GEOCHEMICAL SURVEY OF MISSOURI

Elemental Composition of Corn Grains, Soybean Seeds, Pasture Grasses, and Associated Soils from Selected Areas in Missouri

GEOLOGICAL SURVEY PROFESSIONAL PAPER 954-D

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A study of geochemical variation between four vegetation-type areas as indicated by analyses of cultivated plants and soils

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By JAMES A. ERDMAN, HANSFORD T. SHACKLETTE, and JOHN R. KEITH

ABSTRACT

Plant parts and soils, sampled according to a three-level geographically nested design, were analyzed to determine the nature of the geographic variation in chemical composition. Only about one-half of the soil constituents that were measured exhibited significant variation between vegetation-type areas; most variation was within these areas and was largely between sites within 7½-minute quadrangles. Soils from the Glaciated Prairie tended to be high and those from the Floodplain Forest, low, in the concentrations of most elements. Differences in concentrations of certain elements in cultivated and uncultivated soils suggest that agricultural practices may have caused slight element depletion. Almost all the variation in elemental composition of plant materials was at the between-site level. For the most part, the concentrations of elements in the plant materials do not clearly reflect the total elemental compositions of the associated soils.

INTRODUCTION

Cultivated plants and soils predominate in most arable land areas of the central United States, the native plants and uncultivated soils generally persisting only at locations where steep grades and stony, shallow soils make cultivation impractical. A study of the geochemical characteristics of these areas should include both the cultivated and uncultivated plants and soils; however, crop and pasture plants now provide the major biogeochemical influence on chemical-element cycling and soil development in many parts of this country. An earlier geochemical study of native plants and uncultivated soils of Missouri revealed significant differences in concentrations of many elements in these materials from the six vegetation-type areas of the State (Erdman and others, 1976). The present geochemical study was planned as a second phase of this work, in which the effects of abundance of elements in the soil on the concentrations of these elements in soybeans, corn grains, and pasture grasses could be examined, and baseline data on the elemental composition of these plant products could be established.

The scope and general objectives of the Missouri geochemical investigations, of which the present study is a part, were outlined by U.S. Geological Survey (1972a) and by Connor and others (1972), and were discussed further by Miesch (1976) and by Erdman, Shacklette, and Keith (1976). These reports emphasized that these investigations constituted a pilot study for the development of methods for geochemical surveys of large areas. Particular attention was given to the use of efficient methods of sampling and sampling design and to the synthesis of geochemical data in a rigorous, scientifically defensible manner. Special efforts were made in these studies to unify methodology in sampling, chemical analysis, statistical evaluation, and data presentation for the several disciplines, so that results from each study would be comparable with results of the other studies, insofar as that would be appropriate.

Informal collaboration of the U.S. Geological Survey projects and the Environmental Health Surveillance Center, University of Missouri, was promoted by seven semiannual releases of progress reports (U.S. Geological Survey, 1972a-f, 1973), which described the current status of the geochemical studies and gave results of these studies as available. The surveillance center was simultaneously conducting epidemiological studies in Missouri, in the search for possible geographical patterns of animal and human health problems that might correspond to patterns of geochemical abundances in natural materials. In order to make our geochemical data readily useful in epidemiological and other studies, maps of element concentrations at a regional scale for the several sampling media were prepared, where possible.

We are indebted to many U.S. Geological Survey colleagues for their assistance during the course of this study. A. T. Miesch provided valuable guidance both in coordinating the Missouri geochemical studies as a whole and in using statistical techniques. Josephine G. Boerngen provided technical assistance in the computer processing of the data. Chemical analyses of plant materials were performed by Thelma F. Harms, Harriet G. Neiman, and Clara C. S. Papp. The soil samples were analyzed by Leon A. Bradley, F. W. Brown, G. T. Burrow, Joseph W. Budinsky, J. P. Cahill, I. C. Frost, Johnnie Gardner, B. A. McCall, Leung Mei, Violet M. Merritt, Roosevelt Moore, Harriet G. Neiman, Ramona L. Rahill, G. D. Shipley, M. W. Solt, J. A. Thomas, J. S. Wahlberg, and T. L. Yager. We acknowledge with gratitude the facilities and services provided by Dr. Carl J. Marienfeld and his associates of the Environmental Health Surveillance Center, University of Missouri.

EFFECTS OF AGRICULTURAL OPERATIONS ON NATURAL ECOSYSTEMS

Agricultural operations commonly have a great impact on soil-plant relationships when natural ecosystems are changed to artificial ones. Tillage changes the structure of soils by altering the natural soil horizons within the plow zone (generally 6-8 inches (15-20 cm) thick); it mixes surface materials, including vegetation, throughout the cultivated profile. This mixing affects element mobility through changes in soil-moisture relationships and aeration, and in chemical interactions among the materials. Less weathered minerals may be brought to the surface where oxidation and thermal alteration are accelerated.

Microbial communities react to the altered soil profile by changes in population numbers and species composition, often with the result that the more chemically active microfloral populations increase and the microfaunal populations decrease. With proper management practices, tillage tends to improve the fertility of soils—that is, the ability of soils to produce economically important plants. Improperly managed tillage may lead to excessive erosion and leaching, by which essential chemicals are lost from the plow zone, or to compaction and hardpan formation, which interfere with the drainage and aeration that are essential for high crop yields.

The effects of other practices are superimposed on the effects of tillage in the agricultural system. Manufactured fertilizers add nutritive chemical elements (principally nitrogen, phosphorus, and potassium), commonly along with other elements found in materials that are included as fillers in the fertilizer. Natural fertilizers (manures and composts) contain, in addition to essential elements, organic materials that alter soil texture and may greatly influence the action of soil micro-organisms. Agricultural lime that is used to reduce soil acidity, to hold phosphate fertilizers in a form more available to plants and to improve soil structure, also affects the availability of certain elements to plants and therefore influences element cycling. The application of pesticides to crop plants provides an additional supply of chemical elements to agricultural soils, although because of the controls now in effect on the composition of the pesticides, the present addition is probably small.

Crop plants are, in general, herbaceous annuals and therefore promote element cycling that is rapid compared with that of native vegetation, which is composed largely of woody species (trees and shrubs) in forested regions and perennial forbs and grasses in prairie regions. The annual crop plants generally are shallow rooted, and the geochemical cycling they promote is most active in the plow zone of soils. In contrast, the deep-rooted woody and herbaceous perennial species of natural plant communities may transport elements to the surface from lower soil horizons and from soil parent materials.

Cultivated plants are ordinarily grown in a "monoculture" system—that is, only a single species is grown in a field. Accordingly, all plants in the field have the same requirements for nutritive elements and the same tendency to accept or reject the non-nutritive ones. The physiological reactions of this monoculture vegetation are locally uniform. This uniformity contrasts strongly with the varied reactions brought about by the more diverse native vegetation. The effects of monoculture on geochemical cycling are only slightly diminished by rotation of crops in a field, especially if only one annual species is alternated with another. Of all agricultural lands, pasture land for grazing livestock is probably the least affected by cultivation practices. In many farming systems, however, pastures are rotated with cultivated crops or are fertilized and seeded in a manner designed to encourage a monoculture system.

In agricultural ecosystems, various amounts of chemical elements are continually being removed from the area through the sale of produce, both vegetable and animal. Estimates of the pounds of elements per acre removed annually from the soil by crops in a standard rotation were given (Utz and others, 1938, p. 87) as follows: nitrogen, 60 (327 kilograms/hectare); phosphorus, 25 (136 kg/ha); potassium, 50 (272 kg/ha); calcium 30 (164 kg/ha); and magnesium, 20 (109 kg/ha). The amounts of elements removed annually from an acre by the sale of grazing livestock doubtless are much less than those removed by the sale of plant products, because livestock return much of the total consumed elements to the soil in animal wastes. To these losses through the sale of produce must be added the amount of elements lost through erosion and leaching. Utz and others (1938, p. 87) reported the following average annual losses (pounds per acre) in drainage waters from cultivated silt loam that was devoid of vegetation: nitrogen, 69.0 (376 kg/ha); phosphorus, a trace; potassium, 86.8 (473 kg/ha); calcium, 557.2 (3,036 kg/ha); and magnesium, 104.4 (569 kg/ha).

The agricultural ecosystem was characterized in a report of the Workshop on Global Ecological Problems, University of Wisconsin (1971, p. 20-21) as follows:

> Domestication of animals and selection of crop plants began the progressively intensive management of ecosystems which culminated in modern industrialized agriculture whose levels of production were undreamed of by our ancestors. To maintain this system, however, requires an enormous flow of fertilizers to replace the plant nutrients taken up by the crops or otherwise lost from the soil. It requires an application of pesticides to eliminate unwanted weeds and plant-eating insects and a tremendous input of fossil fuel energy for the mechanized operations. There is little recycling within this system. Man adds phosphorus to the land at a rate of over seven million metric tons per year, and all of it is soon lost, diluted beyond recovery in soils and sediments.

Natural ecosystems, in contrast to agricultural ecosystems, closely approach a steady state wherein input and output of chemical elements are nearly in balance. Duvigneaud and Denaeyer-DeSmet (1968) reported studies of a natural forest ecosystem in Belgium which indicated that only 10 percent or less of the nutrient flow depended on inputs through rain and snow, and that there were no other sizable inputs. The report of the Workshop on Global Ecological Problems. University of Wisconsin (1971, p. 101) commented on this Belgian study as follows:

> It seems to be a universal condition in such undisturbed forests that the mineral nutrients are for the most part bound up in the living plants and animals. As a consequence, the recycling is very tightly controlled. A forest such as the one in Belgium is then almost self-contained, or put another way, it is weakly coupled with its external environment. Similar results have been reported for the second growth Douglas Fir ecosystem of the Pacific Northwest of the U.S.A.

In view of these great differences in element cycling of the two ecosystems, the measurement of the differences by means of geochemical studies may seem to be possible. However, the reported losses from agricultural ecosystems are so small in proportion to the total amount present that they may be impossible to measure by any practical scheme of sampling and laboratory analysis. Furthermore, these losses may be balanced by the additions of fertilizers to agricultural lands, or reduced by aerial deposition of particulates and by soluble elements in precipitation. In a study of the geochemistry of Georgia soils, Shacklette, Sauer, and Miesch (1970) found that concentrations of many elements in samples from two areas of the State differed greatly, but that within each area the chemical composition of garden soil and uncultivated forest soil samples was not different. They concluded (p. C35), "The cultivation of garden soils apparently has not greatly altered their content of the elements that were studied, if judged by the concentrations of these elements in uncultivated soils."

DESCRIPTION OF SAMPLING AREAS

The basis for the sampling plan used in this study was the same as that used in the earlier study of native plants and uncultivated soils—the delineation of vegetation-type areas as modified from Küchler's (1964) map—except that we reduced the vegetation-type areas that were sampled to four (fig. 1). Although data were given by Missouri Crop and Livestock Reporting Service (1970) on production of corn and soybeans in the Oak-hickory-pine Forest and Cedar Glade vegetation-type areas, these crops were not produced at sites that were characteristic of the vegetation-type areas. In the Cedar Glade area, the characteristic native plant communities sampled in the earlier study occurred on thin, dry soils overlying carbonate bedrock of flats, ridges, and slopes. In the Oak-hickory-pine Forest area, these plant communities grew only on shallow overdrained soils overlying sandstone bedrock of ridges. Both of these kinds of sites are not suitable for conversion to agricultural use by tillage and consequently, the crops that are grown within these two vegetation-type areas occur on valley alluvium or, to a lesser extent, on slopes that have deeper, more moist soils than those that support cedar and pine forests. These two vegetation-type areas, therefore, were excluded from the sampling plan for cultivated plants and soils.

A discussion of the original and present natural vegetation and soils of the vegetation-type areas in Missouri, including the areas sampled in this study, was given by Erdman, Shacklette, and Keith (1976);

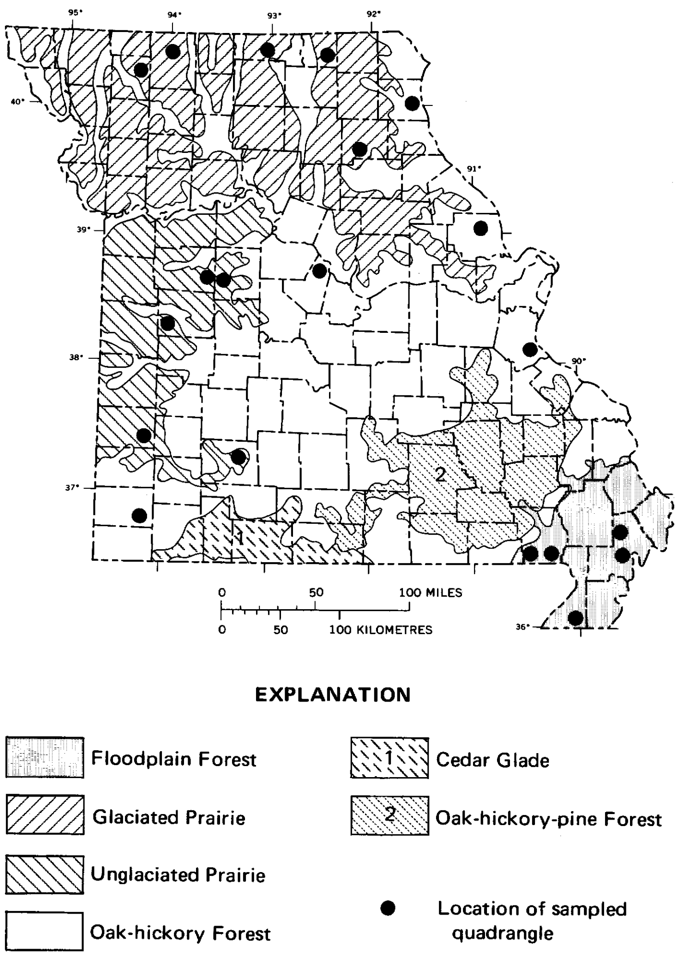


FIGURE 1.—Vegetation-type areas in Missouri, and location of quadrangles in which corn, soybeans, pasture grasses, and associated soils were sampled. The Cedar Glade and Oak-hickory-pine Forest areas were not sampled. Map modified from Kuchler (1964).

therefore, only a synopsis of this discussion will be presented in the descriptions of sampling areas that follow. Statistics of agricultural production in Missouri in 1969 that were given by the Missouri Crop and Livestock Reporting Service (1970) are used to indicate the relative importance, expressed as acres devoted to a crop and the yield per acre, of corn and soybeans in the four areas that were sampled. Statistics for pasture grasses were not given by the reporting service; however, the relative importance of these grasses among the sampling areas can be roughly evaluated from the data that were given on hay production, because meadows are often mowed for hay or are grown in rotation with other hay crops.

The Missouri Crop and Livestock Reporting Service (1970) divided the State into nine reporting districts, as shown in figure 2. Summaries of agricultural production by reporting districts were discontinued

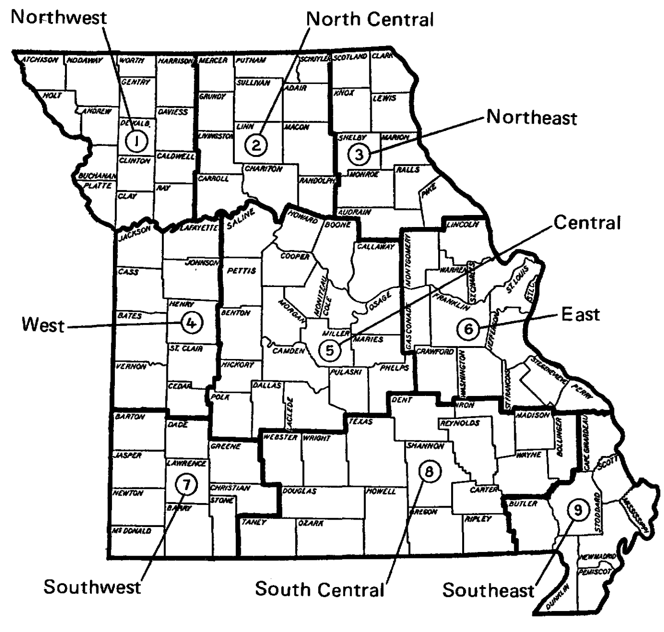


FIGURE 2.—Missouri crop and livestock reporting districts. Numbers on the map indicate locations of reporting-district offices. From Missouri Crop and Livestock Reporting Service (1970).

(except for beef cattle) after 1969; therefore, crop data for 1969 are used in this report, although our sampling of the cultivated plants and soils was done in 1971. These reporting districts roughly coincide, or can be grouped so that their combined areas generally coincide, with the vegetation-type areas that were sampled. The climatological data were obtained from the same reporting service and are based on records of the U.S. Environmental Science Services Administration.

FLOODPLAIN FOREST

This vegetation-type area in Missouri (fig. 1) formerly was densely forested land that was mostly swampy. It has since been cleared of timber and drained by means of an extensive system of canals and ditches, and so now it consists almost entirely of highly productive farm land. The remnants of native vegetation grow mostly on roadsides and banks of drainage streams. The area generally has low relief; moreover, some fields have been leveled by machines until they are nearly flat. The soil is deep and mostly alluvial in origin, and its composition reflects changes in the nature of the waterborne deposits with time. Consequently, the texture of the surficial layer may range from sand to dark organic and clay mixtures within the lateral extent of only a few metres. The technical classification of soils of the area was given by the U.S. Soil Conservation Service (in U.S. Geological Survey, 1970, p. 86) as principally Haplaquepts (seasonally wet soils with weakly developed horizons, with either a light-colored or thin black surface horizon) and Hapludalfs (medium to high in bases) gray to brown surface horizons with subsurface horizons of clay accumulation; generally moist, but intermittently dry for short periods in some seasons).

The total precipitation in 1969 was about 48 inches (122 cm). The average temperatures for the coldest and warmest months were, respectively, January 33.3°F (0.7°C) and July 83.2°F (28.4°C).

The extent of this area closely corresponds to that of the southeast agricultural reporting area 9 (fig. 2). Production data for this area follow:

Corn—200,000 acres (80,940 ha); yield per acre, 71.0 bushels (4,771 kg/ha).

Soybeans—1,329,000 acres (573,846 ha); yield per acre, 24.0 bushels (1,613 kg/ha).

Hay, all kinds—69,000 acres (27,924 ha); yield per acre, 1.74 tons (3.90 tonnes/ha).

GLACIATED PRAIRIE

The pre-settlement vegetation of this area consisted of a mosaic of Bluestem Prairie and Oak-hickory Forest (Küchler, 1964), but this mosaic has virtually disappeared. The prairie soils are mostly under cultivation, and the formerly extensive communities of grasses and forbs generally occur only along roads and fence rows. Most forests are only along streams or in isolated upland groves. In both this study and in the earlier geochemical study of native vegetation in this area, samples were collected at sites that were, or now are, typical of the Bluestem Prairie. Some of the sampled soils were dark prairie loam, classified by the U.S. Soil Conservation Service (in U.S. Geological Survey, 1970, p. 86) as Argiudall (black, friable, organic-rich surface horizon, high in bases; calcium carbonate or gypsum horizons are absent). A second soil type sampled was gray-brown podzolic, classified as Hapludalf (gray to brown surface horizons, medium to high in bases; usually moist, but during the warm season may be intermittently dry for short periods; with thin subsurface horizon of clay accumulation). A third soil of this area was of more limited extent and is classified as Albaqualf (medium to high in bases; with a bleached upper horizon that changes abruptly in texture to an underlying horizon of clay accumulation).

The total precipitation in 1969 ranged from about 30 inches (76 cm) in the west-central part of the area to about 40 inches (102 cm) in the eastern part. Average temperatures for the coldest and warmest months, respectively, were as follows: west-central part—January, 23°F (-5°C), July, 79°F (26°C); eastern part—January, 22°F (-5.6°C), July, 77°F (25°C).

This vegetation-type area roughly corresponds to the combined areas of the northwest, north-central, and northeast agricultural reporting areas 1, 2, and 3, respectively (fig. 2). Combined production data for these three reporting areas follow:

Corn—1,380,000 acres (558,486 ha); yield per acre, 63-81 bushels (4,234-5,443 kg/ha).

Soybeans—1,390,000 acres (562,533 ha); yield per acre, 25-31 bushels (1,680-2,083 kg/ha).

Hay, all kinds—1,060,000 acres (428,982 ha); yield per acre, 1.94-2.32 tons (4.35-5.20 t/ha).

UNGLACIATED PRAIRIE

The original vegetation of this area was similar to that of the Glaciated Prairie, in that it consisted of a mosaic of prairie species and forest species. At present most cultivated land of moderate relief comprises areas that were primarily vegetated with prairie plants, although there is evidence that some cultivated land was originally forested. The soils were derived from bedrock (largely carbonate rocks) and loess deposits. Dark prairie soils predominate in the northern third of the area. These soils were classified by the U.S. Soil Conservation Service (in U.S. Geological Survey, 1970, p. 86) as Hapludoll (nearly black, organic-rich surface horizon, high in bases; usually moist; not horizon of calcium carbonate or gypsum accumulation and no subsurface clay horizon) and Argiudoll (similar to Hapludoll, but with a subsurface horizon in which clay has accumulated). The southern two-thirds of this area is blanketed with a gray to brown surface horizon, and the soil is classified as Albaqualf (having a bleached upper horizon, with an abrupt change in texture to underlying horizons of clay accumulation).

The total precipitation in 1969 was about 51 inches (130 cm). Average temperatures for the coldest and warmest months, respectively, were January, 27°F (-2.8°C) and July, 78°F (25.6°C).

This vegetation-type area approximately corresponds to the western agricultural reporting area 4 (fig. 2). Production data for this reporting area follow:

Corn—335,000 acres (135,574 ha); yield per acre, 71 bushels (4,771 kg/ha).

Soybeans—275,000 acres (111,292 ha); yield per acre, 28 bushels (1,882 kg/ha).

Hay, all kinds—305,000 acres (123,434 ha); yield per acre, 1.88 tons (4.21 t/ha).

OAK-HICKORY FOREST

This vegetation-type area originally was forested with many tree species, several kinds of oaks and hickories being most common. Extensions of this forest type occur along streams in the prairies (fig. 1);

these extensions were not sampled because the forest soil there is generally of alluvial origin and therefore not characteristic of this forest type as a whole. Most land of low to moderate relief has been cleared of trees and is cultivated, except areas where the soil is too shallow for tillage. The area is drained by many streams that commonly are deeply entrenched, and the slopes along the stream banks are forested. Much land is devoted to pasture, either in rotation with cultivated crops or as permanent pasture on lands that are not suited to tillage. The most extensive soils in the western and central part of this area are red-yellow podzolic soils, classified by the U.S. Soil Conservation Service (in U.S. Geological Survey, 1970, p. 86) as Paleudults (low in bases and organic matter; with short or no dry periods during the year; with a thick horizon of clay accumulation; and without appreciable weatherable minerals). Soils of the northeastern part of the area are gray-brown podzolic and are classified as Hapludalfs (medium to high in bases; brown surface soil, with a subsurface horizon of clay accumulation; usually moist during the warm season, but may be intermittently dry in some horizons for short periods).

The total precipitation in 1969 ranged from about 35 inches (89 cm) in the western part of the area to 39 inches (99 cm) in the eastern part. Average temperatures for the coldest and warmest months were as follows: west-central part—January, 33.4°F (0.8°C), July, 80.6°C); (27°C) eastern part—January, about 30°F (-1.1°C), July, 78.4°F (25.8°C).

The major parts of this vegetation-type area correspond, in a very general way, with the combined areas of the southwest, central, and eastern agricultural reporting areas 7, 5, and 6, respectively (fig. 2). Combined production data for these areas follow:

Corn—658,000 acres (266,293 ha); yield per acre, 53-70 bushels (3,562-4,704 kg/ha).

Soybeans—396,000 acres (160,261 ha); yield per acre, 24-28 bushels (1,613-1,882 kg/ha).

Hay, all kinds—1,060,000 acres (428,982 ha); yield per acre, 1.93-2.02 tons (4.33-4.52 5/ha).

METHODS OF SAMPLING PLANTS AND SOILS

SAMPLING DESIGN

The boundaries of the vegetation-type areas that were described earlier outline the categories or mapped units at which sampling was directed. Sampling for the purpose of assessing possible differences between these areas constituted stage 1a of a general sampling plan for geochemical surveys of large regions. The general plan was described by Connors and others (1972) and by Miesch (1976). This sampling was used to estimate the magnitude of the variability in chemical composition of the sampled materials at various geographic scales. No sampling of the stage 1b or phase 2 types was done.

The sampling was based on a three-level geographically nested design in which each level is associated with a specific range of scales. The top level of this design consists of the four vegetation-type areas as modified from Küchler (1964). The two lower levels consist, respectively, of 7½-minute quadrangles within areas and sites within quadrangles. A site was defined as an area where separate fields of corn, soybeans, and pasture grasses were contiguous or in close proximity to each other. A plant and a soil sample were collected at each of the three fields at a site. The geographic units at the two lower levels (quadrangles and sites) were selected for sampling by formal randomization procedures, in an attempt to reduce sampling bias.

The general statistical model employed was:

$$X_{ijk} = \mu + \alpha_i + \beta_{ij} + \gamma_{ijk}, \qquad (1)$$

where X_{ikj} represents the concentration of an element, or other constituent, reported by the analyst in a soil or plant sample at the kth site taken from the jth 7½-minute quadrangle of the ith vegetation-type area; and μ is the grand mean concentration of the element in the material under study within all four areas of the State. α_i represents the difference between the true mean concentration of an element in the ith vegetation-type area and the grand mean, μ ; β_{ij} represents the difference between the true mean concentration for the jth quadrangle and the mean of the ith vegetation-type area; and γ_{ijk} represents, in part, the difference between the element concentration of the sample at the kth site and the mean of the jth quadrangle of the area. Included in the last term, γ_{ijk}, are all effects of sample preparation and laboratory analysis referred to as "laboratory error."

The model in equation 1 follows a specific case of the analysis of variance termed the hierarchical, or "nested" case, discussed in mathematical detail by Krumbein and Slack (1956) and described as it applies to the Missouri studies by Miesch (1976. The terms a_i, β_{ij}, and γ_{ijk} are assumed to be random variables with means of zero and variances of s_α^2, s_β^2, and s_γ^2. The total variance of the element x, estimated s_x^2, may be partitioned into three components of variance:

$$s_x^2 = s_\alpha^2 + s_\beta^2 + s_\gamma^2, \qquad (2)$$

where s_{α}^2 estimates the regional or statewide effect—that is, variation between vegetation-type areas; s_{β}^2 estimates large-scale geographic variation between quadrangles within areas; and s_{γ}^2 estimates small-scale geographic variation between sites within quadranges, plus the variance attributable to laboratory error. The goal of the sampling is to obtain unbiased estimates of these variances.

With the exception of the silicon and pH data for soils, the variance components were estimated on logarithmic transforms (base 10) of the data, because the concentrations of most elements—particularly the trace elements—tended to have marked positive skewness in their frequency distributions.

The sampling design included 4 vegetation-type areas, 5 quadrangles from each area, and 2 sites within each quadrangle, for a total of 40 sites. Corn, soybeans, pasture grasses, and soils associated with each of the crops were sampled in separate fields at each site, where possible. Quadrangles that overlapped two vegetation-type areas about equally were excluded from the population of quadrangles that was to be sampled.

All samples were analyzed in a completely and formally randomized sequence in order to circumvent any effects of systematic variation in laboratory analysis. Included in this sequence was a small number of duplicate samples used to estimate the magnitude of laboratory error. In effect, these duplicate analyses constitute a fourth level of the sampling design (see the section on laboratory procedures).

Results of the analysis of variance of the soil and plant data provided estimates of the three components of variation in equation 2: between-vegetation-type variance, between-quadrangle variance, and the sum of between-site and laboratory variances. These components indicate the geographic scale of element variation in Missouri crop plants and cultivated soils; they may also be used to assess the efficiency of this or any other sampling design directed towards distinguishing between the geochemical characteristics of the four vegetation-type areas.

SAMPLING TECHNIQUES

SOILS

The plow zone of soils comprises the upper 6 to 8 inches (15-20 cm) of the soil that is tilled and generally includes part or all of the original A horizon and part of the B horizon. These horizons ordinarily have been so thoroughly mixed by successive tillage that their identities have been lost. Most soils are more compacted just below the plow zone, and at places a hardpan has formed that restricts root development of most crop plants and retards the downward movement of water. The plants sampled in this study are fibrous rooted, and their roots are largely restricted to the plow zone. Therefore, for the purpose of correlating element concentrations in soils and plants, only the plow zone soil was sampled.

Most of the soil samples were collected by digging to the bottom of the plow zone, using a hand trowel, and taking about 300 to 400 g of soil from points throughout the profile. If the soil at the site was dry and hard, a clamshell digger was used for sampling. Rock fragments larger than about 5 mm, if present, were hand culled from the sample, and the soil was put in a manila paper envelope and allowed to dry. If samples were still moist when received at the laboratory, they were dried in a low temperature (45°-50°C) oven. The soils were sampled at the same sites where the crop and pasture plants were sampled.

PLANTS

The randomly selected sampling sites in each of the sampled quadrangles were examined for the presence of separate fields of corn, soybeans, and pasture grasses that were contiguous or in close proximity. Where such fields could not be found, other randomly selected sites in alternative quadrangles (also randomly selected) were examined. In a few quadrangles, sites containing all three kinds of plants could not be found. At sites where two kinds were present, the third was omitted in sampling.

The selection of the part of a soybean field to sample was limited by the characteristic of mature soybean seeds to fall from the pods if the plants are disturbed; to prevent damage to the crop we did not walk through the fields, but sampled only at or near the edges of the fields. We chose the side of a field for sampling by drawing lots, and the distance from a corner of a field at which to sample was likewise selected. Sampling corn fields and pastures was not restricted by this constraint; therefore all parts of a field had an equal chance of being sampled. Sampling points within these fields were chosen by a randomization procedure based on a coordinate system.

Corn was collected by breaking two ears from the stalk, removing the husk (shuck) from the ears, and placing the ears in a cloth bag. Soybean pods containing the seeds were pulled from the stalks in a quantity sufficient to fill a cloth bag that measured 6x12 inches (15x30 cm). Enough pasture grass leaves and stems to fill a one-quart (about one-litre) freezer carton were clipped from the plants with steel shears.

All samples of corn were of yellow-grain hybrid varieties, except one sample of a white-grain variety, and all soybean samples consisted of yellow-seed varieties. No attempt was made to ascertain varietal names. Pasture grass samples included either one species or a mixture of several species, according to the composition of the pasture that was selected for sampling.

A list of the plant species that were sampled follows:

Corn (*Zea mays* L.)
Soybean (*Glycine max* (L.) Merr).
Pasture grasses:
- Big bluestem (*Andropogon gerardi* Vitman)
- Bluegrass (*Poa pratensis* L.)
- Fescue (*Festuca elatior* L.)
- Foxtail (*Setaria viridis* (L.) Beauv.)
- Johnson grass (*Sorghum halepense* (L.) Pers.)
- Paspalum (*Paspalum setaceum* Michx.)
- Timothy (*Phleum pratense* L.)

LABORATORY PROCEDURES USED

The corn grains were removed from the cobs, the soybean seeds were shelled from the pods, and the cobs and pods were discarded. The samples of grain, seed, and pasture grasses were air dried, then pulverized in a Wiley mill. A part of the pulverized material was weighed, then burned to ash in an electric oven in which the heat was increased 50°C per hour to a temperature of 450°C and held at this temperature for 14 hours. The resulting ash was then weighed to determine the ash yield of the dry plant material. Analytical methods for most elements employ a weighed aliquot of the ash. For determining concentrations of a few elements that would be volatilized and lost by burning the sample, weighed aliquots of the dry plant material were used for analysis.

The soil samples were dried in an oven with circulating air held at 50°C before the samples were pulverized in a ceramic mill to about minus-100-mesh particle size. Before being pulverized, the samples were not sifted through a 200-mesh sieve, as is done in some soil studies; therefore, rock particles larger than this mesh size, if present, were retained and pulverized.

TABLE 1.—*Analytical methods used in this study*

Method	Elements commonly reported, and plant ash	Principal references
Six-step emission spectrographic	In soils and plant ash: B, Ba, Be, Cr, Cu, Ga, La, Mn, Mo, Nb, Ni, Pb, Sc, Sr, Ti, V, Y, Yb, and Zr. In soils only: Co. In plant ash only: Al, Fe, and Mg.	Myers, Havens, and Dutton, 1961; Neiman, 1976.
Atomic absorption, flame	In soils and plant ash: Cd, Li, Na, and Zn. In soils only: Mg. In plant ash only: Ca and Co.	Ward and others 1969; Shacklette and others, 1973; Harms, 1976.
Atomic absorption, flameless	In soils and dry plant material: Hg.	Vaughn (1967); Harms, 1976; Huffman and Dinnin, 1976.
X-ray fluorescence	In soils: Al, Ca, Fe, K, P, Se, and Si.	Wahlberg, 1976.
Colorimetric	In plant ash only: P.	Harms, 1976.
Catalytic	In dry plant material only: I.	Cuthbert and Ward, 1964; Harms, 1976.
Specific ion electrode	In dry plant material and soils: F.	Harms, 1976; Huffman and Dinnin, 1976.
Gasometric	In soils only: Carbonate carbon.	Scott, 1962; Tourtelot, Huffman, and Rader, 1964; Huffman and Dinnin, 1976.
Calculated	In soils only: Organic carbon.	Huffman and Dinnin, 1976.
2-3 diaminonaphthalene fluorimetric	In dry plant material only: Se.	Harms, 1976.
Arsine-spectrophotometric-isotope dilution	In soils and dry plant materials: As.	Harms, 1976; Huffman and Dinnin, 1976.
Gravimetric	Ash.	Ward, Lakin, Canney, and others, 1963; Harms, 1976.

Before submitting the plant samples to the laboratories for chemical analysis, we selected 26 samples of the 3 kinds of plants at random from the total of 115 collected. Each of these selected samples was divided into 2 approximately equal parts in order to obtain duplicate analyses to use as a basis for estimating the error in laboratory procedures; these divided samples were then merged in randomized sequence with the 89 samples that had not been divided. After numbering the entire set of 141 samples in a sequence that was random with respect to both geographical location and kind of plant and that was unknown to the analysts, the samples were submitted to the analytical laboratories.

Following the same procedures used for dividing and randomizing plant samples, we divided 23 samples of soil to provide duplicates. The 46 resulting duplicates were merged with the 92 samples that were not divided, and the total of 138 samples was submitted to the laboratories in a randomized order.

The methods of analysis used for all samples of the Missouri geochemical studies were described in detail in a previous report (Miesch, 1976). An outline of the methods used for analysis of plant and soil samples is given in table 1.

The approximate lower limits of detection for materials analyzed are given in table 2.

TABLE 2.—*Approximate lower limits of determination for elements in soils and plant materials*

[Dry soil was used for analyses of all elements. Dry plant material was used for arsenic, fluorine, iodine, mercury, and selenium analyses; plant ash was used for analyses of all other elements. Limits are given in parts per million. Leaders (...) indicate no data available]

Element	Lower limit of detection		Element	Lower limit of detection	
	Soils	Plant materials		Soils	Plant materials
Al	10,000	50	Li	5	4
As	.2	.25	Mg	300	50
B	20	50	Mn	1	2
Ba	2	5	Mo	3	5
Be	1.5	3	Na	100	25
C, in CO_3	100	....	Nb	10	....
C, organic	1,000	....	Nd	70	150
Ca	1,000	100	Ni	5	5
Cd	1	.2	P	300	40
Ce	150	300	Pb	10	20
Co	5	1	Sc	5	7
Cr	1	2	Se	.1	.01
Cu	1	2	Si	10,000	....
F	40	.5	Sr	5	10
Fe	[1]1,000	[2]20	Ti	2	5
Ga	5	5	V	7	10
Hg	.01	.025	Y	10	20
I	....	1	Yb	1	2
K	1,000	100	Zn	10	25
La	50	70	Zr	10	20

[1]Total Fe as Fe_2O_3.
[2]Fe.

TABLE 3.—*Elements commonly looked for, but rarely or never detected, by semiquantitative spectrographic analysis, and their approximate lower limits of determination, in parts per million, for samples in this report*

[Leaders (....) in a figure column indicate that the element is commonly detected in the sample material listed in the column heading]

Element	Material analyzed		Element	Material analyzed	
	Soils	Plant ash		Soils	Plant ash
Arsenic	1,000	2,000	Palladium	2	5
Antimony	200	500	Platinum	50	100
Bismuth	10	20	Praseodymium[2]	100	200
Cadmium	50	100	Rhenium	50	100
Cerium	200	500	Samarium[2]	100	200
Dysprosium[1]	50	100	Silver	.5	1
Erbium[1]	50	100	Scandium	...	7
Europium[2]	100	200	Tantalum	200	500
Gadolinium[1]	50	100	Tellurium	2,000	5,000
Germanium	10	20	Terbium[1]	300	700
Gold	20	50	Thallium	50	100
Hafnium	100	200	Thorium	200	500
Holmium[1]	20	50	Thulium[1]	20	50
Indium	10	20	Tin	10	15
Lithium	100	200	Tungsten	100	300
Lutetium[1]	30	70	Uranium	500	1,000
Neodymium[2]	70	150	Zinc	300	....
Niobium	10	20			

[1]Looked for if yttrium is greater than 50 ppm.
[2]Looked for if lanthanum or cerium is found.

TABLE 4.—*Error variance attributed to laboratory procedures based on duplicate analyses of cultivated soils and crop plants from Missouri*

[Error variances were estimated from $\log_{10}$ concentrations, except where noted. n = total number of samples analyzed for estimation of error variances. Leaders (....) in figure columns indicate no data available]

Element, ash, or pH	Soils Error variance n=46 (23 pairs)	Plants Error variance n=52 (26 pairs)	Element, ash, or pH	Soils Error variance n=46 (23 pairs)	Plants Error variance n=52 (26 pairs)
Al	0.00018	0.05892	Mn	0.01133	0.00428
As	.00183	....	Mo	....	.01719
B	.03210	.01480	Na	.00010	.00818
Ba	.00304	.01022	Ni	.00790	.03288
C, organic	.01468	....	P	.04446	.00240
Ca	.00017	.00144	Pb	.00964	....
Cd	....	.02287	Sc	.00151	....
Co	.00608	....	Se	.00967	.00149
Cr	.00284	....	Si[1]	2.1011	....
Cu	.00304	.00966	Sr	.00316	.00737
F	.07253	....	Ti	.01786	....
Fe	.00018	.00824	V	.00410	....
Ga	.00558	....	Y	.00997	....
Hg	.02213	....	Yb	.00839	....
I	....	.00246	Zn	.00076	.00223
K	.00003	.00039	Zr	.01471	....
Li	.00016	....	Ash	....	.00133
Mg	.00133	.00606	pH[2]	.02913	....

[1]Error variance estimated from percent concentration rather than logarithms.
[2]Error variance estimated from standard units.

All samples of both soils and plants were analyzed first by semiquantitative emission spectrophotometry, and the concentrations reported for many elements of primary interest were within the limits of determination of the method, as is indicated in table 1. Many other elements were commonly looked for by

TABLE 5.—*Components of logarithmic variance estimated for samples of plow zone soils from cornfields in four vegetation-type areas in Missouri*

[All variances are on the basis of log_{10} concentration, except where noted. *, significantly greater than zero at the 0.05 probability level]

Element	Total log_{10} variance	Between areas		Between 7½' quadrangles		Between sites	
		Variance component	Percent of total	Variance component	Percent of total	Variance component	Percent of total
Al	0.01251	0.00203	16	0.00584*	47	0.00464	37
As	.03714	.01231*	33	0	<1	.02483	67
B	.04219	.01146*	27	0	<1	.03073	73
Ba	.01465	.00190	13	.00371	25	.00904	62
C, organic	.03073	.01075*	35	.00346	11	.01652	54
Ca	.08738	0	<1	.04857*	56	.03880	44
Co	.04261	.00849*	20	.00638	15	.02774	65
Cr	.01983	.00664*	33	.00418	21	.00901	45
Cu	.03971	.00675*	17	.00495	12	.02801	71
F	.07916	.02161*	27	0	<1	.05755	73
Fe	.02875	.00717*	25	.00406	14	.01752	61
Ga	.01574	.00211	13	.00527*	33	.00836	53
Hg	.05922	0	<1	.00933	16	.04989	84
K	.01668	.00181	11	.00996*	60	.00491	29
Li	.01284	.00436*	34	.00161	13	.00637	54
Mg	.04042	.00484	12	.01554*	38	.02004	50
Mn	.07157	0	<1	.01179	16	.05978	84
Na	.04062	.00461	11	.02378*	59	.01223	30
Ni	.08835	0	<1	.04320*	49	.04515	51
P	.08175	.00464	6	0	<1	.07711	94
Pb	.03070	.00187	6	.00630	21	.02253	73
Sc	.01840	.00458*	25	.00352	19	.01030	56
Se	.05813	.02262*	39	.01323	23	.02228	38
Si[1]	33.014	6.7320	20	11.138*	34	15.144	46
Sr	.02774	.00105	4	.01641*	60	.00998	36
Ti	.02940	.00413	14	0	<1	.02527	86
V	.02711	.00511	19	.00862*	32	.01338	49
Y	.02352	.00553*	23	.00444	19	.01357	58
Yb	.01744	.00511*	29	.00236	14	.00997	57
Zn	.02818	.00365	13	.00773	27	.01680	60
Zr	.03074	.00272	9	.00550	18	.02252	73
pH[2]	.74910	0	<1	.30831*	41	.44079	59

[1]Variance components based on percent Si.
[2]Variance components based on standard units.

this analytical method, but were rarely or never detected. These elements are listed in table 3.

The estimated variances associated with laboratory procedures are given in table 4. By subtracting these components from the between-sites variance components in the nested analysis of variance (tables 5, 6, 7, 12, 13, and 14), one can estimate the natural local variability. Because both components are estimates, the analytical variance component may exceed the variance component at the site level, as, for example, occurred for boron and fluorine in all crop soils of this study. Such a result indicates the most, if not all, of the apparent local variability (s_Y^2) is more correctly attributed to laboratory procedures than to natural causes. In these circumstances, a measure of the natural variability between sites will require more precise laboratory procedures.

RESULTS

GEOCHEMICAL CHARACTERISTICS OF CULTIVATED SOILS

Most randomly selected sampling sites, as explained earlier, were sufficiently large to contain separate fields of corn, soybeans, and pasture grasses. A sample of soil was collected at one location in each of these fields, and components of chemical variance were calculated separately for soils supporting corn, soybeans, and pasture grasses. These components, as related to geographic scale, are given in tables 5, 6, and 7.

Only about one-half of the 32 soil constituents

TABLE 6.—*Components of logarithmic variance estimated for samples of plow zone soils from soybean fields in four vegetation-type areas in Missouri*

[All variances are on the basis of $\log_{10}$ concentration, except where noted. *, significantly greater than zero at the 0.05 probability level]

Element	Total $\log_{10}$ variance	Between areas		Between 7½' quadrangles		Between sites	
		Variance component	Percent of total	Variance component	Percent of total	Variance component	Percent of total
Al	0.01100	0.00297	27	0.00542*	49	0.00260	24
As	.04991	.01913*	38	.00861	17	.02217	44
B	.03283	.00154	5	0	<1	.03129	95
Ba	.01630	0	<1	.00513	31	.01107	69
C, organic	.04084	.00993*	24	.00195	5	.02896	71
Ca	.05398	0	<1	.00940	17	.04458	83
Co	.05860	.01043	18	.01918*	33	.02899	49
Cr	.02891	.00741	26	.01411*	49	.00739	26
Cu	.02326	.00537*	23	.00549	24	.01240	53
F	.06716	.01351*	20	.01750	26	.03615	54
Fe	.04497	.01337*	30	.01736*	39	.01424	32
Ga	.01634	.00537*	33	.00169*	38	.00478	29
Hg	.09186	0	<1	.02824	31	.06362	69
K	.01161	.00229	20	.00618*	53	.00314	27
Li	.01623	.00647*	40	.00383	24	.00593	37
Mg	.03948	.00640	16	.02087*	53	.01221	31
Mn	.11369	0	<1	.03983	35	.07836	65
Na	.01860	.00256	14	.00843*	45	.00771	41
Ni	.06900	.00236	3	.03678*	53	.02986	43
P	.08533	.01513*	18	0	<1	.07020	82
Pb	.03397	.00492	14	.00418	12	.02487	73
Sc	.01779	.00767*	43	.00353	20	.00659	37
Se	.07657	.03565*	47	.01063	14	.03029	40
Si[1]	30.5204	6.6957*	22	6.1877	20	17.637	58
Sr	.01895	.00073	4	.00942*	50	.00880	46
Ti	.04135	.02069*	50	0	<1	.02066	50
V	.04161	.01874*	45	.01094*	26	.01193	29
Y	.03620	.01720*	48	.00721	20	.01179	32
Yb	.04920	.03384*	69	.00415	8	.01121	23
Zn	.05029	.00288	5	.01641	33	.03160	63
Zr	.04926	.02932*	60	.00689	14	.01305	26
pH[2]	.68226	.00521	1	.19316	28	.48389	71

[1]Variance components based on percent Si.
[2]Variance components based on standard units.

examined exhibit statistically significant variation at the 95-percent confidence level between the four vegetation-type areas, and the amount of variation, expressed as percent of the total, is relatively minor at this scale. For example, only titanium, ytterbium, and zirconium in soils from soybean and pasture fields exhibit 50 percent or more of their variation between vegetation-type areas. In contrast, calcium, strontium, and nickel in all fields, mercury, manganese, and pH in corn and soybean fields, and barium in soybean and pasture fields exhibit virtually no variation between areas. Tables 5, 6, and 7 indicate that most of the chemical variation in these soils is within vegetation-type areas or, even more important, between sites.

Part of the between-site variance is due to laboratory procedures (sample preparation and analysis), but, because these effects tend to be small for most elements (table 4), most of the variance can be attributed to natural causes—that is, to actual small-scale variation within the soil. Boron and fluorine are notable exceptions to this generalization, in that all of the variance between sites, as given on tables 5, 6, and 7, may be attributed to laboratory procedures rather than to natural causes.

Results of the chemical analyses of the cultivated soils from the four vegetation-type areas that were sampled in Missouri are summarized in tables 8, 9, and 10. The geometric mean (*GM*) for each element in each area is an estimate of the most typical concentrations

TABLE 7.—*Components of logarithmic variance estimated for samples of plow-zone soils from pasture fields in four vegetation-type areas in Missouri*

[All variances are based on $\log_{10}$ concentration, except where noted. *, significantly greater than zero at the 0.05 probability level]

Element	Total $\log_{10}$ variance	Between areas		Between 7½' quadrangles		Between sites	
		Variance component	Percent of total	Variance component	Percent of total	Variance component	Percent of total
Al	0.00951	0.00008	< 1	0.00518*	54	0.00425	45
As	.05665	.00556	10	.01114	20	.03995	70
B	.03541	.00459	13	.00194	5	.02888	82
Ba	.02287	0	< 1	.00896*	39	.01391	61
C, organic	.04468	.01482*	33	0	< 1	.02986	69
Ca	.05583	0	< 1	.00924	17	.04659	83
Co	.03199	.00221	7	.01352*	42	.01626	51
Cr	.02538	.01051*	41	.00730*	29	.00757	30
Cu	.01897	.00400	21	.00609*	32	.00888	47
F	.08298	.00256	3	.02145	26	.05898	71
Fe	.03042	.00155	5	.00960	32	.01927	63
Ga	.01077	.00215*	20	.00220	20	.00642	60
Hg	.05793	.00618	11	0	< 1	.05175	89
K	.01214	.00074	6	.00732*	60	.00409	34
Li	.01227	.00129	11	.00069	6	.01029	84
Mg	.04359	0	< 1	.02790*	64	.01569	36
Mn	.07903	.00798*	10	0	< 1	.07105	90
Na	.02819	.00386	14	.01665*	59	.00768	27
Ni	.05402	0	< 1	.03989*	74	.01412	26
P	.06518	.01062*	16	0	< 1	.05456	84
Pb	.02433	.00235	10	.00360	15	.01838	75
Sc	.01254	.00327*	26	.00348*	28	.00580	46
Se	.05410	.01547*	29	.02556*	47	.01307	24
Si[1]	31.9051	1.7578	6	8.6493	27	21.498	67
Sr	.02377	0	< 1	.01783*	75	.00594	25
Ti	.03263	.01700*	52	.00175	5	.01389	43
V	.02205	.00609*	28	.00290	13	.01306	59
Y	.04598	.01454*	32	0	< 1	.03145	68
Yb	.03424	.01728*	50	.00284	8	.01412	41
Zn	.05122	.00585	11	.00007	< 1	.04532	88
Zr	.03132	.01728*	55	.00058	2	.01346	43
pH[2]	.51212	.03362	7	.05500	11	.42350	83

[1]Variance components based on percent Si.
[2]Variance components based on standard units.

of the element in a randomly selected sample from each kind of field in each vegetation-type area. In those cases where the detection ratio does not equal unity, the mean logarithms were computed using procedures developed by Cohen (1959) and described as they were applied to the Missouri geochemical studies by Miesch (1976). The geometric deviation (*GD*) is a factor used to estimate the degree of scatter of the data around this typical concentration. For example, a *GD* of 1.0 indicates no variation in concentration of the element in the soil material that was analyzed; a *GD* of 2.0 indicates that about two-thirds of the concentrations range from *GM*÷2.0 to *GM*x2.0.

Geometric mean concentrations that differ by as much as a factor of two between the vegetation-type areas are apparent in tables 8, 9, and 10. For about one-half of the constituents tested, at least the highest and lowest means are significantly different at the 0.05 probability level (tables 5, 6, and 7). Most of the higher concentrations occur in soils from the Floodplain Forest area. However, the highest mean values in the pasture fields are evenly distributed between the Glaciated Prairie and the Unglaciated Prairie areas.

Basically, the analysis of variance (tables 5, 6, and 7) assures us only that significant differences in concentrations of many of the elements occur at least between the two vegetation-type areas that have the extreme mean values. This analysis does not indicate

TABLE 8.—*Mean chemical composition and chemical variation of cultivated soils from corn fields in four vegetation-type areas in Missouri*

[Mean concentrations given in parts per million except where percent is indicated. Dry soil used for chemical analysis; soil slurry used for pH determinations. *GM*, geometric means, except where indicated; *GD*, geometric deviation, except where indicated; ratio, number of samples in which element was detected to total number of samples analyzed; leaders (...) in figure column, no data available. Tests using analysis of variance techniques indicated that differences were significant at the 0.05 probability level for concentrations of certain elements in soils from the vegetation-type areas that had the highest and lowest concentrations of these elements, as indicated by **boldface** and *italic*, respectively. Significant differences were not indicated by analysis of variance tests for the concentrations of Al, Ba, Ca, Ga, Hg, K, Mg, Mn, Na, Ni, P, Pb, Si, Sr, Ti, V, Zn, Zr, and pH. Because of insufficient data, differences in concentrations of Be, carbonate C, Cd, La, Nb, and Sn were not tested for statistical significance]

Element or pH	Vegetation-type areas: Floodplain Forest			Glaciated Prairie			Unglaciated Prairie			Oak-hickory Forest		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio
Al, percent	4.0	1.21	8:8	4.8	1.16	10:10	3.4	1.32	10:10	3.9	1.30	10:10
As	*5.5*	1.68	8:8	**10**	1.32	10:10	**10**	1.47	10:10	8.8	1.23	10:10
B	*≅20*	...	7:8	25	1.53	9:10	29	1.52	10:10	**41**	1.39	10:10
Ba	800	1.20	8:8	810	1.28	10:10	600	1.39	10:10	700	1.26	10:10
Be	< 1.5	...	0:8	1.2	1.26	4:10	1.1	1.31	3:10	.94	1.37	2:10
C, organic, percent	*.91*	1.32	8:8	**1.7**	1.26	10:10	1.4	1.33	10:10	1.4	1.56	10:10
C, carbonate, percent	< .01	...	2:8	.0075	4.28	4:10	< .01	...	4:10	< .01	...	4:10
Ca, percent	.48	1.38	8:8	.57	1.30	10:10	.39	2.43	10:10	.44	2.30	10:10
Cd	<1	...	0:8	<1	...	0:10	<1	...	0:10	<1	...	1:10
Co	*5.2*	1.51	6:8	8.1	1.28	10:10	**9.7**	1.81	10:10	8.7	1.41	10:10
Cr	*43*	1.56	8:8	**70**	1.18	10:10	63	1.18	10:10	66	1.24	10:10
Cu	*11*	1.82	8:8	18	1.41	10:10	14	1.33	10:10	**19**	1.51	10:10
F, percent	.021	1.82	8:8	**.044**	1.95	10:10	.022	1.57	10:10	*.020*	1.56	10:10
Fe, percent	*1.4*	1.80	8:8	**2.4**	1.28	10:10	2.3	1.32	10:10	2.1	1.14	10:10
Ga	12	1.23	8:8	15	1.21	10:10	11	1.35	10:10	12	1.37	10:10
Hg	.037	1.93	8:8	.051	1.81	10:10	.042	1.70	10:10	.038	1.56	10:10
K, percent	1.7	1.15	8:8	1.7	1.12	10:10	1.2	1.41	10:10	1.5	1.43	10:10
La	< 50	...	0:8	49	1.09	9:10	45	1.18	7:10	45	1.18	7:10
Li	*15*	1.32	8:8	**22**	1.22	10:10	18	1.22	10:10	19	1.17	10:10
Mg, percent	.27	1.82	8:8	.36	1.36	10:10	.21	1.38	10:10	.26	1.56	10:10
Mn	460	2.32	8:8	590	1.73	10:10	530	1.94	10:10	530	1.41	10:10
Na, percent	.79	1.11	8:8	.69	1.13	10:10	.45	1.84	10:10	.55	1.68	10:10
Nb	7.9	1.24	3:8	8.0	1.23	4:10	9.5	1.10	8:10	10	1.00	10:10
Ni	8.4	2.36	6:8	14	1.51	10:10	10	1.96	9:10	11	2.16	9:10
P, percent	.074	1.64	8:8	.063	1.66	9:10	.041	2.04	8:10	.058	1.87	10:10
Pb	18	1.16	8:8	20	1.29	10:10	23	1.28	10:10	27	1.91	10:10
Sc	*5.2*	1.24	7:8	**8.1**	1.20	10:10	6.3	1.25	9:10	6.3	1.33	9:10
Se	*.31*	1.51	8:8	**.67**	1.67	10:10	.52	1.48	10:10	*.31*	1.43	10:10
Si, percent[1]	38	6.61	8:8	35	3.50	10:10	37	5.02	10:10	38	4.78	10:10
Sn	<10	...	0:8	< 10	...	1:10	<10	...	0:10	< 10	...	1:10
Sr	150	1.21	8:8	150	1.21	10:10	110	1.64	10:10	120	1.53	10:10
Ti, percent	.22	1.49	8:8	.27	1.35	10:10	.31	1.49	10:10	.34	1.35	10:10
V	52	1.74	8:8	84	1.21	10:10	63	1.26	10:10	78	1.35	10:10
Y	*16*	1.46	8:8	22	1.26	10:10	25	1.37	10:10	**27**	1.35	10:10
Yb	*2.0*	1.56	8:8	2.7	1.22	10:10	**3.0**	1.24	10:10	**3.0**	1.00	10:10
Zn	37	1.69	8:8	55	1.29	10:10	41	1.29	10:10	53	1.43	10:10
Zr	190	1.77	8:8	180	1.16	10:10	240	1.23	10:10	260	1.61	10:10
pH[2]	6.4	.80	8:8	6.5	.93	10:10	6.5	.82	10:10	6.5	.81	10:10

[1]Arithmetic means and standard deviations.
[2]Standard units and standard deviations.

whether the two mean values that lie between the extremes are significantly different from each other or from the extremes. To determine if these differences exist, we applied a multiple range test (Duncan, 1955) to the data. The application of this test to geochemical problems was described by Miesch (1976). The results demonstrated that, as a group, the cultivated soils from the Floodplain Forest area tend to be distinctively low in concentrations of certain elements as follows: cornfield soils—lowest in arsenic, organic carbon, cobalt, chromium, iron, and ytterbium; soybean field soils—lowest in titanium and ytterbium; and pasture field soils—lowest in chromium, titanium, ytterbium, and zinc.

The multiple range test also revealed that cultivated soils from the two prairie areas were similar in having distinctively high concentrations of selenium in cornfield soils and selenium and arsenic in soybean field soils. High selenium values in uncultivated prairie soils were reported earlier (Erdman and others, 1976). Cultivated soils from the Glaciated Prairie area differ from soils of the other three areas in having high fluorine concentrations in cornfield soils and high gallium concentrations in soybean field soils. The only other result of this test was the grouping of Floodplain Forest and Glaciated Prairie area soils as distinctive in having low zirconium.

In view of the possible effects of cultivation on native soils that were discussed earlier, the question arises whether the postulated effects on element concentrations can, in fact, be substantiated by results

TABLE 9.—*Mean chemical composition and chemical variation of cultivated soils from soybean fields in four vegetation-type areas in Missouri*

[Mean concentrations given in parts per million except where percent is indicated. Dry soil used for chemical analyses; soil slurry used for pH determinations. *GM*, geometric mean, except where indicated; *GD*, geometric deviation, except where indicated; ratio, number of samples in which element was detected to total number of samples analyzed; leaders (. . .) in figure column, no data available. Tests using analysis of variance techniques indicated that differences were significant at the 0.05 probability level for concentrations of certain elements in soils from the vegetation-type areas that had the highest and lowest concentrations of these elements, as indicated by **boldface** and *italic*, respectively. Significant differences were not indicated by analysis of variance tests for the concentrations of Al, B, Ba, Ca, Co, Cr, Hg, K, Mg, Mn, Na, Ni, Pb, Sr, Zn, and pH. Because of insufficient data, differences in concentrations of Be, carbonate C, Cd, La, Nb, and Sn were not tested for statistical significance]

Element or pH	Vegetation-type areas											
	Floodplain Forest			Glaciated Prairie			Unglaciated Prairie			Oak-hickory Forest		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio
Al, percent	4.0	1.25	10:10	5.2	1.08	10:10	3.8	1.29	8:8	3.8	1.23	9:9
As	*5.9*	1.70	10:10	**12**	1.31	10:10	11	1.52	8:8	7.1	1.38	9:9
B	21	1.46	8:10	29	1.52	10:10	31	1.53	8:8	27	1.54	8:9
Ba	630	1.26	10:10	700	1.26	10:10	640	1.28	8:8	640	1.51	9:9
Be	< 1.5	. . .	1:10	1.2	1.26	4:10	1.0	1.34	2:8	< 1.5	. . .	1:9
C, organic, percent	*.93*	1.57	10:10	**1.6**	1.32	10:10	**1.6**	1.48	8:8	1.1	1.60	9:9
C, carbonate, percent	< .01	. . .	2:10	< .01	. . .	2:10	< .01	. . .	3:8	< .01	. . .	4:9
Ca, percent	.47	1.49	10:10	.58	1.33	10:10	.38	1.76	8:8	.51	2.18	9:9
Cd	< 1	. . .	0:10	< 1	. . .	1:10	< 1	. . .	1:8	< 1	. . .	0:9
Co	5.6	1.44	8:10	10	1.42	10:10	10	2.31	7:8	7.7	1.42	9:9
Cr	40	1.77	10:10	63	1.18	10:10	67	1.13	8:8	65	1.16	9:9
Cu	*12*	1.53	10:10	**19**	1.13	10:10	14	1.34	8:8	16	1.33	9:9
F, percent	*.016*	1.89	10:10	**.036**	1.43	10:10	.022	1.63	8:8	.025	1.76	9:9
Fe, percent	*1.4*	1.96	10:10	**2.8**	1.13	10:10	2.5	1.42	8:8	1.9	1.12	9:9
Ga	12	1.36	10:10	**16**	1.15	10:10	*11*	1.28	8:8	*11*	*1.22*	9:9
Hg	.042	2.00	10:10	.051	1.89	10:10	.046	1.72	8:8	.030	2.29	9:9
K, percent	1.7	1.09	10:10	1.6	1.08	10:10	1.2	1.41	8:8	1.5	1.30	9:9
La	33	1.39	3:10	40	1.28	5:10	50	1.00	8:8	44	1.20	6:9
Li	*15*	1.42	10:10	**24**	1.12	10:10	20	1.20	8:8	18	1.17	9:9
Mg, percent	.26	1.81	10:10	.38	1.18	10:10	.22	1.37	8:8	.23	1.47	9:9
Mn	350	2.31	10:10	500	2.20	10:10	590	1.89	8:8	650	2.09	9:9
Na, percent	.76	1.15	10:10	.68	1.09	10:10	.56	1.50	8:8	.53	1.49	9:9
Nb	6.6	1.33	2:10	7.4	1.27	3:10	9.4	1.11	6:8	9.8	1.07	8:9
Ni	9.8	1.67	9:10	16	1.40	10:10	8.4	2.44	6:8	11	1.80	9:9
P, percent	**.078**	1.57	10:10	.066	1.60	10:10	.048	1.59	7:8	*.041*	1.80	7:9
Pb	18	1.15	10:10	25	1.41	10:10	31	1.82	8:8	25	1.48	9:9
Sc	*5.1*	1.31	8:10	**8.4**	1.21	10:10	6.7	1.25	8:8	6.5	1.16	9:9
Se	.33	1.67	10:10	**.74**	1.71	10:10	.67	1.56	8:8	*.31*	1.31	9:9
Si, percent[1]	37	6.29	10:10	*35*	1.77	10:10	37	4.90	8:8	**38**	5.11	9:9
Sn	< 10	. . .	0:10	< 10	. . .	1:10	< 10	. . .	1:8	< 10	. . .	0:9
Sr	140	1.19	10:10	140	1.14	10:10	120	1.55	8:8	110	1.48	9:9
Ti, percent	*.18*	1.34	10:10	.26	1.36	10:10	.31	1.42	8:8	**.40**	1.31	9:9
V	*42*	1.65	10:10	**93**	1.16	10:10	71	1.47	8:8	60	1.19	9:9
Y	*15*	1.43	10:10	21	1.30	10:10	**32**	1.35	8:8	27	1.37	9:9
Yb	*1.5*	1.48	10:10	2.9	1.14	10:10	3.6	1.30	8:8	**3.8**	1.31	9:9
Zn	42	1.74	10:10	61	1.26	10:10	63	2.11	8:8	41	1.41	9:9
Zr	*150*	1.39	10:10	180	1.34	10:10	270	1.37	8:8	**360**	1.40	9:9
pH[2]	5.8	.77	10:10	6.4	.84	10:10	6.1	.93	8:8	6.5	.70	9:9

[1]Arithmetic means and standard deviations.

[2]Standard units and standard deviations.

of the present study. Our earlier study of uncultivated plants and soils in Missouri (Erdman and others, 1976) provided estimates of mean concentrations of elements in soils from six vegetation-type areas, including the four areas of the present study. The results of the two studies are not directly comparable because somewhat different sampling media were used. Plow zone soils were sampled in the present study, whereas only the lower soil zones were sampled in the earlier study. For this reason, the best comparison that can be made is of the two kinds of soils from the Floodplain Forest area, because these soils are relatively homogeneous with depth. A comparison of the chemical properties of the cultivated and uncultivated soils from this area follows (table 11).

Examination of this table suggests that mean concentrations of some elements (particularly those essential for plant growth) are consistently lower in cultivated soils. Yet these apparent differences in mean element concentration between the two kinds of soil, with the exception of nickel, were not significant at the 95-percent confidence level when tested by the conventional *t* statistic. The *t* test, however, does not take into account the consistency of differences from one chemical element to the next. For example, cultivated soils from the three kinds of fields are at least 25 percent lower in concentrations of boron, cobalt, iron, manganese, and zinc, as well as the nonessential elements arsenic, flourine, lithium, nickel, scandium, vanadium, and ytterbium. Because of this, an intuitive judgment was made that the differences, for the most part, are real and may indicate that depletion in elements has occurred as a result of cultivation. The exact factory responsible for the lower concentrations cannot be stated with

TABLE 10.—*Mean chemical composition and chemical variation of cultivated soils from pasture fields in four vegetation-type areas in Missouri*

[Mean concentrations given in parts per million except where percent is indicated. Dry soil used for chemical analyses; soil slurry used for pH determinations. *GM*, geometric mean, except where indicated; *GD*, geometric deviation, except where indicated; ratio, number of samples in which element was detected to total number of samples analyzed; leaders (...) in figure column, no data available. Tests using analysis of variance techniques indicated that differences were significant at the 0.05 probability level for concentrations of certain elements in soils from the vegetation-type areas that had the highest and lowest concentrations of these elements, as indicated by **boldface** and *italic*, respectively. Significant differences were not indicated by analysis of variance tests for the concentrations of Al, As, B, Ba, Ca, Co, Cu, F, Fe, Hg, K, Li, Mg, Na, Ni, Pb, Si, Sr, Zn, and pH. Because of insufficient data, differences in concentrations of Be, carbonate C, Cd, La, Nb, and Sn were not tested for statistical significance]

Element or pH	Vegetation-type areas: Floodplain Forest			Glaciated Prairie			Unglaciated Prairie			Oak-hickory Forest		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio
Al, percent	4.2	1.25	10:10	4.6	1.11	10:10	3.8	1.24	10:10	3.9	1.33	10:10
As	6.4	2.25	10:10	12	1.63	10:10	9.3	1.41	10:10	8.5	1.22	10:10
B	21	1.56	7:10	28	1.60	9:10	36	1.47	10:10	26	1.46	10:10
Ba	700	1.18	10:10	780	1.33	10:10	670	1.46	10:10	590	1.58	10:10
Be	<1.5	...	0:10	1.1	1.31	3:10	<1.5	...	1:10	<1.5	...	1:10
C, organic, percent	*1.1*	1.69	10:10	**2.2**	1.22	10:10	1.7	1.29	10:10	1.5	1.60	10:10
C, carbonate, percent	<.01	...	0:10	<.01	...	4:10	<.01	...	3:10	<.01	...	3:10
Ca, percent	.48	1.46	10:10	.66	1.38	10:10	.47	2.34	10:10	.44	1.55	10:10
Cd	<1	...	1:10	<1	...	1:10	<1	...	0:10	<1	...	1:10
Co	6.0	1.42	10:10	8.7	1.46	10:10	8.5	1.53	10:10	8.8	1.48	10:10
Cr	*39*	1.54	10:10	63	1.18	10:10	59	1.19	10:10	**70**	1.26	10:10
Cu	12	1.54	10:10	18	1.16	10:10	16	1.23	10:10	16	1.25	10:10
F, percent	.017	1.93	10:10	.029	1.60	10:10	.029	2.32	10:10	.024	1.73	10:10
Fe, percent	1.6	1.96	10:10	2.3	1.20	10:10	2.0	1.28	10:10	2.2	1.23	10:10
Ga	12	1.23	10:10	**15**	1.18	10:10	*11*	1.28	10:10	12	1.24	10:10
Hg	.053	2.16	10:10	.069	1.51	10:10	.038	1.21	10:10	.057	1.68	10:10
K, percent	1.7	1.10	10:10	1.6	1.13	10:10	1.3	1.34	10:10	1.5	1.40	10:10
La	28	1.48	2:10	43	1.23	6:10	47	1.14	8:10	40	1.42	5:10
Li	16	1.49	10:10	21	1.12	10:10	20	1.16	10:10	20	1.21	10:10
Mg, percent	.25	1.91	10:10	.35	1.36	10:10	.25	1.43	10:10	.27	1.60	10:10
Mn	*350*	2.02	10:10	580	1.89	10:10	**600**	1.33	10:10	490	1.50	10:10
Na, percent	.74	1.22	10:10	.70	1.11	10:10	.50	1.50	10:10	.51	1.67	10:10
Nb	8.0	1.23	4:10	8.5	1.19	5:10	9.5	1.10	8:10	8.9	1.16	6:10
Ni	10	1.53	10:10	14	1.23	10:10	9.7	1.77	9.10	13	2.01	9:10
P, percent	**.067**	1.52	10:10	**.067**	1.53	10:10	*.038*	1.52	9:10	.050	1.98	8:10
Pb	18	1.16	10:10	25	1.63	10:10	22	1.33	10:10	25	1.41	10:10
Sc	*5.1*	1.31	8:10	**7.3**	1.12	10:10	6.3	1.18	10:10	6.3	1.26	10:10
Se	*.28*	1.65	10:10	**.62**	1.68	10:10	.47	1.39	10:10	.38	1.43	10:10
Si, percent[1]	37	7.74	10:10	35	2.96	10:10	37	5.07	10:10	37	4.73	10:10
Sn	<10	...	0:10	<10	...	0:10	<10	...	1:10	<10	...	0:10
Sr	140	1.14	10:10	150	1.21	10:10	110	1.58	10:10	120	1.57	10:10
Ti, percent	*.17*	1.34	10:10	.27	1.39	10:10	**.37**	1.30	10:10	.29	1.29	10:10
V	*48*	1.49	10:10	**78**	1.33	10:10	68	1.29	10:10	63	1.18	10:10
Y	*15*	1.43	10:10	22	1.58	10:10	**31**	1.36	10:10	25	1.51	10:10
Yb	*1.7*	1.47	10:10	2.7	1.35	10:10	**3.7**	1.30	10:10	3.0	1.24	10:10
Zn	45	1.70	10:10	68	1.74	10:10	41	1.29	10:10	58	1.74	10:10
Zr	*140*	1.36	10:10	190	1.30	10:10	**290**	1.29	10:10	240	1.30	10:10
pH[2]	5.9	.56	10:10	6.6	.58	10:10	6.4	.66	10:10	6.5	.89	10:10

[1]Arithmetic means and standard deviations.
[2]Standard units and standard deviations.

certainty. It is possible that a loss in essential elements resulted from removal in crops. Moreover, both essential and nonessential elements may have been depleted by erosion and leaching, which often are accelerated by cultivation. On the other hand, concentrations of some elements in the cultivated soils from this area appear to be the same as in uncultivated soils, or even slightly higher. These elements include the major nutrients calcium, magnesium, potassium, and phosphorus, which are the elements most likely to have been added to the soil in fertilizers.

CHEMICAL COMPOSITION OF SELECTED CROP PLANTS

Estimated variance components for elemental concentrations in corn grains, soybean seeds, and pasture grasses for the three geographic levels of the sampling design are listed in tables 12, 13, and 14. The significance of differences between the four vegetation-type areas was tested by analysis of variance techniques. Of the approximately 20 elements tested for each crop plant sample, differences significant at the 95-percent confidence level were found as follows: corn grains, potassium and nickel; soybean seeds, calcium, cadmium, copper, strontium, and zinc; and pasture grasses, barium, calcium, fluorine, sodium, lead, zinc, and ash. However, in general, the amount of variation at this scale, expressed as percent of the total, is relatively small. For example, aluminum, boron, iron, manganese, phosphorus, and selenium concentrations in all three kinds of crop samples exhibit 10 percent or less of their total variance among vegetation-type areas. The greatest amount of variation by far is found between sites within areas, expecially in the composition of seeds and grains. Exceptions to this result are nickel and phosphorus in soybean seeds and aluminum in pasture grasses.

TABLE 11.—*Comparison of mean chemical properties of uncultivated soils and cultivated soils from the Floodplain Forest vegetation-type area in Missouri*

[Means are geometric and are expressed in parts per million, except where noted. *n* in column heading indicates number of samples analyzed]

Element or pH	Uncultivated soil[1], *n*=50	Cultivated soil		
		Cornfield soil, *n*=8	Soybean field soil, *n*=10	Pasture field soil, *n*=10
Al, percent	4.4	4.0	4.0	4.2
As	7.5	5.5	5.9	6.4
B	29	20	21	21
Ba	660	800	630	700
Be	.99	< 1.5	< 1.5	< 1.5
C, carbonate, percent	.046	< .01	< .01	< .01
C, organic, percent	.89	.91	.93	1.1
Ca, percent	.42	.48	.47	.48
Co	8.3	5.2	5.6	6.0
Cr	39	43	40	39
Cu	15	11	12	12
F	250	210	160	170
Fe, percent	2.1	1.4	1.4	1.6
Ga	12	12	12	12
Hg	.057	.037	.042	.053
K, percent	1.8	1.7	1.7	1.7
La	32	< 50	33	28
Li	20	15	15	16
Mg	.31	.27	.26	.25
Mn	710	460	350	350
Na, percent	.62	.79	.76	.74
Nb	5.8	7.9	6.6	8.0
Ni	19	8.4	9.8	10
P, percent	.068	.067	.074	.078
Pb	19	18	18	18
Sc	7.1	5.1	5.2	5.1
Se	.31	.28	.31	.33
Si[2], percent	36	37	38	37
Ti, percent	.26	.17	.22	.18
V	64	48	52	42
Y	23	15	16	15
Yb	2.1	1.7	2.0	1.5
Zn	54	45	37	42
Zr	160	140	190	150
pH[3]	5.8	5.9	6.4	5.8

[1]Erdman and others, 1976.
[2]Arithmetic means.
[3]Standard units.

Error attributed to laboratory procedures (sample preparation and analysis, table 4) contributes to the observed between-site variance, but for most elements in the plant material these effects are small (tables 12, 13, and 14). Therefore, most of the variance at this level of the sampling design can be attributed to natural causes. For example, the analytical error for selenium in corn grains contributes less than one percent to the variance observed between sites. In contrast, virtually all the variance in boron between sites for the crop plants, as with soils, is due to laboratory procedures. Moreover, at least 80 percent of the site variance for magnesium and phosphorus in corn grains and for copper, nickel, and zinc in soybean seeds is due to laboratory error.

Results of the analyses of crop plant samples are summarized in tables 15, 16, and 17. The geometric means (*GM*) for each element in each vegetation-type area are estimates of the most typical concentrations of the elements in a randomly selected sample from that area.

Visual inspection of the data summarized in these tables did not reveal obvious patterns in crop-plant element concentrations that are consistent between the vegetation-type areas and kinds of plants that were analyzed. Areas having significantly different mean concentrations in each crop plant were grouped by Duncan's (1955) multiple range test. Again, no general patterns in crop plant chemistry were found, but the following distinctive associations were revealed: corn grains—nickel low in samples from the Floodplain Forest area; soybean seeds—cadmium high in samples from the Floodplain Forest area, strontium high in samples from the Oak-hickory Forest area, and zinc high in samples from the Oak-hickory Forest and Unglaciated Prairie areas; pasture grass stems and leaves—barium low in samples from the Unglaciated Prairie area, and sodium high in samples from the Floodplain Forest and Unglaciated Prairie areas.

Although significant differences between areas were found for 12 chemical constituents in the 3 kinds of crop samples (tables 15, 16, and 17), the variations appear to be almost completely erratic. The marked differences in mean compositions between the three crops, regardless of origins, support the conclusion by Shacklette, Sauer, and Miesch (1970) that plant chemistry reflects a species (genetic) control much more than a geographic control.

CORRESPONDENCE BETWEEN THE ELEMENTAL COMPOSITION OF CULTIVATED PLANTS AND THAT OF ASSOCIATED SOILS

The correspondence between the elemental composition of corn grains, soybean seeds, and stems and leaves of pasture grasses and that of associated soils was examined by means of correlation coefficients (table 18 and fig. 3). The data in this table and figure show no consistently strong correlations between total concentrations of elements in cultivated soils and in crop plants. Similar results were obtained for uncultivated soils and native plant tissues from Missouri (Erdman and others, 1976) and from Georgia (Shacklette and others, 1970).

Soils utilized in agriculture generally have levels of elements that are well within the range of utilization by, or tolerance of, crop plants; otherwise the soil

TABLE 12.—*Components of logarithmic variance estimated for corn grains from four vegetation-type areas in Missouri*

[All variances are on the basis of $\log_{10}$ concentration, except where noted. *, significantly greater than zero at the 0.05 probability level]

Element	Total $\log_{10}$ variance	Between areas		Between quadrangles		Between sites	
		Variance component	Percent of total	Variance component	Percent of total	Variance component	Percent of total
Al	0.19053	0.00181	1	0	<1	0.18872	99
B	.01672	.00030	2	0	<1	.01642	98
Ba	.13111	0	<1	.01830	14	.11281	86
Ca	.01293	0	<1	0	<1	.01293	100
Cd	.25534	0	<1	.04304	17	.21230	83
Cu	.02286	.00105	5	.00531	23	.01650	72
Fe	.01928	.00184	10	.00090	5	.01653	85
I	.00810	.00114	14	0	<1	.00696	86
K	.00112	.00023*	21	0	<1	.00088	79
Mg	.00507	0	<1	.00002	<1	.00506	100
Mn	.01071	.00036	3	0	<1	.01035	97
Mo	.09947	.00260	3	.02155	22	.07531	75
Na	.03555	.00411	12	0	<1	.03145	88
Ni	.10936	.02440*	22	0	<1	.08496	78
P	.00434	0	<1	.00146	34	.00288	66
Se	.15631	0	<1	.01243	8	.14388	92
Sr	.07561	0	<1	.00067	1	.07494	99
Zn	.00746	0	<1	.00357*	48	.00389	52
Ash	.00611	0	<1	.00006	1	.00605	99

would be unproductive. Within this range the manifold factors that influence element availability tend to override the differences in total element content of the soil in terms of influence on the concentration of elements in the crop plants.

SUMMARY

1. Corn grains, soybean seeds, pasture grasses, and associated soils were sampled in four of the six vegetation-type areas of Missouri, using a three-level geographically nested sampling design.

2. Components of variance were estimated in order to partition the total variance between the three geographic levels of the design. Only about one-half of the 32 soils constituents that were examined exhibited statistically significant variation between the areas. Most of the variation occurred within vegetation-type areas and, predominantly, between sites within quadrangles.

3. Relatively high concentrations of most elements occurred in soils from cultivated fields in the Glaciated Prairie area, and the lowest concentrations were in soil samples from the Floodplain Forest area. Area means were grouped by Duncan's (1955) multiple range test, which revealed that soils of the Floodplain Forest area are distinct from soils of the other areas.

4. An assessment of the possible effects of cultivation and cropping on the element content of soils suggests that many elements have been depleted in cultivated soils compared to uncultivated soils.

5. The variation in element composition of corn grains, soybean seeds, and pasture grasses was (as with soils) largely between sites within quadrangles. The variation between quadrangles and between vegetation-type areas was even less pronounced than that in the soils.

6. No consistent differences in crop-plant element concentrations were found between either the vegetation-type areas or the plants that were sampled—that is, variation between elements and areas appear to be almost completely erratic.

7. No strong correlations were found between concentrations of elements in cultivated soils and crop plant tissues, suggesting that within the normal range of element concentrations in cultivated soils, chemical analyses of corn grains, soybean seeds, and pasture grass stems and leaves do not generally reflect the total elemental composition of the associated soils.

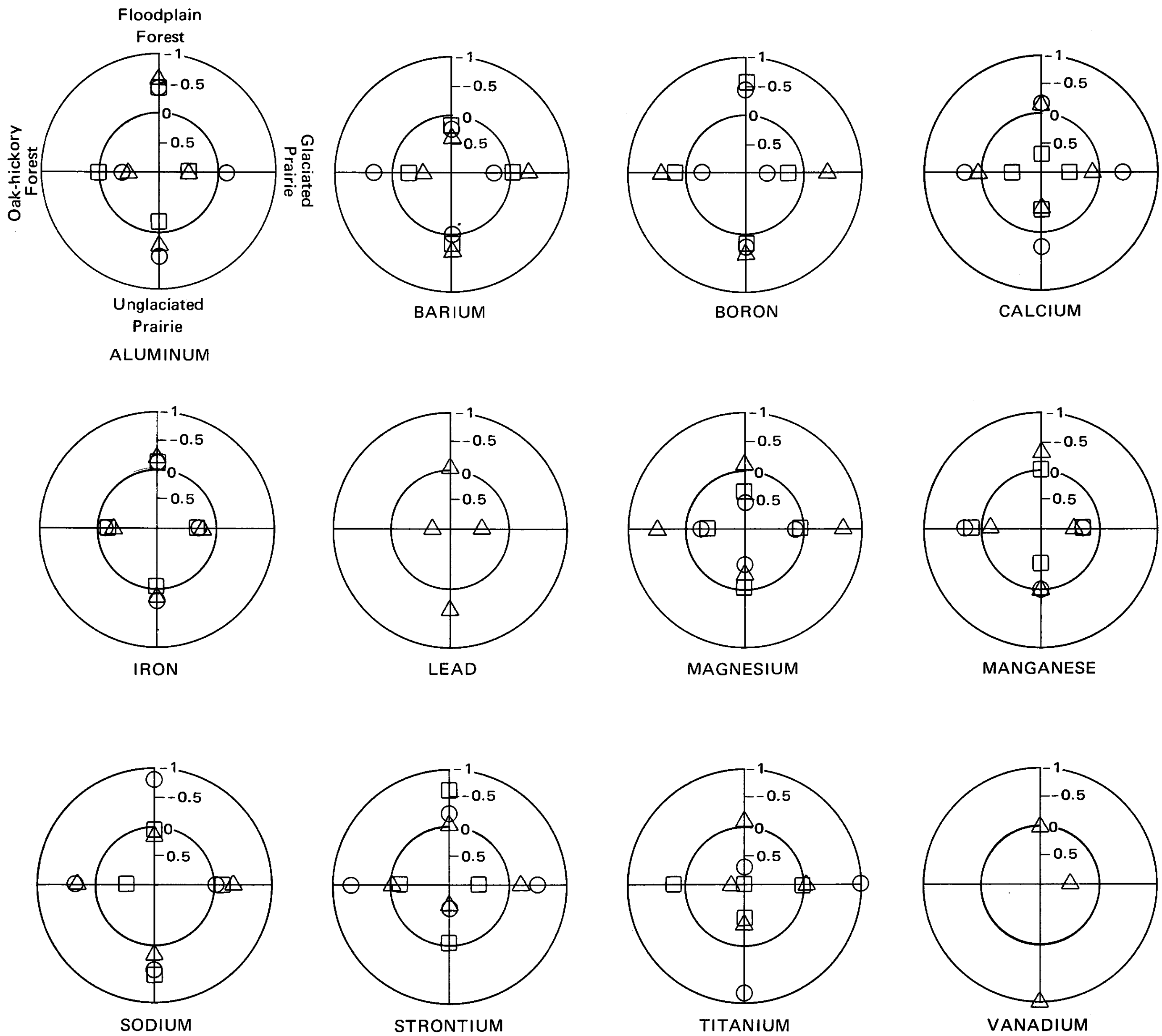
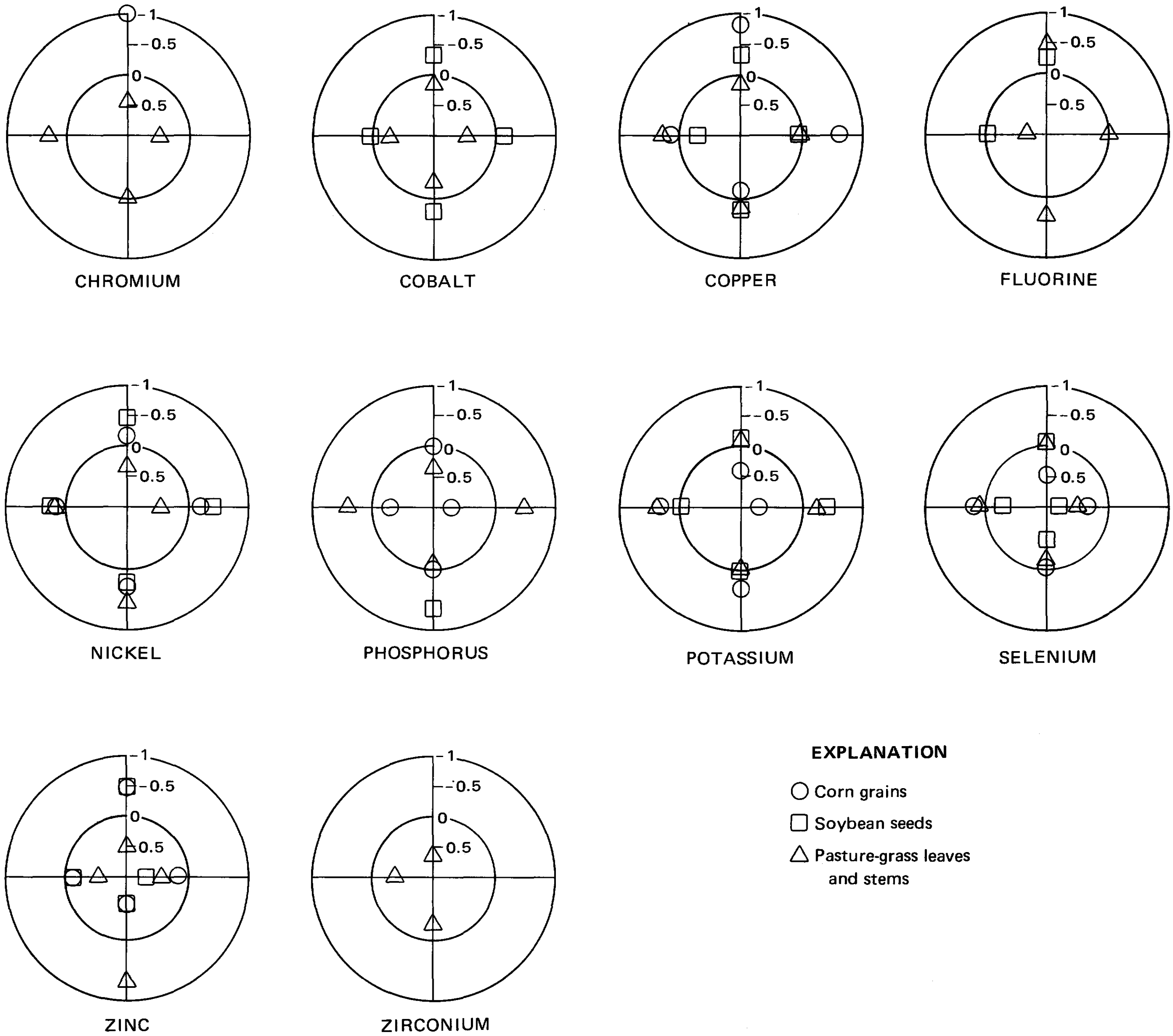


FIGURE 3.—Correlations between the log concentrations of selected elements in crops and cultivated soils within four vegetation-type



areas of Missouri. The locations of the symbols on the radii indicate the correlations by their distances from the center of the circle.

TABLE 13.—*Components of logarithmic variance estimated for soybean seeds from four vegetation-type areas in Missouri*

[All variances based on $\log_{10}$ concentration. *, significantly greater than zero at the 0.05 probability level]

Element	Total $\log_{10}$ variance	Between areas		Between quadrangles		Between sites	
		Variance component	Percent of total	Variance component	Percent of total	Variance component	Percent of total
Al	0.07860	0.00041	1	0	<1	0.07820	99
B	.01906	.00184	10	.00328	17	.01395	73
Ba	.12618	.00612	5	.01897	15	.10109	80
Ca	.00468	.00154*	33	.00048	10	.00265	57
Cd	.15884	.06800*	43	0	<1	.09085	57
Cu	.01149	.00305*	21	.00080	6	.01065	73
Fe	.04206	.00305	7	.00096	2	.03805	91
I	.00443	0	<1	0	<1	.00443	100
K	.00073	.00005	6	0	<1	.00068	94
Mg	.02083	.00264	13	.00192	9	.01628	78
Mn	.02297	0	<1	.00744	32	.01553	68
Mo	.21275	0	<1	.06762	32	.14513	68
Na	.03618	0	<1	.00154	4	.03465	96
Ni	.08169	0	<1	.04800*	59	.03369	41
P	.01324	.00110	8	.01214	92	0	<1
Se	.12631	.00634	5	.03248	26	.08750	69
Sr	.06988	.02084*	30	.00575	8	.04329	62
Zn	.00574	.00259*	45	.00068	12	.00248	43
Ash	.00102	.00002	2	.00038	37	.00062	61

TABLE 14.—*Components of logarithmic variance estimated for pasture grasses from four vegetation-type areas in Missouri*

[All variances based on $\log_{10}$ concentration. *, significantly greater than zero at the 0.05 probability level.]

Element	Total $\log_{10}$ variance	Between areas		Between quadrangles		Between sites	
		Variance component	Percent of total	Variance component	Percent of total	Variance component	Percent of total
Al	0.21553	0	<1	0.11248*	57	0.09306	43
B	.01446	.00092	6	0	<1	.01354	94
Ba	.06296	.01772*	28	0	<1	.04524	72
Ca	.02098	.00411*	20	0	<1	.01686	80
Cd	.11249	.01153	10	.03347	30	.06749	60
Cr	.12752	0	<1	.05114*	40	.07637	60
Cu	.02152	.00096	4	.00301	14	.01755	82
F	.10369	.02375*	23	.00911	9	.07083	68
Fe	.11322	0	<1	.04767*	42	.06556	58
I	.01083	.00138	13	.00221	20	.00724	67
K	.02634	.00098	4	.00421	16	.02116	80
Mg	.02594	.00316	12	.01137*	44	.01141	44
Mn	.04195	.00228	5	.00406	10	.03562	85
Na	.39304	.12948*	33	.09106	23	.17250	44
P	.01501	.00046	3	.00231	15	.01223	82
Pb	.05072	.01068*	21	.00853	17	.03151	62
Se	.09043	.00947	10	.00907	10	.07189	79
Sr	.04420	0	<1	.00160	4	.04260	96
Ti	.18642	0	<1	.05523	30	.13119	70
Zn	.05517	.00753*	14	.00990	18	.03774	68
Zr	.12962	0	<1	.04126	32	.08836	68
Ash	.01623	.00369*	23	0	<1	.01254	77

TABLE 15.—*Mean chemical composition and chemical variation in the ash of corn grains from four vegetation-type areas in Missouri*

[Mean concentrations given in parts per million, except where percent is indicated. *GM*, geometric mean; *GD*, geometric deviation; ratio, number of samples in which element was detected to total number of samples analyzed; leaders (. . .) in figure column, no data available. Tests using analysis of variance techniques indicated that differences were significant at the 0.05 probability level for concentrations of K and Ni in samples from the vegetation-type areas that had the highest and lowest concentrations of these elements, as indicated by **boldface** and *italic*, respectively. Significant differences were not indicated by analysis of variance tests for the concentrations of Al, B, Ba, Ca, Cd, Cu, Fe, I, Mg, Mn, Mo, Na, P, Se, Sr, Ti, Zn, and ash. Because of insufficient data, differences in concentrations of Co, Cr, F, Pb, and Zr were not tested for statistical significance]

Element or ash	Vegetation-type areas											
	Floodplain Forest			Glaciated Prairie			Unglaciated Prairie			Oak-hickory Forest		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio
Al, percent	0.034	5.87	7:8	0.020	1.99	10:10	0.023	1.99	10:10	0.017	1.98	10:10
B	62	1.29	8:8	68	1.29	10:10	59	1.19	10:10	68	1.35	10:10
Ba	21	2.55	8:8	15	1.88	10:10	16	1.92	10:10	21	2.82	10:10
Ca, percent	.30	1.33	8:8	.31	1.27	10:10	.29	1.29	10:10	.32	1.22	10:10
Cd	.37	1.72	6:8	.62	2.34	9:10	.40	1.49	9:10	.64	3.55	9:10
Co	<1	. . .	3:8	1.0	. . .	5:10	.5	4.06	3:10	<1	. . .	2:10
Cr	<2	. . .	2:8	<2	. . .	0:10	<2	. . .	0:10	<2	. . .	0:10
Cu	70	1.30	8:8	69	1.49	10:10	94	1.35	10:10	81	1.42	10:10
F[1]	<.5	. . .	1:8	<.5	. . .	1:10	<.5	. . .	1:10	.43	1.12	2:10
Fe, percent	.17	1.67	8:8	.13	1.28	10:10	.16	1.13	10:10	.13	1.30	10:10
I[1]	5.4	1.16	8:8	5.7	1.17	10:10	5.3	1.22	10:10	4.6	1.24	10:10
K, percent	*29*	1.09	8:8	30	1.07	10:10	**31**	1.05	10:10	**31**	1.06	10:10
Mg, percent	6.2	1.19	8:8	6.3	1.18	10:10	6.5	1.15	10:10	5.9	1.19	10:10
Mn	300	1.00	8:8	260	1.40	10:10	320	1.31	10:10	290	1.14	10:10
Mo	18	1.66	8:8	11	1.83	9:10	7.9	2.72	7:10	11	2.19	8:10
Na	39	1.67	8:8	32	1.51	10:10	25	. . .	7:10	25	. . .	8:10
Ni	*12*	1.95	7:8	23	2.04	10:10	**32**	1.73	10:10	28	2.03	10:10
P, percent	22	1.16	8:8	21	1.16	10:10	20	1.16	10:10	21	1.16	10:10
Pb	<20	. . .	1:8	<20	. . .	1:10	<20	. . .	0:10	<20	. . .	0:10
Se[1]	.062	2.41	8:8	.072	2.61	10:10	.047	1.88	10:10	.040	2.96	10:10
Sr	14	2.73	6:8	17	1.72	9:10	15	1.55	10:10	17	2.04	9:10
Ti	<5	. . .	3:8	<5	. . .	2:10	<5	. . .	3:10	<5	. . .	0:10
V	<10	. . .	1:8	<10	. . .	0:10	<10	. . .	0:10	<10	. . .	0:10
Zn	1,700	1.14	8:8	1,800	1.29	10:10	1,900	1.11	10:10	1,900	1.25	10:10
Zr	<20	. . .	1:8	<20	. . .	0:10	<20	. . .	0:10	<20	. . .	0:10
Ash, percent	1.8	1.17	8:8	1.6	1.23	10:10	1.5	1.19	10:10	1.6	1.19	10:10

[1]Parts per million in dry material, not in ash.

TABLE 16.—*Mean chemical composition and chemical variation in the ash of soybean seeds from four vegetation-type areas in Missouri*

[Mean concentrations given in parts per million, except where percent is indicated. *GM*, geometric mean; *GD*, geometric deviation; ratio, number of samples in which element was detected to total number of samples analyzed; leaders (. . .) in figure column, no data available. Tests using analysis of variance techniques indicated that differences were significant at the 0.05 probability level for concentrations of Ca, Cd, Cu, Sr, and Zn in samples from the vegetation-type areas that had the highest and lowest concentrations of these elements, as indicated by **boldface** and *italic*, respectively. Significant differences were not indicated by analysis of variance tests for the concentrations of Al, B, Ba, Co, Fe, I, K, Mg, Mn, Mo, Na, Ni, P, Se, and ash. Because of insufficient data, differences in concentrations of F and Ti were not tested for statistical significance]

Element or ash	Vegetation-type areas											
	Floodplain Forest			Glaciated Prairie			Unglaciated Prairie			Oak-hickory Forest		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio
Al, percent	0.042	2.20	10:10	0.053	1.29	10:10	0.038	1.51	8:8	0.055	2.00	9:9
B	170	1.34	10:10	220	1.26	10:10	210	1.44	8:8	240	1.36	9:9
Ba	440	2.33	10:10	220	2.43	10:10	290	2.18	8:8	230	1.82	9:9
Ca, percent	*5.0*	1.14	10:10	*5.0*	1.16	10:10	**6.2**	1.12	8:8	5.6	1.11	9:9
Cd	**2.3**	2.33	10:10	*.60*	2.04	10:10	.80	1.53	8:8	.68	1.93	9:9
Co	1.0	. . .	7:10	2.0	2.97	8:10	2.1	3.75	6:8	2.1	2.39	8:9
Cu	*170*	1.26	10:10	180	1.26	10:10	210	1.30	8:8	**230**	1.30	9:9
F[1]	.46	1.85	5:10	.47	1.07	5:10	.49	1.04	6:8	<.5	. . .	3:9
Fe, percent	.10	1.14	10:10	.12	1.24	10:10	.13	1.23	8:8	.13	1.28	9:9
I[1]	13	1.14	10:10	13	1.14	10:10	12	1.15	8:8	13	1.15	9:9
K, percent	41	1.06	10:10	40	1.06	10:10	39	1.03	8:8	41	1.06	9:9
Mg, percent	2.5	1.43	10:10	3.0	1.24	10:10	3.2	1.35	8:8	3.6	1.40	9:9
Mn	400	1.57	10:10	320	1.31	10:10	310	1.42	8:8	360	1.29	9:9
Mo	10	3.77	7:10	17	3.95	8:10	9.4	3.16	6:8	20	2.04	9:9
Na	33	1.43	10:10	≅25	. . .	8:10	37	1.56	8:8	33	1.77	8:9
Ni	130	2.62	10:10	94	1.50	10:10	110	1.50	8:8	87	1.71	9:9
P, percent	12	1.00	10:10	9.1	1.43	10:10	10	1.38	8:8	12	1.00	9:9
Se[1]	.17	2.68	10:10	.098	1.83	10:10	.097	2.28	8:8	.077	1.94	9:9
Sr	330	1.72	10:10	290	1.63	10:10	**430**	1.38	8:8	*170*	1.83	9:9
Ti	<5	. . .	2:10	≅5	. . .	6:10	4.7	2.33	5:8	11	3.67	8:9
Zn	890	1.17	10:10	*870*	1.09	10:10	**1,100**	1.19	8:8	**1,100**	1.08	9:9
Ash, percent	5.1	1.10	10:10	5.5	1.06	10:10	5.3	1.06	8:8	5.2	1.07	9:9

[1]Parts per million in dry material, not in ash.

TABLE 17.—*Mean chemical composition and chemical variation in the ash of pasture grass stems and leaves from four vegetation-type areas in Missouri*

[Samples included one or more of the following species: Bluegrass (*Poa pratensis*), big bluestem (*Andropogon gerardi*), fescue (*Festuca elatior*), foxtail (*Setaria viridis*), Johnson grass (*Sorghum halepense*), paspalum (*Paspalum setaceum*), and timothy (*Phleum pratense*). Mean concentrations given in parts per million, except where percent is indicated. *GM*, geometric mean; *GD*, geometric deviation; ratio, number of samples in which element was detected to total number of samples analyzed; leaders (. . .) in figure column, no data available. Tests using analysis of variance techniques indicated that differences were significant at the 0.05 probability level for concentrations of Ba, Ca, Na, Pb, Zn, and ash in samples from the vegetation-type areas that had the highest and lowest concentrations of these elements, as indicated by **boldface** and *italic*, respectively. Significant differences were not indicated by analysis of variance tests for the concentrations of Al, B, Cd, Co, Cr, Cu, Fe, I, K, Mg, Mn, P, Se, Sr, Ti, and Zr. Because of insufficient data, differences in concentrations of As, Hg, Li, Mo, Ni, V, and Yb were not tested for statistical significance]

Element or ash	Vegetation-type areas											
	Floodplain Forest			Glaciated Prairie			Unglaciated Prairie			Oak-hickory Forest		
	GM	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio	*GM*	*GD*	Ratio
Al, percent	0.63	3.23	10:10	0.57	2.09	10:10	0.32	3.15	10:10	0.38	2.78	10:10
As[1]	< .25	. . .	4:10	< .25	. . .	1:10	< .25	. . .	1:10	< .25	. . .	1:10
B	52	1.11	10:10	63	1.18	10:10	52	1.21	9.10	60	1.51	8:10
Ba	570	2.02	10:10	**620**	1.44	10:10	*310*	1.46	10:10	**620**	1.44	10:10
Ca, percent	*3.7*	1.54	10:10	5.0	1.27	10:10	4.5	1.19	10:10	**5.4**	1.26	10:10
Cd	1.4	1.86	10:10	1.0	1.99	10:10	.68	2.11	10:10	1.5	2.24	10:10
Co	1.5	1.47	9:10	1.2	2.05	6:10	≅1.0	. . .	8:10	1.6	2.25	7:10
Cr	7.3	2.53	9:10	7.9	1.65	10:10	5.8	2.35	9:10	5.0	2.67	9:10
Cu	48	1.47	10:10	46	1.44	10:10	41	1.30	10:10	56	1.32	10:10
Fe, percent	.25	2.44	10:10	.24	1.62	10:10	.20	2.43	10:10	.23	1.98	10:10
Hg[1]	< .025	. . .	2:8	< .025	. . .	0:10	< .025	. . .	1:8	< .025	. . .	0:8
I[1]	5.1	1.16	10:10	6.3	1.21	10:10	6.4	1.32	10:10	6.4	1.28	10:10
K, percent	19	1.45	10:10	16	1.49	10:10	23	1.32	10:10	18	1.48	10:10
Li	< 4	. . .	4:10	< 4	. . .	1:10	< 4	. . .	0:10	< 4	. . .	0:10
Mg, percent	2.0	1.18	10:10	1.5	1.26	10:10	2.0	1.35	10:10	2.3	1.71	10:10
Mn	600	1.39	10:10	380	1.46	10:10	470	1.60	10:10	510	1.82	10:10
Mo	1.0	4.93	2:10	3.2	3.01	4:10	4.2	1.90	5:10	< 5	. . .	1:10
Na, percent	.12	6.72	10:10	*.024*	1.76	10:10	**.15**	3.10	10:10	.032	1.48	10:10
Ni	8.8	2.13	8:10	4.2	3.08	5:10	3.1	2.98	4:10	5.2	2.67	6:10
P, percent	2.3	1.31	10:10	2.1	1.34	10:10	1.8	1.35	10:10	2.1	1.26	10:10
Pb	*26*	1.58	8:10	47	1.42	10:10	40	1.57	10:10	**50**	1.75	10:10
Se[1]	.11	1.71	10:10	.084	2.17	10:10	.063	1.53	10:10	.054	2.21	10:10
Sr	260	1.76	10:10	280	1.32	10:10	250	1.53	10:10	220	1.81	10:10
Ti	240	4.46	10:10	240	1.80	10:10	220	2.16	10:10	260	2.24	10:10
V	11	2.03	6:10	4.8	3.13	3:10	3.4	3.07	2:10	< 10	. . .	1:10
Yb	< 2	. . .	0:10	< 2	. . .	0:10	< 2	. . .	0:10	< 2	. . .	1:10
Zn	260	2.09	10:10	290	1.49	10:10	*190*	1.38	10:10	**370**	1.53	10:10
Zr	34	2.96	7:10	29	2.30	7:10	25	3.04	6:10	32	2.90	7:10
Ash, percent	**11**	1.25	10:10	8.9	1.24	10:10	**11**	1.24	10:10	*8.5*	1.29	10:10

[1]Parts per million in dry material, not in ash.

TABLE 18.—*Correlations between the concentrations of elements in corn grains, soybean seeds, and pasture grasses and in the associated cultivated soils from four vegetation-type areas in Missouri*

[*r*, product-moment correlation coefficient between logarithms of concentrations, *n*, number of pairs used in computation of *r*; leaders (. . .) in figure column, data insufficient for computing correlations]

Element	Corn								Soybeans								Pasture grasses							
	Floodplain Forest		Glaciated Prairie		Unglaciated Prairie		Oak-hickory Forest		Floodplain Forest		Glaciated Prairie		Unglaciated Prairie		Oak-hickory Forest		Floodplain Forest		Glaciated Prairie		Unglaciated Prairie		Oak-hickory Forest	
	r	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*	*r*	*n*
Al	-0.47	7	-0.18	10	-0.39	10	0.38	10	-0.48	10	0.48	10	0.19	8	-0.03	9	-0.60	10	0.46	10	-0.22	10	0.48	10
B	-.41	7	.60	9	-.23	10	.27	10	-.54	8	.23	10	-.13	8	-.11	8	. . .	0	-.38	9	-.31	9	-42	8
Ba	.27	8	.29	10	-.07	10	-.32	10	.21	10	-.06	10	-.22	8	.27	9	.41	10	-.31	10	-.32	10	.52	10
Ca	-.15	8	-.37	10	-.22	10	-.33	10	.77	10	.48	10	.38	8	.52	9	-.20	10	.12	10	.45	10	-.12	10
Co	. . .	0	. . .	0	. . .	0	. . .	0	-.35	5	-.13	8	-.22	5	-.05	8	.10	9	.48	6	.30	8	.26	7
Cr	. . .	2	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	.43	9	.47	10	.09	9	-.26	9
Cu	-.81	8	-.60	10	.10	10	-.11	10	-.35	10	.04	10	-.21	8	.31	9	.12	10	.00	10	-.11	10	-.23	10
F	. . .	0	. . .	0	. . .	0	. . .	0	-.23	5	. . .	0	. . .	0	.09	3	-.49	10	.02	10	-.31	8	.67	7
Fe	-.15	8	.24	10	-.19	10	.10	10	-.15	10	.28	10	.08	8	.18	9	-.21	10	.21	10	-.11	10	-.36	10
K	.38	8	.68	10	-.30	10	-.32	10	-.12	10	-.43	10	-.01	8	.07	9	-.11	10	-.26	10	.01	10	.25	10
Mg	.53	8	.13	10	.41	10	.23	10	.23	10	.07	10	.03	8	.36	9	-.11	10	-.66	10	.30	10	-.46	10
Mn	. . .	0	.24	10	-.06	10	-.28	10	.03	10	.15	10	.40	8	-.10	9	-.30	10	.43	10	-.04	10	.17	10
Na	-.80	8	-.04	10	-.42	7	-.34	8	.07	10	-.14	8	-.52	8	.54	8	.09	10	-.33	10	-.10	10	-.30	10
Ni	-.16	6	-.18	10	-.29	9	-.14	9	-.46	9	-.41	10	-.26	6	-.24	9	.37	8	.52	5	-.50	3	-.14	5
P	.04	8	.70	9	.00	8	.29	10	. . .	0	.17	10	-.63	7	. . .	0	.33	10	-.43	10	.10	9	-.38	8
Pb	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	-.02	8	.45	10	-.33	10	.65	10
Se	.47	8	.33	10	.04	10	-.17	10	-.05	10	.80	10	.47	8	.30	9	-.05	10	.51	10	.13	10	-.08	10
Sr	-.21	6	-.44	9	.61	10	-.68	9	-.57	10	.48	10	.03	8	.12	8	-.08	10	-.22	10	.72	10	.08	10
Ti	.72	3	. . .	2	-.81	3	. . .	0	. . .	2	.09	6	.51	5	-.18	8	-.12	10	-.08	10	.27	10	.82	10
V	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	.00	6	.50	3	. . .	2	. . .	0
Zn	-.52	8	.17	10	.59	10	.13	10	-.49	10	.70	10	.58	8	.11	9	.49	10	.45	10	-.73	10	.53	10
Zr	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	. . .	0	.66	7	. . .	0	.23	6	.36	7

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