.-, Not determined]

Variable, unit of measure	Detection ratio	Geometric mean	Geometric deviation	Observed range
Ash, %	32:32	1.7	1.12	1.1 - 2.0
Al, %	32:32	0.00067	1.70	0.0003 - 0.0022
Ba, ppm	32:32	4.7	1.24	3.2 - 6.7
Ca, %	32:32	0.048	1.16	0.036 - 0.064
Co, ppm	31:32	0.60	1.41	<0.028 - 0.12
Cr, ppm	32:32	0.27	1.20	0.18 - 0.41
Cu, ppm	32:32	4.6	1.32	3.3 - 13
Fe, %	32:32	0.0036	1.44	0.002 - 0.010
K, %	32:32	0.42	1.12	0.34 - 0.53
Li, ppm	7:32	-.-	-.-	<0.08 - 0.14
Mg, %	32:32	0.11	1.11	0.091 - 0.14
Mn, ppm	32:32	50	1.22	36 - 90
Mo, ppm	32:32	0.60	1.34	0.40 - 1.3
Na, %	32:32	0.0020	1.46	0.0011 - 0.0040
Ni, ppm	32:32	0.50	1.85	0.17 - 1.5
P, %	32:32	0.40	1.13	0.26 - 0.48
S-total, %	32:32	0.18	1.11	0.15 - 0.22
Se, ppm	32:32	0.18	2.15	0.03 - 0.56
Sr, ppm	32:32	3.6	1.40	2.1 - 7.0
Zn, ppm	32:32	34	1.30	22 - 57

DISCUSSION

Factor Analysis and Selenium-Sulfur Antagonism

Based on the previous discussion of factor analysis for total element composition of soils in the west-central part of the San Joaquin Valley, we would expect the samples of soil collected in this study to display the following trends (fig. 4):

Figure 4. Expected relationships between concentrations of elements in soil samples and various combinations of factor levels.

	Factor 4: Low	Factor 4: Moderate	Factor 4: High
Factor 3: High	High Se, S Low Ca, C, Sr, (S)	High Se, S Mod. Ca, C, Sr, (S)	High Se, S, Ca, C, Sr
Factor 3: Moderate	Mod. Se, S Low Ca, C, Sr, (S)	Mod. Se, S Ca, C, Sr	Mod. Se, S High Ca, C, Sr, (S)
Factor 3: Low	Low Se, S Ca, C, Sr	Low Se, S Mod. Ca, C, Sr, (S)	Low Se, S High Ca, C Sr, (S)

Factor-3 and Factor-4 both contained sulfur; however its loading on Factor-3 was slightly higher (Tidball and others, 1989a), so its assignment in the above diagram is with both factors (it appears in parenthesis for Factor-4).

The average composition (based on five replicate samples) of soils collected at locations where alfalfa was sampled are as follows for total C, Ca, and S (expressed in percent), and Se and Sr (expressed in parts per million):

These data for total element concentration in soils, in general, follow the trends expected based on the factor analysis for C, Ca, Se, and Sr. The trends for S are, however, more closely related to Factor-4 than to Factor-3. This is not unusual because the factor loadings for S on factors 3 and 4 were nearly the same.

Table 6. Mean concentration, arranged by levels of Factors 3 and 4, for selected elements in soil samples collected at locations where alfalfa was sampled

			Factor 4		
			Low	Moderate	High
Factor 3	High	C	0.66	0.53	0.53
		Ca	1.48	1.71	2.51
		S	0.05	0.17	0.74
		Se	1.22	0.88	2.32
		Sr	222	269	300
	Moderate	C	0.61	1.05	-.-
		Ca	1.55	1.90	-.-
		S	<0.05	0.19	-.-
		Se	0.96	1.17	-.-
		Sr	222	216	-.-
	Low	C	0.47	0.77	0.99
		Ca	1.62	2.27	2.86
		S	<0.05	0.98	1.00
		Se	0.40	0.90	0.28
		Sr	196	242	358

The average composition (based on five replicate samples) of alfalfa are as follows for S (percent dry-weight) and Se (parts per million dry-weight):

These data exhibit no trends in S content in alfalfa tissue in relation to various combinations of factor levels. At the high level of Factor-3, alfalfa Se content increases with increases in levels of Factor-4, but show no trends with other combinations of factor levels. The trends in S and Se content in alfalfa tissue with factor levels should not be the same as for soils if there is a plant Se-S antagonism as has been reported in the literature (see the Introduction). Soils high in Se with varying amounts of S should show the modifying effects of any Se-S antagonism on Se uptake by plants. This relationship is difficult to visualize from the data in the two preceding tables. The triaxial plot (fig. 5) of total Se in soil (X-axis), total S in soil (Y-axis), and Se content of alfalfa (Z-axis) aids in visualizing any Se-S antagonism in Se uptake by alfalfa as related to total S and Se content in soil. This plot was constructed based on 40 individual data points (five replications at each of the eight factor combinations). The slope of the surface suggests that as both soil Se and S increase, alfalfa uptake of Se increases rapidly at intermediate concentrations of soil Se and then the rate of Se uptake by alfalfa decreases at high levels of soil S. At both low and high levels of soil Se, plant uptake of Se is nearly constant or increases slowly as soil S increases. At low levels of soil Se, alfalfa uptake of Se may me affected more by supply of Se than antagonism by soil S. However, the decrease in the rate of Se uptake by alfalfa at intermediate and high soil Se levels may represent a Se-S antagonism, but it may also reflect other soil-plant uptake processes. Under controlled greenhouse conditions, the conclusive demonstration of Se-S antagonism is possible. Under uncontrolled field conditions, the measured plant response may or may not be related to Se-S antagonism.

Table 7. Mean concentration, arranged by levels of Factors 3 and 4, for selenium and sulfur in alfalfa samples

			Factor 4		
			Low	Moderate	High
Factor 3	High	S	0.52	0.46	0.55
		Se	0.26	0.42	0.89
	Moderate	S	0.72	0.39	-.-
		Se	0.36	0.34	-.-
	Low	S	0.61	0.51	0.44
		Se	0.16	0.79	0.25

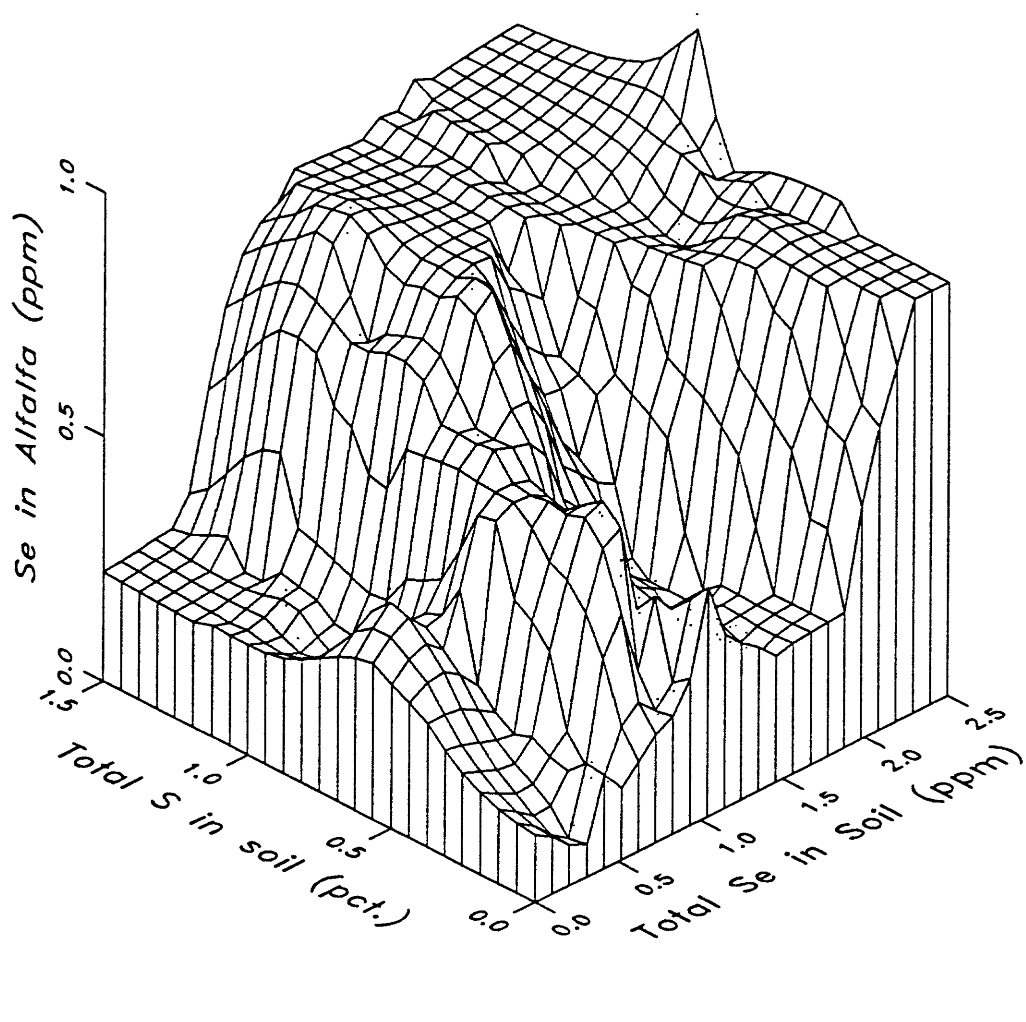

Figure 5. The relationship between selenium in alfalfa and total selenium and sulfur in soil.

The average composition (based on five replicate samples) of soils collected at locations where wheat was sampled are as follows for total C, Ca, and S (expressed in percent), and Se and Sr (expressed in parts per million):

These limited data for total element concentration in soils, in general, follow the trends expected based on the factor analysis for all elements presented.

Table 8.--Mean concentration, arranged by levels of Factors 3 and 4, for selected elements in soil samples collected at locations where wheat was sampled.

			Factor 4		
			Low	Moderate	High
Factor 3	High	C	-.-	0.62	0.59
		Ca	-.-	2.21	2.38
		S	-.-	0.47	0.47
		Se	-.-	1.51	2.17
		Sr	-.-	237	274
	Moderate	C	0.49	1.00	-.-
		Ca	1.47	1.86	-.-
		S	<0.05	0.06	-.-
		Se	1.10	1.36	-.-
		Sr	223	211	-.-
	Low	C	-.-	0.62	-.-
		Ca	-.-	1.77	-.-
		S	-.-	<0.05	-.-
		Se	-.-	0.31	-.-
		Sr	-.-	194	-.-

The average composition (based on five replicate samples) of wheat are as follows for S (percent dry-weight) and Se (parts per million dry-weight):

The S content in wheat grain exhibits a small range and does not show any trends in concentration in relation to the combinations of factor levels. The maximum Se values were measured at the moderate levels of Factor-3. At the high levels of Factor-3, Se content in wheat grain increases slightly with increasing levels of Factor-4. These data suggest there is a Se-S antagonism because the soils with highest Se and S concentration (high level of Factor-3) contain less Se in wheat grain than wheat on soils with moderate concentration of Se and low concentrations of S (moderate level of Factor-3). A triaxial plot (fig. 6), similar to that for alfalfa, is used to illustrate this relationship. This plot was constructed based on 25 individual data points (five replications at each of the five factor combinations). The plot shows that as both Se and S increase in soils, Se in wheat grain reaches a plateau at intermediate soil concentrations of Se and S, and then decreases at the highest concentrations of Se and S in soil. The plot suggests a Se-S antagonism for wheat, although, precautions for interpreting this plot as a conclusive demonstration of Se-S antagonism are the same as were stated for alfalfa previously.

Table 9.--Mean concentration, arranged by levels of Factors 3 and 4, for selenium and sulfur in wheat samples.

			Factor 4		
			Low	Moderate	High
Factor 3	High	S	-.-	0.16	0.19
		Se	-.-	0.17	0.25
	Moderate	S	0.16	0.19	-.-
		Se	0.38	0.37	-.-
	Low	S	-.-	0.17	-.-
		Se	-.-	0.07	-.-

Predicting Selenium in Plants from Soil Geochemistry

Multiple-linear regression between Se in plant tissue (alfalfa tissue or wheat grain) and total concentrations of C, Ca, S, Se and Sr in soils (Factor-3 and Factor-4 elements) was applied to the data from the present study. The following prediction equations resulted from this analysis:

Alfalfa Se = 0.064 -0.30 C +0.52 S +0.26 Se -0.0018 Sr
Wheat Se = 0.45 -0.22 Ca +0.17 Se

The first equation accounts for 72.0 percent of the variability in Se content in alfalfa tissue, the dependent variable. Partial correlation coefficients for the independent variables in the alfalfa equation were -0.40 for C, 0.70 for S, 0.71 for Se, and -0.42 for Sr. The second equation accounts for 39.6 percent of the variability in Se content in wheat grain, the dependent variable. Partial correlation coefficients for the independent variables in the wheat equation were -0.57 for Ca and 0.60 for Se.

The soil samples were analyzed for forms of carbon (organic, inorganic, and total), pH, and water-soluble S as SO_4 and Se. When these additional independent variables were entered into multiple-linear regression between Se in plant tissue (alfalfa tissue or wheat grain) and total concentrations of C, Ca, S, Se and Sr in soils the following prediction equations were generated:

Alfalfa Se = 1.31 -1.19 Carbonate C -0.13 pH +0.22 Total Se +0.000081 SO_4
Wheat Se = -2.66 +0.96 Carbonate C -0.29 Organic C +0.34 pH -0.31 Total S +0.21 Total Se +0.0028 Water-soluble Se

The first equation accounts for 74.7 percent of the variability in Se content in alfalfa tissue, the dependent variable, and partial correlation coefficients for the independent variables were -0.47 for carbonate C, -0.13 for pH, 0.62 for total Se, and 0.66 for SO_4. The second equation accounts for 63.5 percent of the variability in Se content in wheat grain, the dependent variable, and partial correlation coefficients for the independent variables were 0.46 for carbonate C, -0.36 for organic C, 0.44 for pH, -0.50 for total S, 0.71 for total Se, and 0.31 for water-soluble Se.

The prediction equations for alfalfa using total or water-soluble soil constituents are nearly the same (72.0 versus 74.7 percent) in the amount of variation in the dependent variable that each equation explains. Adding water-soluble soil constituents to the prediction equation for wheat grain increases the amount of variation in the dependent variable explained from 39.6 to 63.5 percent. Either prediction equation, using total alone or total plus water-soluble soil constituents, would result in a reliable estimate of Se content in alfalfa tissue. Selenium content of wheat grain could best be predicted by using the equation based on water-soluble plus total soil constituents. The prediction equation for Se content of wheat grain based only on total soil constituents would not be reliable because it explains only a small proportion of the variation.

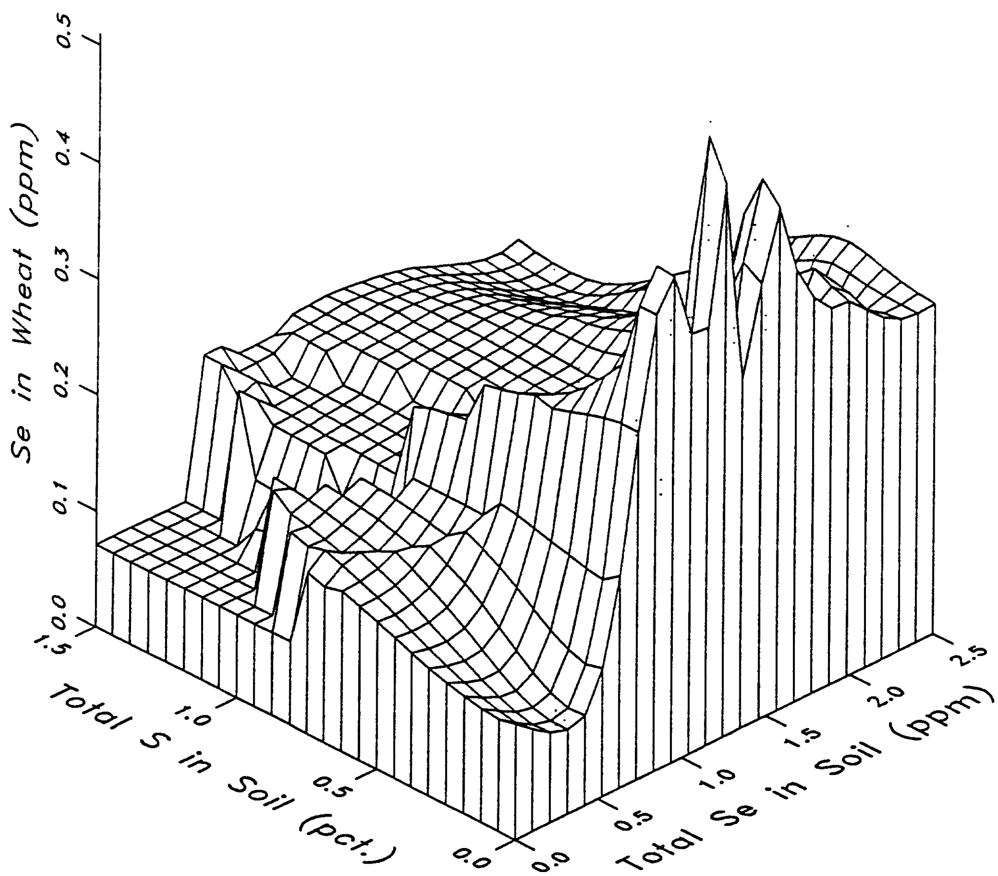

Figure 6. The relationship between selenium in wheat and total selenium and sulfur in soil.

The factor analysis of Tidball and others (1989a) was based on total element analysis of 721 soil samples collected on a one-mile grid. We applied the prediction equation for alfalfa, based on total element analysis, using each of the individual 721 soil samples. Thus, 721 predicted values for Se content of alfalfa tissue were generated and 20 of these, or 2.8 percent, were negative and ranged from -0.02 to -1.15 ppm. These negative values were replaced by small positive values (0.05 ppm was used as the replacement value). The 721 predicted alfalfa Se values then ranged from 0.001 to 2.1 ppm with a geometric mean of 0.37 ppm. The predicted geometric mean is the same as the computed geometric mean for the samples of alfalfa collected in the present study (table 4). The observed range in Se in alfalfa (table 4) is smaller than the predicted range, but is not unrealistic for Se concentrations in alfalfa tissue. A triaxial plot (fig. 7) of total Se (X-axis), total S (Y-axis), and predicted Se in alfalfa tissue (Z-axis) shows the same general patterns as for the triaxial plots presented previously for alfalfa and wheat. The plot shows that as total Se and S in soil increase, the predicted Se content in alfalfa increases rapidly until moderate levels of soil Se and S are reached, then the Se content in alfalfa approaches a plateau and decreases slightly at high levels of Se and S in soil. This plateau at moderate soil Se and S levels and slight decrease at high soil Se and S levels may indicate a Se-S antagonism in uptake of Se by alfalfa.

Prediction of Se content of wheat grain based on the factor analysis data set was not done because such a prediction would not provide reliable estimates. More reliable estimates for Se in wheat grain could be obtained using the water-soluble plus total element content of soils, but no water-soluble element determinations were made on the 721 soil samples used by Tidball and others (1989a) for the factor analysis.

Predicted Spatial Distribution of Selenium in Alfalfa

The predicted Se content of alfalfa, based on the 721 soil samples used for factor analysis, is plotted (fig. 8) to show the spatial distribution in the expected Se values throughout the study area. The contours, representing predicted Se content in alfalfa tissue, were constructed using an inverse-distance-squared algorithm with averaging of the four nearest neighboring values.

Studies (summarized by Erdman and others, 1990) suggest that selenium concentrations in alfalfa above 4.0 ppm are potentially hazardous to livestock when consumed over long periods of time, while concentrations below 0.1 ppm do not meet minimal dietary needs to prevent white muscle disease. The contour lines of predicted values for selenium concentration in alfalfa range from 0.1 to 1.6 ppm (fig. 8). Most of the areas with the highest predicted selenium values correspond to the areas where total selenium in soil was the highest (Tidball and others, 1989b, fig. 5). The exceptions are the two small areas along the central and southern part of the eastern border of the study area where predicted selenium in alfalfa exceed 1.0 and 1.6 ppm. Total soil selenium in these two areas was very low (Tidball and others, 1989b, fig. 5), however total soil sulfur was near the maximum values reported (Tidball and others, 1989b, fig. 10). A small single area where predicted selenium in alfalfa is less than 0.1 ppm occurs along the central part of the eastern border of the study area and adjacent to an area of predicted high selenium in alfalfa. The soil geochemistry of this area is characterized as having minimum amounts of selenium and sulfur

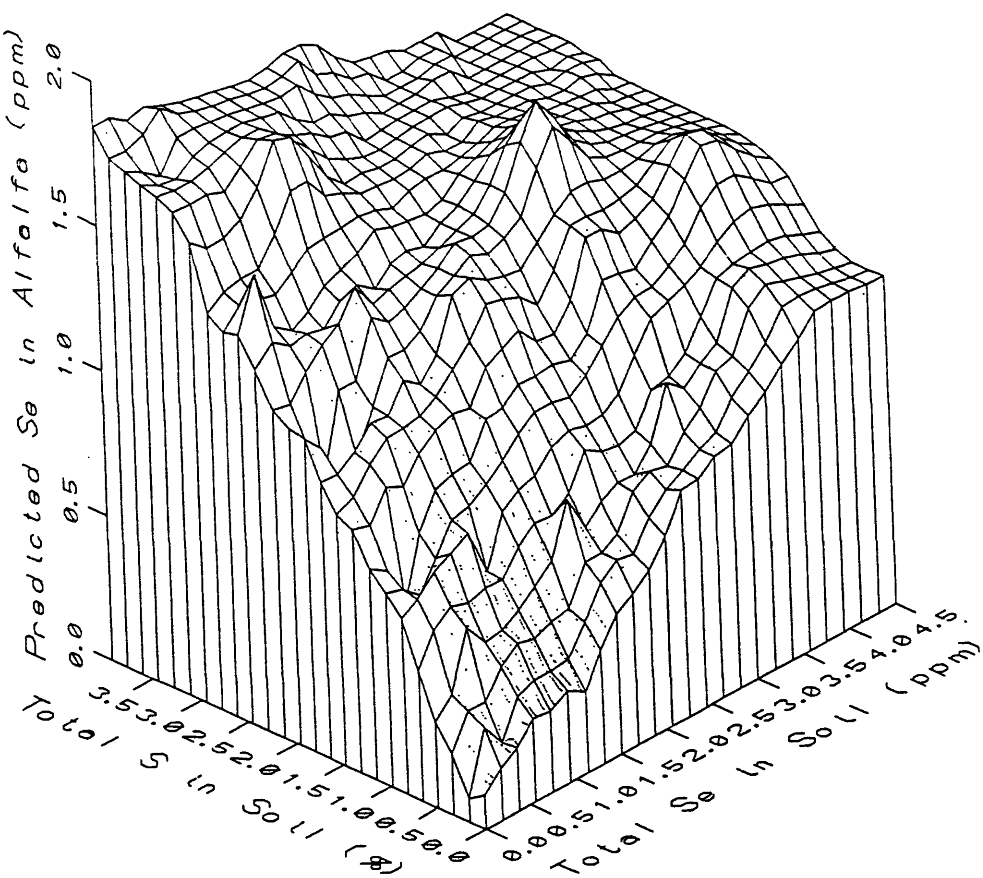

Figure 7. The relationship between predicted selenium in alfalfa and total selenium and sulfur in soil from the Panoche Fan Area of the San Joaquin Valley.

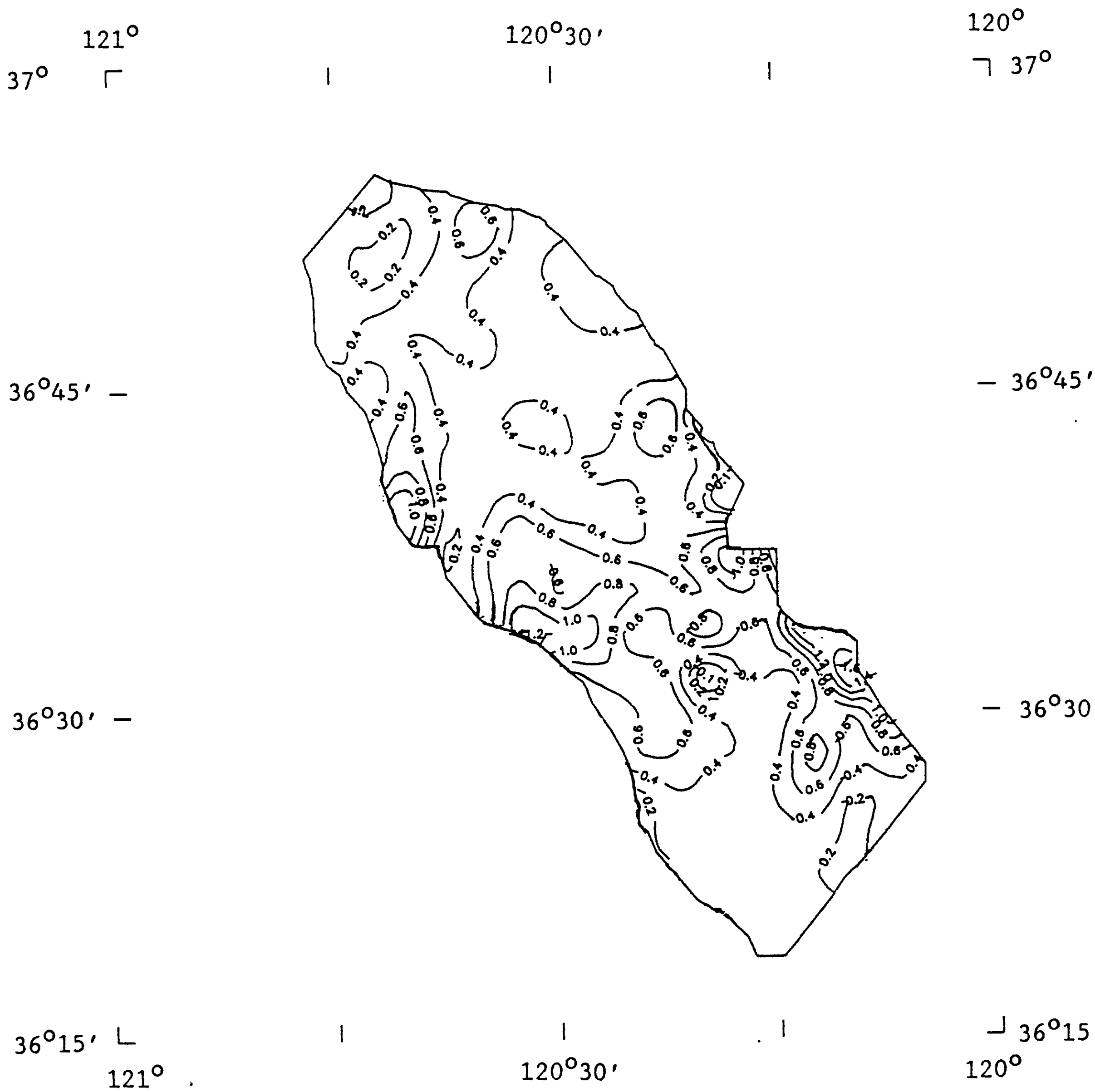

Figure 8. Spatial distribution of selenium concentration in alfalfa for the Panoche Fan Area of the San Joaquin Valley as estimated from multiple linear regression analysis.

(Tidball and others, 1989b, figs. 5 and 10). Another area with predicted Se in alfalfa of less than 0.1 ppm occurs in the south-central part of the study area. The soil geochemistry of this area is characterized as having moderate amounts of Se and high amounts of S (Tidball and others, 1989b, figs. 5 and 10). These areas may produce alfalfa that does not meet minimum dietary needs of selenium to prevent white muscle disease, while the remainder of the study area is within a range that is predicted to produce alfalfa with neither selenium deficiency nor toxicity when consumed by livestock.

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Explanation of Appendix Tables

The Sample ID is coded as follows:

The first character identifies alfalfa (A) or wheat (W). The next two characters identify high (H), moderate (M), or low (L) levels of Factor-3 (3). The fourth and fifth characters identify high (H), moderate (M), or low (L) levels of Factor-4 (4). The sixth character identifies the five replicate samples (1-5) collected within one sampling location. The last character identifies a laboratory split (2) of the previous sample (1).

Table A1.--Listing of analytical data for samples of soils collected at locations where alfalfa was sampled.

[Total concentrations are reported, except as noted]

Sample ID	pH, std.	Al, %	B, ppm[1]	Ba, ppm	Be, ppm	CO_3-C, %	Org. C, %	Total C, %	Ca, ppm	Ce, ppm
AH3H411	7.6	6.6	1.8	1400	1	0.09	0.40	0.49	2.6	35
AH3H412	7.6	6.6	2.0	900	1	0.11	0.44	0.55	2.8	38
AH3H421	7.5	6.7	1.5	990	1	0.09	0.56	0.65	2.7	37
AH3H431	7.6	6.4	1.9	950	1	0.06	0.36	0.42	2.1	37
AH3H441	7.5	6.8	1.5	890	1	0.08	0.43	0.51	2.5	40
AH3H451	7.5	6.6	2.1	1000	1	0.07	0.43	0.50	2.6	44
AH3H452	7.5	6.7	2.3	1000	1	0.08	0.48	0.56	2.5	37
AH3L411	7.9	7.5	2.8	950	1	0.12	0.72	0.84	1.4	44
AH3L421	8.0	7.6	2.1	960	2	0.18	0.54	0.72	1.5	45
AH3L431	8.1	7.2	1.5	980	1	0.15	0.51	0.66	1.4	41
AH3L441	8.0	7.3	1.6	990	1	0.15	0.44	0.59	1.5	40
AH3L451	8.1	6.8	0.8	1100	1	0.20	0.29	0.49	1.6	39
AH3M411	7.7	7.9	5.8	960	2	0.13	0.32	0.45	1.9	49
AH3M421	7.7	7.8	3.8	1000	2	0.14	0.26	0.40	1.9	49
AH3M431	7.6	8.0	2.9	1000	2	0.04	0.55	0.59	1.4	51
AH3M441	7.9	8.2	2.5	930	2	0.20	0.77	0.97	1.8	51
AH3M442	7.6	8.0	2.5	1100	2	0.15	0.35	0.50	2.1	51
AH3M451	7.8	7.6	2.6	1200	2	0.10	0.37	0.47	1.4	48
AL3H411	7.9	7.8	28	800	2	0.19	0.73	0.92	2.6	44
AL3H412	7.8	7.5	20	800	2	0.19	0.70	0.89	2.4	43
AL3H421	7.8	7.5	29	720	1	0.28	0.86	1.14	3.1	40
AL3H431	8.0	7.8	34	730	2	0.17	0.77	0.94	2.5	44
AL3H441	8.1	7.9	33	730	2	0.31	0.73	1.04	2.9	45
AL3H451	8.3	7.7	35	440	1	0.29	0.61	0.90	3.3	42
AL3L411	8.0	7.4	1.7	720	1	0.15	0.32	0.47	1.7	44
AL3L421	8.0	7.5	3.2	840	1	0.11	0.32	0.43	1.5	45
AL3L431	7.9	7.3	0.9	700	1	0.09	0.34	0.43	1.5	45
AL3L441	7.8	7.5	1.2	710	1	0.12	0.31	0.43	1.7	42
AL3L451	7.9	7.3	1.2	740	1	0.18	0.43	0.61	1.7	43
AL3M411	7.8	8.5	44	790	2	0.03	0.68	0.71	2.4	48
AL3M421	7.8	8.6	38	800	2	0.07	0.82	0.89	2.0	49
AL3M422	7.8	8.7	40	800	2	0.06	0.78	0.84	2.1	49
AL3M431	7.9	8.7	61	780	2	0.05	0.61	0.66	2.5	50
AL3M441	7.9	8.6	65	790	2	0.05	0.65	0.70	2.2	50
AL3M442	7.9	8.7	68	480	2	0.06	0.63	0.69	2.6	49
AL3M451	7.8	8.7	37	800	2	0.05	0.87	0.92	2.0	50
AM3L411	7.9	7.5	1	980	1	0.16	0.53	0.69	1.5	43
AM3L421	7.9	7.3	1.1	1100	1	0.18	0.51	0.69	1.6	44
AM3L431	7.8	7.1	1.1	1100	1	0.18	0.48	0.66	1.6	42
AM3L441	8.1	6.5	1.0	1500	1	0.18	0.27	0.45	1.5	38
AM3L442	8.1	6.7	1.1	1400	1	0.17	0.40	0.57	1.6	42
AM3L451	8.1	5.9	0.9	1700	1	0.18	0.34	0.52	1.5	33
AM3M411	7.8	8.9	11	790	2	0.27	0.87	1.14	2.1	51
AM3M421	7.8	9.0	11	810	2	0.26	0.87	1.13	2.0	51
AM3M431	7.5	7.9	2.9	980	2	0.14	0.30	0.44	2.0	48
AM3M432	7.9	8.8	10	840	2	0.29	0.62	0.91	1.9	50
AM3M441	8.0	8.9	10	860	2	0.24	0.95	1.19	1.8	52
AM3M442	8.0	8.5	11	830	2	0.24	0.93	1.17	1.7	50
AM3M451	8.1	8.8	8.2	840	2	0.23	0.88	1.11	1.7	51

[1] Water extractable

[2] Specific conductance, umhos/cm

Table A1.--Listing of analytical data for samples of soils collected at locations where alfalfa was sampled (continued).

[Total concentrations are reported, except as noted]

Sample ID	Cl, me\L[1]	Co, ppm	Cond.[1,2]	Cr, ppm	Cu, ppm	Fe, %	Ga, ppm	Hg, ppm	K, %	La, ppm
AH3H411	10	11	3100	130	27	2.7	15	<0.02	1.6	22
AH3H412	8.0	10	2700	130	29	3.0	15	0.04	1.5	25
AH3H421	18	11	2700	130	31	3.1	16	<0.02	1.5	24
AH3H431	18	10	2800	120	27	2.7	15	<0.02	1.6	24
AH3H441	5.0	11	2200	130	31	3.2	16	0.02	1.5	26
AH3H451	13	11	2800	140	31	3.0	15	<0.02	1.6	29
AH3H452	3.0	11	2800	130	30	3.0	15	<0.02	1.6	24
AH3L411	12	17	310	180	36	3.6	17	0.02	2.0	24
AH3L421	11	19	300	190	39	3.8	17	0.04	2.0	26
AH3L431	6.0	17	240	170	33	3.3	16	0.02	2.1	24
AH3L441	7.0	18	230	170	32	3.5	16	0.04	2.0	23
AH3L451	3.0	17	170	160	27	3.1	15	0.02	2.1	23
AH3M411	10	12	2300	52	30	3.4	17	<0.02	2.2	29
AH3M421	8.0	13	2400	52	31	3.5	17	<0.02	2.3	28
AH3M431	12	14	700	69	35	3.7	18	<0.02	2.2	30
AH3M441	17	15	2400	140	41	4.1	19	<0.02	2.0	30
AH3M442	14	13	2600	71	34	3.6	18	<0.02	2.2	29
AH3M451	4.0	12	190	59	30	3.5	16	<0.02	2.2	25
AL3H411	40	16	4000	140	39	3.8	19	<0.02	2.1	26
AL3H412	30	15	3700	130	42	3.6	17	<0.02	2.1	26
AL3H421	83	15	4300	120	36	3.6	16	0.02	2.0	25
AL3H431	180	15	5400	110	36	3.8	18	<0.02	2.0	26
AL3H441	75	16	4800	130	39	3.9	18	0.04	1.9	26
AL3H451	160	15	7800	110	35	3.7	17	0.02	1.9	26
AL3L411	5.0	14	190	89	34	3.3	16	0.06	1.8	25
AL3L421	5.0	14	250	84	32	3.4	16	0.02	1.9	26
AL3L431	3.0	14	180	100	30	3.2	16	0.04	1.7	25
AL3L441	5.0	14	430	87	31	3.4	16	0.02	1.7	25
AL3L451	4.0	13	200	83	28	3.2	16	0.02	1.9	25
AL3M411	20	17	3900	160	47	4.4	21	0.02	1.9	28
AL3M421	32	18	4000	150	48	4.5	21	0.02	1.8	29
AL3M422	28	18	4400	140	46	4.5	21	0.04	1.9	29
AL3M431	130	18	6000	150	48	4.6	21	0.04	1.8	29
AL3M441	70	17	4600	160	47	4.5	21	0.02	1.8	29
AL3M442	110	18	4900	150	46	4.5	20	0.02	1.8	29
AL3M451	130	18	4500	150	46	4.5	21	0.02	1.8	29
AM3L411	10	19	240	170	34	3.6	16	0.04	2.0	24
AM3L421	8.0	19	220	200	32	3.5	16	0.02	2.1	24
AM3L431	15	19	250	160	29	3.4	15	0.04	2.1	24
AM3L441	3.0	19	180	260	24	3.2	14	0.04	2.1	22
AM3L442	3.0	18	170	240	27	3.4	15	0.18	2.0	24
AM3L451	3.0	17	200	300	19	3.0	13	<0.02	2.2	20
AM3M411	100	17	3300	130	47	4.6	21	0.08	1.9	30
AM3M421	100	17	3300	130	48	4.6	21	0.06	1.9	30
AM3M431	8.0	13	310	52	30	3.4	17	0.06	2.2	28
AM3M432	80	18	2200	140	48	4.5	21	0.06	1.9	29
AM3M441	120	17	1600	140	50	4.5	20	0.06	2.0	30
AM3M442	100	17	1500	140	45	4.3	20	0.04	1.9	28
AM3M451	50	17	800	120	45	4.4	21	0.08	1.9	29

Table A1.--Listing of analytical data for samples of soils collected at locations where alfalfa was sampled (continued).

[Total concentrations are reported, except as noted]

Sample ID	Li, ppm	Mg, %	Mn, ppm	Mo, ppm	Na, %	Nb, ppm	Nd, ppm	Ni, ppm	P, %	Pb, ppm
AH3H411	32	0.93	310	4	1.2	5.0	19	51	0.10	12
AH3H412	35	1.0	330	3	1.1	6.0	20	53	0.10	12
AH3H421	34	1.0	360	3	1.1	6.0	21	55	0.10	12
AH3H431	31	0.92	320	2	1.2	5.0	20	50	0.09	12
AH3H441	37	1.1	340	4	0.99	7.0	21	59	0.11	11
AH3H451	35	1.0	340	4	1.1	6.0	22	55	0.10	13
AH3H452	35	1.0	340	3	1.1	8.0	19	55	0.10	12
AH3L411	60	2.0	530	<2	1.1	7.0	20	140	0.07	18
AH3L421	64	2.1	580	<2	1.2	7.0	22	160	0.07	15
AH3L431	54	1.9	530	<2	1.2	6.0	21	140	0.06	17
AH3L441	56	2.0	530	<2	1.3	6.0	21	150	0.06	16
AH3L451	46	1.9	530	<2	1.4	5.0	19	150	0.06	15
AH3M411	71	1.1	520	<2	1.6	7.0	23	34	0.05	19
AH3M421	69	1.0	570	<2	1.6	7.0	24	34	0.05	22
AH3M431	75	1.1	600	<2	1.4	10	26	41	0.06	23
AH3M441	67	1.6	610	<2	1.0	8.0	25	88	0.07	17
AH3M442	77	1.1	580	<2	1.5	8.0	24	39	0.05	21
AH3M451	63	0.99	620	<2	1.4	8.0	23	30	0.05	22
AL3H411	69	2.8	620	<2	1.2	6.0	21	87	0.12	16
AL3H412	65	2.7	600	<2	1.1	5.0	22	82	0.11	18
AL3H421	67	2.8	590	<2	1.2	6.0	20	82	0.12	17
AL3H431	71	2.9	650	<2	1.4	6.0	22	86	0.11	16
AL3H441	73	3.0	660	<2	1.4	8.0	22	86	0.11	16
AL3H451	70	3.0	600	3	1.7	9.0	21	80	0.11	14
AL3L411	51	1.2	580	<2	1.5	7.0	22	56	0.05	15
AL3L421	56	1.2	580	<2	1.5	7.0	23	52	0.04	16
AL3L431	47	1.1	610	<2	1.6	6.0	23	57	0.05	15
AL3L441	51	1.2	570	<2	1.6	6.0	21	59	0.05	15
AL3L451	48	1.1	580	<2	1.5	9.0	21	51	0.04	17
AL3M411	78	2.3	690	2	0.96	8.0	23	100	0.09	18
AL3M421	78	2.3	710	<2	1.0	9.0	25	100	0.09	17
AL3M422	77	2.3	690	<2	1.0	8.0	25	100	0.08	18
AL3M431	79	2.3	690	2	1.1	7.0	24	100	0.09	18
AL3M441	78	2.3	670	<2	1.1	8.0	24	100	0.08	17
AL3M442	79	2.3	680	2	1.1	9.0	24	100	0.08	15
AL3M451	78	2.2	690	<2	1.1	16	26	100	0.08	16
AM3L411	59	2.1	550	<2	1.2	7.0	21	160	0.07	17
AM3L421	55	2.1	570	<2	1.4	<4	21	160	0.07	18
AM3L431	51	2.0	560	<2	1.4	8.0	20	160	0.06	16
AM3L441	41	2.0	550	<2	1.4	5.0	18	180	0.06	15
AM3L442	45	1.9	570	<2	1.4	4.0	20	170	0.07	17
AM3L451	32	1.6	480	<2	1.3	<4	16	150	0.06	15
AM3M411	80	1.7	630	2	1.1	10	25	88	0.07	18
AM3M421	81	1.7	630	2	1.1	12	24	88	0.08	16
AM3M431	71	1.0	550	<2	1.5	10	23	35	0.05	20
AM3M432	79	1.7	630	<2	1.2	9.0	24	85	0.06	17
AM3M441	78	1.6	640	2	1.2	11	24	82	0.08	19
AM3M442	74	1.6	620	<2	1.2	8.0	23	79	0.07	17
AM3M451	76	1.6	620	<2	1.1	8.0	26	80	0.07	18

Table A1.--Listing of analytical data for samples of soils collected at locations where alfalfa was sampled (continued).

[Total concentrations are reported, except as noted]

Sample ID	Total S, %	Sc, ppm	Se, ppm	Se, ppb[1]	SO4, me/L[1]	Sr, ppm	Th, ppm	Ti, %	V, ppm	Y, ppm
AH3H411	0.78	10	2.3	24	3000	320	7.0	0.28	130	15
AH3H412	0.87	11	2.4	24	2800	300	8.0	0.29	140	16
AH3H421	0.88	11	2.5	110	2600	300	8.0	0.30	150	15
AH3H431	0.50	10	2.2	110	2700	300	8.0	0.27	130	15
AH3H441	0.71	12	2.1	3.0	2100	290	9.0	0.30	160	17
AH3H451	0.79	11	2.4	92	2700	300	8.0	0.29	150	16
AH3H452	0.75	11	2.5	82	2700	300	7.0	0.30	150	16
AH3L411	0.07	12	1.4	17	35	220	10	0.31	110	16
AH3L421	0.06	13	1.2	10	36	210	11	0.33	110	16
AH3L431	0.05	11	1.3	6.0	17	230	10	0.29	100	15
AH3L441	<0.05	11	1.1	40	17	220	11	0.30	99	15
AH3L451	<0.05	10	1.1	7.0	10	230	8.0	0.28	86	14
AH3M411	0.23	12	0.8	9.0	1700	280	13	0.32	92	17
AH3M421	0.24	12	0.8	5.0	1800	280	13	0.32	92	18
AH3M431	0.08	13	1.0	18	400	270	13	0.35	100	19
AH3M441	0.28	14	1.3	15	2300	210	14	0.36	130	17
AH3M442	0.28	13	0.7	12	3000	280	12	0.34	98	18
AH3M451	<0.05	12	0.8	7.0	10	270	13	0.34	96	18
AL3H411	0.70	14	0.2	10	3400	320	11	0.33	120	16
AL3H412	0.54	13	0.2	7.0	3300	300	10	0.32	110	15
AL3H421	1.04	13	0.3	<3	3000	350	11	0.31	110	15
AL3H431	0.94	14	0.2	26	3500	330	11	0.34	120	16
AL3H441	0.86	14	0.3	23	4000	370	10	0.35	120	16
AL3H451	1.52	14	0.4	4.0	4700	430	11	0.33	110	16
AL3L411	<0.05	12	0.4	5.0	15	200	10	0.32	94	17
AL3L421	<0.05	12	0.5	11	23	200	11	0.33	97	17
AL3L431	<0.05	12	0.3	3.0	9	190	9.0	0.33	93	17
AL3L441	<0.05	12	0.4	3.0	9	200	11	0.33	96	17
AL3L451	<0.05	11	0.4	7.0	10	190	11	0.30	88	17
AL3M411	1.07	16	0.8	17	3600	280	12	0.37	140	17
AL3M421	0.74	17	1.0	14	3800	230	12	0.38	150	18
AL3M422	0.85	16	1.0	8.0	3400	240	14	0.37	150	18
AL3M431	1.22	17	1.0	11	3500	240	13	0.38	150	18
AL3M441	1.10	16	0.9	28	4000	240	14	0.38	150	18
AL3M442	1.25	16	0.9	3.0	3400	250	13	0.38	150	18
AL3M451	0.66	16	0.8	4.0	3200	210	15	0.38	150	18
AM3L411	<0.05	12	1.0	16	23	210	11	0.31	100	16
AM3L421	<0.05	11	1.1	4.0	18	220	9.0	0.30	97	15
AM3L431	0.05	11	0.9	23	19	220	10	0.29	91	15
AM3L441	<0.05	9	0.9	6.0	10	230	9.0	0.27	78	13
AM3L442	<0.05	10	0.9	6.0	12	230	9.0	0.30	85	15
AM3L451	<0.05	8	0.9	11	17	230	8.0	0.25	67	12
AM3M411	0.30	17	1.1	14	2000	210	15	0.38	150	18
AM3M421	0.33	17	1.2	6.0	1900	210	15	0.39	150	18
AM3M431	0.06	12	0.7	29	25	270	13	0.32	93	17
AM3M432	0.20	16	1.2	25	1200	210	13	0.39	150	18
AM3M441	0.10	16	1.3	6.0	450	210	12	0.38	150	18
AM3M442	0.11	16	1.3	27	450	200	13	0.37	140	18
AM3M451	0.07	16	1.3	7.0	150	200	14	0.38	140	18

Table A1.--Listing of analytical data for samples of soils collected at locations where alfalfa was sampled (continued).

[Total concentrations are reported, except as noted]

Sample ID	Yb, ppm	Zn, ppm
AH3H411	2.0	100
AH3H412	2.0	110
AH3H421	2.0	110
AH3H431	1.0	93
AH3H441	2.0	110
AH3H451	2.0	110
AH3H452	2.0	110
AH3L411	2.0	100
AH3L421	2.0	110
AH3L431	2.0	90
AH3L441	2.0	91
AH3L451	2.0	79
AH3M411	2.0	98
AH3M421	2.0	98
AH3M431	2.0	110
AH3M441	2.0	120
AH3M442	2.0	100
AH3M451	2.0	95
AL3H411	2.0	100
AL3H412	2.0	100
AL3H421	2.0	98
AL3H431	2.0	100
AL3H441	2.0	110
AL3H451	2.0	100
AL3L411	2.0	80
AL3L421	2.0	83
AL3L431	2.0	78
AL3L441	2.0	84
AL3L451	2.0	75
AL3M411	2.0	120
AL3M421	2.0	130
AL3M422	2.0	120
AL3M431	2.0	130
AL3M441	2.0	120
AL3M442	2.0	120
AL3M451	2.0	130
AM3L411	2.0	98
AM3L421	2.0	91
AM3L431	2.0	86
AM3L441	2.0	74
AM3L442	2.0	79
AM3L451	1.0	65
AM3M411	2.0	130
AM3M421	2.0	130
AM3M431	2.0	96
AM3M432	2.0	130
AM3M441	2.0	130
AM3M442	2.0	120
AM3M451	2.0	130

Table A2.--Listing of analytical data for samples of soils collected at locations where wheat was sampled.

[Total concentrations are reported, except as noted]

Sample ID	pH, std.	Al, %	B, ppm[1]	Ba, ppm	Be, ppm	CO_3-C, %	Org. C, %	Total C, %	Ca, ppm	Ce, ppm
WH3H411	7.8	6.7	1.8	850	1.0	0.14	0.45	0.59	1.8	36
WH3H412	7.6	6.8	2.1	840	1.0	0.15	0.45	0.60	2.2	37
WH3H421	7.8	7.9	1.9	930	2.0	0.17	0.47	0.64	2.2	44
WH3H431	7.6	7.0	2.2	780	1.0	0.13	0.52	0.65	2.1	40
WH3H441	7.5	7.0	1.5	830	2.0	0.11	0.53	0.64	2.0	41
WH3H451	7.6	6.8	1.5	250	1.0	0.10	0.32	0.42	3.6	40
WH3H452	7.7	6.5	1.7	770	1.0	0.11	0.28	0.39	3.6	36
WH3M411	7.5	7.1	1.4	1100	1.0	0.20	0.53	0.73	2.2	38
WH3M421	7.5	6.6	1.7	480	1.0	0.20	0.37	0.57	2.5	34
WH3M431	7.5	6.7	1.8	880	1.0	0.24	0.40	0.64	2.5	36
WH3M441	7.6	6.8	1.8	1100	1.0	0.22	0.35	0.57	2.2	36
WH3M442	7.5	6.7	1.5	1400	1.0	0.21	0.34	0.55	1.9	39
WH3M451	7.6	6.8	2.2	1100	1.0	0.24	0.35	0.59	1.8	38
WL3M411	8.0	7.7	2.4	610	1.0	0.11	0.47	0.58	1.7	39
WL3M421	7.9	7.9	2.7	650	1.0	0.09	0.50	0.59	1.6	40
WL3M422	8.0	8.0	2.8	640	1.0	0.09	0.47	0.56	1.6	42
WL3M431	8.0	7.9	2.8	630	1.0	0.13	0.50	0.63	1.8	40
WL3M441	7.8	8.0	2.3	640	1.0	0.13	0.53	0.66	1.8	43
WL3M442	7.9	7.9	2.5	650	1.0	0.12	0.60	0.72	1.7	41
WL3M451	8.0	7.9	2.4	680	1.0	0.21	0.40	0.61	2.0	41
WM3L411	8.1	6.3	1.2	930	1.0	0.12	0.29	0.41	1.3	33
WM3L421	8.0	6.9	1.4	1100	1.0	0.17	0.31	0.48	1.5	38
WM3L431	8.1	7.2	2.3	1100	1.0	0.14	0.38	0.52	1.5	40
WM3L441	8.1	7.7	1.3	1000	2.0	0.15	0.36	0.51	1.6	46
WM3L442	8.0	7.3	1.2	1000	1.0	0.14	0.36	0.50	1.5	43
WM3L451	8.0	7.3	1.7	1000	1.0	0.13	0.39	0.52	1.5	43
WM3M411	8.0	9.0	4.0	860	2.0	0.28	0.86	1.14	2.0	53
WM3M421	7.8	8.8	9.2	820	2.0	0.28	0.76	1.04	1.9	51
WM3M431	8.0	8.6	3.7	900	2.0	0.22	0.77	0.99	1.8	51
WM3M432	8.1	8.4	4.4	910	2.0	0.23	0.69	0.92	1.8	49
WM3M441	8.0	8.0	3.0	950	2.0	0.21	0.70	0.91	1.7	48
WM3M442	7.9	8.2	2.6	960	2.0	0.21	0.73	0.94	1.8	46
WM3M451	8.1	8.4	5.3	880	2.0	0.30	0.71	1.01	2.0	51

[1] Water extractable

[2] Specific conductance, umhos/cm

Table A2.--Listing of analytical data for samples of soils collected at locations where wheat was sampled (continued).

[Total concentrations are reported, except as noted]

Sample ID	Cl, me\L[1]	Co, ppm	Cond.[1,2]	Cr, ppm	Cu, ppm	Fe, %	Ga, ppm	Hg, ppm	K, %	La, ppm
WH3H411	7.0	11	280	130	27	2.9	15	<0.02	1.7	23
WH3H412	17	12	1600	110	28	3.0	15	<0.02	1.7	23
WH3H421	6.0	14	280	130	33	3.6	18	<0.02	1.9	29
WH3H431	12	12	2200	150	34	3.3	16	<0.02	1.6	25
WH3H441	3.0	11	1900	130	35	3.3	17	<0.02	1.7	26
WH3H451	9.0	11	2700	140	35	3.2	16	<0.02	1.6	25
WH3H452	14	11	2500	140	31	3.0	15	<0.02	1.5	24
WH3M411	20	11	2700	78	25	2.9	15	<0.02	2.1	23
WH3M421	6.0	9.0	2800	76	22	2.7	14	<0.02	2.0	21
WH3M431	23	10	2700	73	22	2.8	15	<0.02	2.0	22
WH3M441	8.0	10	2700	70	23	2.9	15	<0.02	2.1	22
WH3M442	15	11	2000	73	21	2.7	14	<0.02	2.1	24
WH3M451	10	10	1300	75	21	2.6	14	<0.02	2.3	21
WL3M411	3.0	18	210	140	37	4.0	17	0.06	1.7	23
WL3M421	7.0	18	240	140	42	4.1	17	0.02	1.7	23
WL3M422	6.0	19	250	160	42	4.2	18	0.04	1.7	23
WL3M431	4.0	19	200	140	41	4.1	18	0.04	1.7	23
WL3M441	10	19	230	150	40	4.2	18	0.02	1.8	24
WL3M442	10	19	260	150	43	4.2	17	0.02	1.7	24
WL3M451	7.0	19	220	170	43	4.1	18	0.04	1.7	24
WM3L411	4.0	15	220	170	24	2.8	13	0.02	2.1	20
WM3L421	3.0	16	190	150	25	3.1	15	0.04	2.2	22
WM3L431	6.0	16	230	170	29	3.3	15	0.04	2.1	23
WM3L441	2.0	17	180	140	32	3.6	17	0.02	2.1	26
WM3L442	3.0	15	190	130	30	3.4	16	0.02	2.1	25
WM3L451	2.0	15	170	130	27	3.2	15	0.02	2.1	24
WM3M411	11	17	200	130	47	4.6	21	0.08	1.9	31
WM3M421	15	16	600	130	51	4.5	21	0.08	1.8	27
WM3M431	5.0	16	380	120	44	4.3	21	0.08	2.0	29
WM3M432	5.0	16	390	130	44	4.2	20	0.06	2.0	28
WM3M441	8.0	15	220	150	40	3.9	19	0.06	2.0	28
WM3M442	8.0	16	330	140	38	4.0	18	0.04	2.1	28
WM3M451	22	16	500	130	48	4.2	20	0.08	1.9	29

Table A2.--Listing of analytical data for samples of soils collected at locations where wheat was sampled (continued).

[Total concentrations are reported, except as noted]

Sample ID	Li, ppm	Mg, %	Mn, ppm	Mo, ppm	Na, %	Nb, ppm	Nd, ppm	Ni, ppm	P, %	Pb, ppm
WH3H411	36	0.99	350	2.0	1.1	7.0	20	60	0.10	12
WH3H412	36	1.0	420	3.0	1.1	6.0	20	62	0.10	13
WH3H421	43	1.2	420	3.0	1.2	8.0	24	75	0.12	14
WH3H431	41	1.1	380	3.0	1.0	6.0	23	68	0.11	12
WH3H441	40	1.1	360	3.0	0.99	6.0	22	67	0.12	14
WH3H451	42	1.1	360	3.0	0.98	4.0	21	63	0.11	13
WH3H452	39	1.0	330	3.0	0.95	6.0	20	60	0.10	12
WH3M411	50	0.88	390	<2.0	1.0	7.0	18	41	0.05	16
WH3M421	44	0.80	340	<2.0	0.97	6.0	17	37	0.05	14
WH3M431	45	0.89	340	<2.0	0.99	6.0	19	39	0.05	15
WH3M441	47	0.88	390	<2.0	1.0	7.0	19	40	0.05	15
WH3M442	44	0.81	350	<2.0	1.0	5.0	21	38	0.05	15
WH3M451	47	0.84	380	<2.0	1.1	6.0	18	37	0.04	16
WL3M411	50	1.6	710	<2.0	1.5	6.0	20	92	0.05	11
WL3M421	54	1.7	730	<2.0	1.5	8.0	21	96	0.07	12
WL3M422	55	1.7	740	<2.0	1.5	6.0	22	96	0.07	13
WL3M431	53	1.7	730	<2.0	1.5	7.0	21	93	0.06	13
WL3M441	54	1.7	730	<2.0	1.5	6.0	24	95	0.06	14
WL3M442	55	1.7	740	<2.0	1.5	7.0	21	96	0.06	12
WL3M451	54	1.7	740	<2.0	1.5	6.0	21	95	0.06	14
WM3L411	41	1.8	430	<2.0	1.2	6.0	17	140	0.05	15
WM3L421	43	1.7	510	<2.0	1.4	5.0	19	140	0.07	16
WM3L431	51	1.8	520	<2.0	1.4	6.0	20	130	0.07	18
WM3L441	59	1.7	540	<2.0	1.4	7.0	22	120	0.07	17
WM3L442	54	1.6	510	<2.0	1.3	6.0	21	120	0.06	19
WM3L451	53	1.6	500	<2.0	1.4	6.0	20	120	0.07	18
WM3M411	78	1.6	620	<2.0	0.91	8.0	26	84	0.08	17
WM3M421	79	1.6	620	<2.0	0.96	8.0	24	70	0.07	17
WM3M431	72	1.6	620	<2.0	1.0	9.0	26	80	0.08	18
WM3M432	70	1.5	610	<2.0	1.1	8.0	23	79	0.07	18
WM3M441	64	1.6	580	<2.0	1.0	13.0	24	88	0.07	16
WM3M442	65	1.6	590	2.0	1.0	8.0	23	88	0.07	16
WM3M451	73	1.6	600	<2.0	1.1	8.0	25	83	0.07	17

Table A2.--Listing of analytical data for samples of soils collected at locations where wheat was sampled (continued).

[Total concentrations are reported, except as noted]

Sample ID	Total S, %	Sc, ppm	Se, ppm	Se, ppb[1]	SO4, me/L[1]	Sr, ppm	Th, ppm	Ti, %	V, ppm	Y, ppm
WH3H411	0.12	11	1.9	16	18	270	10	0.28	130	15
WH3H412	0.32	11	1.8	15	1100	270	9.0	0.29	130	16
WH3H421	0.14	13	2.0	4.0	24	300	11.0	0.34	160	19
WH3H431	0.38	12	2.1	45	1900	260	10	0.31	150	17
WH3H441	0.32	12	2.5	3.0	1300	270	10	0.3	160	17
WH3H451	1.21	11	2.4	58	2600	270	9.0	0.31	150	16
WH3H452	1.41	11	2.4	57	2500	270	9.0	0.29	140	15
WH3M411	0.47	10	1.5	19	2700	230	10	0.29	96	13
WH3M421	0.74	9	1.6	21	2300	240	9.0	0.26	89	12
WH3M431	0.59	9	1.9	5.0	2100	250	10	0.27	94	13
WH3M441	0.43	10	1.4	3.0	2300	240	10	0.26	92	13
WH3M442	0.31	9	1.3	7.0	1500	230	11	0.26	87	13
WH3M451	0.20	9	1.2	7.0	860	230	11	0.25	85	11
WL3M411	<0.05	15	0.3	3.0	13	190	7.0	0.32	110	17
WL3M421	<0.05	16	0.3	9.0	32	190	7.0	0.34	120	18
WL3M422	<0.05	16	0.3	8.0	30	190	7.0	0.35	120	17
WL3M431	<0.05	16	0.3	8.0	20	200	7.0	0.35	120	18
WL3M441	<0.05	16	0.4	10	17	190	9.0	0.35	120	18
WL3M442	<0.05	16	0.3	11	20	190	6.0	0.35	120	18
WL3M451	<0.05	16	0.3	12	30	200	8.0	0.34	120	17
WM3L411	<0.05	9	1.0	13	20	210	10	0.23	77	12
WM3L421	<0.05	10	1.2	21	14	230	10	0.27	84	14
WM3L431	<0.05	10	1.1	5.0	27	230	9.0	0.29	92	15
WM3L441	0.05	12	1.2	3.0	10	230	11	0.32	100	16
WM3L442	<0.05	11	1.0	43	12	220	11	0.30	94	15
WM3L451	<0.05	11	1.1	16	10	220	10	0.30	91	15
WM3M411	0.06	17	1.4	3.0	40	210	14	0.38	150	19
WM3M421	0.05	17	1.5	38	170	210	15	0.43	160	18
WM3M431	0.06	15	1.4	9.0	20	210	14	0.37	130	18
WM3M432	0.06	15	1.3	8.0	45	210	12	0.36	130	18
WM3M441	0.06	14	1.3	14	37	210	12	0.34	120	17
WM3M442	0.06	14	1.2	6.0	30	210	13	0.34	120	17
WM3M451	0.06	15	1.3	22	100	220	13	0.37	130	18

Table A2.--Listing of analytical data for samples of soils collected at locations where wheat was sampled (continued).

[Total concentrations are reported, except as noted]

Sample ID	Yb, ppm	Zn, ppm
WH3H411	2.0	100
WH3H412	2.0	100
WH3H421	2.0	130
WH3H431	2.0	120
WH3H441	2.0	130
WH3H451	2.0	120
WH3H452	2.0	110
WH3M411	1.0	90
WH3M421	1.0	86
WH3M431	2.0	86
WH3M441	2.0	85
WH3M442	1.0	81
WH3M451	1.0	75
WL3M411	2.0	81
WL3M421	2.0	84
WL3M422	2.0	86
WL3M431	2.0	85
WL3M441	2.0	87
WL3M442	2.0	86
WL3M451	2.0	82
WM3L411	1.0	89
WM3L421	2.0	110
WM3L431	2.0	110
WM3L441	2.0	110
WM3L442	2.0	120
WM3L451	2.0	120
WM3M411	2.0	140
WM3M421	2.0	130
WM3M431	2.0	130
WM3M432	2.0	120
WM3M441	2.0	110
WM3M442	2.0	110
WM3M451	2.0	120

Table A3.--Listing of analytical data for samples of alfalfa.

[Concentrations reported on a dry-weight basis.]

Sample ID	Ash, %	Al, %	Ba, ppm	Ca, %	Co, ppm	Cr, ppm	Cu, ppm	Fe, %	Hg, ppm	K, %
AH3H411	15.6	0.01	35	2.50	0.47	0.94	17	0.02	0.03	5.46
AH3H412	15.6	0.01	35	2.65	0.47	0.94	16	0.02	0.03	4.99
AH3H421	15.6	0.01	37	2.50	0.47	0.62	17	0.02	0.04	5.30
AH3H431	15.0	0.01	39	2.55	0.45	0.60	15	0.02	0.04	5.05
AH3H441	16.9	0.02	43	2.70	0.51	0.85	20	0.02	0.05	5.41
AH3H451	15.0	0.02	36	2.55	0.45	0.45	15	0.02	0.03	4.95
AH3H452	15.0	0.01	33	2.40	0.60	0.45	15	0.02	0.03	4.95
AH3L411	13.0	0.03	26	1.82	0.39	1.0	14	0.03	0.03	4.55
AH3L421	13.1	0.03	28	1.96	0.65	1.1	13	0.03	0.10	4.59
AH3L431	14.0	0.03	30	1.96	0.70	0.70	14	0.03	0.03	4.90
AH3L441	14.0	0.04	32	1.96	0.56	1.1	14	0.03	0.04	5.04
AH3L451	14.2	0.04	58	2.27	0.57	1.4	13	0.03	0.04	4.26
AH3M411	9.9	0.02	38	1.88	0.59	0.50	12	0.02	0.03	2.77
AH3M421	8.6	0.01	29	1.55	0.43	0.43	9.5	0.01	0.03	2.32
AH3M431	10.4	0.01	26	2.08	0.52	0.31	9.6	0.01	<0.01	2.81
AH3M441	10.4	0.02	28	2.08	0.62	0.52	10	0.02	<0.01	2.91
AH3M442	9.1	0.01	26	1.73	0.55	0.46	10	0.01	0.02	2.64
AH3M451	9.2	0.01	30	1.75	0.46	0.28	8.7	0.01	0.04	2.58
AL3H411	11.0	0.02	35	2.09	0.55	0.66	14	0.02	0.02	3.08
AL3H412	9.1	0.01	30	1.73	0.36	0.55	12	0.01	0.02	2.64
AL3H421	10.4	0.01	34	2.18	0.31	0.52	11	0.01	0.03	2.39
AL3H431	8.2	0.01	4.1	1.56	0.41	0.41	11	0.01	0.04	2.30
AL3H441	8.8	0.01	4.1	1.67	0.44	0.53	11	0.01	0.02	2.29
AL3H451	9.5	0.01	3.1	1.52	0.47	0.76	12	0.02	0.02	2.57
AL3L411	12.8	0.03	53	2.43	0.51	0.77	22	0.02	0.06	2.30
AL3L421	13.5	0.03	49	2.16	0.68	0.81	22	0.02	0.03	4.05
AL3L431	10.9	0.03	62	1.85	0.65	0.98	17	0.03	0.06	2.94
AL3L441	13.5	0.02	55	2.30	0.54	0.81	19	0.02	0.14	3.92
AL3L451	12.6	0.02	63	2.14	0.63	0.50	19	0.02	0.05	3.65
AL3M411	12.5	0.02	15	1.75	1.63	0.88	15	0.02	0.03	4.25
AL3M421	12.1	0.02	12	1.57	1.45	0.61	15	0.02	0.02	3.99
AL3M422	12.0	0.02	12	1.68	1.44	0.84	12	0.02	0.02	3.72
AL3M431	11.8	0.01	5.0	1.42	1.06	0.35	14	0.02	0.03	4.25
AL3M441	10.3	0.03	5.8	1.24	0.93	0.72	11	0.02	0.03	3.09
AL3M442	11.6	0.03	7.0	1.39	1.04	0.93	14	0.03	0.04	3.94
AL3M451	10.2	0.03	6.4	1.12	0.71	0.71	12	0.02	0.03	3.37
AM3L411	12.4	0.01	26	1.74	0.62	0.62	12	0.01	0.04	4.22
AM3L421	13.5	0.01	30	1.89	0.54	0.68	15	0.02	0.05	4.73
AM3L431	13.4	0.01	27	2.01	0.54	0.54	13	0.02	0.04	4.69
AM3L441	13.2	0.01	24	2.11	0.40	0.40	11	0.01	0.03	4.09
AM3L442	13.4	0.01	24	2.01	0.40	0.67	12	0.01	0.03	4.56
AM3L451	13.7	0.01	32	2.47	0.55	0.68	11	0.01	0.02	4.25
AM3M411	8.6	0.01	3.4	1.20	---	0.34	11	0.01	0.02	2.75
AM3M421	8.4	0.01	3.7	1.51	0.25	0.50	10	0.01	0.04	2.10
AM3M431	8.5	0.01	4.9	1.45	---	0.43	11	0.01	0.03	2.21
AM3M432	8.4	0.01	4.7	1.43	0.25	0.50	12	0.01	0.02	2.18
AM3M441	8.8	0.01	4.7	1.50	0.26	0.53	11	0.01	0.02	2.38
AM3M442	8.3	0.01	4.2	1.33	0.25	0.50	11	0.01	0.03	2.41
AM3M451	8.8	0.01	12	1.67	0.35	0.62	11	0.01	0.02	2.46

Table A3.--Listing of analytical data for samples of alfalfa (continued).

[Concentrations reported on a dry-weight basis.]

Sample ID	La, ppm	Li, ppm	Mg, %	Mn, ppm	Mo, ppm	Na, %	Ni, ppm	P, %	Sc, ppm	Se, ppm
AH3H411	0.94	2.2	0.42	57	8.1	0.07	3.0	0.50	<0.62	1.0
AH3H412	0.94	2.3	0.41	65	8.0	0.07	2.8	0.56	<0.62	0.81
AH3H421	0.94	2.3	0.42	60	8.4	0.09	3.9	0.69	<0.62	1.1
AH3H431	0.90	2.3	0.42	60	8.6	0.09	2.9	0.59	<0.62	0.88
AH3H441	1.0	2.5	0.46	69	9.6	0.12	3.6	0.71	---	0.78
AH3H451	0.90	2.3	0.41	61	9.2	0.08	3.2	0.54	<0.62	0.87
AH3H452	0.90	2.3	0.42	55	8.4	0.08	3.2	0.53	<0.62	0.72
AH3L411	0.78	2.1	0.36	36	4.3	0.02	3.4	0.47	<0.62	0.21
AH3L421	0.79	2.8	0.38	40	3.7	0.03	5.6	0.50	<0.62	0.30
AH3L431	0.98	2.2	0.38	40	4.1	0.03	5.6	0.50	<0.62	0.35
AH3L441	0.84	2.2	0.39	37	3.6	0.03	5.2	0.53	<0.62	0.22
AH3L451	0.85	2.8	0.40	38	5.7	0.03	6.8	0.58	<0.62	0.24
AH3M411	0.59	3.7	0.29	46	3.4	0.13	2.3	0.43	<0.62	0.58
AH3M421	0.52	4.7	0.25	41	3.6	0.22	2.0	0.37	<0.62	0.64
AH3M431	0.73	2.7	0.29	43	3.5	0.07	2.6	0.45	<0.62	0.27
AH3M441	0.73	3.9	0.27	50	3.2	0.10	2.8	0.47	<0.62	0.39
AH3M442	0.64	3.6	0.25	44	2.8	0.09	2.6	0.41	<0.62	0.35
AH3M451	0.55	2.8	0.23	40	2.5	0.07	2.9	0.39	<0.62	0.24
AL3H411	0.77	1.8	0.32	55	3.5	0.04	1.5	0.36	0.66	0.39
AL3H412	0.46	1.5	0.26	43	2.8	0.04	1.2	0.30	<0.62	0.39
AL3H421	0.62	2.5	0.33	52	3.0	0.07	1.1	0.31	0.73	0.25
AL3H431	0.49	1.7	0.29	44	3.2	0.07	0.98	0.27	<0.62	0.19
AL3H441	<0.45	1.7	0.29	40	4.7	0.13	1.2	0.37	<0.62	0.18
AL3H451	0.57	2.5	0.35	41	4.9	0.17	4.7	0.38	<0.62	0.24
AL3L411	0.77	2.4	0.36	61	3.1	0.02	2.8	0.63	0.64	0.36
AL3L421	0.95	3.9	0.38	63	1.6	0.05	3.4	0.68	<0.62	0.14
AL3L431	0.65	2.1	0.39	57	0.87	0.04	3.8	0.68	<0.62	0.04
AL3L441	0.95	3.4	0.42	49	1.4	0.05	3.7	0.82	<0.62	0.21
AL3L451	0.63	2.9	0.33	57	1.6	0.04	3.3	0.62	0.63	0.07
AL3M411	0.88	2.0	0.36	48	4.3	0.28	4.5	0.57	<0.62	0.66
AL3M421	0.61	2.2	0.36	45	4.5	0.29	3.8	0.54	<0.62	0.78
AL3M422	0.72	2.0	0.36	45	4.6	0.28	3.6	0.56	<0.62	0.95
AL3M431	0.59	1.7	0.37	38	5.0	0.34	3.5	0.52	<0.62	0.89
AL3M441	0.62	1.7	0.29	33	4.1	0.29	3.4	0.44	<0.62	0.96
AL3M442	0.70	2.1	0.34	40	4.8	0.32	3.8	0.50	<0.62	0.84
AL3M451	0.51	1.7	0.28	32	3.6	0.31	3.8	0.44	<0.62	0.61
AM3L411	0.62	2.9	0.32	33	4.7	0.05	4.6	0.48	<0.62	0.66
AM3L421	0.68	1.8	0.34	40	5.7	0.04	5.3	0.55	<0.62	0.55
AM3L431	0.67	2.3	0.36	42	6.4	0.07	4.8	0.63	<0.62	0.20
AM3L441	0.66	2.5	0.38	40	6.1	0.05	4.6	0.50	<0.62	0.18
AM3L442	0.67	2.6	0.39	36	5.5	0.06	4.6	0.48	<0.62	0.18
AM3L451	0.68	2.6	0.44	43	7.1	0.06	4.1	0.59	<0.62	0.19
AM3M411	<0.45	2.9	0.25	31	3.3	0.19	1.6	0.34	<0.62	0.46
AM3M421	0.50	2.8	0.24	31	3.7	0.24	1.3	0.36	<0.62	0.21
AM3M431	0.51	3.1	0.27	29	4.7	0.27	1.4	0.34	<0.62	0.42
AM3M432	<0.45	2.9	0.26	28	4.5	0.25	1.5	0.34	<0.62	0.47
AM3M441	0.53	2.7	0.27	31	5.9	0.18	1.4	0.35	<0.62	0.23
AM3M442	0.50	2.5	0.26	28	5.4	0.17	1.4	0.37	<0.62	0.25
AM3M451	0.53	2.0	0.25	28	5.3	0.11	1.7	0.38	<0.62	0.33

Table A3.--Listing of analytical data for samples of alfalfa (continued).

[Concentrations reported on a dry-weight basis.]

Sample ID	Sr, ppm	Total S, %	V, ppm	Zn, ppm
AH3H411	81	0.54	<0.68	42
AH3H412	82	0.56	<0.68	40
AH3H421	84	0.54	<0.68	42
AH3H431	90	0.52	<0.68	40
AH3H441	91	0.60	<0.68	43
AH3H451	93	0.55	<0.68	39
AH3H452	91	0.53	<0.68	39
AH3L411	122	0.50	<0.68	41
AH3L421	127	0.51	<0.68	39
AH3L431	131	0.56	<0.68	42
AH3L441	134	0.52	0.70	40
AH3L451	184	0.52	0.85	39
AH3M411	178	0.44	<0.68	30
AH3M421	163	0.42	<0.68	22
AH3M431	176	0.48	<0.68	29
AH3M441	176	0.43	<0.68	31
AH3M442	163	0.46	<0.68	30
AH3M451	156	0.51	<0.68	25
AL3H411	242	0.47	<0.68	34
AL3H412	200	0.47	<0.68	28
AL3H421	260	0.43	<0.68	22
AL3H431	147	0.42	<0.68	22
AL3H441	184	0.45	<0.68	27
AL3H451	190	0.45	<0.68	20
AL3L411	192	0.60	<0.68	49
AL3L421	189	0.66	<0.68	59
AL3L431	174	0.51	<0.68	41
AL3L441	189	0.67	<0.68	52
AL3L451	189	0.60	<0.68	50
AL3M411	98	0.53	<0.68	46
AL3M421	99	0.54	<0.68	41
AL3M422	92	0.53	<0.68	42
AL3M431	75	0.50	<0.68	42
AL3M441	71	0.50	<0.68	37
AL3M442	78	0.49	0.70	41
AL3M451	64	0.50	<0.68	35
AM3L411	121	0.53	<0.68	33
AM3L421	114	1.40	<0.68	64
AM3L431	124	0.57	<0.68	44
AM3L441	145	0.56	<0.68	35
AM3L442	147	0.52	<0.68	34
AM3L451	150	0.56	<0.68	36
AM3M411	94	0.38	<0.68	49
AM3M421	100	0.38	<0.68	39
AM3M431	110	0.37	<0.68	43
AM3M432	109	0.38	<0.68	41
AM3M441	105	0.39	<0.68	44
AM3M442	91	0.39	<0.68	44
AM3M451	105	0.40	<0.68	37

Table A4.--Listing of analytical data for samples of wheat.

[Concentrations reported on a dry-weight basis.]

Sample ID	Ash, %	Al, %	Ba, ppm	Ca, %	Co, ppm	Cr, ppm	Cu, ppm	Fe, %	K, %	Li, ppm
WH3H411	1.70	0.0005	4.9	0.05	0.09	0.26	5.9	0.0037	0.44	<0.08
WH3H412	1.90	0.0008	6.7	0.06	0.09	0.28	6.3	0.0040	0.51	<0.08
WH3H421	1.70	0.0007	6.3	0.05	0.09	0.37	6.5	0.0041	0.46	<0.08
WH3H431	2.00	0.0008	3.6	0.06	0.08	0.30	13	0.0042	0.44	<0.08
WH3H441	1.60	0.0005	4.5	0.05	0.10	0.27	6.4	0.0035	0.42	<0.08
WH3H451	1.60	0.0006	3.4	0.04	0.10	0.24	6.1	0.0029	0.40	<0.08
WH3H452	1.70	0.0007	3.7	0.05	0.12	0.27	6.3	0.0029	0.44	<0.08
WH3M411	1.90	0.0008	5.9	0.05	0.06	0.28	4.4	0.0032	0.42	<0.08
WH3M421	1.40	0.0004	3.4	0.04	0.06	0.20	3.6	0.0020	0.36	<0.08
WH3M431	1.70	0.0007	5.6	0.04	0.05	0.26	4.1	0.0027	0.39	<0.08
WH3M441	2.00	0.0010	6.6	0.05	0.06	0.34	4.8	0.0062	0.46	<0.08
WH3M442	1.80	0.0013	5.9	0.04	0.05	0.34	4.0	0.0072	0.41	<0.08
WH3M451	1.60	0.0005	4.3	0.04	0.05	0.26	3.7	0.0024	0.38	<0.08
WL3M411	1.60	0.0003	4.8	0.04	0.05	0.22	3.7	0.0026	0.45	<0.08
WL3M421	1.60	0.0003	5.6	0.04	0.05	0.27	3.2	0.0027	0.45	<0.08
WL3M422	1.60	0.0003	5.1	0.04	0.06	0.24	3.0	0.0026	0.34	<0.08
WL3M431	1.60	0.0003	5.8	0.04	0.05	0.26	3.4	0.0026	0.40	<0.08
WL3M441	1.60	0.0005	4.0	0.05	0.06	0.22	4.2	0.0032	0.43	<0.08
WL3M442	1.90	0.0008	4.8	0.06	0.08	0.28	4.8	0.0038	0.53	<0.08
WL3M451	1.60	0.0008	4.6	0.04	0.05	0.24	3.9	0.0030	0.43	<0.08
WM3L411	1.70	0.0012	3.6	0.05	0.07	0.29	4.4	0.0034	0.41	<0.08
WM3L421	1.90	0.0008	5.9	0.06	0.06	0.28	4.6	0.0034	0.49	<0.08
WM3L441	1.80	0.0022	4.0	0.06	0.07	0.31	4.9	0.0040	0.41	0.09
WM3L442	1.50	0.0012	3.2	0.05	0.07	0.27	3.6	0.0031	0.36	0.09
WM3L451	1.80	0.0004	4.5	0.05	0.04	0.27	4.1	0.0027	0.45	<0.08
WM3M411	1.40	0.0003	4.6	0.04	<0.03	0.20	3.9	0.0036	0.38	<0.08
WM3M421	1.40	0.0006	5.5	0.04	0.03	0.21	4.2	0.0039	0.39	0.10
WM3M431	1.70	0.0022	6.0	0.05	0.05	0.41	5.3	0.0102	0.43	0.10
WM3M432	1.50	0.0014	5.3	0.04	0.04	0.34	4.2	0.0090	0.36	0.09
WM3M441	1.30	0.0007	3.3	0.05	0.05	0.18	4.3	0.0040	0.36	0.13
WM3M442	1.80	0.0007	4.7	0.06	0.07	0.27	5.6	0.0050	0.50	0.14
WM3M451	1.90	0.0008	4.4	0.06	0.06	0.28	4.6	0.0036	0.44	<0.08

Table A4.--Listing of analytical data for samples of wheat (continued).

[Concentrations reported on a dry-weight basis.]

Sample ID	Mg, %	Mn, ppm	Mo, ppm	Na, %	Ni, ppm	P, %	Se, ppm	Sr, ppm	Total S, %	Zn, ppm
WH3H411	0.12	57	0.68	0.0022	0.75	0.43	0.07	2.2	0.20	40
WH3H412	0.12	68	0.74	0.0029	0.93	0.46	0.48	3.0	0.20	43
WH3H421	0.12	66	0.68	0.0022	1.3	0.41	0.34	2.4	0.20	45
WH3H431	0.14	90	0.68	0.0016	1.0	0.46	0.18	2.6	0.22	44
WH3H441	0.11	59	0.67	0.0019	1.2	0.40	0.30	2.1	0.19	44
WH3H451	0.12	56	0.74	0.0016	1.3	0.42	0.16	2.1	0.15	43
WH3H452	0.12	61	0.77	0.0017	1.5	0.43	0.14	2.4	0.15	45
WH3M411	0.13	57	0.70	0.0040	0.63	0.44	0.19	3.6	0.16	34
WH3M421	0.09	36	0.42	0.0028	0.46	0.32	0.19	2.7	0.15	23
WH3M431	0.11	45	0.49	0.0036	0.58	0.39	0.23	3.2	0.17	30
WH3M441	0.13	50	0.60	0.0036	0.56	0.48	0.12	3.6	0.18	30
WH3M442	0.11	45	0.52	0.0038	0.58	0.41	0.17	3.4	0.17	27
WH3M451	0.11	43	0.50	0.0035	0.48	0.38	0.11	3.5	0.16	27
WL3M411	0.10	38	0.46	0.0014	0.21	0.40	0.03	6.2	0.18	22
WL3M421	0.10	40	0.43	0.0018	0.32	0.38	0.07	5.6	0.16	25
WL3M422	0.10	40	0.40	0.0016	0.27	0.38	0.07	5.8	0.16	25
WL3M431	0.10	41	0.48	0.0014	0.29	0.38	0.08	5.9	0.16	24
WL3M441	0.11	41	0.51	0.0019	0.22	0.35	0.07	5.9	0.19	28
WL3M442	0.13	51	0.61	0.0023	0.28	0.42	0.07	7.0	0.20	36
WL3M451	0.10	44	0.40	0.0014	0.22	0.38	0.11	5.6	0.18	28
WM3L411	0.11	45	0.49	0.0012	0.94	0.41	0.47	2.9	0.17	47
WM3L421	0.12	43	0.49	0.0015	0.72	0.42	0.56	4.0	0.17	49
WM3L441	0.12	57	0.58	0.0016	0.74	0.43	0.07	4.3	0.16	46
WM3L442	0.10	43	0.47	0.0012	0.58	0.34	0.35	3.5	0.16	37
WM3L451	0.12	43	0.45	0.0011	0.59	0.47	0.29	3.2	0.16	41
WM3M411	0.10	44	0.74	0.0013	0.22	0.34	0.20	2.8	0.18	26
WM3M421	0.10	49	0.84	0.0018	0.17	0.34	0.51	3.5	0.18	28
WM3M431	0.12	57	0.87	0.0019	0.31	0.44	0.31	3.6	0.18	32
WM3M432	0.11	49	0.76	0.0016	0.28	0.38	0.23	3.0	0.18	28
WM3M441	0.09	44	1.1	0.0025	0.32	0.26	0.29	3.3	0.21	28
WM3M442	0.13	57	1.3	0.0032	0.47	0.38	0.46	4.0	0.22	39
WM3M451	0.13	49	0.49	0.0013	0.74	0.46	0.51	3.6	0.17	57

Table A5.--Listing of analytical data for samples of wheat straw.

[Concentrations reported on a dry-weight basis; ---, Insufficient sample]

Sample ID	Ash, %	Al, %	Ba, ppm	Ca, %	Cd, ppm	Ce, ppm	Co, ppm	Cr, ppm	Cu, ppm	Fe, %
WH3H411	15.2	0.04	40	0.52	<0.68	<1.4	0.46	1.7	3.7	0.03
WH3H421	14.0	0.02	49	0.42	<0.68	<1.4	0.28	1.1	2.5	0.02
WH3H431	11.9	0.02	40	0.29	<0.68	<1.4	---	1.2	2.1	0.02
WH3H441	13.3	0.03	41	0.41	<0.68	<1.4	---	1.7	2.9	0.03
WH3H451	11.9	0.03	24	0.35	<0.68	<1.4	---	1.4	1.9	0.02
WL3M411	10.7	0.02	49	0.45	<0.68	<1.4	0.21	1.2	1.9	0.02
WM3L451	13.0	0.02	31	0.22	<0.68	<1.4	---	0.78	1.6	0.01
WM3M431	14.1	0.09	72	0.34	<0.68	<1.4	0.42	2.1	3.5	0.05

Sample ID	Hg, ppm	K, %	La, ppm	Li, ppm	Mg, %	Mn, ppm	Mo, ppm	Na, %	Ni, ppm	P, %
WH3H411	0.02	3.95	0.91	1.7	0.11	71	2.4	0.18	1.1	0.10
WH3H421	0.04	2.80	---	1.3	0.12	112	2.1	0.15	0.70	0.06
WH3H431	0.01	2.86	1.07	0.95	0.07	70	1.6	0.09	0.59	0.06
WH3H441	0.03	3.06	---	1.5	0.11	89	2.1	0.12	0.93	0.08
WH3H451	0.01	2.50	0.48	0.95	0.09	74	1.3	0.07	0.71	0.03
WL3M411	0.02	3.21	0.54	1.1	0.09	40	0.75	0.12	0.64	0.05
WM3L451	0.01	3.90	---	0.78	0.06	34	0.78	0.01	---	0.05
WM3M431	0.02	3.67	0.85	2.5	0.09	40	2.3	0.37	1.1	0.08

Sample ID	Sc, ppm	Se, ppm	Sr, ppm	Total S, %	Ti, %	V, ppm	Zn, ppm
WH3H411	<0.62	0.41	24	0.25	0.003	1.1	12
WH3H421	<0.62	0.19	21	0.18	<0.002	<0.68	17
WH3H431	<0.62	0.15	15	0.17	<0.002	<0.68	9.6
WH3H441	<0.62	0.20	21	0.19	<0.002	0.80	17
WH3H451	<0.62	0.10	18	0.15	<0.002	<0.68	18
WL3M411	<0.62	0.05	60	0.15	<0.002	<0.68	4.5
WM3L451	<0.62	0.11	21	0.20	<0.002	<0.68	26
WM3M431	<0.62	0.19	30	0.20	0.006	1.7	16