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Chromium Concentration in Plants: Effects of Soil Chromium Concentration and Tissue Contamination by Soil

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The effect of chromium (Cr) concentration of soil on the Cr concentration in plants was investigated. Tissue samples of a number of different plant species were collected from high-Cr and low-Cr soils found in eastern and western United States. Sample contamination by soil, estimated by titanium (Ti) analysis, was an important factor contributing to the total Cr concentration of most plant tissues analyzed. Plant samples taken from plants growing on high-Cr soils contained higher concentrations of Cr than similar plants growing on low-Cr soils. However, some of this Cr was apparently due to plant contamination by soil. The method used to quantitate contamination was not sensitive enough to be able to determine whether the concentration of Cr absorbed by plants was influenced by the total amount of Cr in the soil. However, it is clear that plant samples taken from the field are contaminated with foreign material that may invalidate certain analytical values.

Chromium (Cr) is important to animal and human nutrition because it is required for normal carbohydrate metabolism (Mertz, 1969; Anderson, 1981). Because part of the human population may be deficient in Cr, a number of studies were initiated to investigate the chemistry of Cr in soil and its uptake by plants (Desmet et al., 1975; Cary et al., 1977a,b; Lahouti and Peterson, 1979; Ramachandran et al., 1980). These studies provided evidence that Cr uptake and translocation by plant cells is very low (i.e., Cr concentration associated with the root is greater than in the leaf, which in turn is greater than in the fruit). Evidence favored plant uptake of Cr(VI) over Cr(III) from soils, perhaps because Cr(VI) is mobile in soil while Cr(III) is not (Cary et al. 1977a,b; Lahouti and Peterson, 1978). Bartlett and Kimble (1976) reported that, in soils, Cr(VI) is reduced to Cr(III) by organic matter. However, in 1979 Bartlett and James reported that Cr(III) is also oxidized to Cr(VI) in soil under conditions that may exist in the field. Lyon et al. (1970) reported that some plants growing on some soils containing relatively high Cr concentrations have elevated Cr concentrations but the portion of Cr due to tissue contamination by soil was not recognized. The objectives of this study were to determine the concentration of Cr in a wide variety of plants growing on soils containing a low or a high, naturally occurring, concentration of Cr, to estimate the apparent contamination by soil of carefully collected plant samples, and to investigate whether a relationship between Cr absorption by plants and soil Cr concentration exists.

METHODS AND MATERIALS

Sample sites were located and soils were described in cooperation with soil scientists of the USDA's Soil Conservation Service (Table I). Plant and soil samples were also collected by the Soil Conservation Service. The sites included serpentine areas of Maryland, North Carolina, and northern California. The predominant minerology or parent material of the soils sampled was dunite, granite, ash, mixed ash, montmorilonite, mica shist, olivine, serpentine, and some mixed materials with no known dominant mineral. Surface to 15-cm soil samples were taken at all plant sampling sites, dried in clean cloth bags, and ground with a porcelain mortar to pass a 100-mesh polypropylene sieve. After mixing, 0.2-g subsamples of soil were analyzed for titanium (Ti) and Cr by the ICP method of Cary et al. (1986). Plant samples were placed in clean cloth bags, dried at 70 °C to constant weight, and then separated into various plant parts and ground using a micro Wiley mill fitted with a 20-mesh stainless steel screen. Some, but not all, plants were washed with deionized water, then shaken, and put in the cloth bag. Titanium was determined in plants as in soils, and Cr was determined by the AA method of Cary and Olson (1975). Of the plant samples, about 10% was reanalyzed with use of the AA method of Cary and Rutzke (1983) as a quality control mea-

Cr Concentration in Plants

J. Agric. Food Chem., Vol. 38, No. 1, 1990 **109**

Table I. Sample Location

state	county	soil classification	series or description[a]
NC-1	Wake	Typic Kanhapludlts	Cecil scl
NC-2	Person	Typic Kanhapludlts	Appling
NC-3	Caswell	Typic Hapludalfs	Iredell
NC-4	Wilks	Typic Hapludalfs	Olivine ridge
NC-5	Heywood	NA[b]	Olivine mine spoil
NC-6	Jackson	Typic Rhodudults	Rabun
NC-7	Jackson	Typic Dystrochrepts	Ashe
MC-1	Harford	Typic Hapludalts	Gleneg 1
MC-2	Harford	Typic Hapludalfs	Chrome gsil
MC-3	Harford	NA	Serpentine, quarry residium
MC-4	Harford	Typic Hapludalfs	Chrome sil
MC-5	Harford	Ultic Hapludalfs	Neshaminy gsil
MC-6	Harford	NA	Barrens, serpentine
MC-7	Harford	NA	Barrens, allurium from site MC-6
MD-8	Baltimore	Ultic Hapludalfs	Neshaminy sil
MD-9	Baltimore	NA	Serpentine
MD-10	Baltimore	Typic Hapludults	Elioak sil
MD-11	Baltimore	Typic Hapludults	Elioak sil
MD-12	Baltimore	Typic Hapludults	Glenelg 1
MD-13	Baltimore	Typic Hapludults	Glenelg 1
MD-14	Baltimore	Ultic Hapludalfs	Neshaminy g sil
MD-15	Baltimore	Ultic Hapludalfs	Neshaminy g sil
MD-16	Baltimore	Typic Hapludalfs	Chrome sil
MD-17	Montgomery	Typic Hapludalfs	Chrome sil
MD-18	Montgomery	Typic Hapludalfs	Genelg gl
CA-1	Colusa	Typic Pelloxerert	Leesville gl
CA-2	Amador	Lithic Haploxeroll	Unknown
CA-3	Amador	Typic Haploxeroll	Unknown
CA-4	Amador	Typic Xerorthent	Honcut vfsl
CA-5	Siskiyou	Ultic Haploxeralf	Ishii Pishi gl
CA-6	Siskiyou	Ultic Haploxeralf	Cohasset gsl
CA-7	Siskiyou	Pachic Entic Xerumbrept	Shasta 1
CA-8	Siskiyou	Typic Vitrandept	McCarthy gsl
CA-9	Siskiyou	Typic Xeropsamment	Deetz
CA-10	Siskiyou	Typic Dystrandept	Iller sl
CA-11	Siskiyou	Typic Dystrandept	Sheld vfsl
CA-12	Siskiyou	Dystric Xerorthent	Oosen sl
CA-13	Siskiyou	Dystric Xerorthent	Avis sl
CA-14	Siskiyou	Typic Agrixeroll	Shadow Ranch
CA-15	Siskiyou	Typic Chromxerert	Shadow Ranch
CA-16	Siskiyou	Abruptic Durixeroll	Bieber gcl
CA-17	Siskiyou	Chromic Pelloxert	Maxwell like
CA-18	Siskiyou	Aquic Duviorthid	Gazelle si
CA-19	Siskiyou	Ultic Haploxeralf	Kinkel gl
CA-20	Siskiyou	Ultic Haploxeralf	Dubakella stl
CA-21	Siskiyou	Ultic Haploxeralf	Ishii Pishi gl

[a] Soil series is not known in every case; descriptive information is included instead. [b] Soil material sampled was not classified.

Table II. Scientific Names of Plants Analyzed

no.[a]	name
1	*Zea mays* L.
2	*Sorghum biocolor* L.
3	*Panicium miliaceum* L.
4	*Dactylis glomerata* L.
5	*Andropogon virginicus* L.
6	*Bromus marginatus* Nees
7	*Stipa pulchra* Hitchc.
8	*Poa bulbosa* L.
9	*Festuca elatior* F.
10	*Elymus glaucus* Buckley
11	*Festuca idahoensis* Elmer
12	*Lolium perenne* L.
13	*Triticum vulgare* L.
14	*Avena sativa* L.
15	*Festuca elatior* F.
16	*Bromus carinatus* Hook. and Arn.
17	*Bromus mollis* L.
18	*Lolium* L.
19	*Poa compressa* L.
20	*Bromus arvensis* L.
21	*Festucia arundinacea* Schreber
22	*Pinus virginiana* Miller
23	*Pinus echinata* Miller
24	*Quercus stellata* Wangenh.
25	*S. albidum* Nees
26	*Smilax* L.
27	*Quercus alba* L.
28	*Cornus florida* L.
29	*Kalmia latifolia* L.
30	*Gaylussacia baccata*, K. Koch.
31.	*Quercus prinus* L.
32	*Qurecus falcata* Miehaux
33	*Nyssa sylvatica* Marshall
34	*Quercus phellos* L.
35	*Oxydendrum arboreum* L.
36	*Carya texana* Buckley
37	*Acer rabrum* L.
38	*Juniperus virginiana* L.
39	*Ceanothus* L. (Whitethorn)
40	*Purshia tridentata* L.
41	*Artostaphylos pungens* L.
42	*Ceanothus integerrimus* L.
43	*Quercus marilandica* Muenchh.
44	*Smilax rotundifolia* L.
45	*Phaseolus lunatus* L.
46	*Lycopersicon lycopersicum* L.
47	*Brassica oleracea* L.
48	*Capsicum annuun* L.
49	*Cucurbita mixta* Pang.
50	*Brassica rapa* L.
51	*Phaseolus vulgaris* L.
52	*Beta vulgaris* L.
53	*Cucumis melo* L.
54	*Solanum tuberosum* L.
55	*Lactuca sativa* L.
56	*Raphanus sativus* L.
57	*Dancus carota* subsp. *sativus* Hoffm.
58	*Vigna unguiculata* L.
59	*Asparagus officinalis* L.
60	*Brassica napobrassica* L.
61	*Medicago sativa* L.
62	*Trifolium pratense* L.

[a] Refers to plants analyzed in Tables III–VIII.

sure. With both methods the standard deviation is about ±2% in the milligrams of Cr per kilogram concentration range. Correction for plant sample contamination by soil was performed by assuming that no Ti would be absorbed by plants. Thus, the percent soil in the plant sample could be calculated from the plant to soil Ti ratio and a correction made for Cr analysis based on the Cr concentration in soil (Cary et al., 1986). The major categories of plants sampled included trees, shrubs, legumes, grasses, vegetables, and small grains. Their scientific names are listed in Table II. In some cases, plants sampled on a low-Cr soil site were matched as closely as possible with similar plants on a high-Cr soil site. All sampling was accomplished within several weeks in Maryland and North Carolina. Samples from California were taken several years later during the same growing season period as in Maryland and North Carolina.

RESULTS AND DISCUSSION

When attempting to understand the relationship between the concentration of an element in the soil and in the plant grown on that soil, one should distinguish between the element absorbed by the plant and the element in the sample due to contamination by soil. In this study, the soils were classified as low- or high-Cr soils. The low-Cr soils contained less than 181 mg of Cr kg^{-1} with a range of 20–180 mg of Cr kg^{-1}. The Ti concentration for low-Cr soils ranged from 1170 to 20 040 mg of Ti kg^{-1}. The high-Cr soils contained from 190 to 11 060 mg of Cr kg^{-1}. The soil Ti concentration varied from 400 to 5900 mg of Ti kg^{-1}.

Table III. Cr and Ti Concentrations (mg/kg) in Low-Cr Soils and in Gramineae Species Grown on Them

no.	common name	organ	soil mineralogy	soil Cr	soil Ti	plant Cr	plant Ti	plant contam by soil, g/kg	corr plant Cr concn, mg/kg
				Mica Shist					
1	corn, field	leaf, stem	MD-1[a]	60	6150	0.41	5.18	0.842	0.36
1	corn, sweet	leaf, stem	MD-10	70	7140	0.27	4.19	0.587	0.24
1	corn, field	leaf, stem	MD-11	80	6570	0.34	5.25	0.799	0.28
1	corn, field	leaf, stem	MD-12	80	11190	0.22	4.49	0.401	0.19
2	sorghum	leaf, stem	MD-12	80	11190	0.16	2.05	0.183	0.15
3	millett	leaf, stem	MD-12	80	11190	0.34	2.40	0.214	0.32
				Granite					
4	orchard grass		MD-11	80	6570	0.15	4.17	0.635	0.10
5	broomsedge		NC-7	20	1170	0.17	1.97	1.684	0.14
				Dunite					
5	broomsedge		ND-1	30	5870	0.12	3.47	0.591	0.10
5	broomsedge		NC-4	60	3890	0.04	3.26	0.838	0.0
				Ashy					
6	mountain brome		CA-7	65	3390	0.18	3.16	0.932	0.04
6	mountain brome		CA-11	180	4960	0.18	4.17	0.841	0.06
7	needlegrass		CA-9	30	1820	0.28	6.58	3.615	0.18
8	bulbous bluegrass		CA-12	80	4610	0.24	4.31	0.935	0.16
				Mixed Ashy					
9	alta fescue		CA-17	75	1720	0.50	10.03	5.830	0.07
				Mixed					
10	blue wildrye		CA-6	90	3910	0.20	0.81	0.207	0.18
11	Idaho fescue		CA-19	130	3220	0.26	2.33	0.725	0.17
12	perennial ryegrass		CA-4	140	3820	0.17	3.92	1.026	0.02
13	wheat	grain	CA-4	140	3820	0.02	0.70	0.183	0.02
13	wheat	leaf	CA-4	140	3820	0.37	3.89	1.019	0.23
13	wheat	stem	CA-4	140	3820	0.46	2.63	0.689	0.40
14	oat	grain	CA-4	140	3820	0.04	2.15	0.563	0.01
14	oat	leaf	CA-4	140	3820	0.50	7.34	1.922	0.26
14	oat	stem	CA-4	140	3820	0.16	1.64	0.429	0.14
13	wheat	grain	CA-18	ND[b]	ND	0.003	0.63		
13	wheat	leaf	CA-18	ND	ND	0.18	6.01		
13	wheat	stem	CA-18	ND	ND	0.08	1.31		

[a] See Table I for cross-reference. [b] Not determined.

In this study the soil Cr to Ti ratio for low-Cr soils was generally 0.04 or less. For high-Cr soils it was often greater than 1. If one assumes that Ti is a measure of soil in a plant tissue, sample corrections based on Cr and Ti concentrations for the low-Cr soil–plant system appear valid. As the ratio of soil Cr to Ti increases as in the high-Cr soil–plant system, corrected Cr values become negative. The accuracy of the method is not adequate to make reasonable corrections in analytical data in the case where the concentration of the element in the contaminent is high and the uptake by the plant is small. It is unreasonable to assume that plants contain no Cr. If corrected values become negative, then it is impossible to demonstrate that the concentration of Cr in soil influences the concentration of Cr naturally absorbed by many plants.

Large errors could arise if (1) the soil sample analyzed is not representative of the contaminating soil faction, (2) part or all of the Cr or Ti contaminating the plant sample comes from some source other than the soil the plant is growing on (e.g., atmospheric contamination), and (3) all of the Cr or Ti is not accounted for in the plant and soil analysis (e.g., errors in analytical methodology).

Reanalysis of selected samples for Cr by a second method (Cary and Rutzke, 1983; Cary, 1985) indicated that the initial method used (Cary and Olson, 1975) was reliable.

Table III lists corrected Cr concentration in Gramineae species growing on low-Cr soils. Clearly, Cr concentration in these plants is often less than 0.3 mg of Cr kg^{-1} (column 9). Even though these plant materials generally included less than 1 g of soil kg^{-1} of plant material

(column 8), it was important to recognize this fact and correct for it (compare Cr in columns 6 and 9).

For similar plants growing on high-Cr soils, the overall Cr concentrations in the samples are generally, but not always, greater (compare average data for field corn (*Zea mays* sp.), 0.32 vs 0.33, broomsedge (*Andropogon virginicus* sp.), 0.11 vs 0.92, and orchard grass (*Dactylis glomerata* sp.) 0.15 vs 0.71 in column 6, Tables III and IV). The Ti concentration in comparable samples is similar, but due to a marked change in soil Cr to soil Ti ratio, adjustment of Cr data downward, due to the presence of soil in the plant sample, is often unrealistic (less than zero). Under these circumstances, one can only conclude that the plant sample is surely contaminated and the Cr values obtained for the plant samples must be assumed to be high. There is no conclusive evidence that the concentration of Cr in soil is related to the amount of Cr naturally incorporated into a specie of Gramineae. The concentration of Cr in the grain of either wheat (*Triticum* sp.) or oat (*Avena* sp.) grown on low-Cr or high-Cr soils is low and unaffected by soil Cr concentration (Tables III and IV). These Cr concentrations in wheat grain are similar to those reported in a number of varieties by Welch and Cary (1975) and Jones and Buckley (1977).

The concentrations of Cr in leaves and needles of various evergreen and deciduous trees and shrubs are given in Tables V and VI. Leaves of plants growing on low-Cr soils contained generally less than 0.2 mg of Cr kg^{-1} and often less than 0.1 mg of Cr kg^{-1}. The concentration of Ti in the tree and shrub samples was usually higher than observed in most of the grass samples. There is no evi-

Cr Concentration in Plants

J. Agric. Food Chem., Vol. 38, No. 1, 1990 **111**

Table IV. Cr and Ti Concentrations (mg/kg) in High-Cr Soils and in Various Gramineae Species Grown on Them

no.	common name	organ	soil mineralogy	soil Cr	soil Ti	plant Cr	plant Ti	plant contam by soil, g/kg	corr plant concn,[a] mg/kg
				Serpentine					
1	corn, field	leaf, steam	MD-5[b]	190	18750	0.29	3.61	0.193	0.25
1	corn, field	leaf, steam	MD-8	190	5900	0.38	6.34	1.075	0.19
2	sorghum	leaf, steam	MD-8	190	5900	0.42	8.08	1.369	0.18
1	corn, sweet	leaf		4760	1860	0.44	5.24	2.817	<0.44
5	broomsedge			ND[c]	ND	0.73	1.92	<0.73	
5	broomsedge			8730	2400	0.29	4.94	2.058	<0.29
5	broomsedge		MD-9	6850	1400	0.83	5.36	3.829	<0.83
5	broomsedge		MD-16	4790	3690	0.32	1.85	0.501	<0.32
15	California fescue		CA-5	8500	4820	0.50	6.45	1.339	<0.50
16	California brome		CA-15	970	3190	0.62	4.26	1.336	<0.62
9	alta fescue		CA-15	970	3190	0.94	3.80	1.192	0.09
17	soft chess		CA-15	970	3190	0.21	2.63	0.825	<0.21
	soft chess		CA-16	1140	1800	0.35	1.79	0.994	<0.35
18	areal ryegrass		CA-16	1140	1800	0.43	2.01	1.117	<0.43
11	Idaho fescue		CA-20	4250	1130	0.32	2.50	2.212	<0.32
11	Idaho fescue		CA-21	4700	1690	0.34	2.05	1.213	<0.34
				Dunite					
5	broomsedge		NC-5	11060	400	0.97	17.37	43.86	<0.97
5	broomsedge		NC-6	10680	420	0.67	9.95	23.47	<0.67
19	wire grass		NC-6	10680	420	1.12	14.42	34.01	<1.12
				Mixed					
20	annual bromegrass		CA-2	6760	1280	1.55	4.22	3.289	<1.55
21	tall fescue		CA-2	6760	1280	0.45	1.13	0.881	<0.45
21	tall fescue		CA-3	550	3670	2.15	5.86	1.597	1.27
4	orchard grass		CA-3	550	3670	0.71	2.65	0.722	0.31
				Montmorillinite					
13	wheat	grain	CA-1	830	3580	0.09	0.52	0.145	<0.09
13	wheat	leaf	CA-1	830	3580	0.92	8.03	2.244	<0.92
13	wheat	stem	CA-1	830	3580	0.45	2.93	0.819	0.01
14	wild oat	grain	CA-1	830	3580	0.24	0.90	0.252	0.04
14	wild oat	leaf	CA-1	830	3580	1.73	13.07	3.653	<1.73
14	wild oat	stem	CA-1	830	3580	0.89	5.09	1.423	<0.89

[a] If contamination of a plant sample leads to a negative value for Cr, the corrected Cr concentration is reported as less than the uncorrected Cr value. [b] See Table I for cross-reference. [c] Not determined.

dence of accumulation of Cr in needles of plants growing on low-Cr soil, over that of leaves of deciduous trees, but leaves appear to contain a higher concentration of Cr than the stems (Table V). On high-Cr soils at sites MD-4 and MD-9 (Table VI) Virginia pine (*Pinus virgeniana*) needle and stem tissues contain higher concentrations of Cr than leaves of white oak (*Quercus alba* sp.) or black jack oak (*Quercus mari-landica* sp.). Among the tree and shrub samples, a number of species can be compared as to the effect of soil Cr concentration on leaf Cr concentration (Tables V and VI) if sample contamination is ignored. For example, post oak (*Quercus stellata*) and Virginia pine had much higher concentrations of Cr in leaf and needle samples from trees grown in high-Cr soils than those grown in low-Cr soils. Ratios of Cr to Ti in the respective soils lead to uncertainty in the concentration of Cr absorbed and translocated to the leaves and needles because corrected values are less than zero in the high-Cr soil plant samples. Thus, it is uncertain whether the concentration of Cr in these soils influences the concentration of Cr taken up by these trees.

The corrected concentration for vegetable plant parts ranged from 0.01 mg of Cr kg⁻¹ to less than 6.50 mg of Cr kg⁻¹, while Ti concentrations of the same samples ranged from as low as 0.96 to 34.69 mg of Ti kg⁻¹ (Table VII). When Cr concentration in squash fruit grown on low-Cr soil is compared to squash (*Cucurbita mixta* sp.) fruit grown on high-Cr soil, there is no difference. Comparison of results for cabbage (*Brassica oleracea* sp.) are inconclusive. Cabbage grown in low-Cr soils contained 0.04 and 0.34 mg of Cr kg⁻¹ and grown in high-Cr soils con-

tained from <0.23 to 1.01 mg of Cr kg⁻¹. The high-Cr concentration found in cabbage in both the low-Cr and high-Cr soil situation was associated with high concentrations of Ti in the plant sample. At the same time, Cr concentration in the soil was much higher in the high-Cr soil situation when the cabbage Cr concentration was relatively low (0.23 and 0.72 mg of Cr kg⁻¹) compared to when the cabbage Cr concentration was calculated to be 1.01 mg of Cr kg⁻¹ (1860 and 3490 vs 910 mg of Cr kg⁻¹ soil). The Cr concentration in other plants was generally higher when the plant was grown on a Cr-rich soil as compared to a low-Cr soil. Even when the plant samples were washed at sampling time, the Ti concentration in the table beet (*Beta vulgaris* sp.) and radish (*Raphanus sativa* sp.) top remained so high that residual soil contamination is to be suspected (Table VII). It is impossible to remove all soil contamination by washing procedures (Cherney et al., 1983). Mitchell (1960) suggested that soil particles may become lodged in plant parts as they emerge from the soil. Rain drop impact on exposed soil surfaces could transfer soil to aerial surfaces of plants growing close to the ground. In the case of tree leaves, the most likely source of contamination is fine dust that may or may not originate from the soil or in the immediate vicinity in which the sample is taken. For elements with a soil to plant ratio of more than 100, the possibility of soil contamination will be important (Mitchell, 1960). Generally, this criterion is met in the case of Cr.

Alfalfa (*Medicago sativa* sp.) and red clover (*Trifolium pratense* sp.) samples from a high-Cr soil con-

112 J. Agric. Food Chem., Vol. 38, No. 1, 1990

Cary and Kubota

Table V. Cr and Ti Concentrations (mg/kg) in Low-Cr Soils and in Trees and Shrubs Grown in Them

no.	common name	organ	soil mineralogy	soil Cr	soil Ti	plant Cr	plant Ti	plant contam by soil, g/kg	corr plant Cr concn,[a] mg/kg
			Granite						
22	Virginia pine	needle	NC-2[b]	20	2090	0.21	18.46	8.833	0.11
23	shortleaf pine	needle	NC-2	20	2090	0.20	11.40	5.456	0.09
24	post oak leaf	needle	NC-2	20	2090	0.21	10.31	4.933	0.11
25	sassafras	needle	NC-2	20	2090	0.10	9.07	4.340	0.01
26	smilax	leaf, vine, berry	NC-2	20	2090	0.14	10.35	4.952	0.04
27	white oak	leaf	NC-7	20	1180	0.17	1.97	1.677	0.14
28	dogwood	leaf	NC-7	20	1180	0.10	3.44	2.928	0.04
25	sassafras	leaf	NC-7	20	1180	0.12	1.55	1.319	0.10
29	kalmia	leaf	NC-7	20	1180	0.19	3.26	2.774	0.14
30	huckleberry	leaf, stem	NC-7	20	1180	0.34	3.14	2.672	0.29
			Dunite						
31	jack oak	leaf	NC-1	30	5870	0.08	5.10	0.869	0.06
32	red oak	leaf	NC-1	30	5870	0.13	4.49	0.765	0.11
27	white oakd	leaf	NC-1	30	5870	0.07	3.52	0.600	0.05
33	black gum	leaf	NC-1	30	5870	0.17	3.51	0.598	0.15
30	huckleberry	leaf	NC-1	30	5870	0.31	9.36	1.596	0.26
27	white oak	leaf	NC-3	90	20040	0.13	6.03	0.301	0.10
24	post oak	leaf	NC-3	90	20040	0.18	10.76	0.537	0.13
34	willow oak	leaf	NC-3	90	20040	0.14	7.01	0.35	0.11
34	willow oak	leaf	NC-4	60	3890	0.21	10.70	2.751	0.10
24	post oak	leaf	NC-4	60	3890	0.22	12.56	3.229	0.02
23	shortleaf pine	needle	NC-4	60	3890	0.34	28.65	9.913	<0.34
35	sourwood	leaf	NC-4	60	3890	0.34	13.44	3.455	0.13
36	hickory	leaf	NC-4	60	3890	0.24	12.73	3.272	0.04
37	red maple	leaf	NC-4	60	3890	0.19	9.81	2.522	0.03
28	dogwood	leaf	NC-4	60	3890	0.17	15.29	3.931	<0.17
38	red cedar	needle	NC-4	60	3890	0.29	24.53	6.306	<0.29
25	sassafras	leaf	NC-4	60	3890	0.18	6.24	1.604	0.08
			Ashy						
39	mountain white thorn	leaf	CA-7	65	3390	0.14	3.78	1.115	0.08
39	mountain white thorn	stem	CA-7	65	3390	0.07	2.37	0.069	0.04
40	bitterbrush	leaf	CA-7	65	3390	0.16	4.62	1.363	0.06
40	bitterbrush	stem	CA-7	65	3390	0.16	6.07	1.791	0.04
41	greenleaf manzanita	leaf	CA-8	60	2690	0.07	2.60	0.966	0.01
41	greenleaf manzanita	stem	CA-8	60	2690	0.25	10.06	3.738	0.02
40	bitterbush	leaf	CA-9	30	1820	0.50	13.11	7.211	0.29
40	bitterbush	stem	CA-9	30	1820	0.37	8.10	4.455	0.25
41	greenleaf manzanita	leaf	CA-9	30	1820	0.19	1.18	0.649	0.17
41	greenleaf manzanita	stem	CA-9	30	1820	0.16	2.87	1.579	0.11

[a] If contamination of a plant sample leads to a negative value for Cr, the corrected Cr concentration is reported as less than the uncorrected Cr value. [b] See Table I for cross-reference.

Table VI. Cr and Ti Concentrations (mg/kg) in High-Cr Soils and in Trees and Shrubs Grown on Them

no.	common name	organ	soil mineralogy	soil Cr	soil Ti	plant Cr	plant Ti	plant contam by soil, g/kg	corr plant Cr concn, mg/kg
			Serpentine						
42	deer brush	leaf	CA-20[a,b]	4250	1130	0.13	1.10	0.970	<0.13
42	deer brush	stem	CA-20	4250	1130	0.09	ND[c]		0.09
42	deer brush	leaf	CA-21	4700	1690	0.14	1.22	0.723	<0.14
42	deer brush	stem	CA-21	4700	1690	0.07	0.64	0.379	0.07
27	white oak	leaf	MD-4	1270	4460	0.97	8.83	1.980	<0.97
22	Virgina pine	needle, stem	MD-4	1270	4460	0.95	4.99	1.119	<0.95
30	huckleberry	leaf, stem	MD-4	1270	4460	1.30	10.09	2.262	<1.30
28	dogwood	leaf, stem	MD-5	195	18750	0.87	9.55	0.509	0.73
25	sassafras	leaf, stem	MD-5	195	18750	0.50	3.56	0.190	0.48
22	Virgina pine	needle, stem	MD-6	8735	2400	0.49	7.79	3.244	<0.49
38	red cedar	needle, stem	MD-6	8735	2400	1.15	14.89	6.202	<1.15
26	smilax	leaf, stem	MD-6	8735	2400	0.76	7.77	3.236	<0.76
26	smilax	leaf, stem	MD-7	3030	2595	0.42	6.13	2.362	<0.42
25	sassafras	leaf, stem	MD-7	3030	2595	0.72	7.31	2.817	<0.72
32	red oak	leaf, stem	MD-7	3030	2595	0.39	5.21	2.008	<0.39
43	blackjack oak	leaf, stem	MD-9	6850	1405	1.80	17.85	12.71	<1.80
22	Virginia pine	needle, stem	MD-9	6850	1405	2.50	16.73	11.91	<2.50
			Dunite						
44	greenbrier	leaf, vine	NC-6	10680	420	0.32	5.46	12.88	<0.32
24	post oak	leaf	NC-6	10680	420	2.00	21.32	50.28	<2.00
22	Virginia pine	needle	NC-6	10680	420	1.24	17.09	40.31	<1.24

[a] If contamination of a plant sample leads to a negative value for Cr, the corrected Cr concentration is reported as less than the uncorrected Cr value. [b] See Table I for cross-reference. [c] Not determined.

Table VII. Cr and Ti Concentrations (mg/kg) in High-Cr and Low-Cr Soils and In Vegetables Grown in Them

no.	plant common name	organ	soil mineralogy	soil Cr	soil Ti	plant Cr	plant Ti	plant contam by soil, g/kg	corr plant concn,[a] mg/kg
			Mica Shist						
45	lima bean	pole, leaf	MD-10[b]	70	7140	0.50	13.13	1.839	0.38
46	tomato	leaf, stem	MD-10	70	7140	0.38	4.68	0.655	0.32
47	cabbage	leaf	MD-10	70	7140	0.45	12.03	1.685	0.34
48	pepper	leaf, stem	MD-10	70	7140	0.27	4.65	0.651	0.23
46	tomato	fruit	MD-18	85	6150	0.04	2.48	0.403	0.01
46	tomato	leaf	MD-18	85	6150	1.01	34.69	5.636	0.54
47	cabbage	leaf	MD-18	85	6150	0.06	1.56	0.253	0.04
49	squash	fruit	MD-18	85	6150	0.02	0.96	0.156	0.01
46	tomato	leaf, stem	MD-13	ND[c]	ND	0.48	7.29		
50	turnip	top	MD-13	ND	ND	0.28	7.37		
51	bush bean	pod	MD-13	ND	ND	0.09	3.84		
			Serpentine						
52	beets	root, top	MD-17	910	4250	1.10	10.47	2.463	<1.10
47	cabbage	leaf	MD-17	910	4250	4.30	15.66	3.684	1.01
48	pepper	leaf, stem, fruit	MD-17	910	4250	0.89	6.37	1.498	<0.89
46	tomato	leaf, fruit	MD-17	910	4250	5.50	17.91	4.213	1.66
53	cantelope	fruit	MD-17	910	4250	0.14	2.61	0.614	<0.14
49	squash	fruit	MD-17	910	4250	0.04	2.16	0.508	<0.04
54	potato	tuber	MD-17	910	4250	0.65	2.00	0.470	0.28
55	lettuce, red	leaf, washed	CA-14	1220	1920	0.73	ND		
52	beet, table	top	CA-14	1220	1920	0.71	4.23	2.201	<0.71
52	beet, table	root top	CA-14	1220	1920	2.82	6.36	3.309	<2.82
56	radish	top	CA-14	1220	1920	2.03	5.69	3.101	<2.03
56	radish	root	CA-14	1220	1920	0.84	ND		
57	carrot	top	CA-14	1220	1920	0.91	ND		
57	carrot	root	CA-14	1220	1920	2.28	ND		
58	black eyed pea	leaf, stem	MD-2	1860	4670	1.28	18.40	3.940	<1.28
47	cabbage	leaf	MD-2	1860	4670	0.23	3.43	0.734	<0.23
55	lettuce	leaf	MD-2	1860	4670	9.60	ND		
46	tomato	leaf, stem	MD-2	1860	4670	9.50	ND		
51	bush bean	leaf, stem	MD-14	3490	3550	4.30	ND		
46	tomato	leaf, stem	MD-14	3490	3550	4.75	20.66	5.818	<4.15
54	potato	leaf	MD-14	3490	3550	6.50	33.09	9.318	<6.50
47	cabbage	leaf	MD-14	3490	3550	0.72	3.25	0.915	<0.72
46	tomato	leaf, stem	MD-15	8510	3120	2.18	8.27	2.653	<2.18
55	lettuce	leaf	MD-15	8510	3120	0.51	6.07	1.947	<0.51
48	pepper	leaf	MD-15	8510	3120	0.46	ND		
59	asparagus	leaf, stem	MD-15	8510	3120	1.42	8.20	2.631	<1.42
60	rutabagus	leaf	MD-15	8510	3120	1.79	6.37	2.044	<1.79
54	potato	tuber	MD-15	8510	3120	0.65	1.11	0.356	<0.65

[a] If contamination of a plant sample leads to a negative value for Cr, the corrected value is reported as less than the uncorrected valued. [b] See Table I for cross-reference. [c] Not determined.

Table VIII. Cr and Ti Concentrations (mg/kg) in Low-Cr and High-Cr Soils and in Forage Legumes Grown on Them

no.	plant common name	organ	soil mineralogy	soil Cr	soil Ti	plant Cr	plant Ti	plant contam by soil, g/kg	corr plant Cr concn, mg/kg
			Mica Shist						
61	alfalfa	leaf, stem	MD-11[a]	80	6570	0.34	6.41	0.976	0.11
62	red clover	leaf, stem	MD-11	80	6570	0.14	3.86	0.588	0.10
			Mixed Ashey						
61	alfalfa	leaf, stem	CA-17	75	1720	0.99	7.40	4.300	0.68
			Serpentine						
61	alfalfa	leaf, stem	MD-5	195	18750	0.14	3.36	0.179	0.12
62	red clover	leaf, stem	MD-5	195	18750	0.14	3.61	0.193	0.11

[a] See Table I for cross-reference.

tained very little soil. Doubling the Cr concentration of soil had no influence on the Cr concentration in these legumes (Table VIII).

Often, plants growing on low-Cr soils will appear to have lower concentrations of Cr than similar plants grown on high-Cr soil, but this may be due to contamination. Evidence that addition of up to 1% Cr as $Cr(OH)_3$ to soil would increase the Cr concentration in alfalfa and buckwheat (Cary et al., 1977b) must now be viewed cautiously because no measure of sample contamination was attempted. Even though Cr(III) will oxidize to Cr(VI)

under some field conditions (Bartlett and James, 1979), and the presence of chromate ion appears to enhance the uptake of Cr by some plants (Cary et al., 1977b), there are no data given here that supports the contention that plants grown on high-Cr soils will absorb more Cr than similar plants grown on low-Cr soils. Indeed the soil samples in this study were not treated so that meaningful measurements of Cr(III) and Cr(VI) concentrations could be made (Bartlett and James, 1980). In future work this would be important to measure. For samples for which species were split into stem or leaf or fruit, these data

support other data that the lowest Cr concentration will be found in the fruit, with increases in the stem and the highest concentration in the leaf (Desmet et al., 1975; Lahouti and Peterson, 1979; Ramachandran et al., 1980; Cary et al., 1977a,b). Possibly, contamination of leaves by soil is a function of morphology. Leaves that are hairy, as tomato leaves, might be more efficient in collecting and retaining soil particles than a smooth-leaf species. Leaf age may be an important factor because needles appeared to contain higher concentrations of Ti than leaves of deciduous trees. However, more research is required to prove this hypothesis. There is a need to identify the source of Cr and Ti occurring on plants growing on high-Cr soils.

Registry No. Cr, 7440-47-3; Ti, 7440-32-6.

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Nonprotein Nitrogen Contents of Animal and Plant Foods

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Nonprotein nitrogen (NPN) was extracted from 20 primary food products and purified by constant-volume ultrafiltration (10 000 MW cutoff) before separation and quantification of free and acid-hydrolyzable amino acids (AA) and their amides. Animal, fish, and poultry products contained 0–35 mg, cereal and pulse grains had 12–44 mg, and roots, vegetables, and fruits contained 65–240 mg of NPN/g of N. Free AA constituted one-third and half of total hydrolyzable AA in the animal and plant foods, respectively, and 70–90% of NPN was composed of non amino acid nitrogen. Glu/Gln and Asp/Asn were prominent in most free AA and peptide fractions, and Lys was a major AA in the free AA pool.

Nonprotein nitrogen (NPN) of food products is of interest to food processors, nutritionists, and dieticians for quite different reasons. NPN is defined as peptides too small to be precipitated and filtered, free amino acids (AA), amides, and other nonpolymeric nitrogen (N) constituents of the plant or animal product. The interactions of free AA with simple sugars in Maillard reactions are important contributors to food color and flavor (Buck-