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THE MINERAL COMPOSITION OF CROPS WITH PARTICULAR REFERENCE TO THE SOILS IN WHICH THEY WERE GROWN

A REVIEW AND COMPILATION

By

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By Kenneth C. Beeson, *chemist, Bureau of Plant Industry*[2]

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INTRODUCTION

The nutritional value of such inorganic elements as calcium, phosphorus, iodine, copper, and iron has been demonstrated by many investigators, and it is generally recognized that quantitative variations of these elements in foods and feeds are important factors in human and animal health. These and other mineral elements, especially those occurring in trace amounts, are receiving greatly increased

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[2] The author wishes to express his appreciation to the several persons who have assisted him. Many helpful suggestions were received from C. A. Browne, under whose direction the work was originally organized, and from Charles E. Kellogg, in charge of the Division of Soil Survey, Bureau of Plant Industry, who originally proposed the study. J. A. LeClerc, of the Bureau of Agricultural Chemistry and Engineering, took an active part in the early stages of the work and contributed much time and effort to it. L. A. Maynard, director of the United States Regional Plant, Soil, and Nutrition Laboratory, and H. G. Byers, in charge of the Division of Soil Chemistry and Physics, both of the Bureau of Plant Industry, made many helpful suggestions and carefully reviewed the manuscript. For her part in the translations of the Italian and Spanish literature, in the systematic handling of the abstracts and cross-references (several thousand such references were involved), in the compilation of the data, and in the careful reading of the manuscript for verbal accuracy, the author is deeply grateful to Ruth B. Rice. The files of the Bureau of Home Economics were very helpful.

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attention in both popular and scientific literature dealing with soils, fertilizers, plant growth and composition, food quality, and animal and human health and nutrition.

It is also significant that greater and greater emphasis is being placed upon the problem of the interrelationships among these fields of investigation. It is believed, and the evidence will be cited in this review, that many nutritional diseases are caused by deficiencies or excesses of particular minerals in food plants grown in different soils, in different localities, and with different cultural practices. Although there is abundant evidence, as shown by this literature survey, that these relationships are real and profound, the data are wholly insufficient for defining such relationships in definite practical terms that can be translated into recommendations for agricultural practice on specific soils for the culture of specific food plants. Aside from the fact that the many unsolved aspects of this problem are certainly responsible for much poor nutrition and poor husbandry, this kind of situation is leading to all sorts of conjecture on the part of the public and to many unwarranted claims in regard to the special advantage or disadvantage of certain soils, fertilizers, and food plants. The Department of Agriculture does not have the necessary facts to judge all of these claims.

It is not the purpose of this review to discuss animal nutrition, plant physiology, pedology, or other disciplines closely related to this general problem, as such. It cannot be held to be within the scope of any one worker's experience or capabilities to venture to discuss the special techniques in such a broad variety of fields. Furthermore, within each field, certain facts are well known or appreciated, and it is neither necessary nor desirable to repeat or duplicate the readily available surveys that have already been made. For example, remarkably complete bibliographies on the minor elements and on the relation of mineral deficiencies to animal diseases are available (*486, 589, 595*).[3] A few surveys of the role of minerals in plant or animal nutrition have been made (*87, 88, 168, 194, 243, 295, 305, 360, 388, 405, 410, 412, 439, 494, 605*), but the discussion in these surveys centers generally around the requirements of plants and animals for minerals. Orr (*443*) has made a survey of pasture research in the British Empire relating to the composition of herbage and the health of the animal, and brief reviews of the importance of soils in the United States to human and animal nutrition have been made by Maynard (*402*), Beeson and LeClerc (*53*), Browne (*93*), and Auchter (*36*).

In the investigation of any nutritional disorder in plants or animals, the difficulties of identification of the cause of that disease multiply as the mobility of the subject increases. Thus, a plant, being stationary as far as its orbit of activity is concerned, represents a relatively simple subject for investigation. Any discrepancies or abnormalities in its growth or appearance can be readily discerned and checked against its source of nutrients, the soil. As a result, the effects of more than 40 elements on the growth and health of plants have been investigated and are more or less known.

The typical domestic animal is, likewise, confined to a relatively small area, particularly in modern times. The animal apparently

[3] Italic numbers in parentheses refer to Literature Cited, p. 59, and such numbers followed by "x" refer to Sources of Unpublished Material, p. 91.

develops some sense of values in regard to the healthfulness of its foods, and when, as in ancient times, it was allowed to roam over large areas of the better lands, nutritional disorders were probably not often observed. However, the ever-increasing population forced the adoption of fundamental changes in the habits of the herdsman. He was required to confine his cattle to that portion of the landscape that he controlled, or he was required to move them to an entirely new and probably much less desirable environment to which they were not adapted. Those who were fortunate enough to have chosen or to have preempted the better lands experienced no difficulties with their cattle, but those to whom fell the less desirable lands or who were driven to some other locality deficient in some respect soon found that their cattle developed disorders that could not be combatted by any known methods. The fact that cattle thrived better on some lands than on others was thus quickly noticed, and we have many references as early as the eighteenth century of the adverse effects of grazing of cattle on certain lands while often adjacent lands were found to be healthful.

Man, in general, has derived his food, in modern times, from such a variety of localities that mineral deficiencies are seldom traceable to any specific soil cause, although such disorders as goiter are confined largely to persons living in areas where the soils and waters are deficient in iodine. Because of the varied diet and the modern methods of food processing and transportation, the fundamental problem of the relation of sources of food to human disease is more difficult to solve. However, some of our people do live in restricted localities and on highly restricted diets, and it should be possible to approach the problem of human nutritional diseases in such localities in much the same manner as one would for animals. Such relationships between the soil as an environmental factor and the occurrence of human disorders have already been observed, but it is very probable that some of these are quite accidental or at least very indirect, such as the observation of Virtanen (*576*) in 1928 that tuberculosis in Finland is more prevalent among people who live on acid soils than among those living on soils that are more nearly neutral. Many such observations of cause and effect are, however, quite direct, as, for example, the fact observed by Byers (*102*) that in certain localities in Mexico the inhabitants exhibit the characteristics of selenium poisoning, while in the selenium areas in South Dakota "a high incidence of symptoms pointing to gastric or intestinal dysfunction, and a few instances of apparent hepatic dysfunction, both probably the result of continual selenium ingestion," have been reported (*531*).

Thus, even cursory observations throughout the past two or three centuries have indicated that certain soils were good while others were poor, and Corlette (*123*) has stated:

> In working through veterinary literature on osteomalacia, rickets and associated conditions of disease, I found my attention over and over again attracted to the character of the soil, climate and vegetation in their relation to the prevalence of cases.

The nutritional diseases of animals which have been traced to soil characteristics may be divided into two general classes. The first, and more important, are those reported to be due to a deficiency of one or more of the inorganic nutritional elements in the food, eventually resulting in bone maladies, anemia, goiter, and related diseases. The second are those claimed to be the result of excesses of certain elements in the soils and in the plants growing therein. Of the latter class, only selenium has been extensively studied, although investigations would doubtless indicate that other serious disturbances may really be due to poisoning of the animal.

The problem that confronts us is more complicated and insidious in nature than that of correcting observable deficiencies in the domestic animal, for although the humane and economic aspects of this part of the difficulty are great, the more important aspect is man, who depends upon a high quality of food for his growth, health, and reproduction.

It is probably true that not only are a large portion of our people existing on a diet deficient in the protective foods such as milk, eggs, fruits, and vegetables, but also a large portion are obtaining only a minimum amount of these foods. If this is true, we are then confronted with the problem of the variation in the nutritive value of such foods as the fruits and vegetables in particular. Are these fruits and vegetables as highly nutritious as is possible? The calcium content of cabbage, one of the most commonly used protective foods of the vegetable class, may vary from 0.40 to 1.60 percent of the dry weight (refer to appendix), and the average is about 0.73 percent. Comparable variations in other nutritive elements in this and other foods are often reported. It is entirely probable, therefore, that the value of a minimum diet of protective foods may be reduced significantly below the minimum requirement through the use of inferior foods. The necessity for maintaining these foods at an optimum nutritive level is thus apparent.

The problem is intensified because of the location of our large cities and of our truck farms that supply these cities with food. Most of our large cities are located on the well-leached Podzols and podzolic soils that are acid in reaction and low in the bases. The truck farms are of necessity located near the cities on the same soils, and large quantities of truck crops and fruits are shipped to these cities from localities where nutritional disorders due to mineral deficiencies in the soils have been noted in both humans and animals.

Although many factors other than the poor quality of food probably are responsible for dietary difficulties, this factor is believed to be an important one; and if it is important, then it certainly remains the duty of the agriculturalist to supply for at least the protective portion of the diet a food of the highest nutritional quality.

SOME SOIL CHARACTERISTICS CITED IN RELATION TO THE OCCURRENCE OF CERTAIN NUTRITIONAL DISEASES OF MAN AND ANIMALS

In the discussion that follows, the occurrences of certain nutritional deficiency diseases are cited only as indicators of observed differences in soils. No attempt has been made to discuss the diseases themselves.

Studies of the Relation of Soils to Bone Diseases

The occurrence of many disorders in animals, believed to be due to deficiencies of elements such as calcium or phosphorus, are often suspected to be related to deficiencies of one or more of these elements in the soil. Direct evidence of such relationships is, however, generally difficult to obtain, because of the numerous factors involved and the overlapping of these factors. Thus, climatic conditions may be such as to cause in some years a significant reduction in the quantity of an element in the plant or a marked change in the usual ratio of one element to another. Mineral deficiencies in the animal may also be due to an inadequate supply of food in general, to the unavailability to the animal of the mineral elements in the plant, or to the species of plant available to the grazing animal. Many of the factors causing variations from the normal in plants are very closely interrelated, and a discussion of them will be found in the second part of this review. It is generally agreed, however, that frequently there are differences in soils, often in the same locality, that are associated with the occurrence of disorders in animals, and it is the purpose of this part of the review to cite some of the observed characteristics of these soils.

An appreciation of differences in the capabilities of soils to produce healthful food for animals is not a recent achievement, for Neyen (*436*) stated that Gleditsch in 1787 noted the occurrence of a bone trouble of cattle in certain localities in Europe, and other early observations were made by Le Vaillant (*555*) and by Lichtenstein (*350*) in their accounts of their travels in South Africa at the beginning of the nineteenth century. Von Gohren (*217*) reported in 1861 that a disease of the bones of cows occurred over a considerable region in Germany in 1859, a year of drought. He associated the disease with a low content of inorganic elements in the feed, and he reported that the addition of bone meal to feeding stuffs cured the disease. Among other early investigators of the relationship between the composition of the forage and the occurrence of bone diseases were Grouven (*230*) in 1865, Karmrodt (*310*) in 1868, Roloff (*498*) in 1869, Klimmer and Schmidt (*317*) in 1906, Scheunert, Schattke, and Lötsch (*511*) in 1911, and Zuntz (*607*) in 1912. All of these workers reported that the calcium or phosphorus content of pasture or hay in the abnormal areas differed from that in the healthful areas, and in many cases their analyses indicate that these differences were real and significant. In other cases, however, particularly where differences in calcium are cited as being important, the minimum value of calcium given is often not less than that now believed to be the minimum required by animals (*403, p. 354*), which may indicate, of course, that certain of the conclusions of these early investigators were not justified. It is interesting to note, nevertheless, that considerable importance was attached to soils and their properties as factors in animal health. Later investigators may have been more accurate in some of their classification of diseases, but many of them have not improved their soil investigation technique to any important degree.

A bone disease of livestock was first observed in Australia in 1895 by Potts (*471*) following a severe winter and a hot, dry summer. A note of the investigator indicates that the soils involved were largely formed from granites and that there was a scarcity of lime. Henry (*260*, *261*, *262*) has reported that the occurrence of bone disease in Australia was related to definite areas and soils that were often sharply marked off from those parts of the same country where the disease did not occur.

Guthrie and coworkers (*234*) stated in 1914 that bone diseases in Australia were generally most acute where the soils exhibited a marked deficiency in lime, and that when animals in one portion of a district were affected and in another unaffected a notable difference in the lime content of the soils of the two localities usually existed. The normal areas were described as being mostly dark-colored soils, well supplied with lime and possessing a porous subsoil. The deficient areas had light-colored, poor soils and clayey subsoils. The diseases were reported to be most prevalent on geological formations like sandstones, aplites, and granites, which yield silicious sandy soils, poor in lime. The normal areas were located on limestone, basalt, dolerite, diorite, and gabbro formations, which are well supplied with lime. Unaccountable exceptions to these general observances were reported, however. A comparison of soils in some of these good and poor regions is shown in table 1.

TABLE 1.—*Comparison of composition of soils from coastal areas of New South Wales on which animals were affected and on which they were unaffected with bone disease*

[Guthrie and coworkers (*234*)]

Character of area	Reaction of soil	Clay	N	CaO	K_2O	P_2O_5
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
Affected (17 soils)	Usually strongly acid	43.2	0.157	0.168	0.087	0.047
Unaffected (17 soils)	Neutral to acid	58.0	.282	.465	.143	.184

Although observations in South Africa more than a century ago indicated that cattle were subject to a bone disease, no formal investigations seem to have been conducted until fairly recently, when in 1918 Viljoen (*575*) studied the occurrence of lamziekte, a disease later described by Theiler and others (*554*) as "an indirect consequence of phosphorus deficiency, the direct cause of the disease being a 'ptomaine poisoning' brought about by infection of carcass debris with a specific toxigenic saprophyte; an anaerobic bacterium reminiscent of, but not identical with, *Bacillus botulinus*." Viljoen reported that in the Bechuanaland area lamziekte was most prevalent on limestone and dolomite formations. Sandy soils, especially shallow ones or those mixed with limestone, seemed to be the most common formation on which the disease occurred. He stated that lamziekte was unknown or very rare on farms where the soil formation is a deep alluvial one. He believed that the moisture relationships of the soils were very important, for he observed that the disease appeared most commonly on farms where the soil formation is such that very little moisture is retained. Plants growing in such soils quickly responded to changes in the climatic conditions.

This relationship between climate and the occurrence of bone disease had already been indicated by Von Gohren (*217*), and Lewite (*348*) had found in 1907 that oat plants grown in dry years, characterized by outbreaks of bone diseases near Leipzig, contained less phosphorus and more calcium than did the normal plant. Viljoen, however, appears to be the first to relate this phenomenon to such definite soil characteristics as structure and the water relationships.

Further investigations by Theiler, Green, and du Toit (*554*) in 1924 confirmed the effect of climate as well as soil on plant composition and the occurrence of deficiency diseases. Thus, in table 2 the phosphorus contents of the vegetation consumed by cows suffering from osteomalacia and lamziekte in South Africa are given for different times of the year.

TABLE 2.—*Composition of dry matter in vegetation from Armoedsvlakte veld with special reference to phosphorus*

[Theiler, Green, and du Toit (*554*)]

Date	Composition of dry matter						
	Crude protein	Ether extract	N-free extract	Crude fiber	P	Estimated energy value (starch=100)	Ratio of starch equivalent to P
	Percent	*Percent*	*Percent*	*Percent*	*Percent*		
Nov. 10, 1919	19.4	5.5	41.0	22.5	0.26	56	100:0.46
Dec. 8, 1919	14.3	5.6	46.8	25.6	.14		
Jan. 15, 1920	13.8	5.5	48.0	25.0	.10	52	100:0.19
Mar. 4, 1920	7.2	3.4	49.8	23.7	.10		
Apr. 19, 1920	4.9	2.4	51.6	35.0	.05	32	100:0.16
May 11, 1920	4.1	2.2	52.9	34.9	.03		
June 8, 1920	4.0	2.0	53.7	33.1	.04	25	100:0.16

It is stated that except for the very early grass this veld is deficient in phosphorus as well as protein and other desirable constituents all the year round. That this deficiency may be due to the unavailability rather than to a deficiency of phosphorus in this soil is apparent from the fact that the available P_2O_5 in the soil is reported to vary from 0.0005 to 0.001 percent as compared with a total P_2O_5 content of 0.03 to 0.12 percent. These authors cite another soil in the same area that contains 0.009 percent of available P_2O_5 and that is said to support a pasture that will maintain healthy cows.

The Armoedsvlakte soil is described as a shallow soil, varying from dolomitic outcrop to a few feet of leached material. According to the extent of leaching it varies from a heavy dolomitic loam to a sandy soil containing very little carbonate, although still alkaline.

More detailed descriptions of soil characteristics, particularly parent material, as related to the occurrence of bone diseases in animals have been made in New Zealand than in any other locality. The earliest reference by Reid and Aston (*479*) in 1910 cites this abnormal condition among pastured animals as being the result of "an excess of organic matter and a deficiency of salts in the soil upon which the animals were depastured [sic]."

The interest in soils probably arose from the observation that adjacent pastures often had quite different effects on the health of the animal. Thus, Aston (*33*) in his study of the occurrence of osteomalacia in the Wairarapa district observed, in 1930:

> The district is a very large one, in which, while it contains the most phosphorus-deficient pastures yet met with in New Zealand, certain areas afford soils of great fertility and pastures of high nutrient value. *The evidence of the relationship between soils and animal health is convincing and continuous from the soil, the pasture, and to the animal.*

In a further investigation of the soil characteristics in relation to the occurrence of osteomalacia in the Wairarapa district, no definite relationship between soil structure and the occurrence of disease was noted, for it was stated in 1931 by Aston and others (*34*):

> The soil-analyses reveal no soil of excessively course nature, such as pumice, sandy silts or even the coastal dune sands, so that from a mechanical point of view the soils involved show no inherent structural defect. The finest textured soils on which the disease occurs are silt clays, and the coarsest are fine sandy loams.

The investigations of the New Zealand workers in connection with the occurrence of bone diseases included many analyses of both pastures and soils (*34*), observations of the characteristic flora of good and affected pastures (*32, 34*), and descriptions of soils with particular reference to parent materials (*27, 32, 34*). Thus an affected soil at Martinborough was described as being quite heavy with a hardpan formation in the flat lands, while a good soil in the same area was classified as a clay loam derived from limestone (*34*). Many difficulties with bone diseases were reported as occurring on certain soils derived from an air-borne volcanic material in a region of heavy rainfall (*32*). The pH-value range was reported to vary from 5.0 to 5.8 for the affected soils and 6.1 to 6.3 for the better soils.

An occurrence of a bone disease referred to as osteomalacia was investigated in Norway by Tuff (*567*) in 1923. The disease was more severe in dry years, but Tuff stated that there are also typically osteomalacia districts where the disease occurs as an enzootic, independent of the amount of rain.

He reported that if hay from normal farms was given to the stock affected with osteomalacia, or if the owner of a threatened farm hired summer pasturage on a normal farm, his animals were not subject to the disease. Conversely, animals moved to pasture on deficient soil acquired the disease. Tuff examined the mountain rocks in the abnormal areas and reported that they contained only 0.002 percent of P_2O_5, as compared with 2 percent in the substratum of the normal areas.

In 1926 Elliot and his coworkers (*165*), from their quite extensive investigations in Great Britain of the effect of the mineral composition of pastures on the health of the animal, concluded that a comparison of the

health, quality, and number of sheep grazing a pasture with the analytical data for the individual (pasture) samples seem to indicate that the highest mortality amongst the sheep * * * is found where the pasture shows the lowest percentage of mineral matter. It is interesting to compare the results for two very poor pastures and a very rich pasture with the average results for cultivated pastures. [See table 3.] As types of very poor pastures, the samples from the island of Lewes and the Falkland Islands are taken. * * * there is a high mortality amongst sheep in the Falkland Islands. Samples taken from the paddocks at Lord Astor's racing stables at Taplow, where the grass has received special treatment to render it suitable for grazing for race horses, have been chosen as representative of a very rich pasture.

TABLE 3.—*Composition of some British pastures*

[Analyses of William Godden (*211*)]

Locality	Composition of dry matter					
	Crude protein	K	Na	Ca	P	Cl
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Island of Lewes (eaten)	8.37	0.563	0.280	0.204	0.106	1.340
Island of Lewes (not eaten)	6.43	.448	.281	.211	.077	1.029
Falkland Islands	10.31	1.644	.215	.161	.213	1.650
Taplow pastures	22.26	1.991	.518	1.767	.435	3.562
Average for cultivated pastures	17.69	2.637	.182	.718	.321	2.830

The deficiency of mineral elements in the poor pastures is apparent. Even the "eaten" areas in the island of Lewes contain about one-third as much calcium and phosphorus as well as only one-half the protein found in the average pasture, while a comparison with the Taplow pasture is even more unfavorable.

Orr (*444*) in 1929 reported on the difference in composition of good and poor pastures in the hilly districts in the Western Highlands and in the southwest of Scotland, where it is claimed a bone disease, locally referred to as croitich, in sheep occurs. Some of his data are given in table 4, and they indicate that both calcium and phosphorus in the affected areas may be deficient (*403, p. 354*).

TABLE 4.—*Composition of good and poor Scottish pastures*

[Orr (*444*)]

Description	Composition of dry matter						
	Crude protein	Ash	K	Na	Ca	P	Cl
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Healthy hill pasture	15.62	5.85	2.21	0.27	0.46	0.29	0.64
"Croitich" area	12.80	2.82	1.25	.09	.15	.13	.52

Elliot, Orr, and Wood (*164*) reported in 1926 little or no difference in the energy values of good and poor pastures and, in agreement with other investigators (*126*) in England and other localities, emphasized that the poor nutritive values of some pastures were due in part to their botanical composition. A more complete discussion of the influence of soils on botanical composition will be presented in subsequent sections.

Aphosphorosis, or sickness from deficiency of phosphorus, has been reported in certain areas in Ontario, particularly in dry years (*384*), and soil descriptions have been made in some cases. Thus the Brookston silt loam in Canada has been reported as a soil on which grazing animals do well, and herbage growing on this soil, which in one locality has an available phosphorus content of 368 pounds per acre, according to Atkinson and Woodward (*35*), contains nearly twice as much phosphorus as does herbage growing on the Berrien sandy loam, which contains, according to these authors, only 84 pounds of phosphorus and is considered to be less desirable for pasture. This is in contrast with the experience in Michigan (*229*), where the medium-textured soils such as the Brookston and Gilford loams are claimed to support plants of low phosphorus content and on these soils nutritional disorders in cattle are reported to occur. Such anomalies appear to be common, and their occurrence suggests that much of fundamental importance as to soil and plant and animal relationships is as yet obscure.

In France, Maume and Monteil (*400*) in 1938 observed animal diseases in some areas where soils were developed from gneiss, mica schists, or granites. The authors stated that the forage grown on these soils was deficient in calcium and phosphorus. In India, Davis (*143*) states that it has long been known that the native cattle of Bihar are small and give far less milk than the cattle in many other districts where it is claimed the soils are more favorable so that good nutrition is possible. Other observations of the importance of soil characteristics in the incidence of bone diseases have been made by Crawford (*127*) working in Ceylon and by Rubino (*499*) in Uruguay.

Although American investigators have generally recognized that soil conditions may be responsible for bone diseases in animals grazing certain pastures, few careful descriptions of abnormal soils have been made. Faville (*173*) in 1896, a report of the Bureau of Animal Industry for 1898 (*571*), and Parker (*449*) in 1904 refer to possible environmental conditions as being important in the occurrence of nutritional diseases. In 1920 Cary (*111*) described a deficiency disease in southern Alabama along the Coastal Plain region, sometimes called the wire grass region. The terms "sweeny" or "creeping sickness" were applied to the disease, which Cary states was actually osteomalacia. The soil was described as being sandy and deficient in lime. Schmidt (*512*) in 1924 investigated a fatal disease of cattle in Texas known as "loin disease" or "down-in-the-back." He observed that the occurrence of the disease was "limited to the low, flat area bordering on the Gulf of Mexico and extending inland to the north to a distance of about 100 miles. The soil is usually noncalcareous." Becker (*52*) in 1933 stated in connection with his investigation of "bone chewing" in Florida that the deficient areas were associated with certain of the "clay soils of the lower Appalachian Mountain regions, soils of the flatlands more distant from the flood plains of rivers that drain more fertile fields, and the muck and lighter sandy soils of the coastal plains."

Welch (*582*) in 1924, in his report on bone chewing in Montana, stated that throughout large areas in Montana, cattle showed symptoms of a deficiency disease. The occurrence of the disease was usually associated with the feeding of wild hay and usually that grown on low ground. As a rule the hay contained redtop, wire grass, bluejoint, and various swamp grasses. Cattle that were fed alfalfa, clover, or other legumes were not often observed to chew bones, even though legume forage may have been used for only a part of the year. Although the disease had been observed since 1910, it did not become acute until the better lands were taken over for farming and the poorer lands only were reserved for grazing.

Scott (*516*) in 1929 examined the forage in several localities in Montana where depraved appetite of cows had been observed. The data on grasses from normal and deficient areas indicate that the cattle must obtain in any of the areas studied in Montana a forage relatively low in phosphorus and that there is little difference in the composition of forage from "good" or "poor" lands. The data in table 5 illustrate the point.

TABLE 5.—*Calcium and phosphorus content of forage crops in Montana*

[Scott (*516*)]

Forage	Year sampled	Description of area	Number of analyses [1]	Analysis of dry matter	
				Ca	P
				Percent	*Percent*
Alfalfa	1925	Normal	11	1.44	0.181
Do	[2] 1927	do	9	1.54	.164
Do	1926	Deficient	6	2.32	.161
Do	1926	do	3	2.02	.160
Do	1927	do	1	1.49	.141
Clover	1925	Normal	3	1.05	.170
Do	1927	do	2	1.23	.123
Do	1926	Deficient	1	1.82	.147
Do	1927	do	1	1.46	.139
Wild grass		Normal	9	2.44	.157
Do		Deficient	14	2.94	.113

[1] Maximum and minimum values are not given by the author.
[2] The season of 1927 was wet. No information available for other years.

The phosphorus content of the alfalfa from even the better areas is about as low as that found anywhere in the world for this plant when harvested at the one-half bloom stage. (See appendix.) The calcium is slightly below average for alfalfa, but the Ca:P ratio is 10 as compared with 7.5, the ratio of the average values shown in the appendix. The phosphorus contents of the clovers from both regions are not of sufficient difference to be significant. The analyses of the wild grass samples do indicate a difference of phosphorus, although the amount found in the deficient areas is not so low as it was in the pasture grasses studied by Theiler (table 2). It is instructive to note that the calcium content of forages from deficient areas was generally found to be higher than in those from the normal areas, which may mean that a Ca:P ratio less favorable to the animal is a factor to be considered.

According to Eckles, Becker, and Palmer (*161*), mineral deficiencies in cattle have been noted in 32 counties in Minnesota. The soils, which at one time were covered with grass, are of glacial origin and are described as young gray drift. While the phosphorus contents of the forages from these areas show some differences according to the prevalence of disease, it must be admitted that they are all very low. For example, the average phosphorus content of 9 samples of alfalfa from normal regions in Minnesota was 0.257 percent, and that from abnormal regions was 0.189 percent, while the average of all available data for alfalfa at one-half bloom stage is 0.272 percent. The average prairie hay in abnormal regions contained only 0.100 percent of phosphorus, while that from normal regions contained 0.108 percent. Such differences are probably negligible, and the forages in the good regions are probably on the border line as far as their nutritional value is concerned.

In harmony with the results from other deficient areas, it was found that osteomalacia was more severe in years of drought than in wet years. Likewise, the forage contained more phosphorus in the years of higher rainfall.

Later work from Minnesota by Eckles, Gullickson, and Palmer (*162*) showed extreme cases of phosphorus-deficient forage in prairie hay grown on the Nygaard farm. From 1925 to 1931 the phosphorus contents of the hay from this farm varied from 0.047 to 0.094 percent. Such values compare very well with the results of Theiler in South Africa, and they are lower than the values found in Montana. It was estimated by the authors that a cow receiving this hay along with the usual ration of oats would receive only 68.6 percent of the phosphorus necessary for maintenance and milk supply.

Huffman and Taylor (*281*) in 1926 surveyed areas in Michigan where depraved appetite occurred and found that soils in these areas contained approximately one-half as much phosphorus as did normal soils. Analyses of three samples of forage collected by these investigators do not indicate a phosphorus deficiency, but the rather unusual circumstance is presented of a low phosphorus content in their forage samples collected in the early spring followed by a 40-percent increase by midsummer and a further increase by fall. They state that depraved appetite in Michigan cattle seemed to be most severe in the spring and abated during the fall. They further found that, although a mineral mixture similar to the mineral combination found in alfalfa hay failed to relieve depraved appetite, well-cured alfalfa hay effected a cure in all cases tried.

Ten samples of Michigan alfalfa hay examined by Reed and Huffman (*478*) had a phosphorus content well below the average for alfalfa shown in the appendix of this publication.

Phosphorus-deficient areas have been reported from various localities in Wisconsin by Hart and others (*242*), but apparently no relationships have been determined between the occurrence of the disease and the soils or the nature of the forage. Mineral-deficient areas have also been suspected in Merced County, Calif., according to Hart and Guilbert (*245*). Soil studies have not been reported, however, from this area.

A recent survey in Pennsylvania (*193*) is reported to have failed to reveal any deficiency of phosphorus in the forage of that State. It had been assumed that since a large proportion of the soils in the State are responsive to phosphate fertilization, there might be a deficiency in the forages in some places. The conclusions were that the data obtained did not support this assumption.

Studies of the Relation of Soils to the Nutritional Anemias

The properties of soils in many parts of the world have been described in connection with the occurrence of troubles in which anemia has been reported as a symptom. From the discussion that follows it is not to be inferred, of course, that a direct connection with soil conditions has been established, but it will be noted that evidence has repeatedly been produced that would indicate significant differences in soils associated with healthy animals and those associated with affected ones. McGowan and Smith (*367*) state in 1922, for example, that a disease of sheep referred to as "pining" was noted in the southern part of Scotland as early as 1807, and a recognized cure was to shift the sheep to a more succulent herbage or pasture grown on limed soils. Sheep on moors or moss-covered lands were always susceptible to the disease, but no symptoms were ever noticed in sheep grazing on the steep and rocky lands where herbage was sweet and short. Regions underlain by porphyritic rock were associated with the occurrence of pining, and it appeared occasionally in the sandstone regions, but the limestone regions were almost always free of it. Investigations of soils in these areas by Greig and others (*226*) in 1933 seemed to indicate that the iron content was low in affected soils, although it was reported by Godden and Grimmett (*212*) in 1928 that additions of iron to these soils did not result in any increase in the iron content of either oats or mustard. The work of Corner and Smith (*124*) in 1938 indicates that cobalt may be the limiting factor in these areas.

A nutritional anemia referred to as bush or Tauranga disease was known in New Zealand in 1900, when Gilruth (*210*) stated that in localities where the disease occurred there were "healthy" and "unhealthy" lands, and that vegetation grew as luxuriantly on one as on the other. Aston (*30*) examined these soils in 1912 and found that abnormal soils were composed largely of air-borne pumice, an acid lava that had been so mixed with gases in the molten state that on cooling it presented a spongy structure with the hardness of rock. He reported also that the available phosphorus was generally low and that manganese was high in these soils.

Manurial experiments (*475, 476*) indicated that applying iron compounds to the soil did not always alleviate the disease, although improved health of the cattle could usually be obtained by dressing pastures with superphosphate, blood, bones, and guano. Heavy applications of superphosphate to soils with a low content of available iron were reported to be sometimes successful in combatting the disease, and the use of iron salts as a drench in advanced cases was sometimes satisfactory (*477*).

More recent investigations of the soils associated with bush sickness showed that most of them were well leached and that they did not contain any appreciable amounts of calcium and manganese likely to be antagonistic toward the availability of iron. Taylor (*549*) believed that leaching was primarily the reason why certain Mairoa farms were unsound for stock. He inspected 12 farms with a definite history of abnormality and found that

> The predominating structure in each case was volcanic ash upon porous sandstones or loose sands. In the neighboring healthy areas the sands were practically absent, and the ash was underlain by limestone with its attendant residual clay, or by Jurassic mudstones.

Grange et al. (*218*) later claimed that profiles of six typically "bush-sick" soils showed evidence of distinct podzolization. They were all coarse-textured soils containing only small percentages of clay. The chemical analyses of the soils showed that some contained a moderate supply of available phosphorus and potash, while others were definitely low in both of these constituents. However, normal volcanic soils were also found to be low in these constituents, and they were often of coarse texture. Texture, in fact, does not seem to be an important factor, for Aston (*31*) states that certain coarse sandy soils near Rotorua are recognized locally as "hospital" lands and supply a nutritious food for animals.

In their study of bush sickness at Glenhope, Nelson, New Zealand, in 1932, Askew and Rigg (*26*) reported that the deficient soils were well leached and occurred mostly over granitic formations. Evidence that a deficiency of iron in these soils was a factor in the disease was not demonstrated (*487*).

Dawson (*144*) seems to have been the first to associate "salt-sick," an anemic condition of cattle, to certain characteristics of some of the soils of Florida when in 1906 he stated: "The disease is usually confined to regions where the predominating soil is light, sandy, and more or less unproductive of nutritious grasses." He believed the disease to be comparable to that occurring on Cape Cod Peninsula and in certain counties in southern Texas. He observed that salt-sick occurs in nearly all parts of Florida.

In 1931 Becker, Neal, and Shealy (*51, 429*) found that "'salt-sick' is a naturally occurring nutritional anemia in cattle, the feed of which has been restricted largely to grass forage grown on certain white and gray sandy soils, residual muck and peat soils not subject to overflow from more fertile watersheds." No trouble was experienced on clay soils.

More detailed soil work by Bryan and Becker (*94*) in 1935 showed that soils from healthy areas contained over twice as much silt and clay in the first foot and over three times as much in the second foot as did those soils in the salt-sick area. Their survey revealed that for many years cattlemen "have found it necessary to transfer 'salt-sick' animals to healthy ranges, sometimes known locally as 'hospital' lands. Where this practice was observed, the so-called hospital lands have been either on sandy loam or on one with a sandy clay strata from 15 to 30 inches below the surface."

It was found that salt sickness occurred on both calcareous and low-lime soils, and it was believed that this indicated that the disease was not related to calcium deficiency. The soils associated with salt-sick were Dade sand, Leon sand, Leon fine sand, Portsmouth fine sand, Norfolk sand, and Norfolk fine sand. Those in the healthy areas were the Bladen fine sand, Fellowship sandy loam, Gainesville fine sand, Hernando sandy loam, Hernando sand, Lakewood sand, Norfolk sand, Norfolk fine sand, Orangeburg loamy sand, Orangeburg fine sandy loam, Orangeburg fine sand, and Ruston sand. The average composition of each of these groups is given in table 6. The authors explain that the Norfolk soils have a wide range of types and phases which vary greatly in texture and natural fertility. This fact may account for this group of soils occurring in both the "salt-sick" and healthy ranges.

Table 6.—*Mineral composition of first foot of Florida soils in salt-sick and healthy areas*

[Bryan and Becker (*94*)]

Description of area	CaO	P_2O_5	Fe_2O_3	Cu	Silt and clay	pH
	Percent	*Percent*	*Percent*	*P.p.m.*	*Percent*	
"Salt-sick"	0.050	0.027	0.057	3.97	4.3	5.17
Healthy	.227	.130	.604	8.56	9.9	5.24

Neal and Becker (*428*) examined samples of wire grass in 1933 from many of the healthy and salt-sick areas in Florida. Their data show that the mineral content of forage growing on burned areas is higher than that growing on unburned areas, and that the calcium and phosphorus are higher in forage from healthy areas than from salt-sick areas. Unfortunately, their extensive iron data are open to question because of the method of preparing the samples.

A nutritional anemia in calves described as a deficiency of iron was reported by Archibald and coworkers (*12, 13*) in 1938. They concluded from their analyses that the iron content of the roughage available to the animals in the abnormal areas was somewhat below that for hays from other sections of the State and of the country where such trouble is not experienced.

A trouble referred to as "pica," "coast disease," or "coastiness" was first observed in Australia about 1913, when it was claimed, according to Filmer (*182*), that in certain areas of the Denmark district of Western Australia farmers had been unable to rear calves since first settling in the area. In some cases certain paddocks only were affected, while adjacent ones were normal. Soil descriptions were rather sketchy, but they indicate a similarity to some soils in New Zealand. The disease is said to occur in various parts of Australia (*386*). The investigations of Filmer and Underwood (*183*) in 1934 indicated that a deficiency of iron in the forage was not a cause of coastiness, and in 1935 these authors (*570*) reported that a deficiency of cobalt in the soil and herbage was a factor, while later investigations by the same authors indicate that nickel is of importance (*184*).

In Dartmoor, England, it was reported by Patterson (*451*) in 1937 that soils on which sheep suffer from "pining" have a mean cobalt content of 3.9 p. p. m., while lowland soils on which sheep recover have a cobalt content of 16.7 p. p. m. Analyses of the pastures show that those in the unhealthful areas have a mean cobalt content of 0.20 p. p. m. and those in the recovery areas 0.45 p. p. m. It was also indicated by Kidson (*316*) that the cobalt contents of soils in this area are in general related to the magnesium content of their parent rocks.

In New Zealand (*22, 24, 25, 148*) it was reported that the cobalt content of soils in bush-sick areas contained only a trace of cobalt as compared with the healthful areas, although "soil results indicate that a low cobalt status of the soil is not always a satisfactory index of the need for cobalt supplements for stock." Generally, however, Kidson (*315*) believed that "soils affected with 'bush-sickness' and allied stock ailments have comparatively low cobalt contents, often less than 2 p. p. m. of cobalt." It was reported by Josland (*308*) that 1 mg. $CoSO_4$ per 200 gm. of live weight of the animal is not toxic.

A disease of cattle known as "nakuruitis" has been reported from certain areas of Nakuru, in the Kenya Colony in East Africa, by Orr and Holm (*446*). "The top soil in the affected areas consists of material which has obviously been erupted from the adjoining extinct Menengai volcano."

Neal and Ahmann (*427*) in 1937 reported that cobalt was not detected in forage from certain areas in Florida associated with a nutritional disturbance in cattle that was cured when cobalt was fed as a supplement, but later work by Rusoff and others (*500*) failed to demonstrate that cobalt was present in forage from either salt-sick or healthy areas. In fact, a spectrographic estimation of copper and several other trace elements was reported as giving no indications of differences in samples of wire grass collected from these areas.

A nutritional anemia among children in certain areas of Florida was investigated by Abbott, Neal, and Bryan (*2*) in 1934. In a brief report they state that in one section situated on soils overlying hard rock phosphate subsoils only 3 percent of the children had anemia, but within a distance of 6 miles, where the soil is for the greater part Leon, located in the flatwoods country, 96 percent of the children were affected. They add: "Hookworm and malaria are known to contribute to this condition, but it was found that the number of children infected with these parasites was comparable in the two localities."

In a later study by these authors (*1*) it was reported that the Leon, Portsmouth, and Norfolk series (all low in iron) prevail in those districts having the highest percentage of anemic children, and that the sands and sandy loams of the Hernando and Hoffman series (all high in iron) predominate in the districts having the lowest percentage of anemia.

Riceman, Donald, and Piper (*484*) have recently described what may be a copper deficiency along the southeastern coast of South Australia. The soil is derived from blown calcareous sand containing over 60 percent of $CaCO_3$ in the surface soil. Sheep grazing the area were reported to suffer from an ailment similar to coast disease. Normal vegetative development was attained with the use of $CuSO_4$, but no statement was made relative to any improvement in the sheep.

The clinical aspects of a deficiency disease in sheep in Western Australia have been studied by Bennetts (*54*), who reported in 1937 that copper seemed to be the limiting factor. In their investigations of the soils in this district Hosking and Greaves (*279*) state: "The presence of this deficiency disease (enzootic ataxia) is closely associated in Gingen with any soil underlain by Cretaceous rocks." Country adjacent that is underlain by granite and gneiss is apparently unaffected, although "recent investigations show that the disease sometimes occurs on granitic formations."

Indications of a copper deficiency in Florida forages was reported by Becker, Neal, and Shealy (*51*) in 1931. These investigators stated that sometimes copper in addition to iron was necessary in order to prevent or to cure salt sickness.

In 1934, Svanberg (*544*) discussed the environmental relationships of an anemia of horses grazing on the very acid soils of northern Sweden. The pH value of these soils was found to be about 4.8 or less, and they are described as being sterile alum soils (*546*). Over comparatively large areas these soils are used for hay production and the crops serve as horse fodder. Although most of the major constituents and the iron, aluminum, and copper contents of the forages are normal, the manganese content is strikingly high, often 10 times as much in abnormal as in normal areas. Svanberg states that favorable natural conditions under which anemia in horses will not occur seem to include a soil rich in lime and containing not too much manganese.

Further investigations of this disease of Swedish horses by Carlstrom and Hjärre (*105*) in 1938 have attempted to show a relationship between vitamin B_1 and manganese. Carlstrom and Hjärre claim that this anemia is

> due to an insufficient content of vitamin B_1 in the hay and this insufficiency is probably caused by too large a proportion of manganese in the hay. Everything leads to the belief, in effect, that this element destroys through oxidation the vitamin B_1 of the hay.

Further investigations will no doubt be necessary to clarify many of the factors involved in the occurrence of this disease.

Studies of the Relation of Soils to "Lecksucht"

A relationship between some property or properties of soils and the occurrence of a disturbance in cattle in Europe, known as lecksucht, has long been suspected (*287, 288, 289, 296, 297, 318, 346, 435, 448, 457, 470, 534, 545, 564*). In some districts it was reported that the poor soils were developed from granites or mottled sandstone, whereas the unaffected or good soils were derived from gneiss. In other areas the poor soils were peaty in character and were low in potassium as well as in phosphorus, and the acidity was reported as being quite high.

Sjollema (*526, 527*) reported in 1933 that the copper content of hay-fed cows suffering from what he calls lecksucht was much less than that fed cows in good health. Nicolaisen and Seelbach (*437*) in 1938 reported that the application of copper sulfate to pastures not only improved the pastures but also the health of the animals suffering from what they also refer to as lecksucht.

"Alkali Disease" or Selenium Poisoning

In 1934, as a result of a preliminary field survey of "alkali disease," Franke and coworkers (*197*) concluded that

Soil seems to be an important factor in the occurrence of this diseased condition of livestock. Every case investigated occurred on certain soils that were called Pierre clay or Pierre clay loam, or could be attributed to grain or hay grown on such soils. These soils have developed from the geological formation known as Pierre shale.

It hardly seems necessary to discuss extensively in this report alkali disease, or what is now known to be selenium poisoning, inasmuch as such complete summaries as those of Byers (*100, 101, 104*) and Moxon (*419*) are available and well known. It is sufficient to state that the disease is closely related to certain soils, and that the work of identifying these soils and the relative toxicity of their selenium contents has now practically been completed by Byers and his coworkers in the Division of Soil Chemistry and Physics of the Bureau of Plant Industry. A brief discussion of their work with plants and soils will be presented in later sections.

Iodine

Probably the first reference to the relationship of goiter to iodine deficiency in soils is that of Chatin (*112*), who in 1851 observed that the

air is less iodized in the Alps than in Paris; the same is true of the rain waters. *The iodine content of tillable soil and its products is also higher than in the countries where goiter is more prevalent.*

Chatin offered no data to substantiate his statements.

Many investigations have been made of the iodine content of foods grown in goitrous regions and in goiter-free regions (*3, 45, 174, 175, 265, 363, 445, 548*), but only those dealing with actual soil conditions will be discussed here.

Von Fellenberg (*176*) in 1924 reported that the soil at Effingen, Switzerland, a goiter-free area, contained 11.9 p. p. m. of iodine, while that at Hunzenschwill, where 56.2 percent of the populations suffered from goiter, contained 0.620 p. p. m. of iodine.

Goiter is reported to be quite prevalent in New Zealand, and "its incidence is in general roughly inversely proportional to the average iodine in the soil," according to Hercus and others (*264*). Hopkirk and coworkers (*277*) showed in 1930 that the iodine content of soils in a certain goitrous region of New Zealand varied from a few parts up to 900 parts in 10 million. They found little correlation between the iodine contents of the soil and those of pastures grown on them. They state that, generally speaking, alkaline soils do not give up iodine to plants, while acid soils do so very readily. They found, however, that cows' milk from the goiter-free regions contained three time as much iodine as did that from affected regions.

Sykes (*547*) reported that limestone regions in particular were characterized by complete absence of goiter. Aston in 1930 reported the soil in a goiter region to be low in iodine (*33*). He made the

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interesting observation "that stock make every effort to break bounds in order to escape, it is thought, from the iodine deficient pasture to other areas which are not deficient."

It was observed in New Zealand by Hercus and others (*263*) "that variation in the average amount of iodine in soils containing more than 10 p. p. m. has little effect on the small incidence of goiter which there exists; but as the amount of soil iodine decreases so the incidence of goiter rises." The same report states that the most important

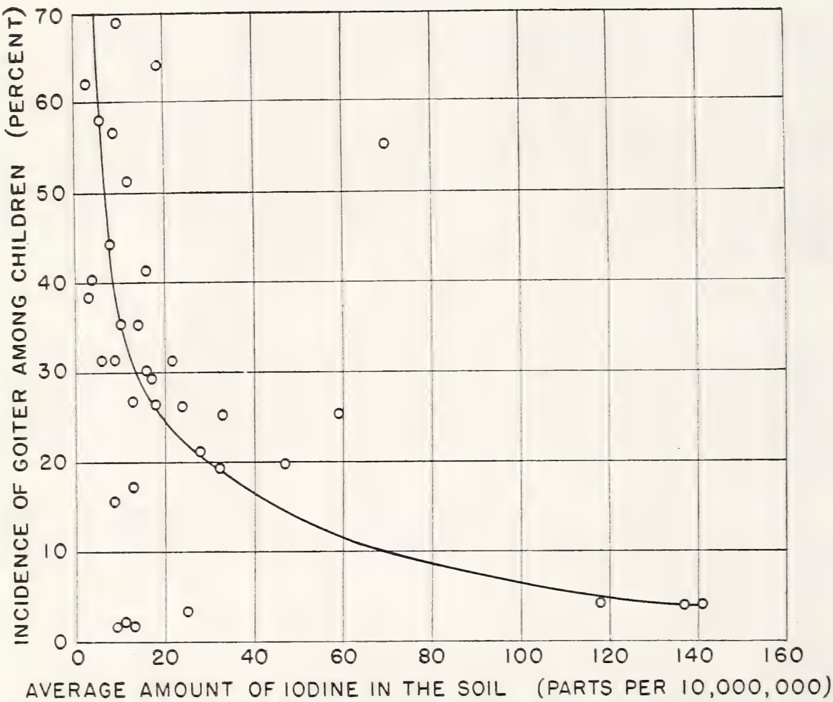

FIGURE 1.—Relationship between the average amount of iodine in the soils and the regional incidence of goiter among school children in New Zealand. (Based on data from Hercus, Benson, and Carter (*264*).)

causes of variation are (1) the combination of the iodine in the soil (an analogy to the observation of Byers (*104*) concerning selenium), and (2) the presence of abundant iodine in the drinking water in regions in which the soil is relatively poor in that element.

The data of Hercus, Benson, and Carter (*264*) have been plotted (fig. 1) in order to bring out these approximate relationships as clearly as possible. The positions of the points indicate that several notable exceptions occur in the inverse relationship between incidence of goiter and soil iodine, but that there is a general agreement.

A striking inverse correlation between the quantity of iodine in the soils and foods and the incidence of goiter was reported by Hercus and coworkers (*263*) in 1931. Their data are given in table 7.

TABLE 7.—*Relation of iodine in food to incidence of goiter and to soil iodine in New Zealand*

[Hercus (*263*)]

District	Goiter incidence	I in soils	I in grass	I in foods	
				Eggs	Milk
	Percent	*P. p. m.*	*P. p. b.*	*P. p. b.*	*P. p. b.*
Samoa	Nil	285	326	394	11
Otago	19	64	68	58	8
Canterbury	64	25	67	41	6

Many anomalies occur in relating the iodine content of the soil and plant to incidence of disease, but Green (*225*), in his discussion of minerals in relation to disease, states that "a direct iodine deficiency is not the only cause of thyroid hyperplasia, and any factor which reduces absorption of iodine or increases the utilization of the thyroid hormone may also cause goiter." Similar views have been stated by Marine (*395*) and by McCarrison and coworkers (*361*, *362*).

The incidence of goiter has received a great deal of attention in the United States, but studies relating this to the iodine content of soils or food plants are exceptional. In 1917 Smith (*530*) defined some areas in Montana in which sows had farrowed hairless or otherwise defective young, and observed that in many instances the rancher could save his pig crop by moving his pregnant sows a mile or two out of the affected district during the gestation period.

Welch (*583*) in 1928 described soil conditions in Montana that were associated with goiter, but his geological statements do not agree with the known facts, and his reasons for iodine deficiencies in these areas may, therefore, not be accurate. He attributes a lack of iodine in these soils to the leaching action of former lake waters on what he calls sedimentary soils. Actually, however, the soils in the eastern half of Montana, the goiter area, are Chestnut soils developed from a highly calcareous glacial drift, and it is quite probable that in such an alkaline soil the availability of the iodine is very low.

Kalkus (*309*) in 1920 noted that goiter and associated conditions were common among domestic animals grazing the valleys of certain rivers and lakes in north-central Washington. He found that "wild animals which range in the mountains above the goitrous districts are not affected. These animals visit the so-called 'deer-licks' that contain high percentages of iodine."

Several investigators in the United States have attempted to relate the iodine content of different crops to that of the soil, but their data will be discussed in the section "Factors Affecting the Mineral Composition of Plants" of this publication, inasmuch as they are not related to the incidence of disease.

OTHER NUTRITIONAL DISORDERS ASSOCIATED WITH SOILS

A nutritional disturbance believed to be caused by molybdenum was described by Ferguson, Lewis, and Watson (*180*) in 1938:

> A large area under pasture in Somerset cannot be grazed by cows during the normal grazing season (April–October) without milk yields falling rapidly, causing marked loss of condition and even death. The available information seems to rule out bacteria, parasites, water supply or a particular herb as causal agents, and points to the presence of some constituent of the soil taken up by the herbage.

An extensive and systematic spectrographic examination of samples of herbage in abnormal and normal areas has shown that the molybdenum content of affected herbage is much higher than what is believed to be normal. Soluble molybdenum fed to cows produced symptoms similar to those observed in cows grazing affected pastures. In connection with this it might be noted that Stanfield (*538*) found 7 p. p. m. of molybdenum in alfalfa and 89 p. p. m. in barley hay, while 317 p. p. m. of molybdenum was found in *Atriplex nuttalli* S. Wats. growing in Steele shale in Wyoming (*48*).

Losses of cattle due to eating of oat hay have recently been observed in Wyoming by Bradley, Beath, and Eppson (*86*). It is not known what influence, if any, the soil may have upon the development of the toxicant, but "the localization of the problem suggests that local influence must be of basic significance." The difficulty is apparently believed not to be related to the occurrence of selenium.

Other nutritional disturbances confined to certain areas have been observed in British Guiana by Bone (*82*) and in Morocco by Velu (*574*). An endemic disease of horses in the mountainous districts of the island of Hondo off Japan has been observed recently (*563*). The appearance of the disease coincides with the growth of vegetation—May to November—and the pasturing of the animals during this period. A botanical examination of the pastures failed to establish that selenium-loving plants were present. No definite conclusions have been drawn as to the cause of the disease.

A chronic copper poisoning in sheep grazing in the vicinity of a nickel smelter has been investigated by Bisset (*74*). Copper, which was present in large amounts in the livers of older sheep, was believed to have been ingested with the soil rather than as a constituent of the grass.

A few observations have been made on the effect of deficiencies of other elements such as magnesium, manganese, and zinc on animals (*55*, *376*, *485*, *507*), but relationships to environment have not been observed. Among the rather interesting although inconclusive studies is one from Czechoslovakia (*433*) in which it is claimed that 60 gm. of gold per metric ton was found in the horn of a roe grazing on a soil containing 0.1 gm. of gold per ton. No gold was found in the horn of an animal grazing on plants grown in a soil that contained no gold.

Several investigators in Europe (*145*, *146*, *152*, *491*, *513*) purport to have found inverse relationships between the magnesium content of the soil and the occurrence of cancer, but their studies are not of sufficient extent to be thoroughly reliable.

Summary of Sections on Soil Characteristics in Relation to Nutritional Diseases of Man and Animals

The inability of some soils to supply in proper amounts and proportions those elements essential to the well-being of man and animals has been known for more than a century. Investigations of certain nutritional diseases of animals during the last 25 years have emphasized the importance of soils, for, throughout the world, the occurrence of bone diseases, nutritional anemias, or of the effect on animals of excessive quantities of some inorganic elements has been characterized by the interspersion of normal and abnormal areas.

This fact has encouraged the study of soils in these areas, and many references in the literature describe the materials from which the soils were developed and the relation of these geological differences to the occurrence of disease. Unfortunately, however, in only a very few instances were the soils studied and described by competent soil scientists. Most of the descriptions give insufficient information about the true soils for their proper classification, and it is almost certain that many of the apparent anomalies could have been resolved with the aid of a competent soil taxonomist.

In general, it has been found that the low, poorly drained lands of the humid coastal regions, the moors, and the peaty soils are associated with bone diseases. Other physiographic regions are not free of soils on which these diseases occur, for many of the mineral soils over the entire world are deficient in nutrients, or, because of climatic conditions, fail to supply sufficient quantities of available nutrients essential to plant and animal life. Investigations of the forage growing on these soils indicate that two factors operate to prevent the animal from obtaining adequate supplies of minerals. (1) The pasture flora of fertile soils often are quite different from those of infertile ones on which the acid-loving plants of low nutritive requirements are able to crowd out plants such as the Leguminosae that require more of the nutritive elements. (2) Actual differences occur in the composition of the plant, and studies such as that of Greaves and Greaves (*219*) show that these variations have an important bearing on the health of the animal.

Nutritional anemias ascribed directly or indirectly to deficiencies of some of the minor elements such as iron, copper, and cobalt have been found to occur on many soils in the United States, New Zealand, Australia, and other countries. In both the Kenya Colony and New Zealand many of the soils have developed on erupted volcanic materials. These volcanic showers usually lie upon porous sandstones or loose sands in the abnormal regions and upon limestone in the normal regions, and many of these soils show some podzolization. In Florida the disease has been observed on the white or gray sands such as the Leon fine sand, Everglade mucks, and the young, poorly drained soils developed from marl in the vicinity of Homestead.

References to osteomalacia and anemia in human beings that may be correlated to the soil are few, but studies in Florida indicate that a nutritional anemia in children has been correlated with the soils from which the children derived the major portion of their food.

The causes of some nutritional diseases such as licking disease have not been well defined, although in some areas, at least, copper is said to be the limiting factor. Whatever the cause of this disease, descriptions of soil parent materials are often made, and, although true soil descriptions are lacking, some distinctive differences between deficient soils and normal soils have been noted. Thus, the soils in abnormal regions were often found to be developed from granites or mottled sandstone, whereas those in normal regions were developed mostly from gneiss, a potash-bearing rock, and in general, deficient soils were described as low moor soils or very light sands. A vast amount of work has been done in Europe on the composition of forages in connection with the occurrence of licking disease.

The presence of undesirable or toxic elements in the soils and their relation to disease has nowhere been studied in the systematic and comprehensive manner in which the selenium survey was conducted by the United States Department of Agriculture and some of the State experiment stations. That selenium poisoning is related to soils and their characteristics through the vegetation growing on them seems to have been demonstrated beyond doubt, while a nutritional disturbance in a certain area of England has been ascribed to the presence of excessive quantities of molybdenum in the herbage.

There are probably more contradictory data relating to the effect of soils on the occurrence of goiter troubles than to the occurrence of any other nutritional disturbance. A careful survey of the facts indicates, however, that the iodine in soils, either because of deficiencies or because of its low availability when present, must play some part in animal and human nutritional disorders.

Actually contradictory data are found in studies of all of these diseases considered in this review. The solutions of problems of this nature are difficult because of the large number of variables, and it may be necessary in the future to undertake studies statistical in nature, because the minute quantities and the catalytic character of the mineral elements involved often make it difficult to determine by chemical or physical means the role these elements play. Furthermore, modern techniques for soil examination and classification must be employed if the part played by soils is to be properly evaluated.

FACTORS AFFECTING THE MINERAL COMPOSITION OF PLANTS

Effect of Soil Composition on Mineral Composition of Plants

The complex relationships between the composition of the plant and that of the soil have never been fully understood by man, although investigations of those relationships have been conducted for more than 300 years. Many problems confronting the agriculturist of the seventeenth century were not unlike those of today; and for this reason, and because of the remarkable ingenuity of the early workers, a few references to these investigations will be quoted from the unpublished portion of a manuscript prepared by C. A. Browne [4] for the Yearbook of Agriculture, 1938, Soils and Men.

Nehemiah Grew was the first who attempted to make quantitative determinations and analyses of plant ashes. In his "Anatomy of Plants," 1682 [(*228*)], he recognized three classes of salts in vegetable materials: (1) The mineral or marine salts, such as common salt, (2) the essential salts, which occur in plants, such as tartar, and (3) the lixivial salts or water-soluble ash of plants and plant products. The influence of soil upon the yield of lixivial salts is shown in the experiments with scurvy grass, which in a garden soil yielded 1.69 percent of lixivial salt and in a soil near the seashore 7.29 percent. In his studies of plant composition and growth Grew recognized the important relationships of soils, which he classified into mellow, sandy, clayey, chalky, etc., and mixtures of the same. He recommended that experiments upon the growth of plants be conducted on single soils of types, "that it may appear how far any of these may contribute to the growth of a plant, or to one above another."

John Clayton's remarks [(*114*)], in 1688, upon the relationship of the quality of tobacco to the soils upon which it is grown is the earliest correlation of this character in the history of American agriculture. "The same sort of seed in different earth," writes Clayton, "will produce tobacco much different as to goodness."

[4] Supervisor of chemical research, Bureau of Chemistry and Soils, U. S. Department of Agriculture.

Theodore de Saussure, of Switzerland, in 1804 made the first approximate analyses of the ashes of the leaves, stalks, bark, wood, straw, seeds, fruits, etc., of 79 different plant products, the results of which were assembled in the earliest published tabulations of this character [(*504*)].

Saussure's work demonstrated the falsity of the old view that plants could produce any of their mineral constituents by the transmuting action of vital forces. His numerous experiments established the following facts:

(1) The mineral constituents of plants are obtained in solution through the roots from the soil.

(2) Plants do not absorb mineral constituents in the same proportion in which they occur in the soil solution, but they have a marked selective power, some elements being assimilated in greater amounts than others.

(3) Herbaceous plants assimilate more mineral matter and exhaust the soil more markedly than do woody plants.

(4) Different soils have a profound influence upon the quantity and composition of the mineral constituents of the same species of plants.

(7) The different organs of plants differ in the content and composition of their mineral constituents.

(8) The percentage of ash in herbaceous plants reaches its maximum before the flowering stage and thereafter begins to decline.

Carl Sprengel, a German agriculturalist, was the first (1838) to attempt an enumeration of the various mineral elements of the soil that are necessary for the normal growth of crops [(*535*)]. Because of the general occurrences of the 10 mineral elements, potassium, sodium, calcium, magnesium, iron, aluminum, manganese, sulfur, phosphorus, and chlorine, in the ashes of all plants, he drew the conclusion that the elements named were all essential for the growth of crops. Sprengel also remarked that other mineral elements not yet discovered in plants, as fluorine, bromine, iodine, lithium, and copper, even though occurring in minute amounts, might also be necessary—a statement that foreshadowed modern investigations of a century later upon the so-called trace or minor elements of soils and crops.

Sprengel maintained that in addition to the soil elements which promoted the growth of plants, there were other elements, as lead, arsenic, and selenium, which injured the growth of plants if they existed in combinations that were easily soluble in water. He stated, however, that all plants were not affected alike by these injurious elements, one species having a greater power of resistance than another. Sprengel seems to have been the earliest to call attention to the possible injurious effects of selenium upon the growth of plants.

Of the early developments in the United States, Browne states that "the first scientists to make studies of the correlation of differences in American soils with the mineral constituents and nutritive value of the crops were the State geologists." Among these men was Amos Eaton, who "made an agricultural survey of Rensselaer County, N. Y., as early as 1821. Hitchcock, Jackson, Emmons, Shepard, Owen, Booth, and the other early State geologists made chemical analyses of the soils and crops of their respective States." Browne continues:

> No writer has more clearly expressed the vital need of correlating the mutual chemical relationships of soils and crops than has Jackson. In the Patent Office Report on Agriculture for 1858 [(*296*)], Jackson published a comparative research upon the relationship of the chemical composition of soils in Massachusetts and Maryland to the chemical composition of the ash of the tobacco which was grown thereon. The ash of Maryland tobacco was higher in magnesia and lower in lime than the ash of the Massachusetts tobacco, a circumstance which led Jackson to the conclusion that these bases might replace each other to a certain extent without alteration in the healthy condition of the plant. He remarks that the limits of such substitution can be determined only "by making a long series of analyses of the same varieties of plants grown on peculiar soils, or on such as are artificially prepared for the experiments."

There are many factors that may operate to modify the mineral composition of the plant. These would include differences in soils, cultivation and the use of soil amendments, rainfall and other climatic influences. These factors are overlapping in their effect or work simultaneously. One factor may influence another, as, for example, the climate is a dominant influence in the development of the soil, and through the soil, therefore, climate influences the plant. Differences in these factors will naturally operate to modify the plant in different ways. For example, it is possible (1) for the mineral composition of two plants of the same variety growing in different soils to be significantly different without there being any important difference in their size or the distribution of their parts such as leaf, stem, or seed head; (2) for the growth of the same variety of plants to vary (differences in yield) in different soils without any important differences in the proportions of the plant; (3) for two plants of the same variety growing in different soils to have quite different distributions of leaf, stem, or head; and (4) for properties of soils to so modify the quantities of plant constituents such as protein, carbohydrates, lignin, and cellulose as to influence the percentage distribution of other constituents, such as a greater deposition of starch or formation of lignin with a consequent reduction in the percentage composition of the mineral elements. The properties of two soils may be such as to modify the natural flora, and thus to produce plants quite different in mineral composition. The evaluation of these factors is still proceeding, and much valuable information of fundamental importance is being obtained.

For the purpose of this discussion, the subject of the variation in the mineral content of plants and the factors that affect it will be treated in three sections, namely:

(1) The soil. The summarization of this literature will be as complete as possible.

(2) Fertilizers. Typical investigations, particularly as they relate to our own soil types, and to the effect of the addition of one element on the absorption of others, will be reviewed.

(3) Miscellaneous. A few pertinent papers relating to the following factors will be reviewed: Stage of maturity, climate, irrigation, different varieties of the same species, and the composition of different parts of the same plant.

In discussing the effect of soils on plant composition, it must be remembered that almost all work in this field should really be classified as general environmental studies, since the effect of locality instead of the soil as an isolated entity has more often been the subject of inquiry.

In 1873, Fliche and Grandeau (*186*) determined the principal inorganic constituents in needles of the maritime pine (*Pinus pinaster* Soland) grown in two soils in France. They found that the variations of phosphorus, magnesium, and sodium were small when compared with those of calcium and potassium, which are given in table 8. The data show that the calcium content of the needles of the tree grown in the calcareous soil is higher than that of the other needles. Although the effect of the calcareous soil at Bas-du-Cellier is reflected in the calcium content of the plant growing on that soil, no explanation is readily apparent as to the differences in potassium, except that it is known that the availability of potassium in soils varies to a far greater degree than does that of calcium.

TABLE 8.—*Calcium and potassium in pine needles and in the soils in which the trees grew*

[Fliche and Grandeau (*186*)]

Locality and material	Constituent as percentage of ash		Locality and material	Constituent as percentage of ash	
	CaO	K_2O		CaO	K_2O
	Percent	*Percent*		*Percent*	*Percent*
Quatre-Arpents:			Bas-du-Cellier:		
Soil	0. 35	0. 07	Soil	3. 25	0. 04
Subsoil	. 20	. 03	Subsoil	24. 04	. 16
Pine needles	40. 20	16. 04	Pine needles	56. 14	11. 09

Liebscher and coworkers (*352*) in 1898 determined the potassium, nitrogen, and phosphorus contents of oat plants grown in pots containing 24 different German soils. The tests were conducted under fairly uniform conditions, and the results may reasonably be expected to show differences in the soils. The phosphorus content of the plants, for example, varied from 0.141 to 0.419 percent, and the potassium from 0.648 to 2.610 percent. The high value for potassium in the plant agrees with a high content in the soil in which it was grown, but with the lower values there is no agreement. Likewise, there is no correlation between the phosphorus content of the plants and of the soil.

One of the first attempts at a systematic study of the soils of the United States was initiated in 1895 by Wiley, Moore, and Ewell, of the Division of Chemistry of the United States Department of Agriculture (*23x*). Forty-four soils, some virgin and some cultivated, were collected from widely separated localities and brought to Washington to be used in greenhouse-pot tests. Oats and buckwheat in one series of tests and beans and buckwheat in another were the rotations used each year over a period of about 8 years. The crops were grown under uniform conditions, except for the soils used, and the results (unpublished) show wide variations in the nitrogen, potassium, and phosphorus contents of these crops. Thus the potassium content of the oat plant varied from 1.23 to 3.34 percent of the dry weight, depending on the soil in which it was grown, while the phosphorus varied from 0.15 to 0.52 percent in the same series. For example, the data show that all crops grown in a virgin sandy loam from Massachusetts had very low contents of both potassium and phosphorus, while those grown in an adobe soil from California were high in both of these elements. Of course these pot tests do not reflect local conditions such as the natural moisture content of the soil, climatic factors, and other environmental characteristics found in the field; but they do indicate some fundamental differences in soils and their ability to supply, under ideal conditions, those elements essential to the health and well-being of the animal consuming the products of that soil.

Other work of Moore's includes pot and field tests made in 1903 of soils in the northern part of the United States (*415*) and an unpublished report of a field investigation of about 5 different soil types in 26 localities in Kentucky (*16x*). The data from the latter report show differences up to 150 percent in the phosphorus and potassium contents of the hemp plant, and even greater differences in magnesium contents. It is interesting to note that the highest phosphorus contents were found in hemp grown in what Moore's descriptions indicate to be the Maury silt loam, a soil derived from phosphatic limestone.

As early as 1909, Russian agriculturalists were using soil characteristics as units in the study of plant composition. Kossowitsch (*320*) determined the absorption of phosphorus by the grain and straw of flax, oats, and mustard and by red clover and hays. He reported, for example, that a greater quantity of phosphorus was absorbed by the mustard grown in a Chernozem than in any other soil.

Ames (*7*) in 1910 analyzed several wheat crops grown in different soils from the fertility plots at the Ohio Agricultural Experiment Station. His data indicate little or no difference in the phosphorus contents of either grain or straw grown in soils at Wooster and at Strongsville, but the potassium in the straw from Strongsville is nearly 50 percent higher than that in the Wooster soil, and this difference is in agreement with the values reported for potassium soluble in N/5 HNO_3 in each of the soils. No difference in available phosphorus was found, which is also in accord with the similar phosphorus content of the plants.

In their study of the composition of bluegrass in different parts of Ohio in 1910, Forbes, Whittier, and Collison (*195*) observed that

> while the mineral content of vegetable crops is without doubt the resultant of a considerable number of varying factors, the most important of these is the composition of the soil. While it seems unlikely that the variations in soils would cause acute or immediately perceptible effects on animals in Ohio, it seems entirely probable that in the course of the lifetime of animals they do cause, through a gradual molding of the growth, differences of considerable practical importance.

They reported that samples of bluegrass (collected when first coming into bloom) taken from some pastures in Ohio contained more than twice as much phosphorus or calcium as did those from other pastures. They also observed that while the inherent fertility of the soil was important, the use of manure and other fertilizers on poor soils often resulted in bluegrass rich in mineral nutrients.

Pot tests similar to those of Wiley and Moore were conducted by Lemmermann, Einecke, and Fischer in 1911, using German soils (*344*). They grew oats, barley, rye, and wheat, and in every case the straw from the plant grown in a sandy soil from near Petkus contained the lowest amount of calcium. This was not typical of sandy soils, however, for another soil of this type produced crops that compared favorably with loamy sands and sandy soils of very high humus content. The differences in plant composition were distinctly not related to soil structure.

Gile (*208*) in 1911 reported that the ash of plants grown in calcareous soils differs from the ash of plants grown in noncalcareous soils chiefly in containing a larger amount of calcium and a smaller amount of iron. Chlorotic pineapple plants were produced in Puerto Rican soils to which limestone had been added, and the iron content in these plants was less than half that in plants grown in the more acid soils.

Cohen (*116*), investigating in 1914 the composition of tobacco grown in Javanese soils, found some relationship between available phorphorus content of the soil and that of the plant, but none between the potassium of the soil and plant. In general the heavier soils, poor in citric acid-soluble phosphorus, produced a tobacco with a lower phosphorus content than tobaccos grown in light soils. Some relationship was also established between the "available" lime in the soils and the calcium content of the plant.

Robinson, Steinkoenig, and Miller (*495*) in 1917 made a number of analyses of plants collected on different soils. Their analytical work is the most complete that has ever been published in this field, but, unfortunately, comparisons of the different samples cannot always be made in order to determine differences in soil properties, because the stage of growth of the plants differs. Specific references to most of their analyses are given in the appendix, and an examination of their data reveals interesting variations in some of the minor element contents of the plants studied. Thus, the manganese content of wheat grown in the Durham soil is very high as compared with that of wheat grown in the Penn silt loam, but the manganese content of the Durham soil is about one-eighth of that of the Penn soil. The magnesium content of the red clover grown in a Penn silt loam was higher than that of the clover grown in a Hagerstown loam, although the relative magnesium contents of the two soils are the reverse of that of the plants. Similar results are shown for the manganese, strontium, and aluminum contents of this plant. Both soils are classified as gray-brown podzolic soils, but the Penn silt loam is developed from shale while the Hagerstown loam is developed from limestone. It is evident from these data that no direct relationship necessarily exists between any single characteristic of the soil and any characteristic of the plant.

These authors also studied the occurrence of a number of unusual elements such as rubidium, which was not detected at all in the wheat plant from a Penn silt loam, whereas 2.7 p. p. m. was found in the plant from the Durham loam. In other samples of vegetation these authors found caesium in plants grown in two soils known to contain caesium beryls, whereas they reported that most of the vegetation did not contain this element. Chromium was occasionally found, though in very small amounts. Vanadium was detected in only six instances, and then only in traces.

Maschhaupt (*397*) determined the composition of summer barley, field beets, oats, two varieties of winter barley, potatoes, and rye grown in rotation in several Dutch soils from 1909 to 1922. His soils, transported from their original environment, included peat soils, loams, and clays and lay adjacent to one another but separated by concrete walls. He reported that the influence of soil type on the content of nitrogen and the ash constituents was greater on grain straw, potato leaves and beet leaves than on the grain itself, beet roots, or potato tubers. The silica content of the straws from the clay soil were nearly five times as high as those of the straws grown in a "heidebode," and significant variations were noted in the phosphorus contents of potatoes and the calcium contents of beets grown in different soils.

Carefully sampled and prepared specimens of crabgrass (*Digitaria sanguinalis* (L.) Scop.) obtained from a garden soil and from a limestone roadway were analyzed by Buckner (*96*) in 1919. The samples grown on the roadway soil contained about 50 percent more calcium and more phosphorus and magnesium in the ash than did the other samples, but calculated on the dry basis rather than on the ash, the difference in composition between the two samples is negligible, which illustrates the possibility of misjudging the composition of a plant when it is calculated as percentage of the ash.

Headden (*256*) in 1921 determined titanium, barium, strontium, and lithium in alfalfa grown in several soils of Colorado. He found over 20 times as much titanium in plants grown in one soil as in those grown in another, and variations of 200 to 1,000 percent in strontium were found. The barium contents were more uniform, and, except in one case, only traces of lithium were found.

In 1923, Neidig, McDole, and Magnuson (*430*) determined the sulfur and nitrogen contents of alfalfa grown in greenhouse tests in six different soils from localities in Idaho. The sulfur contents varied from 0.140 to 0.300 percent.

In some unpublished work done on fertility problems at the New York State (Cornell) Agricultural Experiment Station (*2x*), samples of three soils—Dunkirk silty clay loam, Volusia silt loam, and Petoskey gritty sandy loam—were placed in lysimeter tanks. Corn, oats, barley, wheat, and timothy were grown in the soils, and the crops were analyzed for potassium, calcium, magnesium, phosphorus, and sulfur. The data obtained for 3 years on corn stover grown in two of these soils are presented in table 9. The data indicate little or no difference in the potassium and phosphorus contents of the two crops, but there is a significant difference in the magnesium contents of the stovers grown in the unfertilized soils. Furthermore, the addition of manure modified the magnesium content of the stover grown in the Dunkirk silty clay loam to a greater degree than it did that of the crop grown in the other soil. It is equally possible, however, that these relative differences in the crop composition are due to differences in the climatic effects on the soil, for the various fertilizer treatments were studied in different years.

TABLE 9.—*Mineral composition of corn stover*[1] *grown in New York soils in lysimeter tanks* (*2x*)

Year	Fertilizer	Composition of stover grown in—							
		Dunkirk silty clay loam				Volusia silt loam			
		K	Ca	Mg	P	K	Ca	Mg	P
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1915	None	1.39	0.20	0.01	0.27	1.19	0.15	0.08	0.22
1920	Manure	1.39	.30	.21	.28	1.76	.10	.12	.42
1925	Manure and Na_2HPO_4	.77	.21	.16	.37	.82	.24	.22	.32

[1] Moisture-free basis.

Neller, investigating the influence of sulfur on the yield and composition of legumes (*432*), used two Washington soils in his greenhouse tests in 1925. His analyses of alfalfa cut in the early blossoming period are given in table 10. The sulfur content of the Ritzville soil was found to be 0.020 percent, as compared with 0.043 percent for the Sagemoor soil, and this difference seems to correlate very well with the sulfur content of the vegetation.

TABLE 10.—*Mineral composition of alfalfa* [1] *(average of duplicate experiments grown in pots without fertilizer treatments)*

[Neller (*432*)]

Soil	Yield	Ash	N	K	Ca	P	S
	Gm.	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Ritzville silt loam	31.8	8.30	1.64	3.13	1.38	0.230	0.120
Sagemoor very fine sandy loam	25.1	----	2.57	2.32	1.92	.139	.242

[1] Moisture-free basis.

Meinck (*406*), in studying the relationships between the iodine content of the soil, water, and foods in goitrous regions in Germany, reported in 1927 little correlation between the iodine content of potatoes and either the total or hydrochloric acid soluble iodine in the soil. Potatoes grown at Schwalbach in a soil having 168 p. p. b. of iodine soluble in acid contained more than three times as much iodine as did potatoes grown at Mammolsheim in a soil having 502 p. p. b. of soluble iodine. The total iodine in the soil in both cases was nearly the same.

The variations in the composition of soybean forage grown in six Michigan soils were determined by Austin (*37*) in 1928. The plots, located in different parts of the State, were all planted and harvested at the same time, so that the age factor was eliminated. In determining the composition of the plants the entire above-ground portion of the plant was used for analysis. The data obtained on samples from the unfertilized plots are presented in table 11. A study of the data indicates that some of the constituents vary to a marked extent, and that certain trends during the whole season are observable. The calcium content of the plants grown in the Hillsdale soil is without exception higher than the average throughout the season, while that of the plants grown in the Kewanee is below average throughout the season. The average seasonal value for calcium in the plants grown in the Hillsdale is 2.206 percent, as compared with 1.729 percent for that grown in the Kewanee. The magnesium content of the plants grown in the Brookston soil is in some cases nearly double that of plants grown in other soils, and it remains high throughout the season. It is apparent that the plants grown in the Kewanee soil are consistently high in potassium throughout the season as compared with those grown in other soils. The plants grown in the Miami are likewise low in phosphorus, while those grown in the Brookston and Coloma soils are consistently above the average in this respect. The differences (0.278 compared with 0.411 and 0.425 percent respectively) are important.

TABLE 11.—*Mineral composition of soybean plants (above-ground portion)* [1] *grown in Michigan*

[Austin (*37*)]

Stage of growth and soil type on which grown	K	Ca	Mg	P	S
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
35 days after seeding (July 13):					
Hillsdale sandy loam	0.695	2.702	0.586	0.234	0.232
Brookston clay loam	.635	2.162	1.083	.469	.289
Coloma sand	.504	2.799	.694	.411	.318
Kewanee loam	.812	2.081	.663	.345	.275
Miami loam	.663	2.370	.832	.312	.258
Average	.662	2.423	.772	.354	.274
73 days after seeding (Aug. 19):					
Hillsdale sandy loam	.722	2.050	.846	.287	.283
Brookston clay loam	.627	1.792	1.086	.374	.291
Coloma sand	.729	1.760	.644	.403	.321
Kewanee loam	.623	1.813	.643	.383	.236
Miami loam	.774	1.834	.773	.242	.260
Fox sandy loam	.511	1.894	.665	.377	.347
Average	.664	1.857	.776	.344	.290
110 days after seeding (Sept. 26):					
Hillsdale sandy loam	.576	1.865	.719	.329	.249
Brookston clay loam	.713	1.681	.795	.390	.326
Coloma sand	.591	2.115	.607	.462	.286
Kewanee loam	.738	1.294	.536	.423	.277
Miami loam	.532	1.291	.637	.280	.229
Average	.630	1.649	.659	.377	.273
Averages for each soil:					
Hillsdale sandy loam	.664	2.206	.717	.283	.255
Brookston clay loam	.658	1.878	.988	.411	.302
Coloma sand	.608	2.225	.648	.425	.308
Kewanee loam	.724	1.729	.614	.384	.263
Miami loam	.656	1.832	.747	.278	.249

[1] Moisture-free basis.

Fonder in 1929 investigated the composition of the leaves and stems of several plants grown in different soil types in different areas in Michigan, and he attempted to correlate his data with the composition of the soil solutions (*188, 189, 190, 191*). Some of his data are presented in table 12, because they show how the mineral composition of one part of the plant may vary when the plants are grown in different soils. The data for alfalfa leaves only are given here, but the discussion would also apply to the composition of the stems of alfalfa or of leaves and stems of the green bean plant or pea plant which Fonder also studied. The data show that alfalfa leaves grown in the Plainfield loamy sand contain less calcium than the average throughout the growing season, while those growing in the Fox sandy loam contain more than the average. The average calcium throughout the season in the plant leaves growing in the Plainfield soil is 1.648 percent, and that of the plant leaves growing in the Fox soil is 2.609 percent, a significant difference. The magnesium in the plant leaves grown in the Brooktons loam is low throughout the season, in contrast with the data of Austin (table 11), while that in plant leaves grown in the Fox sandy loam (table 12) is high. The potassium data are not so consistent throughout the season, but well-defined trends are observable. The data show also that calcium accumulates at a rapid rate in the leaves, in contrast with potassium, which decreases appreciably, while magnesium increases more slowly throughout the growing season.

TABLE 12.—*Variations in the potassium, calcium, and magnesium content of alfalfa leaves* [1] *grown in different soil types*

[Fonder (*188, 189*)]

Stage of growth and soil type on which grown	K	Ca	Mg
	Percent	*Percent*	*Percent*
May 8:			
Plainfield loamy sand	4.63	1.103	0.256
Coloma loamy sand	2.98	1.211	.224
Hillsdale sandy loam	2.70	1.182	.226
Fox sandy loam	2.22	1.571	.268
Conover loam	2.40	1.353	.313
Brookston loam	3.02	1.161	.241
Miami silt loam	1.62	1.468	.265
Average	2.80	1.293	.256
May 22:			
Plainfield loamy sand	1.69	0.826	.285
Coloma loamy sand	1.82	1.683	.309
Hillsdale sandy loam	2.18	2.120	.244
Fox sandy loam	1.90	1.737	.297
Conover loam	1.64	1.710	.250
Brookston loam	2.05	1.748	.203
Miami silt loam	1.50	1.917	.284
Average	1.83	1.677	.267
June 7:			
Plainfield loamy sand	3.02	2.140	.258
Coloma loamy sand	2.02	1.695	.199
Hillsdale sandy loam	1.56	2.339	.241
Fox sandy loam	1.22	3.108	.397
Conover loam	.67	3.830	.444
Brookston loam	1.14	2.568	.263
Miami silt loam	.88	2.148	.262
Average	1.50	2.547	.295
July 2:			
Plainfield loamy sand	2.26	2.522	.337
Coloma loamy sand	2.13	2.930	.321
Hillsdale sandy loam	1.34	4.060	.330
Fox sandy loam	.95	4.020	.587
Brookston loam	1.39	2.250	.263
Miami silt loam	2.20	2.610	.298
Average	1.71	3.065	.356
Averages for each soil:			
Plainfield loamy sand	2.90	1.648	.284
Coloma loamy sand	2.24	1.880	.263
Hillsdale sandy loam	1.94	2.425	.260
Fox sandy loam	1.57	2.609	.387
Conover loam	1.57	2.298	.336
Brookston loam	1.90	1.932	.242
Miami silt loam	1.55	2.036	.277
Average	1.95	2.118	.293

[1] Moisture-free basis.

In his investigation of the soil solution, Fonder reported that although the amounts of calcium and magnesium present in the several soil solutions varied greatly at the beginnning of growth, by the time the plant had reached the mature stage the amounts had been reduced until there was but little difference among the soil types. The reduction in the concentration of the two elements in the solution was not rapid and was very uniform, the soil types maintaining the same order with respect to each other during most of the growth period. He concludes: "In general, the calcium contents of the plants grown in two soils of like or nearly the same degree of acidity and of similar texture vary with the calcium content of the soil solution." The data in table 13 illustrate this point.

TABLE 13.—*Relation between the calcium content of the leaves of the pea plant*[1] *and that of the soil solution*

[Fonder (*191*)]

Soil	pH of soil	Ca in soil solution	Ca content of leaves after—				
			3 weeks	6 weeks	8 weeks	Budding	Maturity
Light soils:		*P. p. m.*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Onaway	7.40	24.55	0.259		0.260	0.462	0.536
Plainfield	7.35	10.60	.193	0.286	.285	.379	.384
Kewanee	6.25	44.70	.196	.359	.274	.292	.418
Hillsdale	5.10	14.62	.185	.332	.255	.292	.282
Heavy soils:							
Miami	5.00	30.06	.197	.384	.278		.582
Brookston	7.05	19.00	.193	.293	.336		.436

[1] Moisture-free basis.

Brown (*91, 92*) analyzed apples grown in different soils in England during two seasons (1926 and 1929). Her results show that the seasonal variations are comparatively small, whereas quite large and significant differences occurred in those fruits grown in different soils. Differences in the calcium and phosphorus contents were particularly noticeable.

Increasing interest in soil-plant relationships has led to considerably more active investigations in this field since 1930 than had been evidenced during any other period. The investigations during this time will be taken up in their geographical order, so that a clear picture can be had of the work on any group of soils.

Coleman and Ruprecht (*119, 5x*) in 1935 analyzed tomatoes, celery, potatoes, oranges, grapefruit, string beans, cabbage, and lettuce grown in different soils in Florida. Their data, included in the compilation in the appendix, show clearly the influence of soils on the calcium content of the plant. Thus, the calcium content of tomatoes grown in the Bladen soil, a strongly acid soil with a small amount of organic matter, was reported as 0.22 percent, while that of tomatoes grown in the Hernando soil, developed from a phosphatic limestone, was 0.45 percent. Similar variations were reported for cabbage and other vegetables.

Bryan and Neal (*95*) in 1936 reported slight variations in the phosphorus contents of vetch and sorghum grown in three Florida soils in pots. The variations, although consistent in both crops, are not large. Thus, the vetch grown in Norfolk sand contained 0.114 percent of phosphorus, in Norfolk fine sand 0.092 percent, and in Orangeburg fine sand 0.087 percent.

Bishop (*71*) grew a number of vegetables in some Alabama soils in the greenhouse, and her analyses, published in 1934, show enormous variations in the calcium and phosphorus contents of the edible portions of these crops. Thus, cabbage grown in a Eutaw soil contained 0.208 percent of phosphorus, while that grown in a Hartsell soil contained only 0.086 percent. In general, the calcium contents of the vegetables were found to be the lowest in those grown in the Norfolk soil, while the phosphorus contents were consistently the lowest in those grown in the Cecil soil. Bishop's data also show that the calcium and phosphorus contents vary inversely, so that the calcium-phosphorus ratio fluctuates even more markedly.

Weathers' (*580*) recent analyses of lespedezas from three soils of varying fertility in Tennessee show quite clearly the effect of soil and locality as contrasted with that of variety. The data tabulated in the appendix show that the hay grown in the Maury silt loam, a gray-brown podzolic soil developed from a phosphatic limestone, contains the highest quantity of calcium and phosphorus, while that grown in the Clarksville loam contains the least quantity. The phosphorus content of the lespedeza grown in the Clarksville loam, a nonphosphatic soil, is less than half that grown in either the Maury or the Cumberland soils, and there is a corresponding disturbance in the calcium-phosphorus ratio.

Pierre (*17x*) analyzed a number of grass, clover, and alfalfa samples growing in association in old established pastures in West Virginia, and his data for alfalfa are presented in table 14. The collections of grass and clover samples were not made at any stated stage of maturity nor at any uniform time, and they are not, therefore, comparable. Likewise, his soils were chosen in different localities, so that rainfall, management, and other factors might have influenced the composition of the plant. These data indicate that throughout the season all cuttings of alfalfa grown in the Hagerstown soil were lowest in phosphorus as well as calcium. This is in relative agreement with the available phosphorus in the soils, although the results as between DeKalb and Hagerstown are contradictory to what would be expected unless amendments were used liberally on the former.

TABLE 14.—*Calcium and phosphorus in alfalfa* [1] *grown in different soil types in West Virginia*

[Pierre (*17x*)]

Cutting	Ca			P		
	DeKalb silt loam [2]	Holston silt loam [3]	Hagerstown silt loam [4]	DeKalb silt loam	Holston silt loam	Hagerstown silt loam
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
First	2.80	3.22	1.92	0.184	0.166	0.139
Second	1.85	1.98	1.43	.324	.245	.171
Third	2.18	2.15	1.79	.268	.240	.195
Average	2.28	2.45	1.71	.259	.217	.168

[1] Harvested at one-third to one-half bloom. Moisture-free basis.
[2] Available phosphorus, 16 p. p. m.; pH, 6.83.
[3] pH, 7.30.
[4] Available phosphorus, 9 p. p. m.; pH, 6.20.

Magistad (*15x*) analyzed five varieties of grass, each grown in four different soil types in Hawaii. His data (unpublished) are very consistent in indicating definite relationships between the calcium and phosphorus contents of all varieties and each of the soil types. Thus, all varieties grown in certain soils are low in these constituents, while those grown in other soils are high. The predominance of soil over variety is quite marked in these experiments.

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Hester and coworkers made a number of fundamental studies on three soils occurring in Virginia, a Portsmouth loamy fine sand, a Bladen sandy loam, and a Norfolk loam (*266*, *267*, *268*, *269*). They found significant differences in the power of plants (greenhouse tests) to absorb the nutrient from each of the soils because of the differences in the exchange capacity of the soils for the nutrients. The Bladen soil, for example, was found to possess a high power for fixing potash in a nonreplaceable state, whereas plant absorption of this element from the Portsmouth is high. The utilization of phosphorus from the different soils by the plants was in the descending order of Portsmouth, Bladen, Norfolk, the reverse of the phosphorus fixation capacity of these soils. These authors conclude that

The presence of a large amount of a particular replaceable base in the soil colloidal complex influenced the elemental composition of a plant material even though the yields were affected but little. A high replaceable calcium content suppressed the absorption of potassium, nitrogen and magnesium; a high replaceable magnesium content suppressed the absorption of potassium, calcium, and nitrogen; and a high potassium content suppressed the absorption of calcium, magnesium, and nitrogen.

Garner, McMurtrey, Bowling, and Moss (*201*) found that the magnesium content of tobacco leaves was closely correlated with the occurrence of magnesium deficiency diseases and with the particular soils of Maryland, Connecticut, and North Carolina in which the plants grew.

The influence of soils on the composition of several vegetables grown under different soil conditions in Maryland and in Virginia was studied by Davidson and Le Clerc (*140*) in 1936. Their data, compiled in the appendix, do not indicate many consistent differences in the mineral composition of the crops. However, these soils had been heavily fertilized, and it is recognized that the Norfolk and the Sassafras are both quite responsive to fertilization.

The effect of soil type on the composition of corn stover was studied by Wimer (*596*) in his recent experiments in Illinois. No significant differences in composition of the stover were found in plants grown in Saybrook silt loam and in the deep phase of this soil. The soils are, however, identical except for variations in depth. In another field in which more significantly different soils occur, differences in the composition were found. In discussing this point the author states:

Drummer clay loam is rich in total nutrients, has a high content of available phosphorus, and requires no limestone to grow sweet clover. This soil yielded 1,514 pounds more stover and 20.2 bushels more grain per acre than Sidell silt loam, which is less fertile, lower in available phosphorus, and more acid in reaction.

The composition of the stover from each soil in this field is given in table 15.

TABLE 15.—*Mineral composition of corn stovers* [1] *grown in different* (*untreated*) *soils in the same field*

[Wimer (*596*)]

Soil type	N	P	K	Ca
	Percent	*Percent*	*Percent*	*Percent*
Drummer clay loam	0.83	0.115	0.79	0.24
Sidell silt loam	.86	.082	.31	.21

[1] Moisture-free basis.

According to the author,

The wide variations in climate in different parts of Illinois have made it very difficult to study the effect of soil types, throughout the area of their occurrence, on the composition of corn stover. Widely different soil types ordinarily do not occur on the same experimental field; therefore, seldom under the same seasonal conditions of rainfall, temperature, and other climatic factors. Because of these and other limitations (particularly variety of plant), comparisons that will show the effect of soil type on the composition of stover are indeed rare.

Grizzard (*229*) determined the variations in composition of the leaves and the stems of alfalfa plants grown in different soils in different localities of Michigan. Differences of 105 percent of phosphorus and 73 percent of calcium in the leaves of the plants were found. The author states:

The heavy soil types, such as Brookston clay loam, tend to give a higher nitrogen content in the alfalfa plants than the lighter soil types, such as Isabella sandy loam, both when fertilized and unfertilized. On the other hand, the lighter soil types tend to give a decidedly higher phosphorus content in the alfalfa plants than the heavy soil types, this being true both in the fertilized and the unfertilized condition. In the case of calcium, there is a tendency for this element to be decidedly higher in the intermediate soil types, such as the Gilford and Brookston loams, than in either the heavy or light soil types. Apparently, these data indicate that soil type predominates over fertilizer treatments in the composition of alfalfa; although fertilization tends to influence the composition of alfalfa, especially in certain soils.

Some of the factors responsible for the variation in the calcium and phosphorus contents of peas were studied by Peterson and coworkers (*4x*). A summary of their unpublished data is given in table 16. The date indicate that peas grown in the Knox soil contain less calcium than those grown in the other two, and that variety of peas may influence the absorption of calcium.

TABLE 16.—*Calcium and phosphorus contents of Wisconsin peas* [1]

[Peterson and others (*4x*)]

Variety of pea and soil type	Ca	P	Variety of pea and soil type	Ca	P
	Percent	*Percent*		*Percent*	*Percent*
Smooth Alaska:			Perfection:		
Miami silt loam	0.263	0.649	Miami silt loam	0.226	0.611
Carrington silt loam	.203	.578	Carrington silt loam	.174	.640
Knox silt loam	.179	.582			

[1] Moisture-free basis.

Holtz (*275*) in 1930 studied the variations in calcium and phosphorus contents of oats and red and white clover grown in different western Washington soils in different localities. He concludes that "the calcium content of oat hay is influenced by the calcium content of the soil in any particular group," that is, residual, glacial or alluvial soils. The composition of oat hay and red clover both follow the available phosphorus in the residual soil, but in the upper glacial soils the composition of oat hay responds to the total phosphorus content of the soil, whereas clover follows the available phosphorus. The results of the experiments were influenced, of course, by climate and other factors as well as by the soil itself. Other investigations of Washington soils include those of Baker and Vandecaveye (*44*) in 1935 and Vandecaveye and Bond (*572*) reported in 1936.

Greaves and Anderson (*220*) reported in 1936 that the copper content of wheat, barley, and oats (grains) varied tremendously as grown in different localities. No correlation was found, however, between the content of copper in the wheat and that of the soil. These investigators also determined the copper content of several varieties of wheat grown in the same soil and concluded "that variety is more important than soil, except where the copper content of the soil falls below a certain minimum." The variations that they found on different soils are in direct contradiction to some unpublished work of Bailey and Hutchinson (*1x*), who found practically no variation in the copper content of wheats grown over a large part of the northwestern wheat country.

The sulfur contents of two samples of alfalfa grown in two localities in Utah were not significantly different, according to Evans and Greaves (*169*). No descriptions of the soils were given, but the sulfur contents of the soils were quite different.

A recent comprehensive survey of New Mexico grasses by Watkins (*579*) indicated that there were 12 counties in New Mexico in which the average phosphorus content of the range grasses for the year 1932 was insufficient for normal growth and reproduction of range cattle. However, the grasses were collected late in the fall and early in the spring, so that the samples might have been leached, and undoubtedly they did not represent whole plants of any particular stage of maturity.

The effect of soil type on the composition of clover was studied by Myers and Metzger (*425*) in Kansas, but no indication is given that the samples chosen were consistent in stage of maturity.

Poehlman (*469*), investigating in 1935 the analyses of plant juices as indicators of the nutrient needs, found that

> the phosphorus and potassium concentration in the plant juice differs significantly with the different soils [in Missouri] upon which the plants were grown and the soil type is an important factor in determining the concentration of these elements in the plant juice.

He states, however, that uncontrolled factors in his experiments include "variations due to age or maturity of the plant, moisture content of the plant, rate of growth, soil heterogeneity, and climatic factors such as light, temperature, rainfall, humidity and soil moisture."

Daniel and Harper (*134*), in studying the composition of prairie grasses in Oklahoma in 1934, found that the moisture relationships in the soil were very important with respect to the phosphorus content of the plant. Thus, a sample of grass (*Andropogon furcatus* Muhl. and *A. scoparius* Michx.) collected from an alluvial soil where moisture conditions were favorable during the growing season contained more than twice as much phosphorus as usually occurs in the average sample of upland prairie hay.

Variations in the nutrient content of soils have less effect on the seed than on any other part of the plant. A comparative analysis of Chinese and American rices by Davidson and Chambliss (*139*) in 1932 did not "indicate any striking differences in composition between the Chinese rices, grown on a soil presumably cropped for thousands of years, and the rices grown under the American method of cropping."

Lincoln (*354*) studied differences in soil and plant relationships by examining samples of *Stenotaphrum dimidiatum* Bronger, growing in Mauritius pastures. Samples collected at the same stage of growth varied considerably in composition, depending upon the character of the soil. Thus, the calcium content of this grass growing in red soil averaged 0.38 percent as compared with an average of 0.67 percent for that grown in calcareous soils and 0.54 percent for that grown in the dark-brown soils.

Depardon (*152*) in 1938 reported on the effect of soil, climate, and geology of three regions in France on the composition and quality of wheat, forage beets, and potatoes. He concluded that the predominant factor in the production of plants was distinctly the soil. Thus in every case studied, the phosphorus content of plants grown in Perche was lower than that in plants from either of two other localities.

A few studies have been made that were concerned with the more unusual minor elements in the soil. The most comprehensive study of this nature is that conducted by the Department of Agriculture and some of the State experiment stations on selenium. The importance of selenium in relation to the health of the animal has already been noted, and a brief discussion will be presented concerning the relation between selenium in soils and its occurrence in plants growing in the soils.

Byers and Knight (*103*) reported in 1935 on the selenium content of soils and two species of grass. All of the soils and grasses contained selenium, and variations occurred in the amounts, but the greatest variations by far were between the different species of grasses.

Beath and coworkers (*48*) published the selenium contents of a number of crops grown in certain shales in Montana. Their data seem to indicate that certain species, such as alfalfa, do not absorb selenium, and that crops grown in soils developed from the Niobrara shales contain less selenium than do those grown in soils from Steele shales.

Byers, in a series of reports on the occurrence of selenium-bearing soils in South Dakota, Colorado, Kansas, and Montana (*100, 101, 104*), states:

> The distribution of selenium in soils appears to be general. No true soils containing colloids in any significant quantity have been found in which the presence of selenium cannot be demonstrated. The source of the selenium is believed to be the residual selenium derived from the soil parent material, supplemented by that derived from direct absorption from the air by rain. It has been demonstrated that selenium may exist in soils as the element; as a substituent in sulfide minerals, particularly pyrites; as selenite, particularly basic ferric selenite; as selenate, particularly as calcium selenate; and as organic selenium compounds of undemonstrated composition. Of these forms apparently those most available to the soil solution are the organic and selenate forms.
>
> The distribution of selenium within the soil profile is extremely variable, and definite general statements are not possible concerning these variations.
>
> When plants grow in seleniferous soil they seemingly absorb selenium to some degree in all cases, though under many circumstances the quantity so absorbed is vanishingly small. For a given species [of plant] the quantity found by analysis appears to depend upon a number of variables. These include at least the following: The quantity and character of the selenium in the soil [(*282*)] and its distribution in the soil; the portion of the plant examined, whether seed, blossom, leaves, stem or root; the stage of maturity of the plant; and seasonable variations which might be attributed to rainfall. It is also certain that variations in selenium absorption are brought about by variation of available sulfur [(*285*)].

In a later publication (*331*), Lakin, Williams, and Byers state: "A lack of quantitative correlation between the selenium content of the soil and the vegetation has been evident throughout the entire investigation of seleniferous areas." They reported, for example, that the Yunes silt loam of Hawaii contains from 2 to 10 p. p. m. of selenium in the surface horizon, while a soil in Teton County, Mont., contains only 0.2 p. p. m. Examination of the vegetation from the Hawaiian soil showed that none contained more than 1 p. p. m., while *Astragalus pectinatus* growing in the Montana soil contained 190 p. p. m. of selenium.

Boron has been studied quite extensively, both because of its injurious effect and its essentiality for plant growth. The boron contents of leaves of citrus trees suffering from a disease was shown by Kelley and Brown (*312*) in 1928 to be several hundred times as high as those of healthy trees. They stated in this connection:

> The results of this investigation strongly indicate that boron is readily absorbed by citrus and walnut trees and that this element tends to accumulate in the leaves of these species. Because of this fact, a determination of the boron content of the leaves affords a valuable indication as to the boron conditions of the soil.

They concluded that irrigation water is responsible for some difficulties with boron, and Eaton (*160*) in 1935 supports this when he states:

> Notwithstanding evidence of the occasional occurrence of appreciable concentrations of boron in unirrigated soils in the San Joaquin Valley, the general inference to be drawn from the appearance of crops is that boron carried by irrigation water is for the most part responsible for such depression in yield and such crop injury as have occurred.

Eaton further concludes that "much of the boron found in soils, whether irrigated or not, is not very soluble."

Woodbridge (*598*) in 1937 found that "a low boron concentration in tissues can be correlated with high incidence of disease [of apples]. A correlation between low boron in the soil and incidence of disease was not established."

Definite relationships between manganese in the soil and that in the plant are few. Wester (*586*) in 1923 determined manganese in several soils in the Netherlands along with that in digitalis leaves growing in the soils. His data are given in table 17.

TABLE 17.—*Manganese in some Netherland soils and in digitalis leaves growing thereon*

[Wester (*586*)]

Material	Mn per 100 gm. of dry matter in—		
	Noordwyk	Delft	Haag
Soil	2.4	14.4	10
Digitalis leaves	.94	1.32	2.57

Carlyle (*106*) in 1931 determined the manganese contents of several plants grown in pots containing different Texas soils. He reported differences of 200 to 500 percent in the manganese content, according to the soil used.

Leeper (*340*) stated that "manganese deficiency disease is confined to soils of pH 6.7 or more and occurs especially on heavily limed podzols."

Iodine has been extensively discussed in relation to the occurrence of goiter, but it is interesting to note that McHargue (*377*) in 1933 reported 250,000 p. p. b. of iodine in one sample of corn, whereas 18 other samples from other soils in Kentucky contained from 98 to 650

p. p. b. Bishop and Lawrenz (*72*) reported that they detected cobalt in different species of plants, as well as in some species grown in certain soils. Robinson, Whetstone, and Scribner (*497*) found most of the rare earths in hickory leaves taken from a tree growing in a pegmatite vein of the Moorefield Mine, Amelia, Va. Later unpublished work by Robinson (*18x*) seems to indicate that this group of elements may normally be present in the hickory tree wherever it may be found. Dingwall, McKibbin, and Beans (*155*) reported, in 1934, that molybdenum was found in plants grown on one farm, while none was found in those grown in any other soils. The molybdenum, they state, "may have been present in the parent rock or it may have been carried down with drainage waters." Dingwall and Beans (*154*) also reported the presence of chromium in some plants grown in certain localities. Nemec, Babicka, and Oborsky (*433*) recently claimed to have found considerable quantities of gold in certain plants growing in gold-bearing soil in Czechoslovakia. Their data indicate that *Equisetum palustre* L. accumulated gold to the extent of 610 gm. per ton of plant ash.

Effect of Soils on Botanical Composition of Herbage of Pastures

In 1873, Müller (*420*) reasoned that pastures grazed by animals suffering from nutritional diseases must, either positively through poisoning or indirectly through mineral deficiencies, adversely affect the animal. A botanical analysis of some pastures revealed no great difference in the amount or quality of the different forage plants in normal and abnormal pastures, but in other cases an unusual number of undesirable plants such as "sauergräsern" and marsh plants were found in abnormal pastures, whereas sweetgrasses and clovers prevailed in the better pastures. Similar observations were made by Lawes and Gilbert (*333*) in 1900 and by Armstrong (*14*) in England, who found that white clover, ryegrass, crested dogstail, and fiorin (*Agrostis stolonifera* L.) were most abundant on the best grazing lands. The herbage of the inferior types of grassland in the same districts consisted very largely of bentgrass (*A. vulgaris* With.) and various weeds, while white clover and ryegrass were present in comparatively small quantities. Woodman, Blunt, and Stewart (*599*) noted seasonal variations in the botanical composition of pastures.

Barnes (*47*), in 1911, found that treating Ohio pastures with limestone and acid phosphate was accompanied first by a marked increase in percentage of legumes. This was later followed by a renewal of the bluegrass sod, which, however, did not reach its optimum until at least the end of the fourth summer after treatment. Brown (*89*, *90*) reported in 1933 that fertilization with phosphorus, lime, and potassium, as compared with other systems of manuring, resulted in a maximum increase of white clover in Connecticut pastures.

Robinson (*492*), in his recent comprehensive investigations of pasture flora and soil fertility in West Virginia, concluded that

> A comparison of samples from the same pastures shows that, in general, soils supporting Kentucky bluegrass are higher in pH, percentage base saturation, total exchangeable bases, available phosphorus, total nitrogen, and exchangeable potassium, than are soils supporting Danthonia. Base exchange and available phosphorus are the limiting factors, however. In the Hagerstown soil there is a high correlation between the percentage of Kentucky bluegrass plus white clover in the pasture and the amount of phosphorus in the soil.

Summary of Effects of Soils on Plant Composition

Investigations designed to study the effect of the single factor, soils, on the composition of plants are rare indeed, which is unusual when one realizes for what length of time the importance of this one factor has been understood. Probably not more than one or two field experiments and a small number of greenhouse experiments may really be considered to have demonstrated that differences in soils alone are responsible for differences in such constitutents as calcium and phosphorus in the plant.

It is recognized, of course, that there are two approaches to any study of the capabilities of soils to supply the proper amount of minerals to plants. First, a field study of the soil in its natural environment over a period of several years will indicate how that soil, in the sense that the soil is a summation of its environmental factors, in relation to all other soils in that or other localities, will affect plant composition. In such studies the elimination of climatic and physical differences is not desirable. The advantage of such a study is that information is obtained as to the properties of the one soil being studied in relation to all other soils. The disadvantage of such a study lies in the fact that since several variables are not accounted for or eliminated, no predictions based on any one or several factors may be made concerning the behavior of this one soil type in another locality, even though it is recognized that over a long period of time the climate will not differ greatly on different areas of the same soil type. Thus, if a plant grown on a certain soil be deficient in cobalt, that deficiency may be due, among other causes, to an inherent deficiency or unavailability of this element in the soil, or it may be due to climatic factors. If the first factor be the cause, one would naturally suspect that that soil type would be deficient in cobalt wherever found. If the latter factor be the cause, one would expect that, over relatively short periods of time, this soil type in some localities would support plants with a normal quantity of cobalt. If one wished, therefore, to determine the effect of soil alone on plant composition, that soil must be compared with others under exactly the same conditions of climate, relief, and management practices.

Climate and soils are, moreover, so interrelated that greenhouse tests or other methods designed to bring soils together under the same conditions cannot be depended upon to give accurate information as to the ability of the soil in situ to supply the proper amounts of any nutrients required for the development and health of the plant and the animal or human consuming it. It must be recognized, however, that in spite of their limitations, translocation tests of soils, whether in greenhouse or open air, are the only means of differentiating between effect of soil and climate, unless the soils are situated in such a way as to eliminate climatic and other factors. While such tests are of limited value in determining differences in soil, they are of much greater value in studying the means of modifying with amendments soils that fail to support plants of the highest nutritive value.

There is an abundance of evidence that plants and their parts vary greatly and significantly in the principal elements when grown on different soils in different environments, or even in environments that differ only in small degree.

Conclusive evidence is to be found in the literature to prove that significant differences occur in the minor or trace element content of the plant or its part, that these differences may be directly attributed to differences in soils, and that they are responsible for nutritional disorders. Thus, the selenium content of a plant may be related to the amount of selenium occurring in a soil; but enormous differences are also observed that are the result of (1) differences of distribution of the selenium in the profile, (2) differences of availability of the selenium compounds that occur in the soil, (3) the presence of inhibitory agents such as certain compounds of sulfur, or (4) the water relationships in the soil. Information of such complete nature is available for no other element except selenium, but the sporadic deficiencies or occurrence of other trace elements such as boron, iodine, chromium, and even gold, may be taken as an indication that similar relationships would be found for all elements. This and other investigations emphasize moreover that there is probably no direct relationship between any single characteristic of the soil and any characteristic of the plant or of plant production.

The influence of soils on the botanical composition of flora of pastures has long been known. This is also an important factor in soil genesis, for the character of a soil will vary tremendously, depending upon whether it is developed under a high-calcium grass, a high-sodium grass, or under forests, for example, of beech-maple or of conifers.

Difference of species of pasture herbage should also affect the health of the animal, for, as will be shown in the appendix, these different species vary markedly in their chemical composition.

That a relationship should obtain between the soil taken as a whole and the composition of the plant grown therein is a reasonable assumption, for soils, being the products of their environments, show marked variations because of differences in climate, vegetation, parent material, and relief. Thus, the Podzolic and Lateritic soils are well-leached acid soils generally quite low in bases and phosphorus, while the Chernozem and Chestnut soils are not leached, are high in base constituents, and are nearly neutral in reaction.

Within any soil group, however, there will be variations in fertility and reaction because of differences in parent material or relief. Thus, in the Chernozem soils we may find deficiencies in potash and phosphorus where the parent materials were very low in these elements, and in Kentucky and Tennessee bluegrass regions we find variations from the well-leached acid soils common to the gray-brown Podzolic group. In the rolling or hilly sections of these States, erosion removes the acid and leached materials as rapidly as they are formed. The soil that remains is young and relatively immature, and calcareous soil lies within the reach of the plant roots. These soils often have the additional advantage of being formed from parent materials relatively high in phosphorus, and a very evident result of an abundance of these bone-forming materials is the excellent type of horse developed in those localities.

Effect of Fertilizers on Plant Composition

Fertilizer experiments have, for the most part, been concerned with the study of yields, and, in comparison with the number of investigations of this nature, very few have included the probelem of modifying the composition of the plant. That the composition of the plant is modified by the use of fertilizers has been known since the earliest soil fertility studies were made, and, in fact, plant composition has often been used as a guide for determining the nutrient requirements of a soil. One of the first and most comprehensive investigations of this nature ever undertaken is that of Lawes and Gilbert (*332*) in 1884. They analyzed 92 wheat-grain and the same number of wheat-straw samples collected over a period of years. Every sample was from a crop of known history of growth, as to soil, season, and manuring. Nine different fertilizer treatments were investigated, and much valuable information was obtained concerning yields and crop quality. They concluded, for example, that

the proportion of both potassium and phosphorus in the grain, which if normally ripened is assumed to be a comparatively uniform product, varies very considerably according to season; whilst at any rate as between the grain grown with farmyard manure and that grown without manure, the mean proportion over the sixteen years differs but little. The grain grown under the influence of ammonium salts alone shows not only a wide range in the proportions of both potassium and phosphorus according to season, but much lower mean amount than either with farmyard manure or without manure.

Among other early workers in this field of investigation was Robert Peter (*454*), who in 1884 reported that calcium sulfate applied to a Kentucky soil caused an increase in the calcium and potassium content of the hemp plant. Anderson (*9*) in Alabama, Lechartier (*334*) in France, and Godlewski (*213*) in Austria were also pioneers in this work of determining the composition of plants grown in fertilized and unfertilized soils. Hills made quite extensive investigations, in 1898, of the composition of potatoes and of corn and corn stover grown in Vermont soils with and without fertilizers (*271, 272*). His data do not show any marked differences in the composition of the plants when different fertilizer elements or combinations of these elements were applied to either a sandy loam or a clay loam soil. Similar results on potatoes were reported by Davidson (*142*) in 1898 in connection with his work in Virginia.

NITROGEN, PHOSPHORUS, AND POTASSIUM

It does not seem necessary to consider in detail the great number of experiments that dealt with the change in the nitrogen, phosphorus, and potassium contents of plants when these plants were grown in differently fertilized soils. Few of the investigations included observation on soils, climate, or other pertinent factors, and they are, therefore, of little value in any general interpretation. For the most part, therefore, only those fertility experiments of rather recent date that deal with well-identified soils, and those that deal with the specific effects of each, or definite combinations of the elements, on the mineral composition of the plant, will be discussed.

Nolte (*438*) reported in 1923 that fertilization with potash, either with or without phosphates, did not materially modify the composition of the grain or straw of barley, field beans, or field bean straw, or beets or beet leaves, when these crops were grown in soils of quite different character in Germany.

Price (*472*) in 1923 reported a 500-percent increase in the calcium content and a 300-percent increase in the phosphorus content of the first cutting of alfalfa hay when he applied 2 tons of limestone per acre.

The addition of 250 pounds of superphosphate resulted in a further increase in phosphorus.

Austin (*37*) found that the phosphorus content of the soybean plant grown in the Brookston clay loam was actually reduced when phosphates alone were applied to the soil. In general, however, the effects of fertilizer treatments upon the composition of the plants were small, except possibly that of plants grown in the Coloma sand.

Lagatu and Maume (*324*, *325*, *326*, *327*, *328*, *329*, *330*) have made a number of fundamental studies in recent years of the requirements of the plant for the mineral nutrients. They describe a method of sampling which consists of taking the two leaves just below the fruiting branch of the plant. They claim that these samples give a true index of the plant's fertilizer requirements, and they made the following observations from their results:

1. The lack of one of the three fertilizer constituents [nitrogen, phosphorus, or potassium] increases the absorption of the other two above the amounts ordinarily absorbed from a medium containing a balanced supply of plant nutrients.
2. In the presence of an incomplete fertilizer the plant fails to absorb from the soil the missing constituent in amounts as great as that from an unfertilized plot.

The work of Lagatu and Maume has been supported by that of Thomas (*557*, *558*, *559*, *560*), using the potato vine grown in a Pennsylvania soil. He showed that the two observations of Lagatu and Maume were "contrary to Liebig's 'law of the minimum,'" and that whatever effect the absence of an element from a fertilizer has on the yield, "it is not due to a depression of absorption of the other elements, but, on the contrary, to a nutritional lack of balance due to increased absorption of the remaining elements."

The results obtained by Thomas on leaves of potato vines are presented graphically in figure 2, and his summary of the indications given by the graphs follows:

Nitrogen graphs.—The content of nitrogen in the leaves of plants which received mineral nitrogen applications is higher throughout the whole period than in those which received none.

Phosphoric acid graphs.—The content of phosphoric acid in the foliage of plants which received phosphate applications is higher throughout the whole period than in those which received none.

Potash graphs.—The content of potash in the foliage of plants which received mineral potash applications is very much higher than in those which did not.

In his concept of the nutrition of the plant, Thomas makes use of two terms, viz, *quantity* and *quality* of the mineral constituents. "The concept of *quantity* or intensity of nutrition of the selected leaves consists of the sum ($N+P_2O_5+K_2O$) of each element at the moment of sampling, expressed as a percentage of the dried material. The *quality* of nutrition is the ratio of these entities to each other at the moment of sampling." The quantity of nutrition may be expressed as follows:

$$S=X+Y+Z,$$

where X is the percentage of N, Y the percentage of P_2O_5, and Z the percentage of K_2O. The quality of nutrition may then be expressed as

$$1=\frac{X}{S}+\frac{Y}{S}+\frac{Z}{S}.$$

This expression, according to Thomas, gives "the physiological ratios between N, P_2O_5, and K_2O." When this proportion of elements is expressed as milligram equivalents, and the terms of the equation are multiplied by 100 to avoid fractions, Thomas obtains his expression for the NPK unit, and the properties of this expression are such that "for each simultaneous value of N, P, and K there is one point and only one on an equilateral triangle each of whose sides equals 100 [units]."

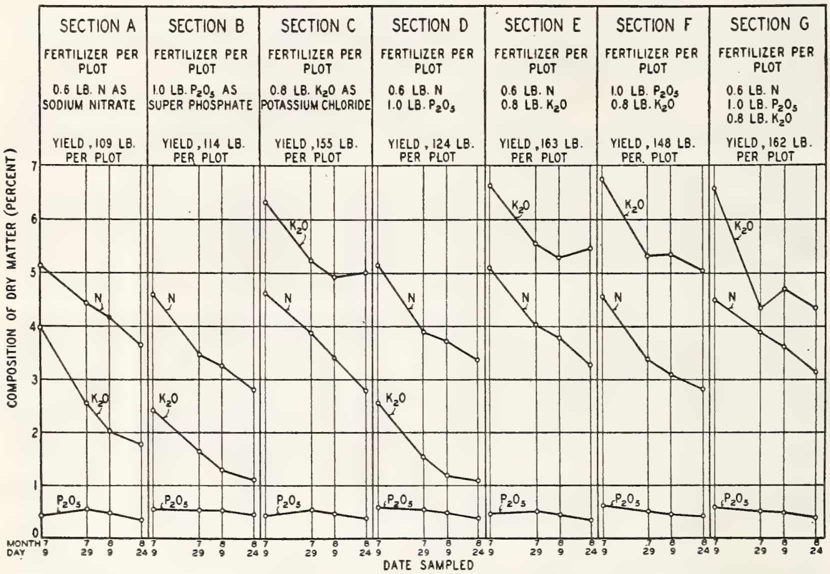

FIGURE 2.—Influence of different fertilizer treatments on the nitrogen, phosphoric acid, and potash content of potato leaves at different stages of growth. (From Thomas, *560*.)

Thomas assumes that a fertilizer may modify the composition of a plant by (1) "an increase in the sum, $(N+P_2O_5+K_2O)$, i. e., in the intensity of nutrition, or (2) a change in the composition of the NPK-unit, or (3) a change in both (1) and (2) simultaneously."

His data, plotted in figure 2, when analyzed on the NPK-unit basis show that compared to a balanced fertilizer:

(1) The omission of nitrogen from the complete fertilizer has increased the potash and phosphoric acid in the NPK-unit of the leaf throughout the whole period, resulting in decreased yields.

(2) The omission of potash from the complete mixture has increased the nitrogen and the phosphoric acid in the NPK-unit, resulting in decreased yields.

(3) The omission of phosphorus has increased the potash in the NPK-unit of the leaf at the expense of the nitrogen, resulting in a slight increase in yield.

(4) The omission of both phosphorus and potash has increased the nitrogen in the NPK-unit, resulting in considerably decreased yields.

(5) The omission of both nitrogen and potash has increased the nitrogen and the phosphorus in the NPK-unit, with considerable reduction in yields.

(6) The omission of both nitrogen and phosphorus has resulted in increasing the potash in the NPK-unit, resulting in decreased yields.

McCool and Weldon (*366*) in 1928 noted that 36 days after planting, the phosphorus content of the juice of barley plants had increased with both phosphorus and potassium fertilization. After 90 days, however, a lower phosphorus content of the juice of both leaves and stems accompanied potassium fertilization. They also found that the potassium content of the juice paralleled the potassium applied as fertilizer, whereas the phosphorus fertilization decreased the potassium content in young, rapidly growing plants.

Mather (*398*) claimed in 1929 that fertilization increased the inorganic, but not the organic, phosphorus content of hays grown in Minnesota and Canada.

Murphy (*422*), working with the Kirkland sandy loam in Oklahoma, in 1930, reported an increase of about 20 percent in the phosphorus content of wheat grain when he applied superphosphates. Neither the application of potash nor of nitrogen alone resulted in any change in the phosphorus content of the grain.

Hester and Shelton (*267*, *268*, *269*), investigating the relationship between the replaceable bases in Virginia soils and the composition of vegetable crops, concluded that a high absorption of calcium at high pH value to the exclusion of the other ions (potassium in particular) was probably responsible for depressed yields. In general, he observed that

> The presence of a large amount of a particular replaceable base in the soil colloidal complex influenced the elemental composition of plant material even though the yields were affected but little. A high replaceable calcium content suppressed the absorption of potassium, nitrogen and magnesium; a high replaceable magnesium content suppressed the absorption of potassium, calcium and nitrogen; and a high potassium content suppressed the absorption of calcium, magnesium and nitrogen.

The investigations of Tyson (*569*) in 1930 of the relationship between soil conditions in Michigan and the chemical composition of sugar beets indicated that the addition of potassium to unlimed plots resulted in increased potassium content of the leaves and roots and caused a decrease in the percentages of calcium, magnesium, sodium, and phosphorus. Applications of calcium resulted in a decrease in the potassium content and increased the phosphorus, sodium, and calcium content. Applications of phosphorus caused an increase in phosphorus and a decrease in potassium in the plant.

Wimer (*596*), studying the composition of mature corn stover in Illinois, reported in 1937 that

> The general tendency of limestone was to raise the nitrogen, phosphorus, potassium and calcium contents of the stover and to increase the stover and grain yields. The chief exceptions were in the stover yields on soils naturally well supplied with carbonates, where the addition of limestone might be expected to have little or no effect.

Rock phosphate, when used in addition to residues (green manures) and limestone, resulted in increased nitrogen and phosphorus contents of the stover, but little or no change was observed in the contents of potassium and calcium. The use of potassium resulted in an increase in the potash content, a decrease in nitrogen and phosphorus, and no change in the calcium content.

Opitz, Rothsack, and Morgenroth (*442*), working with barley grown in a German soil, stated in 1937 that the omission of phosphorus from a complete fertilizer caused a reduction in the phosphorus content of the plant, a slight increase in the potash, and a significant increase in nitrogen. The omission of potassium resulted in a decrease in potassium and a slight increase in nitrogen, but no material change in phosphorus. Byczkowski (*99*), working with Polish soils, found that the amount of potassium absorbed by a plant was dependent upon the anion of the salt used, the chloride being more readily assimilated than the sulfate.

Stalé (*537*) in 1937 reported that phosphates alone increased yields as much as did phosphorus and potassium together on certain glacial soils in Switzerland that were rich in available potash. An increase in the phosphorus content and a decrease in calcium content of hay was observed with phosphate fertilization. No consistent effect was noted on the magnesium and potassium contents. Potash alone resulted in no increased yields, a marked increase in the potash content, and a decrease in the calcium and magnesium content of the plant. No effect was observed on the phosphorus content of the plant.

Increases in the phosphorus content of hays, as a result of fertilization, have been reported by several investigators in Minnesota (*6*), Montana (*98*, *440*), Florida (*95*), and Germany (*321*). Bishop (*71*) obtained increases in the phosphorus content of a number of vegetables (both leaves and roots) when phosphates were applied to Alabama soils, but the increases in phosphorus in plants grown in some soils as a result of fertilization were not large enough, in many cases, to produce plants that contained as much phosphorus as did those grown in other soils. Thus, a marked increase in the phosphorus content of turnip tops was obtained by the use of 1,000 pounds of superphosphate per acre of Oktibbeha soil, but still the phosphorus content did not equal that of turnip leaves grown on the Eutaw soil without phosphorus fertilization.

The effect of the liming of soils has been studied by a number of investigators. Gile and Ageton (*209*) in 1914 made extensive investigations of the effect of liming on the composition of crops grown in Puerto Rican soils. They reported that

> The limestone apparently had no effect on the amount of nitrogen, potassium and phosphorus contained in the various plants, but did increase slightly the total carbon-free ash in all plants except rice. The calcium, magnesium and iron contents were all modified, the iron content sometimes being greatly reduced.

Ames and Schollenberger (*8*) showed in 1924 that the effect of liming on plant composition varied markedly with the soil. In general, however, they noted a tendency for liming to result in a decreased phosphorus content in the plant. Hjorth-Hansen (*273*) in 1931 reported that the contents of phosphorus, potassium, and calcium in the plant were influenced to a great extent by a change of soil reaction resulting from liming. The magnesium content remained quite constant.

Emmert (*167*), investigating liming practices in Kentucky, reported that the average percentages of the phosphorus and manganese in the plants grown in the more acid soils were greater than the average of those grown in the more nearly neutral soils, while Lott (*358*) found that calcium carbonate greatly decreased the absorption of zinc by plants.

Carolus (*108*) in 1933 reported that even small amounts of limestone increased the absorption of magnesium under conditions of excessive rainfall in Virginia. The available magnesium content of soils under such conditions is readily depleted by leaching, unless the soil contains in its internal colloidal phase an abundance of organic matter. Rendering the soil more alkaline with limestone results in an increase in this necessary organic material.

Naftel (*426*), investigating Alabama soils in 1937, found that liming with increasing increments of $CaCO_3$ increased the percentage of calcium in the plants but decreased the magnesium, potassium, phosphorus, manganese, and iron. Where soils were limed with dolomite there were similar decreases in mineral content, with the exception of magnesium, which was increased.

THE MINOR FERTILIZER ELEMENTS

Carolus (*109*) found that the addition of magnesium to the soil had a more pronounced effect on the magnesium content of the plant than it did on the yield or the nitrogen or calcium contents. Scharrer and Schropp (*508*) observed, in 1938, that the efficiency of magnesium absorption is clearly correlated with the natural magnesium content of the soil, decreasing with an increase in soil magnesium. An increase in magnesium fertilization, they state, resulted many times in an increase in the magnesium content of the plant, but the highest efficiency in absorption was found when the least magnesium was applied. Garner, McMurtrey, Bowling, and Moss (*201*) showed that the use of 120 pounds of magnesium applied to the Collington sandy loam in Maryland increased the magnesium content of tobacco leaves and prevented symptoms of magnesium hunger.

The application of magnesium resulted in increased content of this element in corn stover, oats (grain and straw), barley (grain and straw), millet, and buckwheat, but no increase was found in rutabagas (roots or tops) or Sudan grass, according to the experiments of Beaumont and Snell in Massachusetts (*50*).

Wiaddrowska (*591*), in her experiments with magnesium, using Polish soils, reported no increase in the magnesium content of lettuce, cabbage, carrots, or beans, although the calcium content of all vegetables except cabbage was depressed as a result of magnesium fertilization.

Wheeler, Hartwell, Kellogg, and Steel (*590*) reported in 1906 that sodium salts applied to Rhode Island soils increased the percentage of phosphorus in the plant. The carbonate was more efficient in this respect than was the chloride.

Deficiencies of sulfur have been studied extensively in the western part of the United States, and some of these investigations have included determinations of the effect of sulfur on the chemical composition of the plant.

In 1923, Neidig, McDole, and Magnuson (*430*) determined from pot tests that the sulfur content of alfalfa grown in several Idaho soils could be doubled by the application of sulfur at the rate of 100 pounds per acre. Even greater increases were obtained when 500 pounds of sulfur was applied. Smaller increases in sulfur were obtained when gypsum or lime and sulfur were added to the soil. All forms of sulfur produced an increase in the total nitrogen removed by the alfalfa. They stated, furthermore, that "the arid soils gave a greater [yield] response to applications of phosphorus and less to sulfur than did the humid soils." All applications of phosphorus increased the percentage of sulfur in the alfalfa and produced in all but two of these soils slight increases in the nitrogen content of the alfalfa.

Reimer and Tartar (*480*), in 1919, obtained an increase in both the sulfate-sulfur and organic-sulfur content of alfalfa grown in three Oregon soils when they fertilized with 300 pounds of sulfur per acre. Very large increases in the sulfur content of alfalfa were obtained by Neller, using two Washington soils, the Ritzville and the Palouse silt loams. The calcium content of the alfalfa was lowered and the phosphorus content was increased, but no significant change was observed in the potassium or nitrogen contents. Ligon (*353*), on the other hand, reported in 1935 that 1,000 pounds of sulfur applied per acre of muck soil in Michigan resulted in a decrease in the phosphorus as well as the calcium in the plant, with little or no change in potassium or nitrogen. Increases in the sulfur content of alfalfa following fertilization with sulfur, gypsum, or ammonium sulfate were found by Evans and Greaves (*169*).

No increase in the sulfur content of the plant was found by Barbier (*46*), who investigated the influence of sulfur and chlorine on the mineral nutrition of the plant. In the case of beets, an increment in the chloride content brought about by fertilization with chlorides was accompanied by an increment in the basic ions.

The addition of aluminum to culture solutions containing phosphates did not result in an appreciable increase in the aluminum content of lettuce, but the aluminum content of the roots was more than doubled, according to some investigations of Pierre and Stuart (*465*), reported in 1933. They state:

> The results obtained definitely show that the problems of aluminum toxicity and phosphate availability are very closely interrelated. The so-called toxic action of soluble aluminum in very acid soils can be ascribed to two general causes. First, aluminum in high concentration directly injures the root hairs and thus causes stunted and poor development of the roots. Secondly, the aluminum absorbed by the plant precipitates part of the phosphate present, which interferes with phosphate translocation and assimilation. The addition of large amounts of phosphorus to the soil precipitates some of the aluminum out of the soil solution and enables the root to obtain a sufficient amount of phosphorus for nutritional purposes.

Hester (*266*) found that aluminum appeared in the soil solution at pH 3.9 to 4.4 in Portsmouth loamy fine sand, 4.2 in Bladen sandy loam, and 5.2 and below in Norfolk fine sand. He claimed that this was directly responsible for the low yields at these pH values, a problem that was overcome by applying lime to the soils. Other studies of aluminum in plants include those of Myers and Voegtlin (*424*) in 1914, Burgess and Pember (*97*) in 1923, Winter and Bird (*597*) in 1929, and Meunier (*407*) in 1935.

Densch and Hunnius (*149*) reported, in 1924, that fertilization with copper sulfate, although increasing yields of barley grain, caused no change in the mineral content of the plant except to depress the amount of iron assimilated.

Elvehjem and Hart (*166*) reported in 1929 increases of from 10 to 148 percent in the copper content of different vegetables when 50 pounds of copper sulfate per acre was used. Miller and Mitchell (*411*) in 1931 were able to increase the copper content of lettuce fourfold by adding 20 pounds of copper sulfate per acre in four equal doses. Much smaller increases were obtained in spinach. Copper had a slight depressive action on manganese and a stimulative action on the assimilation of iron, under the conditions of their experiments. Arnd and Hoffman (*15*) and Coleman and Ruprecht (*119*) reported that fertilization with copper resulted in increased copper assimilation by the plant, but Rademacher (*473*) observed no such increase, even when increased yields resulted from the use of copper.

Iodine added as a fertilizer seems to be easily assimilated by the plant, and some investigators have reported manyfold increases in the iodine content of plants in this way. The work of Stoklasa (*542*) in 1926, Scharrer and Strobel (*510*) in 1927, Scharrer and Schwaibold (*509*) in 1927, Pfeiffer and Courth (*463*) in 1929, and Balks (*45*) in 1935 in Germany, Orr and coworkers in England (*447*) in 1928, and Beaumont and Karns (*49*) in the United States in 1932, may be cited as examples. McHargue, Young, and Calfee (*383*) in 1935 added potassium iodide from time to time to soils in which corn plants were growing, and they obtained, according to their report, an iodine content in the leaves of these plants of as much as 30,000 p. p. b. at one time during the season.

When no iodine was included in the fertilizer mixture, neither McHargue (*383*) nor Mack and Brasher (*385*) reported any relationship between the fertilizer treatment and the iodine in crops. The latter investigators, however, obtained large increases in iodine in beans and turnips by applying potassium iodide about 30 days after planting. Dietz (*153*) in 1938 was able to increase the iodine content of head lettuce (grown in pots) from 4,620 p. p. b. to 91,560 p. p. b. by applying 20 pounds of potassium iodide per acre 4 days before harvest.

Claims that Chile saltpeter contains sufficient iodine for plant growth have been disputed and affirmed by several authors (*150, 206, 604*). In general, it would seem that there are so many factors involved in determining the specific value of any trace element in such a material that no sound conclusions could be reached as to its effect on plant growth or composition.

Cook and Wilson (*121*) reported in 1917 the presence of boron in wheat grown in soils fertilized with borax and colemanite. No boron was found in plants grown without the use of this element as a fertilizer. Increased concentrations of boron in both leaves and stems of alfalfa were obtained by McLarty, Wilcox, and Woodbridge (*387*) after treating the soil with boric acid. The boron in the leaves of untreated plants was 11.4 p. p. m., while that of treated plants ranged from 214 to 734 p. p. m., depending upon the amount of boron added. Askew, Thomson, and Chittenden (*29*) reported in 1938 that the boron content of apples in areas top-dressed with boron was appreciably greater than that of the control fruit. Applications of 100 pounds of borax per acre had no greater influence on the boron content of the apple, however, than did 50 pounds of borax per acre. Hudig and Lehr (*280*), studying soils in the Netherlands, claim to have shown that the boron in Chile saltpeter was responsible for increased growth and boron content of plants.

Studies of the effect of arsenic on plant composition have originated with the problem of spraying. Pirotta (*468*) investigated this problem in Italy in 1906 and reported that the application of a dilute arsenical spray to plants resulted in an increase in the arsenic content of the plant. Increase of arsenic in the plant resulting from spray on the soil has not been reported, and Jones and Hatch (*307*) stated in 1937: "Analytical data on commercial orchard soils and fruits indicate plainly that orchard welfare is not directly affected by soil spray residue accumulations, however long the period of accumulation." Their conclusions, of course, relate only to the fruit of trees and not to any crop such as a legume or cereal that might be planted in the soil. Hurd-Karrer (*283*) has observed that arsenic injury is inhibited by phosphorus applications to certain soils that do not fix the phosphorus in an unavailable state.

Stewart and Smith (*540*) in 1922, using a gravelly bench loam for pot tests, reported enormous increases in the arsenic content of pea, radish, wheat, potato, and bean plants. Disodium arsenate was added to the pots after the plant was fairly well developed.

McHargue and Shedd (*382*) studied the effect of manganese, copper, zinc, boron, and arsenic on the growth of oats. Their data, reported in 1930, show the effect of manganese only, for in only one experiment did they use a single element. In the remainder of the tests, manganese was used with copper or with copper and zinc, etc. The manganese content of oat straw was increased from 0.004 to 0.0644 percent, but no other significant change in the composition of the plant was found with manganese fertilization. Coleman and Ruprecht (*119*) in 1932 reported that increases in the manganese content of vegetables grown in Florida soils was obtained when manganese was applied as a fertilizer element.

Olsen (*441*) found that the absorption of manganese was related to the degree of acidity of the soil, and that increased quantities of manganese were assimilated by plants when the manganese content of the nutrient solution was increased. This observation is in harmony with those of Svanberg (*544, 545, 546*) and of Leeper (*340*).

Haselhoff (*249*) found traces of strontium in barley and bean plants grown in pots with soils to which had been added strontium carbonate. Calcium was found by Hurd-Karrer (*284*) to inhibit injury to plants by strontium.

Geilmann and Brunger (*205*) found germanium in plants grown in soils in pots to which germanium had been added.

Nemec and Kas (*434*) in 1923 obtained very slight increases in the titanium content of plants as a result of using Na_2TiO_3 in pot tests.

The influence of lead compounds on the growth of barley was investigated by Keaton (*311*) by adding lead nitrate or carbonate to soils in pots. His experiments show that while nearly all of the lead was fixed in an insoluble state in the soil within a few days, some lead was absorbed by the plant (2.53 to 5.40 p. p. m.) and a very large amount was absorbed by the roots (94.2 to 1475.0 p. p. m.).

Lepape and Trannoy (*345*) claimed to have found an increase in the radium content of plants grown in soils to which radium ores had been added.

Hart, Phillips and Bohstedt (*244*) studied the relation of soil fertilization with superphosphate and rock phosphate to the fluorine content of plants. They concluded that

> Plant materials from plots receiving fluorine-carrying phosphates, such as rock phosphate and acid phosphates, for periods of sixteen to thrity-six years, did not show consistent or greatly increased fluorine content over plant materials grown in plots receiving a low fluorine-carrying phosphate such as bone meal.

A rather interesting survey was conducted in 1932 by Hartwell (*247*). He submitted three questions to several thousand agricultural workers concerning the effect of fertilizers on the quality of the crops. A brief tabulation of some of the replies follows.

1. Effect of fertilizers on carbohydrates:
(a) Phosphorus increases the starch content of barley and alfalfa.
(b) Potassium produces greater hardness of rice kernels.
(c) Calcium and magnesium, by making potassium more available, increase carbohydrate content.
(d) Manganese increases the sugar content of beets.
2. Effect of fertilizers on proteins:
(a) Nitrogen generally increases the protein content of seeds and tubers.
(b) Phosphorus increases phosphorus and nitrogen of cereals.
(c) Phosphorus usually decreases gluten of wheat.
(d) Potassium tends to reduce protein content.
(e) Sulfur increases protein content of barley and wheat.
3. Effect of fertilizers on fats:
(a) Phosphorus has no influence on fat of flax.
(b) Potassium favors production of fat in flax, mustard, and pecans.
4. Effect of fertilizers on fiber:
(a) Too much nitrogen affects fiber unfavorably.
(b) Potassium increases length and strength of cotton fiber.
5. Effect of fertilizers on enzymes and vitamins:
(a) Phosphorus hinders enzymatic activity in plant tissues.
(b) Lack of manganese in spinach is correlated with decreased vitamin A.

Ashton (*17*) observed that the strength of oat straw was associated with a relatively high content of certain ash constituents, particularly silica, and a low fiber content. Studies on the relationship between the calcium content of the plant and the organic acids in the plant have been made by Iljin (*290*) in 1938; and Pfutzer and Pfaff (*464*) have recently reported on the effect of minerals on the vitamin content of plants.

Garner, McMurtrey, Bowling, and Moss (*202*) reported in 1930 that

From the standpoint of quality the chloride content of the cured [tobacco] leaf may affect its properties either favorably or adversely depending on the quantity of chlorine present, the use to be made of the tobacco, and the stage in handling and manufacturing operations which it has reached.

SUMMARY OF EFFECT OF FERTILIZERS ON PLANT COMPOSITION

Out of the confusion of contradictory results of fertilizer experiments one can draw a very few definite conclusions. First among these is the important fact that no fundamental study has ever been made of the effect of soil amendments on plant composition taking into consideration that most important of factors, the characteristics of the soil used in the experiment. It is true that physical characteristics of the soil such as structure have been observed, and that the availabilities of a few of the principal plant nutrients have been arbitrarily measured; but fundamental studies of what changes take place in the soil when the fertilizers are applied and the effect these changes will have on the plat are lacking.

One or two recent empirical investigations have quite definitely shown that Liebig's "law of the minimum" never represented the mechanism of absorption of nutrients by plants, and that the actual facts seem to indicate that when one of the principal nutrients is deficient in the soil solution the others are taken up by the plant in amounts greater than normal, while even less of the deficient nutrient is absorbed than would be expected normally. The necessity for a balanced source of nutrients for the plant is thus indicated, and the variance in results by most investigators would tend to prove that this is a problem that can be solved only by study of the characteristics of each soil type.

In general it can be stated that in many instances known deficiencies of some particular element can be remedied by adding that element to the soil. Deficiencies of phosphorus and iodine are good examples of such a situation that seems to be easily remedied.

The use of soil amendments to prevent injury to plants by certain elements seems to be a promising field of investigation, although the experience of Franke and Painter (*196*) with selenium emphasizes the necessity for knowing in what form the toxic element may exist in the soil, or, as in the case of the inhibition of aluminum injury by phosphorus, whether or not the phosphorus may become "fixed" by the soil before it reacts with the aluminum.

Liming of soils has varied effects on the composition of the plant, but in most cases it exerts a depressing effect on iron and manganese. Depending upon the soil, for example, the phosphorus in the plant may be depressed, unchanged, or increased by liming. The same observations apply to the effect of liming on magnesium and other elements. The Virginia work (*108*) cited in this report shows clearly how indirect effects of soil treatment may result in conclusions being made in one place that are directly opposed to those in some other locality.

The effect of the applications of minor elements to the soil has been studied mainly from the viewpoint of increasing that element in the plant, and not from the viewpoint of modifying the general plant composition. The latter type of investigations would seem to be of paramount importance.

The influence of the fluorine in phosphatic fertilizers on the fluorine content of the plant has been determined in a very limited area. What the effect is on plants grown in soils of different types than those studied is entirely unknown.

Some observations of the effect of fertilizers on the quality and the technological uses of crops have been made.

Miscellaneous Factors Influencing the Mineral Composition of Plants

AGE OF PLANT

It has already been noted that changes in the mineral composition of the plant as it matured were observed in the early part of the nineteenth century, and many investigations since that time have emphasized the importance of this factor in relation to animal nutrition problems. A few of these investigations are cited here in order to demonstrate the necessity of making observations on the age of the plant in interpreting soil and fertilizer studies.

Hills (*270*) in 1893 noted that both the phosphorus and potassium contents in corn decreased rapidly with the age of the plant, until, in some cases, less than half of the amounts present in the plant at tasseling stage were found in the mature plant.

Recent investigations include those of the sunflower by Neidig and Snyder (*431*) in 1925 and of the alfalfa plant by Sotola (*532*) in 1927. Sotola determined the chemical composition, digestibility, and protein utilization of the first, second, and third cuttings of alfalfa grown in Washington. Each of these three cuttings was studied at the one-fourth, one-half, and three-fourths bloom. His data show that the protein content of the hay decreased and the fiber content increased as the plant matured. Plants cut at one-half bloom stage contained more calcium than similar samples harvested at the one-fourth and three-fourths stages.

Radu (*474*) in 1936 reported a maximum concentration of calcium in the alfalfa plant during its growth, but Bettini (*69*), studying the composition of alfalfa in Italy, found a progressive increase in calcium throughout the life of the plant until the advanced-bloom stage, after which it remained constant until the seeds were mature.

Determination of the variation in composition of spinach was made by Fondard and Margaillan (*187*) in France in 1928. They reported that the phosphorus content increased for about the first 30 days of growth, after which it rapidly decreased until it was less in 48 days than it had been at the end of 10 days. The potash increased during the first 17 days but remained quite constant thereafter. According to Tuorila (*568*), the potash content of potatoes grown in Finland decreased with maturity.

A comprehensive study of the composition of the different parts of the soybean plant at different stages of growth was reported by Borst and Thatcher (*84*). Their data show that a reduction of calcium, magnesium, potassium, and phosphorus occurred in the stems as the plant approached maturity. A reduction in the potassium and phosphorus contents was also found in the leaves, but the other elements remained fairly constant.

A number of investigations in changes in the composition of grasses have been conducted by workers in Great Britain (*171*, *172*, *601*). In general, except for timothy, they reported that the phosphorus content is reduced with the age of the plant.

Van Itallie (*292*), working with three Dutch soils, reported in 1934 that the differences in composition of one variety or species of grass at different stages of growth are greater than differences between different species at the same stage of growth.

Murphy (*423*) in 1936 found that both the calcium and phosphorus content of the cotton plant decreased with age, and that the rate of decrease in calcium was accelerated after the bolls started to form.

Considerable attention was given in the compilation of the mineral composition of crops to classifying the crop as to its age or stage of maturity (see appendix). Thus, with alfalfa the average contents of calcium and of phosphorus at the bud stage were 2.45 and 0.36 percent, respectively, while the corresponding values at one-half bloom were 2.01 and 0.27 percent. The alfalfa data are not sufficiently numerous to illustrate the change in composition throughout the life of the plant, but other examples include the compilation of data on Kentucky bluegrass and on rape plant. In the latter case single analyses of the plant grown in Iowa show a maximum in the calcium content during the life of the plant and a steadily diminishing phosphorus content.

Variations in the nutritive value of plants at different stages of growth and the stage of maturity at which most plants have the highest nutritive value are well-known. In general, the nutritive elements attain maximum values during the life of the plant although some differences in observations of how the mineral composition of plants varies with the age of the plant are not explainable at the present time, but a very likely cause is the availability of these elements or the rate at which they become available in the soil. Although it has long been known that forage and other crops must be harvested at certain stages of development so that they will be palatable and so as to obtain maximum yields of dry matter, comparatively little attention has been given to obtaining maximum yields of nutrients. As the plant matures, particularly beyond the bloom stage, the percentage of digestible nutrients and of available mineral matter may drop so low as to nullify completely the effects of increased yield of total dry matter.

CLIMATE

Climate was shown by LeClerc and coworkers (*336*, *338*, *339*) to be of greater influence on the protein content and slightly more influence on the phosphorus and potassium contents of wheat grain than was the soil. Unfortunately, their work did not include the composition of the straw nor of any part of the plant that would respond more accurately to soil deficiencies than does the seed. The work is of interest, however, because of the procedure, which consisted of transporting fairly large amounts of soils from two of three localities (California, Kansas, and Maryland) to the third locality for plot tests.

In similar experiments with sugarcane, Borden (*83*) failed to demonstrate the predominance of climate over that of soil as an influence on the mineral composition of the plant. The two localities for this experiment, although only 3 miles apart in Hawaii, differed markedly in climatic conditions, for, although the temperature range is about the same for both places, Manoa receives nearly four times as much rainfall and 40 percent less sunshine than does Makiki. Tubs of soil from both localities were planted with three different varieties of sugarcane, which were allowed to grow at each locality. The results, classified as to soils and as to localities, are given in table 18. The climate at Makiki was apparently quite favorable for the production of sugar, but while the cane grown at Manoa has a slightly higher potassium and phosphorus content than has that grown at Makiki, the dominating influence of soils is evident, for the average content of these minerals in the cane grown in the Makiki soil at both localities is much higher than that of cane grown in the Manoa soil.

TABLE 18.—*Influence of soil and of climate on the sugar, phosphorus, and potassium content of sugarcane*

[Borden (*83*)]

Items	Sugar produced	P in 100 cc. of juice	K in 100 cc. of juice
Averages by soils:	*Pounds*	*Percent*	*Percent*
Makiki soil	5.41	0.044	0.21
Manoa soil	6.26	.014	.10
Averages by localities:			
Makiki soil	8.93	.027	.134
Manoa soil	2.73	.031	.172

Kunze (*322*) in 1914 determined the phosphorus, potassium, and calcium content of oats grown in normal and dry years in Germany. No significant differences were observed in the phosphorus content of the grain, but about half as much phosphorus was found in the straw and chaff in dry years as in good years. Both the calcium and potassium contents were much higher in the dry years, that in the straw and chaff often being double the amount found in these parts in normal years.

The data of Daniel and Harper (*135*), reported in 1935 from their study of the relation between effective rainfall in Oklahoma and total calcium and phosphorus in alfalfa and prairie hay, support these findings. They state that

Although the mathematical correlation between the actual amount of rain and the phosphorus in the alfalfa hay is not high, the figures show that the phosphorus content of alfalfa fluctuates with the rainfall, and that the calcium content of the hay is inversely proportional to the quantity of effective rainfall which occurs. The moisture requirement of a crop is affected by the temperature and humidity of the atmosphere; consequently, the total rainfall could influence plant growth quite differently, depending upon whether high rainfall occurs during the spring or summer months. A greater variation in the calcium and phosphorus content of alfalfa occurred between the rainfall and the different cuttings of hay harvested in 1932 than in the hay harvested in 1933. During the season of 1932, the period of high rainfall was in May and June, while in 1933 the period of high rainfall was in March, April, and May.

Salgues (*501*), working with two soils in France, reported in 1938 that the phosphorus content of plants grown in calcareous soils was increased with high rainfall, but that this was not true of plants growing in siliceous soils. With lower precipitations, the phosphorus-calcium ratio was lowered for all species grown in calcareous soils, but the ratio was actually higher for the same species grown in siliceous soils.

The effect of rainfall on leaching of minerals from plants was investigated by LeClerc and Breazeale (*337*) in 1909. They found that mineral nutrients, exuded upon the surface of the leaves of plants, are washed off by rain and dew. They concluded, therefore, that the analysis of plants gathered at maturity may give erroneous or misleading results, especially for comparative purposes. Guilbert, Mead, and Jackson (*233*), found that leached plants contained considerably less phosphorus than did normal plants, although the calcium contents of the leached and normal plants did not materially differ.

While plants are dependent upon the soil for their mineral nutrients, climatic conditions so affect respiration, assimilation, photosynthesis, metabolism, and other physiological processes that the composition of both the mineral and the organic matter of crops may be greatly modified even though the crops are grown upon identical soils. Indirect influences of climate are also reflected in the composition of the plant, for the significant differences in the characteristics of our great soil groups are largely differences due to climate. Thus, in the Southeast we have well-leached acid soils low in the basic constituents, while in the Northwest the soils are more nearly neutral and high in bases. Differences within any soil group have, furthermore, been effected by the particular vegetation growing in the soil, which in turn was influenced by climatic factors. Thus, a soil developed under grass will be quite different from one developed under forest.

Investigations that show clearly the effect of climate on the mineral metabolism and composition of the plant are not available, however because differences in soils, species of plants, time of rainfall in relation to the growing season, and other factors have not always been considered. It seems quite safe to conclude, however, that the plant composition is modified by both the climate and the soil in which it is growing, and that both of these factors are closely inter-related, often one modifying the effect of the other. Thus the assimilation of phosphorus by the plant growing in calcareous soils may be less in dry than in wet years, whereas entirely contrary results may be obtained in plants growing in siliceous soils. The period of plant growth at which high rainfall occurs is of paramount importance in the assimilation of nutrients by the plant as well as in the growth of the plant, and, for this reason, crops growing in the same soil type separated by a sufficient distance so as not to receive the same amount of rainfall at the same time in any one year may be quite different in their chemical composition.

IRRIGATION

The discussion under climate indicates that the composition of the plant, under some conditions at least, is closely related to the moisture or rainfall available during certain times of the growing period. Irrigation is a climatic factor, inasmuch as moisture is supplied artificially instead of naturally.

In 1900, von Daszewski and Tollens (*137*) studied the effect of irrigation in Germany on the composition of potatoes. They concluded that although yields were increased with irrigation, no change in the phosphorus and potassium content of the plant occurred. Stahl-Schroder (*536*) reported that increasing the water in a soil from 35 up to 95 percent of its water capacity resulted in a large increase in ash, silica, and phosphorus in the grain of oats. The nitrogen content decreased to a minimum at 90-percent water capacity, but increased markedly at 95 percent.

Irrigation in varying amounts had no effect on the nitrogen content of the corn grain, according to Harris and Pittman (*241*), in Utah. The same observation held for phosphorus, calcium, and magnesium, although a large variation in the mineral nutrients was observed in the crops grown in different years, but with the same amount of irrigation. The opposite effect was reported by Greaves and Carter (*221*) in 1923, in their experiments with wheat, oats, and barley. These authors found that phosphorus, potassium, calcium, and magnesium in the grain were all increased as a result of irrigation. Greaves and Nelson (*224*) showed that while the iron, chlorine, and sulfur contents of wheat were increased by irrigation, these elements in oats and barley either underwent no change or actually decreased. Further work of Greaves and Nelson (*223*), in 1925, using corn, confirms the work of Harris and Pittman, who used the same crop.

The addition of irrigation water to potatoes grown in Georgia had no influence on the iodine content of that crop, according to the experiments of Holley, Pickett, and Brown (*274*), reported in 1935.

The effect of irrigation, like climate,varies with other factors such as the species of plant, the soil, or the amount of water added. The data are too few and too narrow in scope to justify any general conclusions regarding this factor.

VARIETY

Whether different varieties of the same species differ in mineral content when grown in the same soil is still an unsolved problem. It would seem reasonable that there should be differences, for the differences in yields among varieties indicate variations in the feeding power of the plant that might be reflected in their mineral composition. Considerable work has been done by Fort (*10x*) on the mineral variations in different varieties of the juice of sugarcane, and his data indicate that this factor may be of considerable importance. His studies did not include careful soil surveys, but the same varieties of cane occupied the same relative positions in regard to mineral content in each area in which they were grown. Ayres (*38*) in 1936 found little difference in the phosphorus content but significant variations in the potassium content of two varieties of sugarcane grown on the same soil. Similar results were obtained by Deomano (*151*) with four varieties of sugarcane, and by Maxwell (*401*), who analyzed 13 varieties of cane grown under uniform conditions.

Remy (*483*), in 1922, failed to find any variation in the phosphorus content of different varieties of corn grain, and Maume and Bouat (*399*) reported, in 1937, similar findings on the sulfur content of different varieties of wheat. Greaves and Anderson (*220*), on the other hand, reported in 1936 that they obtained about one-third as much copper in Kofod × Turkey variety of wheat as in Montana 36, and many varieties of wheat varied significantly in copper when grown in the same soil. Likewise, Bertrand and Levy (*59*) stated that while aluminum is present in all phanerogams, the amount present varies significantly with the species, exceptional species containing as much as 1 gm. per kilogram of dry matter.

Peterson and coworkers (*456*, *459*, *460*) found that different varieties of cabbage were remarkably uniform in their contents of calcium, phosphorus, iron, and nitrogen, and similar results were reported in 1938 by Vogel and von Hosslin (*577*).

Delbet (*145*) examined potatoes grown in the same soil in Egypt and found only normal variations in calcium, magnesium, potassium, sodium, and phosphorus content of the several different varieties. Poehlman (*469*), in some comprehensive experiments on two varieties of soybeans, concluded in 1935 that

> Variance due to varieties is not significantly different from the variance due to experimental error. This signifies that we cannot measure any significant differences between Morse and Virginia varieties of soybeans by chemical analyses of the expressed plant juice for nitrogen, phosphorus or potassium.

Weathers (*580*) apparently obtained no differences due to variety in the calcium, magnesium, potassium, iron, manganese, or phosphorus content of four varieties of lespedeza, all varieties having been grown in three different localities.

Some differences in potassium and phosphorus contents of corn stover due to varietal differences were reported by Wimer (*596*). These variations were not always consistent under different conditions, however, but they seemed to be affected greatly in some cases by grain and stover yields.

Ashton (*18*) reported in 1938 that different varieties of oats showed only very slight differences in chemical composition. Van Itallie (*293*) working with soils in the Netherlands, in 1937, found that there was a fairly consistent relationship between the variety of sugar beets and their potassium and sodium contents. A variety consistently high in potassium was usually found to be low in sodium.

Smirnova and Lavrova (*529*), working with the soybean plant in Russia, concluded that variations of the ash content of different varieties grown on one soil are not significant. Conditions of growth were associated with greater differences in mineral content than was varietal difference.

Definite conclusions as to the effect of the variety of the plant on the chemical composition cannot be made at this time. It is entirely possible that in some species one variety is a better feeder on certain nutrients than are other varieties of the same species. Such a supposition would seem to be at least a reasonable one. There are few data to support this assumption, however, because experiments of this nature have not included careful investigations that would assure uniform soil conditions.

MINERAL CONTENT OF DIFFERENT PARTS OF THE PLANT

Many examples of variations in the mineral content of the different parts of the plant have been cited in the compilation of analyses given in the appendix. Thus, the average value for calcium in the stem of the alfalfa plant is nearly 40 percent less than that in the leaf, and the data for the corn plant show that the leaf contains about 14 times as much calcium and less than one-third the phosphorus as does the grain. Similar differences are always found among the seed, stalk, or leaves of plants. As an example of the care that must be taken in sampling a crop, the data in table 19 are presented, showing the enormous differences in the calcium content of the leaves of the same head of cabbage.

TABLE 19.—*Calcium content of leaves of cabbage*

[Cowell (*125*)]

Sample No.	Description of leaf	Ca per 100 gm. moist leaf
		Mg.
1	Outer dark-green leaf	476
	Inner pale-green leaf	35
2	Outer dark-green leaf	910
	Inner yellowish-heart leaf	34
3	Outer dark-green leaf	998
	Inner pale-green leaf	53
4	Outermost leaf, dark-green	708
	Third leaf from outside, pale-green	96
	Yellowish white-heart leaf	26
5	Outermost leaf, dark-green	1,058
	Third leaf from outside, dark-green	216
	Inner leaf, pale-greenish yellow	71
	Heart leaf, yellowish-white	32

Sarata (*502*), on the contrary, reported in 1937 only slight differences in the copper content of different leaves of the Pe-tsai cabbage. The structure of this plant is, however, quite different from the compact head of common cabbage. Darkis and coworkers (*136*) have recently determined the difference in composition of the leaves from different parts of the tobacco plant, and they report that both calcium and potassium vary considerably according to the position of the leaf on the stalk. This factor is also of importance in the studies of Thomas and of Lagatu and Maume already cited.

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SOURCES OF UNPUBLISHED MATERIAL

In May of 1937 Dr. James T. Jardine, Director of Research, United States Department of Agriculture, invited the workers in the State agricultural experiment stations and in the Department to participate in a cooperative survey of unpublished data on the relationship of the chemical composition of plants to the soils in which they were grown. A large amount of material was received, and reference has been made in this report to this unpublished material as follows:

(1x) Bailey, C. H., and Hutchinson, Willis S. Minn. Agr. Exp. Sta. Data obtained through the U. S. Dept. Agr., Bur. of Home Econ.

(2x) Bizzell, J. A. N. Y. (Cornell) Agr. Expt. Sta.

(3x) Brannen, C. O. Ark. Agr. Expt. Sta.

(4x) Burnham, Mary C., Marks, Catherine G., Taylor, Dona G., and Gerhardt, Warda G. THE EFFECT OF VARIOUS FACTORS ON THE VARIATION IN THE CALCIUM AND PHOSPHORUS CONTENTS OF PEAS. Theses, Wis. Univ. Submitted for this survey by W. H. Peterson, Wis. Agr. Expt. Sta.

(5x) Coleman, J. M., and Ruprecht, R. W. THE EFFECT OF FERTILIZERS AND SOIL TYPES ON THE MINERAL CONTENT OF PLANTS. Thesis, Fla. Univ. Data obtained through the U. S. Dept. Agr., Bur. Home Econ.

(6x) Culbertson, C. C. Iowa Agr. Expt. Sta.

(7x) Dutcher, R. Adams, and Haley, D. C. Pa. Agr. Expt. Sta. Data obtained through the U. S. Dept. Agr., Bur. Home Econ.

(8x) Eisenmenger, Walter S. Mass. Agr. Expt. Sta.

(9x) Fletcher, S. W. Pa. Agr. Expt. Sta.

(10x) Fort, C. A. EFFECT OF LOCATION AND VARIETY ON THE MINERAL CONTENT OF SUGARCANE. U. S. Dept. Agr., Bur. Chem. and Soils.

(11x) Heller, V. G. Okla. Agr. Expt. Sta.

(12x) Hof, Josephine K., and Schwoegler, June K. THE MANGANESE AND COPPER CONTENTS OF WISCONSIN POTATOES. Theses, Wis. Univ. Data submitted by W. H. Peterson, Wis. Agr. Expt. Sta.

(13x) Jones, H. D. Mimeograph 1934. Submitted by the U. S. Dept. Agr., Bur. Home Econ.

(14x) McHargue, J. S. Ky. Agr. Expt. Sta.

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(16x) Moore, C. C. U. S. Dept. Agr., Div. Chem.

(17x) Pierre, W. H. W. Va. Agr. Expt. Sta.

(18x) Robinson, W. O. U. S. Dept. Agr., Bur. Plant Indus.

(19x) Smith, John B. R. I. Agr. Expt. Sta.

(20x) Tobiska, J. W. Colo. Agr. Expt. Sta.

(21x) Vandecaveye, S. C. Wash. Agr. Expt. Sta.

(22x) Weathers, E. K. Tenn. Agr. Expt. Sta.

(23x) Wiley, Harvey W., Moore, C. C., and Ewell, E. E. COMPARATIVE FERTILITY AND NITRIFYING POWER OF SOILS. Unpublished manuscript. U. S. Dept. Agr., Bur. Chem.

APPENDIX

Tables of Crop Composition

In the following tables there is tabulated the mineral composition, insofar as it is known, of the principal crops of interest in the United States. The data were compiled from several hundred published foreign and domestic reports and from unpublished data submitted by State agricultural experiment stations and by various bureaus of the United States Department of Agriculture. In every case in which individual analyses have been used, reference to the source of the data is given, and in addition the sources of data used in the summaries in the minor-element tables are given. Thus, the reader can quickly verify almost any item in which he is particularly interested.

The data have been chosen with every possible care, and particular attention was given to methods of handling the crops and to methods of chemical analysis. Thus, data on forages sampled from weathered materials are not included, and the results of pot tests or other artificial conditions have not been compiled. Data from other compilations have not been included, all data in this compilation having been obtained from original sources.

Furthermore, only analyses published on the moisture-free basis or those that could be calculated from given moisture contents to that basis were used. Moisture contents of forages and most vegetables vary considerably after harvest, and analyses on the fresh basis have little meaning unless the moisture content at the time of analysis is also given.

It was desirable in many instances to discard certain data that seemed to be entirely out of agreement with most of the known results. This was ordinarily done, however, only where a large number of values were available for comparison. Many extremes have been included where the lack of data did not justify their elimination, but occasionally in these instances the reader's attention is called in the tables to data that do not seem to be reasonable.

It is believed that the data in these tables should be of value to nutritionists, agronomists, and others interested in the composition of crops, and the descriptions of the crops and of the soils and the fertilizers used have been made with this in mind.

TABLE 20.—*The principal chemical elements in some important crops*

[Moisture-free basis]

Plant or plant part, soil type, and location[1]	Fertilizer used[2]	Analyses	K	Ca	Mg	P	S	Reference No.[3]
		Number	*Percent*[4]	*Percent*[4]	*Percent*[4]	*Percent*[4]	*Percent*[4]	
Alfalfa, above-ground portion, in bud, all cuttings:								
Isabella sandy loam, Michigan	None	1		2.88		0.38		229
	L	4		2.97		.38		
	P	1		3.12		.38		
	PL	4		2.95		.36		
	K	1		2.34		.29		
	KL	4		2.25		.30		
	PK	1		2.27		.41		
	PKL	4		2.51		.36		
Summary:								
Maximum			3.31	3.40		.45	0.96	
Minimum			1.10	1.56		.28	.24	
Mean			2.37(13)	2.45(33)	0.25(1)	.36(33)	.63(13)	
Alfalfa, above-ground portion, one-tenth to one-quarter bloom, all cuttings:								
Burgin silt clay loam, Kentucky	None	1	1.59	2.39		.34		14x
Maury silt loam, Kentucky	do	1	1.75	2.32		.32		
Summary:								
Maximum			2.76	3.23		.43		
Minimum			1.59	1.10		.16		
Mean			1.93(4)	2.34(31)	.34(1)	.32(32)	.36(1)	
Alfalfa, above-ground portion, half bloom, all cuttings:								
Burgin silt clay loam, Kentucky	None	1	1.37	2.83		.31		14x
Brookston clay loam, Michigan	do	1		2.94		.23		229
	P	2		2.69		.28		
	PK	2		2.85		.25		
Brookston loam, Michigan	None	2		2.51		.18		
	P	2		2.73		.21		
	PK	2		2.48		.20		
Brookston silt loam, Michigan	None	4		2.60		.21		
	P	4		2.45		.24		
	K	2		2.57		.22		
	PK	6		2.70		.23		
Gilford loam, Michigan	None	1		4.15		.16		
	P	1		3.72		.18		
	PK	1		3.39		.23		

[1] "Summary" items are not summaries of the immediately preceding data but represent independent summaries including other data.

[2] L=liming material; M=manure; N=nitrogen (mineral or organic); P=phosphate; K=potash; Mn=manganese salts; Cu=copper salts; Na=sodium salts; S=sulfur.

[3] Numbers without letters refer to "Literature Cited," p. 59; numbers followed by x refer to "Sources of Unpublished Material," p. 91.

[4] Figures in parentheses (after percentage of mean) denote number of analyses on which the "summary" data are based.

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Alfalfa, above-ground portion, half bloom, all cuttings—Con.								
Isabella sandy loam, Michigan	None	4		2.68		0.40		229
	L	16		2.63		.31		
	P	4		2.51		.38		
	PL	16		2.75		.33		
	K	4		2.43		.43		
	KL	16		2.26		.28		
	PK	4		2.55		.38		
	PKL	16		2.37		.29		
Miami silt loam, Michigan	None	1		3.43		.20		
	P	1		3.30		.21		
	PK	1		2.29		.23		
Dungeness silt loam, Washington	None	1	1.96	1.51		.23		572
	N	1	3.49	1.20		.24		
	NP	1	3.32	1.58		.36		
	PK	1	2.80	1.45		.33		
	NPK	1	2.88	1.27		.32		
Felida silt loam, Washington	None	3	2.64	1.46		.42		
	N	3	2.41	1.32		.36		
	NP	3	2.42	1.31		.33		
	PK	3	2.58	1.46		.40		
	NPK	3	2.55	1.31		.35		
Lynden sandy loam, Washington	None	2	1.80	2.15		.32		
	N	2	1.92	2.21		.23		
	NP	2	1.62	1.96		.24		
	PK	2	1.96	1.94		.27		
	NPK	2	1.54	2.35		.30		
Palouse silt loam, Washington	None	1		1.77		.32		
Puget silt loam, Washington	do	5	1.76	1.80		.24		
	N	5	2.30	1.42		.26		
	NP	5	1.88	1.38		.24		
	PK	5	1.78	1.68		.26		
	NPK	5	1.73	1.46		.24		
Puget sandy loam, Washington	None	2	2.43	1.25		.20		
	N	2	2.24	1.27		.21		
	NP	2	2.52	1.20		.25		
	PK	2	2.57	1.21		.25		
	NPK	2	2.56	1.21		.26		
Ritzville sandy loam, Washington	None	2	2.44	1.94		.32		
	N	2	2.58	1.78		.29		
	NP	2	2.68	1.64		.29		
	PK	2	2.50	1.75		.27		
	NPK	2	2.14	1.60		.29		

Winchester sand, Washington	None	4	2.44	1.71		.22		572
	N	4	2.48	1.79		.20		
	NP	4	2.73	1.51		.25		
	PK	4	2.56	1.48		.24		
	NPK	4	3.01	1.54		.25		
Dekalb silt loam, West Virginia	None	12		2.21		.27		17x
Holston silt loam, West Virginia	do	12		2.38		.25		
Hagerstown silt loam, West Virginia	do	12		1.73		.23		
Summary:								
Maximum			4.29	4.15	.37	.51	.32	
Minimum			.55	.59	.17	.14	.20	
Mean			2.22(130)	2.01(301)	.25(18)	.27(288)	.26(2)	
Standard deviation			±.57	±.72		±.07		
Mode			2.15–2.29	1.30–1.49		.23–.25		
Alfalfa, above-ground portion, three fourths bloom, all cuttings; summary:								
Maximum				1.56		.18		
Minimum				1.28		.10		
Mean				1.41(6)		.14(6)		
Alfalfa, above-ground portion, full bloom, all cuttings, Burgin silty clay loam, Kentucky.	None	1	1.20	1.74		.41		14x
Summary:								
Maximum			2.21	3.66	.33	.41	.43	
Minimum			.85	1.54	.25	.20	.25	
Mean			1.29(4)	2.26(6)	.29(2)	.27(7)	.34(2)	
Alfalfa, above-ground portion, cut for hay, maturity unknown; summary:								
Maximum			4.72	3.92	.72	.64	.53	
Minimum			.69	.77	.06	.11	.08	
Mean			2.40(78)	1.70(225)	.34(126)	.28(232)	.29(54)	
Alfalfa, leaves, half bloom, all cuttings, grown in Michigan; summary:								
Maximum				6.00		.53		229
Minimum				2.47		.19		
Mean				3.71(133)		.35(133)		
Alfalfa, stems, half bloom, all cuttings, grown in Michigan; summary:								
Maximum				2.04		.47		229
Minimum				.92		.11		
Mean				1.43(133)		.25(133)		
Alfilaria, above-ground portion, blooming, grown in California; summary:								
Maximum				2.07		.48		246
Minimum				.99		.24		
Mean				1.58(11)		.37(11)		
Alfilaria, above-ground portion, heading, grown in California; summary:								
Maximum				2.15		.46		246
Minimum				1.50		.30		
Mean				1.75(4)		.34(4)		
Apple, entire fruit, Gloucester stony loam, New Hampshire	None	1	.83	.04	.04	.68	.09	495

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Apple, entire fruit; summary:								
Maximum			1.41	0.11	0.059	0.142	0.09	
Minimum			.49	.023	.018	.020	.034	
Mean			.78(34)	.04(26)	.029(14)	[5].067(35)	.06(2)	
Apple, edible portion; summary:								
Maximum			.90	.177		.113		
Minimum			.62	.021		.055		
Mean			.74(25)	[6].077(24)		.071(27)		
Barley, grain; summary:								
Maximum			.76	.150	.22	.62	.28	
Minimum			.30	.015	.07	.15	.08	
Mean			.55(133)	.064(252)	.14(170)	.41(316)	.17(165)	
Standard deviation			±.03	±.022	±.03	±.08	±.03	
Mode			.57-.60	.050-.059	.12-.13	.45-.48	.16-.18	
Barley, straw; summary:								
Maximum			1.96	.60	.13	.56	.23	
Minimum			1.08	.15	.04	.04	.08	
Mean			1.48(10)	.35(18)	.08(10)	.12(53)	.15(9)	
Beans, field (*Phaseolus vulgaris* L.); mature seed:								
Bridgehampton very fine sandy loam, Rhode Island	NPK	1		.100	.145	.319	.552	19x
	NPL	1	1.187	.079	.175	.262	.324	
Summary:								
Maximum			1.62	.28	.25	.78	.55	
Minimum			1.07	.07	.11	.26	.06	
Mean			1.41(16)	.17(16)	.19(17)	.63(40)	.26(16)	
Beans, field (*P. vulgaris*); straw, without hulls, summary:								
Maximum			1.50	2.96	.20	.19	.12	
Minimum			.75	1.06	.08	.07	.11	
Mean			1.22(3)	1.71(3)	.13(3)	.11(27)	.11(3)	
Beans, field (*P. vulgaris*); hulls only; summary:								
Maximum			2.77	1.12	.23	.16	.06	
Minimum			1.34	.62	.16	.08	.04	
Mean			2.29(3)	.83(3)	.19(3)	.11(3)	.05(3)	
Beans, garden (*P. vulgaris*); edible pods and seeds:								
St. Lucie series, Florida	NPKMn	4		.97		.67		5x
Summary:								
Maximum			3.23	1.21	.52	.84		
Minimum			1.49	.41	.05	.20		
Mean			2.85(6)	.64(53)	.34(11)	.48(50)	.37(1)	
Beans, garden (*P. vulgaris*); immature seed; grown in Kentucky		1	2.00	.274	.324	.744	.867	379
Beans, garden (*P. vulgaris*); edible hulls; grown in Kentucky		1	2.58	.671	.341	.553	.191	379
Beans, lima (*P. vulgaris*); mature seed; grown in Kentucky		1	1.89	.104	.200	.412	.227	379
Beans, mung; mature seed		1	.62	.61	.17	.39	.02	85

Beets, roots only:									
Gloucester stony loam, New Hampshire	None	1	3.26	.156	.180	.48	.12	495
Bridgehampton very fine sandy loam, Rhode Island	NPK	5	2.72			.41		
	NP	3	2.31					19x
	NK	3				.48		
Beets, roots only: summary:								
Maximum			4.11	.38	.45	.6[illegible]	.16	
Minimum			.67	.09	.013	.1[illegible]	.12	
Mean			2.17(46)	.19(46)	.16(23)	.27(8[illegible])	.13(6)	
Beets, leaves: Bridgehampton very fine sandy loam	NPK	5	3.83			.41		
	NK	3				.41		19x
	NP	3	3.88					
Summary:								
Maximum			6.45	2.34	1.16	.56		
Minimum			1.68	.78	.69	.15		
Mean			3.91(31)	1.59(7)	.97(4)	.28(41)	.35(1)	
Broccoli, edible portion; summary:								
Maximum			3.63	1.57	.29	1.07	1.42	
Minimum			3.33	.92	.21	.69	1.15	
Mean			3.52(3)	1.29(4)	.24(3)	.79(4)	1.26(3)	
Buckwheat, above-ground portion, flowering stage; grown in France		1					.298	58
Buckwheat, above-ground portion, flowering stage; summary:								
Maximum			3.17	3.15	1.22	1.02		
Minimum			2.38	1.97	.29	.26		
Mean			2.88(4)	2.62(3)	.60(3)	.54(4)		
Buckwheat, above-ground portion, past bloom; grown in Massachusetts.		1	2.92	2.59	.27	.39		214
Buckwheat, above ground portion, grain and straw, grown in Massachusetts; summary:								
Maximum				2.90	.44			
Minimum				1.76	.27			
Mean				2.32(4)	.34(4)			
Buckwheat, forage; grown in Germany; summary:								
Maximum						.54		
Minimum						.47		321
Mean						.50(4)		
Buckwheat, grain; grown in Minnesota; summary:								
Maximum						.38		
Minimum						.24		
Mean						.33(9)		
Buckwheat, straw; grown in Minnesota; summary:								6
Maximum			3.59			.45		
Minimum			.75			.03		
Mean			2.08(15)			.21(15)		
Bur-clover (*Medicago hispida* Gaertn.), above-ground portion, early green; summary:								
Maximum				1.26		.48		
Minimum				.91		.32		
Mean			2.31(1)	1.03(6)	.338(1)	.40(7)		
Bur-clover (*M. hispida*), above-ground portion, in bloom; grown in California.		1		1.38		.22		246

[5] The phosphorus content of the sample from the Gloucester stony loam was omitted in determining this mean.
[6] This value, which may be too high, was obtained almost entirely from the analyses of Hopkins and Gourley (*276*), using only what appeared to be mature fruit. The minimum value was obtained from two analyses of Marañon (*393*).

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Bur-clover (*M. hispida*), above-ground portion, advanced stage of maturity but still green; grown in California.		2		0.94		0.26		233
Cabbage, edible portion:								
Decatur series, Alabama	NPK	1		1.50	0.032	.692		13x
Hartsell series, Alabama		1			.040	.645		13x
Norfolk series, Alabama	Na	1		1.22	.024	.442		13x
	Compost	1		.413	.024	.692		13x
	PK	1		1.776	.110			13x
	NPK	1		1.206	.071			13x
Coxville series, Florida	NPK	1		.58		.51		5x
Leon series, Florida	NPK	8		.84		.69		5x
	NPKMn	2		.76		.61		5x
	NPKCu	2		.76		.57		5x
Parkwood series, Florida	NPK	1		1.31		.56		5x
Cecil clay, North Carolina		1	3.66	1.43	.233	.389	1.00	495
Bridgehampton very fine sandy loam, Rhode Island	NPK	12	3.48			.40		19x
	NP	4	3.19			.18		19x
	NK	1				.48		19x
	PK	1				.15		19x
	N	2	4.03			.50		19x
Clyde silt loam, Wisconsin	None	4		.63		.40		460
Miami silt loam, Wisconsin	do	9		.69		.46		459, 460
Cabbage, edible portion; summary:								
Maximum			9.02	1.78	.38	.77	1.91	
Minimum			1.03	.41	.02	.13	.82	
Mean			2.71(34)	.73(89)	.16(13)	.38(113)	1.16(4)	
Standard deviation				±0.25		±.12		
Canada bluegrass (*Poa compressa* L.), above-ground portion, maturity unknown; summary:								
Maximum			4.19	.92	.33	.64		
Minimum			.82	.15	.07	.07		
Mean			2.04(19)	.39(18)	.16(11)	.25(20)		
Carrots, roots:								
Gloucester stony loam, New Hampshire		1	5.92	.376	.187	.35	.15	495
Bridgehampton very fine sandy loam, New Jersey	NPK	6	3.37	.32	.17	.32		19x
	NP	2		.38	.16	.47		19x
Summary:								
Maximum			5.95	.56	.25	.65	.18	
Minimum			.48	.24	.12	.14	.13	
Mean			2.10(27)	.40(35)	.17(24)	.33(53)	.16(5)	
Cauliflower, edible portion; summary:								
Maximum			3.71	.71	.29	.88	1.13	
Minimum			3.45	.13	.24	.51	1.01	
Mean			3.58(2)	.35(5)	.26(3)	.76(7)	1.07(2)	

Celery, edible portion:								
Bladen series, Florida	NPK	3	3.98	1.32	.46	.80	1.15	5x
Bridgehampton very fine sandy loam, Rhode Island	NPKL	9	4.94			.59		
	NKL	2				.74		
	NPK	6	5.12			.58		19x
	NP	1	4.61					
	NPL	1	5.48					
Summary:								
Maximum			6.81	3.57	.52	.90	1.98	
Minimum			1.09	.31	.14	.43	.49	
Mean			3.92(49)	2.36(34)	.39(33)	.64(55)	1.46(33)	
Clover, hop (*Trifolium agrarium* L.); above-ground portion, before bloom: Maury silt loam, Tennessee.	None	1	2.46	1.16	.19	.42		22x
Clover, hop (*T. agrarium*), above-ground portion, in bloom: Maury silt loam, Tennessee.	do	2	1.67	1.19	.17	.29		22x
Clover, hop (*T. agrarium*); above-ground portion, cut for hay: Maury silt loam, Tennessee.	do	1	1.56	1.11	.18	.30		22x
Clover, hop (*T. agrarium*); leaves only, cut for hay: Maury silt loam, Tennessee.	do	1	1.45	1.31	.24	.36		22x
Clover, hop (*T. agrarium*), stems only, cut for hay: Maury silt loam, Tennessee.	do	1	1.68		.89	.11	.24	22x
Clover, Egyptian (*T. alexandrinum*); above-ground portion, maturity unknown; grown in Kentucky.	do	1	2.21			.30		452
Clover, alsike (*T. hybridum* L.), above-ground portion, just coming into bloom; grown in Kentucky.	do	1	3.88			.37		453
Clover, alsike (*T. hybridum*), above-ground portion, full bloom; grown in Massachusetts.	do	2	2.55	1.48		.280		214, 216
Clover, alsike (*T. hybridum*); above-ground portion, maturity unknown: Bridgehampton very fine sandy loam, Rhode Island.	NPK	10		1.03		.24		19x
Clover, alsike (*T. hybridum*), above-ground portion, maturity unknown; summary:								
Maximum			5.90	2.87	.57	.53	.44	
Minimum			.86	.57	.13	.12	.08	
Mean			2.74(29)	1.29(47)	.31(47)	.26(37)	.21(25)	
Clover, crimson (*T. incarnatum* L.); above-ground portion, full bloom: Cecil sandy loam, North Carolina.		1	2.37	1.13	.291	.282	.22	495
Summary:								
Maximum			2.95	1.59		.41		
Minimum			.87	1.13		.26		
Mean			1.97(6)	1.38(4)	.291(1)	.30(6)	.22(1)	
Clover, crimson (*T. incarnatum*); above-ground portion, maturity unknown; summary:								
Maximum			5.92	1.84	.42	.53	.40	
Minimum			.71	1.10	.19	.08	.11	
Mean			3.12(29)	1.37(22)	.29(22)	.27(32)	.28(11)	
Clover, mammoth (*T. medium* L.); above-ground portion, beginning to bloom; grown in Kentucky.	None	2	.88			.33		452
Clover, red (*T. pratense* L.); above ground portion, young plant, grown in Germany.		8	2.16	2.02	.51	.35		250
Clover, red (*T. pratense*); above-ground portion, shortly before bloom; grown in Germany.		8	2.57	1.92	.51	.32		250

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Clover, red (*T. pratense*), above-ground portion, in bloom; Hagerstown loam, Pennsylvania.		1	1.97	2.09	0.473	0.247	0.19	495
Summary:								
Maximum			3.41	2.12	.68	.29		
Minimum			1.11	1.07	.35	.21		
Mean			1.96(12)	1.67(11)	.51(9)	.25(12)	.19(1)	
Clover, red (*T. pratense*), above-ground portion, with blossoms and seeds: Gloucester stony loam, New Hampshire.		1	1.53	1.45	.363	.271	.16	495
Clover, red (*T. pratense*), above-ground portion, end of bloom; grown in Germany.		8	1.78	1.81	.53	.25		250
Clover, red (*T. pratense*), above-ground portion, maturity unknown:								
Burgin silty clay loam, Kentucky	None	6	1.76	2.19		.33		
Maury silt loam, Kentucky	do	5	2.16	1.91		.38		14x
Tilsit silt loam, Kentucky	do	5	1.04	1.45	.507	.163	.224	
Penn silt loam (Pennsylvania)		1	1.32	2.07	.694	.227	.19	495
Bridgehampton very fine sandy loam, Rhode Island	NPK	15		1.03	.274			19x
Naragansett stony loam, Rhode Island	NPK	2	2.42	1.55	.35	.25	.15	
Summary:								
Maximum			2.82	3.07	.75	.52	.29	
Minimum			.66	.61	.13	.11	.05	
Mean			1.62(90)	1.53(127)	.37(104)	.22(112)	.16(75)	
Clover, red (*T. pratense*); leaves only in bloom; grown in Wales		1		2.030		.231		170
Clover, red (*T. pratense*); stems only, in bloom; grown in Wales		1		1.284		.122		170
Clover, red (*T. pratense*); flowering head, in bloom; grown in Wales		1		1.185		.376		170
Clover, hop (*T. procumbens* L.); above-ground portion, prebloom; grown in Tennessee.		1	2.457	1.165	.193	.424		580
Clover, hop (*T. procumbens*); above-ground portion, in bloom; grown in Tennessee.		1	1.718	1.351	.217	.354		580
Clover, hop (*T. procumbens*); above-ground portion, bloom dying; grown in Tennessee.		1	1.660	1.029	.127	.236		580
Clover, white (*T. repens* L.); above-ground portion, beginning bloom; Hagerstown loam, Pennsylvania.		1		1.59	.434	.310		495
Clover, white (*T. repens*); above-ground portion, end of bloom; summary.		2	3.38	1.05	.338	.34	.25	
Clover, white (*T. repens*); above-ground portion, maturity unknown:								
Maury silt loam, Kentucky		1	4.02	1.56		.428		14x
Merrimac fine sandy loam, Massachusetts		1	2.24	1.61	.25	.45		11
Puget sandy loam, Washington	None	5		.98		.51		231
	NPK	5		1.07		.52		
Westmoreland silt loam, West Virginia		1		1.61		.291		
Dekalb silt loam, West Virginia		4		1.96		.339		17x
Huntington silt loam, West Virginia		2		.91		.432		

Clover, white (*T. repens*); above-ground portion, maturity unknown; summary:								
Maximum			7.51	2.47	.51	.68	.55	
Minimum			1.33	.65	.21	.21	.13	
Mean			2.87(41)	1.42(65)	.34(16)	.37(64)	.33(34)	
Clover, sweet. *See* Sweetclover.								
Collards, leaves:								
Vaiden series, Alabama	None	1		2.14	.08	.66		13x
Norfolk series, Alabama	do	3		1.58	.10	.66		
Summary:								
Maximum				2.24	.27	.78		
Minimum				1.07	.07	.48		
Mean				1.59(5)	.13(5)	.62(5)		
Corn, grain:								
Dunkirk silt clay loam, New York	None	1	.43	.03	.11	.35	.18	2x
	M	1	.38	.02	.11	.35	.15	
	L	1	.34	.03	.10	.35	.18	
	ML	1	.39	.01	.10	.40	.16	
	MP	1	.45	[7] Trace	.14	.34	.12	
	MPL	1	.42	[7] Trace	.14	.35	.11	
Petoskey gritty sandy loam, New York	MP	1	.92	[7] Trace	.11	.30	.09	
	MPL	1	.83	[7] Trace	.15	.34	.13	
Volusia silt loam, New York	None	1	.38	.03	.09	.36	.30	
	M	1	.33	.01	.11	.38	.15	
	L	1	.42	[7] .06	[7] .07	.37	.18	
	ML	1	.34	.01	.09	.37	.15	
	MPL	1	.42	[7] None	.17	.34	.11	
Summary:								
Maximum			.92	.045	.27	.80	.30	
Minimum			.22	.006	.09	.23	.04	
Minimum excluding Utah samples [8]				.010				
Mean			.40(44)	.015(127)	.16(121)	.43(197)	.14(22)	
Mean excluding Utah samples [8]				.024				
Standard deviation				±.009	±.04	±.13		
Mode				.012	.13	.37		
Corn, stover, mature:								
Carrington silt loam, Illinois	(9)	14	.56	.36		.124		596
Cisne silt loam, Illinois	(9)	26	.43	.24		.130		
Drummer clay loam, Illinois	(9)	6	.59	.26		.073		
Elliot silt loam, Illinois	(9)	5	.34	.21		.074		
Grundy clay loam, Illinois	(9)	10	.65	.35		.072		
Grundy silt loam, Illinois	(9)	29	.56	.31		.059		
Muscatine silt loam, Illinois	(9)	19	.70	.32		.077		
Onarga sandy loam, Illinois	(9)	5	.73	.54		.154		
Putnam silt loam, Illinois	(9)	9	.60	.36		.177		
Saybrook silt loam, Illinois	(9)	9	.43	.29		.107		
Seidell silt loam, Illinois	(9)	13	.59	.30		.112		
Tilsit silt loam, (Kentucky)		2	1.02	.35	.36	.055	.20	14x

[7] Excluded in determining the means in the summary following.

[8] 90 analyses of the calcium content of corn have been reported from Utah, and 80 percent of these show less than 0.015 percent of calcium. The mean value of the Utah samples is 0.012 percent.

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Corn, stover, mature—Continued.								
Dunkirk silty clay loam, New York	None	2	1.39	0.25	0.21	0.27	0.23	2x
	L	2	1.67	.29	.23	.28	.21	
	P	1	.77	.21	.16	.37	.14	
	PL	1	.69	.26	.11	.25	.11	
Petoskey gritty sandy loam, New York	P	1	1.42	.15	.23	.36	.16	
	PL	1	1.34	.21	.27	.42	.18	
Volusia silt loam, New York	None	2	1.47	.12	.10	.32	.25	
	L	2	1.10	.12	.15	.32	.24	
	P	1	.82	.24	.22	.32	.11	
	PL	1	1.40	.29	.22	.37	.15	
Bridgehampton very fine sandy loam, Rhode Island	None	1				.22		19x
	P	1				.29		
	K	1				.10		
	NP	2				.24		
	NK	2				.12		
	PK	2				.24		
	NPK	1				.21		
Summary:								
Maximum			1.89	.84	.51	.42	.31	
Minimum			.26	.10	.08	.04	.08	
Mean			.74(219)	.32(192)	.24(43)	.15(231)	.17(32)	
Standard deviation			±.37	±.11		±.08		
Mode			.50	.32		.06		
Corn, stover, leaves only, mature:								
Carrington silt loam, Illinois	([9])	14	.44	.37		.124		596
Cisne silt loam, Illinois	([9])	26	.32	.31		.133		
Drummer clay loam, Illinois	([9])	6	.72	.25		.072		
Elliot silt loam, Illinois	([9])	5	.40	.15		.106		
Grundy clay loam, Illinois	([9])	10	.47	.41		.093		
Grundy silt loam, Illinois	([9])	29	.36	.31		.103		
Muscatine silt loam, Illinois	([9])	19	.46	.37		.098		
Onargo sandy loam, Illinois	([9])	5	.78	.72		.203		
Putnam silt loam, Illinois	([9])	9	.45	.43		.158		
Saybrook silt loam, Illinois	([9])	9	.42	.25		.120		
Seidell silt loam, Illinois	([9])	13	.48	.27		.118		
Summary:								
Maximum			1.02	.91		.234		
Minimum			.23	.11		.052		
Mean			.42(145)	.34(145)		.117(145)		

Corn, plant, above-ground portion, young, 60 cm. high; grown in Germany.		2	9.89	.68	.30	.39	.42	
Corn, plant, above-ground portion, before bloom; grown in Germany.		5	6.24	.55	.27	.21	.32	
Corn, plant, above-ground porton, beginning to bloom; grown in Germany.		1	7.12	.66	.23	.55	.37	368
Corn, plant, above-ground portion, milk stage, cut for silage; grown in Germany.		10	2.62	.50	.24	.21	.30	
Corn, sweet; edible portion, milk stage: Hagerstown series, Pennsylvania.	PK	2		.020		.378		
	NK	2		.027		.431		7x
	NP	3		.030		.432		
	NPK	5		.023		.408		
Summary:								
Maximum			1.10	.041		.56		
Minimum			1.06	.017		.30		
Mean			1.07(3)	.026(27)	.18(1)	.40(31)	.09(1)	
Cotton, lint; summary:								
Maximum			.75	.27	.11	.124	.06	
Minimum			.46	.013	.07	.025	.04	
Mean			.59(10)	.13(11)	.09(5)	.054(11)	.05(3)	
Cotton, burs, all grown in Oklahoma; summary:								
Maximum			5.74	1.02	.34	.21		
Minimum			1.42	.44	.19	.07		239
Mean			3.50(32)	.67(32)	.26(32)	.10(32)		
Cotton, seed; summary:								
Maximum			1.63	.31	.44	1.79	.36	
Minimum			.94	.08	.18	.48	.05	
Mean			1.20(10)	.15(10)	.35(5)	.75(10)	.26(3)	
Cowpeas, cut for hay; summary:								
Maximum			5.44	2.26	1.10	.64		
Minimum			.86	.49	.15	.08		
Mean			2.80(32)	1.52(20)	.41(16)	.32(37)	.35(1)	
Cowpeas, above-ground portion, in bloom; grown in South Carolina.		1	1.523	1.327	.449	.184	.093	
Cowpeas, above-ground portion, pods forming; grown in South Carolina.		1	1.114	1.201	.361	.192		359
Cowpeas, above-ground portion, pods formed; grown in South Carolina.		1	3.295	1.570	.460	.299		
Cowpeas, above-ground portion, first pods beginning to turn yellow; grown in Missouri.		1	.739			.146		514
Cowpeas, leaves; grown in Arkansas		1	.963			.175		550
Cowpeas, stems; grown in Arkansas		1	1.469			.070		
Cowpeas, hulls; grown in Arkansas		1	.722			.065		550
Cowpeas, seeds:								
Norfolk series, Alabama		1		.835	.349	.742		13x
Summary:								
Maximum			1.76		.349	.74		
Minimum			1.26		.242	.36		
Mean			1.46(16)	.12(1)	.296(2)	.52(18)	.28(1)	
Cucumber, entire fruit; Sassafras loam, New Jersey		1	4.46		.314	.450		593
Cucumber, fruit; grown in Virginia		2		.518	.307			109
Cucumber, edible portion; summary		2	4.48	.74		.75		

[9] For detailed fertilizer treatments the reader is referred to the original paper.

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Flax, seed; summary:								
Maximum						.85		
Minimum						.43		
Mean			0.63(1)	0.28(1)	0.43(1)	.59(14)	0.06(1)	
Flax, straw; summary:								
Maximum						.135		
Minimum						.026		
Mean						.066(8)		
Kafir, above-ground portion, cut before heads appeared; grown in Oklahoma		4		.44	.40	.13		
Kafir, heads removed, mature plant; grown in Oklahoma		3		.60		.10		133
Kafir, mature heads and grain only; grown in Oklahoma		3		.12		.25		
Kafir, grain; grown in Ohio		1	.29	.013	.14	.19	.12	192
Kafir, stover; grown in Africa		1	1.47	.18		.11		291
Kafir, above-ground, portion, cut for forage; grown in Hawaii		2	2.23	.13		.11		523
Kale, edible portion:								
Yolo silt loam, California		1	2.38	1.51	.74	.65	1.05	
Sassafras sandy loam, Maryland		2	3.97	1.97	.25	.73	1.12	140
Norfolk loam, Virginia		2	3.80	2.21	.31	.60	1.11	
Summary:								
Maximum			4.37	3.60	.74	.78	1.20	
Minimum			2.38	1.37	.24	.25	.64	
Mean			3.47(6)	2.16(9)	.36(6)	.62(9)	1.04(7)	
Kale, marrow-stem, above-ground portion; grown in England		4	3.35	2.13	.30	.35	1.16	600
Kale, thousand-head; above-ground portion; grown in England		2	2.72	1.75	.28	.35	.98	600
Kentucky bluegrass, young blades; grown in Kentucky		1	2.585	.470	.197	.952	.656	375
Kentucky bluegrass, above-ground portion, 4 to 5 inches high:								
Dunkirk silt loam, New York		1		.23		.59		304
Miami silt loam, Wisconsin	None	8		.57		.44		418
Kentucky bluegrass, above-ground portion, 8 to 10 inches high: Miami silt loam, Wisconsin.	do	5		.55		.41		
Kentucky bluegrass, above-ground portion, 12 to 15 inches high; grown in Iowa.	do	5		.28		.27		6x
Kentucky bluegrass, above-ground portion, clipped at 10-day intervals: Grundy silt loam, Iowa.	do	51		.38		.30		
	NPK	29		.38		.35		6x
Kentucky bluegrass, above-ground portion, clipped at 40-day intervals: Grundy silt loam, Iowa.	None	30		.86		.27		
	NPK	30		.36		.32		
Kentucky bluegrass, above-ground portion, first coming into bloom:								
Volusia silt loam, Ohio	None	1	2.61	.222		.283		
Miami clay, Ohio	do	1	1.75	.229		.284		195
Yazoo clay, Ohio	do	1	1.86	.254		.247		

Kentucky bluegrass, above-ground portion, first coming into bloom; grown in Ohio and Kentucky; summary:								
Maximum			2.85	.424		.403		
Minimum			1.41	.135		.164		
Mean			2.02(46)	.256(46)		.269(46)		
Kentucky bluegrass, above-ground portion, full bloom; grown in New York.	None	9	1.96	.13	.11	.25		122
Kentucky bluegrass, above-ground portion, past bloom; grown in Massachusetts.		2	1.52	.30		.20		214
Kentucky bluegrass, above-ground portion, in seed: Penn silt loam, Pennsylvania.		1	2.07	.189	.115	.299	.18	495
Kentucky bluegrass, above-ground portion, maturity unknown:								
Maury silt loam, Kentucky	None	7	1.93	.44		.40		14x
Merrimac fine sandy loam, Massachusetts		10	2.13	.49	.18	.38		11
Dekalb silt loam, West Virginia	None	9		.49		.30		
Huntington silt loam, West Virginia	do	1		.64		.45		17x
Westmoreland silt loam, West Virginia	do	1		.43		.29		
Miami silt loam, Wisconsin	do	32		.60		.44		418
Summary:								
Maximum			2.92	1.35	.26	.73	.20	
Minimum			1.33	.21	.09	.17	.05	
Mean			1.94(31)	.52(74)	.18(15)	.36(75)	.14(5)	
Kentucky bluegrass, seeds; grown in Kentucky		1	.670	.315	.197	.850	.202	375
Lemon, entire fruit; summary:								
Maximum			1.46	.92	.14	.22	.05	
Minimum			1.08	.39	.09	.16	.04	
Mean			1.31(8)	.58(8)	.11(8)	.19(8)	.05(8)	
Lespedeza, above-ground portion, before bloom:								
Clarksville silt loam, Tennessee		4	1.19	1.08	.19	.16		
Cumberland loam, Tennessee		13	1.13	1.20	.26	.22		
Decatur silt loam, Tennessee		1	1.31	1.17	.22	.15		22x
Maury silt loam, Tennessee		2	1.41	1.24	.20	.30		
Montevallo silt loam, Tennessee		1	1.34	.99	.21	.13		
Lespedeza, above-ground portion, early bloom:								
Clarksville silt loam, Tennessee		3	.93	.91	.15	.10		
Cumberland loam, Tennessee		7	1.04	1.22	.27	.22		22x
Maury silt loam, Tennessee		3	1.15	1.21	.19	.27		
Lespedeza, above-ground portion, full bloom:								
Clarksville silt loam, Tennessee		3	1.16	1.05	.21	.20		
Cumberland loam, Tennessee		13	1.08	1.30	.22	.23		
Dandridge silt loam, Tennessee		2	1.04	1.00	.20	.13		22x
Fullerton silt loam, Tennessee		1	1.08	1.10	.26	.15		
Montevallo silt loam, Tennessee		1	1.34	1.37	.24	.18		
Lespedeza, above-ground portion, late bloom:								
Clarksville silt loam, Tennessee		6	.87	.92	.18	.12		
Cumberland loam, Tennessee		3	1.09	1.12	.20	.23		22x
Maury, silt loam, Tennessee		1	1.12	1.18	.20	.28		
Lespedeza, above ground portion, in seed:								
Clarksville silt loam, Tennessee		1	.77	1.04	.16	.12		22x
Cumberland loam, Tennessee		10	.93	1.01	.21	.18		

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
Lespedeza, above-ground portion, maturity unknown:		*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Burgin, silt clay loam, Kentucky		3	1.02	1.28		.30		
Decatur silt loam, Kentucky		4				.18		14x
Maury silt loam, Kentucky		3	.94	1.44		.31		
Tilsit silt loam, Kentucky		6	.85	.90		.13		
Clarksville silt loam, Tennessee		4	1.00	.97	0.17	.16		22x
Cumberland loam, Tennessee		28	1.01	1.04	.22	.24		580, 22x
Hartsells silt loam, Tennessee		17	.79	.94	.21	.14		22x
Maury silt loam, Tennessee		6	1.26	1.27	.20	.29		580, 22x
Lespedeza, above-ground portion, all stages of maturity; summary:								
Maximum			1.95	2.08	.42	.38		
Minimum			.62	.69	.13	.08		
Mean			1.02(144)	1.10(152)	.22(138)	.20(160)		
Standard deviation			±.24	±.22	±.05	±.07		
Mode			.70-.80	.90-1.00	.15-.20	.19-.23		
Lettuce, head:								
Cecil series, Alabama		1		.93	.05	1.05		13x
Norfolk series, Alabama		2		.80	.11	.48		
Leon series, Florida	NPK	13		1.25		.75		
	NPKMn	3		1.35		.76		5x
	NPKCu	2		1.40		.76		
Portsmouth series, Florida	NPK	1		1.38		.74		
Bridgehampton very fine sandy loan, Rhode Island	NP	3	7.46					
	NK	1	6.86			.65		19x
	NPK	5	6.38			.69		
Lettuce, head; summary:								
Maximum			7.91	1.38	.44	1.05	0.31	
Minimum			2.69	.33	.04	.19	.25	
Mean			5.98(16)	.77(17)	.24(11)	.56(30)	.28(3)	
Mangel-wurzel (*Beta vulgaris* var. *macrorhiza*), roots: Bridgehampton very fine sandy loam, Rhode Island	NPK	4		.24	.17	.08		19x
Summary:								
Maximum			3.87	.31	.36	.29		
Minimum			.89	.13	.11	.07		
Mean			2.20(5)	.21(6)	.21(5)	.18(10)	.23(1)	
Mangel-wurzel, crowns only: Bridgehampton very fine sandy loam, Rhode Island	NPK	4		.81	.24	.12		19x
Mangel-wurzel, leaves only: Bridgehampton very fine sandy loam, Rhode Island	NPK	4		1.76	.77	.16		19x
Millet, variety unknown, above-ground portion, fruiting; grown in Philippine Islands		1		.80		[10] 1.03		394
Millet, German Golden; above-ground portion, cut for hay: Bridgehampton very fine sandy loan, Rhode Island	NKL	5				.14		19x

Millet, Japanese, above-ground portion, cut for hay: Bridgehampton very fine sandy loam, Rhode Island	NKL	5				.15		19x
	PKLMg	2	7.42	1.12		.10		
Millet, above-ground portion, variety and maturity unknown, cut for hay; summary:								
Maximum			7.59	1.14	.46	.62		
Minimum			1.54	.71	.37	.09		
Mean			3.20(11)	.96(7)	.41(4)	.22(22)		
Milo, above-ground portion, flowering; grown in Philippine Islands		1		.94		1.10		394
Milo, above-ground portion, cut before heads appeared; grown in Oklahoma		10		.58		.18		133
Milo, above-ground portion, fruiting; grown in Philippine Islands		1		.13		.04		394
Milo, above-ground portion, heads removed, mature plant; grown in Oklahoma		10		.64		.12		133
Milo, mature heads and grain; grown in Oklahoma		10		.18		.30		133
Milo, above-ground portion, maturity unknown; grown in Kentucky		3	3.06			.38		452, 453
Mustard, edible leaves: Norfolk series, Alabama		2		1.95	.05	.71		13x
Summary:								
Maximum				2.59	.06	.97	1.31	
Minimum				1.76	.05	.42	.88	
Mean				2.13(5)	.05(2)	.71(5)	1.09(2)	
Oats, grain: Bridgehampton very fine sandy loam, Rhode Island	NKL	7				.24		19x
Summary:								
Maximum			.73	.19	.29	.53	.29	
Minimum			.28	.05	.06	.15	.07	
Mean			.48(99)	.10(170)	.16(76)	.34(233)	.19(52)	
Standard deviation			±.09	±.01	±.04	±.08	±.05	
Mode			.45–.50	.08–.10	.14–.16	.35–.40	.22–.24	
Oat straw; summary:								
Maximum			3.52	.67	.54	.36	.51	
Minimum			.59	.15	.06	.02	.09	
Mean			1.51(72)	.21(147)	.24(23)	.11(212)	.25(26)	
Oats, above-ground portion, flowering stage; grown in France		1	2.01	.73	.33	.48	.57	58
Above-ground portion, milk stage:								
Penn silt loam, Pennsylvania		1	2.20	.30	.23	.33	.28	495
Chehalis clay loam, Washington	None	1	.57	.24		.25		21x
	(11)	7	.99	.27		.22		
Colville silt loam, Washington	None	1	.20	.20		.25		
	(11)	4	.38	.23		.20		
Huson clay loam, Washington	None	1	.63	.17		.17		
	(11)	4	.69	.20		.17		
Olympic clay loam, Washington	None	1	.59	.28		.25		
	(11)	5	.54	.31		.23		
Orting loam, Washington	None	1	1.44	.13		.24		
	(11)	4	1.62	.14		.30		
Palouse silt loam, Washington	None	2		.29		.29		
Salkum silty clay, Washington	do	1	1.19	.19		.40		
	(11)	5	1.51	.18		.27		

[10] Omitted from summary following.
[11] Average of all fertilizer treatments. No consistent influence of fertilizers was noticeable, and no experiments were conducted using any single fertilizer elements except nitrogen.

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Oats, above-ground portion, grain matured; summary:								
Maximum			1.71	0.51	0.41	0.40	0.09	
Minimum			.78	.21	.13	.16	.07	
Mean			1.15(6)	.35(9)	.25(9)	.23(6)	.08(5)	
Onions, bulb: Bridgehampton very fine sandy loam, Rhode Island	NPK	1				.42		19x
Summary:								
Maximum			1.92	.59	.16	.74		
Minimum			1.03	.26	.11	.17		
Mean			1.52(29)	.39(28)	.13(3)	.26(33)	.60(1)	
Parsnip, roots:								
Bridgehampton very fine sandy loam, Rhode Island	NP	2	1.35					19x
	NPK	6	1.41			.31		
Summary:								
Maximum			2.62	.33		.84		
Minimum			.86	.25		.20		
Mean			1.85(12)	.28(6)	.12(1)	.37(14)		
Peas, edible portion, all sizes:								
Dunkirk fine sand, New York	NP	11	1.42	.15				505
	NPL	4	1.52	.14				
	NPK	8	1.49	.14				
	NPKL	8	1.55	.17				
Carrington silt loam, Wisconsin		17		.25		.59		4x
Knox silt loam, Wisconsin		4		.18		.58		
Miami silt loam, Wisconsin		45		.21		.64		
Summary:								
Maximum			1.89	.43	.22	.78	.15	
Minimum			.79	.10	.15	.23	.09	
Mean			1.41(54)	.19(127)	.18(6)	.57(100)	.13(4)	
Peas, foliage of plant:								
Norfolk sandy loam, Virginia	None	1	2.84	4.84	.52	.18		450
	L	6	1.95	6.53	.26	.18		
Peas, above-ground portion, cut for forage; summary:								
Maximum			3.15	2.32	.46	.51	.29	
Minimum			.74	.77	.27	.07	.18	
Mean			1.40(10)	1.37(27)	.37(9)	.28(36)	.23(4)	
Potatoes, tubers:								
Fort Collins loam, Colorado	None	5	2.13	.051	.103	.27	.09	257
	N	5	2.29	.061	.107	.26	.09	
Bladen series, Florida	NPK	6	2.37		.18	.32	.24	5x
	NPKMn	1	2.19		.19	.36	.25	
	NPKCu	1	2.56		.19	.35	.25	

Coxville series, Florida	NPK	4	2.18		.22	.30	.24	5x
	NPKMn	3	2.12		.22	.28	.25	
	NPKCu	2	2.27		.19	.32	.22	
	NPKCuMn	1	2.38		.20	.28	.25	
Leon series, Florida	NPK	4	2.32		.21	.45	.24	
Norfolk series, Florida	NPK	1	2.61		.23	.27	.21	
Gloucester stony loam, New Hampshire		1	2.73	.028	.11	.24	.18	495
Hagerstown series, Pennsylvania		16		.051		.24		7x
Bridgehampton very fine sandy loam, Rhode Island	NP	1	2.05			.24		19x
	NPK	5	1.72	.025	.13	.24		
	NPNa	1				.31		
Summary:								
Maximum			3.96	.140	.23	.49	.42	
Minimum			1.05	.017	.05	.11	.06	
Mean			2.28(773)	.049(369)	.13(315)	.25(588)	.12(420)	
Standard deviation			±.43	±.021	±.03	±.06	±.04	
Mode			2.05–2.20	.045–.059	.11–.12	.23–.25	.09–.10	
Potatoes, vines only; grown in Germany		16	1.62	4.12	1.15	.26	.68	137, 368
Pumpkin, edible portion; summary		3	2.47	.50	.26	.24		
Pumpkin, entire fruit; grown in New Jersey	None	1	2.86	.48	.16	.25		593
Rape, above-ground portion, plant 6–8 inches high, green and succulent; grown in Iowa.		1		1.67		.60		6x
Rape, above-ground portion, plant 15 inches high, half grown; grown in Iowa.		1		2.46		.47		6x
Rape, above-ground portion, plant 20–27 inches high; grown in Iowa.		3		1.92		.38		6x
Rape, above-ground portion, plant 30–34 inches high; grown in Iowa.		3		1.96		.33		6x
Rape, above-ground portion, cut before bloom; grown in Massachusetts.		1	4.36	2.97	.36	.28		215
Rape, above-ground portion, flowering stage; grown in France		2	3.41	3.40	.37	.51	1.16	
Rape, above-ground portion, maturity unknown:								
Norfolk series, Alabama		1		1.50	.03	.78		13x
Colts Neck loam, New Jersey	None	2				.39		75
	P	8				.40		
Bridgehampton, very fine sandy loam, Rhode Island	NPK	6				.22		19x
Summary:								
Maximum			5.27			.86	.99	
Minimum			1.37			.11	.16	
Mean			3.40(6)	1.50(1)	.03(1)	.41(33)	.66(5)	
Rape, leaves only, mature plant; grown in Iowa		4		2.77		.48		6x
Rape, stems only, mature plant; grown in Iowa		4		2.28		.30		6x
Rape, stalks only, mature plant; grown in Iowa		4		.90		.27		6x
Redtop, above-ground portion, full bloom: Maury silt loam, Kentucky.		2	1.59	.52		.28		14x
Redtop, above-ground portion, stage of maturity unknown:								
Dekalb silt loam, Kentucky	None	1	1.45	.304	.170	.124	.314	14x
	ML	1	1.25	.438	.135	.118	.290	
	M	1	1.28	.394	.164	.143	.239	
	LSP	1	1.28	.443	.168	.161	.239	
Maury silt loam, Kentucky	None	4	2.20	.74		.44		14x

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
Redtop, above-ground portion, stage of maturity unknown—Con.		*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Tilsit silt loam, Kentucky	None	1	1.52	0.316	0.210	0.112	0.250	14x
	NPL	1	1.34	.407	.204	.111	.296	
	NPS	1	1.28	.230	.245	.148	.331	
Bridgehampton very fine sandy loam, Rhode Island	PK	1	1.65	.31	.11	.20		19x
	NPK	5	1.51	.33	.12	.19		
Summary:								
Maximum			3.94	.63	.33	.41	.33	
Minimum			.71	.07	.07	.05	.09	
Mean			2.12(48)	.42(47)	.18(34)	.25(53)	.26(15)	
Redtop, above-ground portion, in seed; grown in Hawaii		1		.26		.11		490
Rice, paddy; summary:								
Maximum			.48	.138	.17	.43		
Minimum			.32	.057	.14	.29		
Mean			.38(15)	.090(10)	.16(7)	.36(18)		
Rice, straw; grown in Hawaii; summary		15	1.64	.30	.11	.13		313, 561
Rutabaga, roots:								
Bridgehampton very fine sandy loam, Rhode Island	NPK	16				.25		19x
	NKL	1				.26		
	NPKL	1				.32		
Summary:								
Maximum			4.77	.80	.19	.78		
Minimum			.60	.13	.11	.05		
Mean			1.91(24)	.49(23)	.14(7)	.27(66)	.30(1)	
Rutabaga, tops:								
Bridgehampton very fine sandy loam, Rhode Island	NPK	3				.34		19x
Summary:								
Maximum				2.92	.28	.93		
Minimum				2.12	.17	.29		
Mean			3.84(1)	2.50(5)	.22(4)	.49(5)		
Rye, grain; summary:								
Maximum			.63	.207	.19	.52	.41	
Minimum			.48	.043	.11	.21	.08	
Mean			.53(11)	.115(10)	.14(4)	.37(71)	.18(3)	
Rye-straw; summary:								
Maximum			1.51	.40	.133	.30	.20	
Minimum			.53	.16	.036	.04	.07	
Mean			.97(33)	.28(31)	.073(25)	.10(41)	.11(29)	
Rye, above-ground portion, cut before heads appeared; grown in Oklahoma.		13		.290		.234		132
Sorghum, above-ground portion, cut before heads appeared; grown in Oklahoma; summary		18		.36		.103		
Sorghum, above-ground portion, cut for fodder; grown in Hawaii		5	1.70	.19		.27		523
Sorghum, green stalk; grown in Texas		1	1.23	.22	.77	.19	.05	420

Sorghum, green heads and seed; grown in Texas		1	.55	.22	.11	.51	.06	240
Sorghum, mature stalk; grown in Oklahoma		3		.53		.59		133
Sorghum, mature heads and seed; grown in Oklahoma		3		.081		.22		133
Sorghum, straw; grown in Africa		1	1.29	.16		.13		291
Soybean, leaves; grown in France		1	.80	3.18	.79	.16	.25	335
Soybean, pod; grown in France		1	1.95	.56	.41	.51	.22	335
Soybean, stem; grown in France		1	.67	.89	.42	.20	.27	335
Soybean, hulls and vines; grown in South Carolina		1	.96	.46	.23	.42		359
Soybean, vine, in full bloom; summary		9	2.31	1.47	.73	.39	.18	
Soybean, vine, pods forming; grown in Massachusetts		1	.93	2.10	.76	.31		215
Soybean, hay, maturity unknown:								
Dekalb silt loam, Kentucky	None	1	1.46	.94	.441	.194	.274	14x
	ML	1	1.01	1.15	.439	.182	.241	
	MP	2	.96	1.07	.448	.356	.344	
	MLP	2	.63	1.23	.512	.274	.250	
	MLPK	2	1.48	.99	.353	.237	.201	
Tilsit silt loam, Kentucky	None	1	1.25	1.05	.656	.214	.333	
	M	1	1.24	1.19	.611	.148	.306	
	ML	1	.96	1.20	.608	.200	.254	
	MP	2	.79	1.09	.822	.304	.322	
	MPK	3	1.28	1.15	.619	.257	.290	
	MLP	2	.79	1.11	.720	.265	.292	
	MLPK	1	1.16	1.32	.543	.154	.259	
Summary:								
Maximum			2.31	2.11	.86	.58	.52	
Minimum			.54	.52	.16	.09	.14	
Mean			1.24(64)	1.12(119)	.50(98)	.26(124)	.29(31)	
Soybean, entire plant including roots; grown in Kentucky		10	2.62			.40		452
Soybean, green, shelled, matured as for food; summary:								
Maximum				.333		.773		
Minimum				.161		.506		
Mean				.232(40)		.668(4)		
Soybean, mature seed; summary:								
Maximum			2.39	.30	.34	1.08	.45	
Minimum			.81	.19	.24	.50	.10	
Mean			1.83(29)	.24(9)	.31(7)	.78(37)	.24(6)	
Spinach, above-ground portion:								
Cecil series, Alabama		1		.58	.23	.68		13x
Norfolk series, Alabama		2		1.26	.17	.82		
Sassafras sandy loam, Maryland	NPK	2	4.24	1.97	.35	.86	.49	140
Bridgehampton, very fine sandy loam, Rhode Island	NPK	4				.61		19x
	NPMn	1	8.09					
	NKMn	3		.76		.89		
	NPKMn	12	6.58	1.00	.52	.88		
Norfolk loam, Virginia	NPK	2	7.18	1.37	.4[illegible]	.87	.47	140
Summary:								
Maximum			9.09	2.78	1.24	1.17	.66	
Minimum			3.03	.51	.15	.27	.14	
Mean			6.16(27)	1.21(45)	.53(27)	.72(62)	.39(11)	
Squash, entire fruit; Bridgehampton very fine sandy loam, Rhode Island.	NPK	3	1.61			.33		19x

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
Strawberries, fruit:		*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Derby fine sandy loam, Oklahoma	None	16				0.13		252
Summary:								
Maximum			2.35	0.41		.37		
Minimum			1.58	.22		.10		
Mean			2.05(7)	.31(2)		.20(30)		
Sudan grass, above-ground portion, 6 to 12 inches high, entirely edible; grown in Iowa.	None	4		.56		.52		6x
Sudan grass, above-ground portion, 20 to 30 inches high, mostly edible; grown in Iowa.	None	4		.44		.43		6x
Sudan grass, above-ground portion, 30 to 60 inches high, slightly headed, partly edible; grown in Iowa.	None	4		.47		.27		6x
Sudan grass, above-ground portion, mature, partly edible; grown in Iowa.	None	2		.30		.21		6x
Sudan grass, above-ground portion, before flowering; grown in Philippine Islands.	None	1		.44		.88		394
Sudan grass, above-ground portion, flowering; grown in Philippine Islands.	None	1		.29		.59		394
Sudan grass, above-ground portion, early seed stage: Clarksville silt loam, Arkansas.	NPK	5	1.48					3x
Sudan grass, above-ground portion, maturity unknown; summary:								
Maximum				.86	0.43	.40		
Minimum				.43	.26	.19		
Mean			1.46(1)	.73(6)	.35(5)	.29(2)	0.05(1)	
Sugar beets, roots; summary:								
Maximum			1.39	.35	.23	.33	.13	
Minimum			.37	.11	.11	.03	.03	
Mean			.64(57)	.22(49)	.16(31)	.11(52)	.07(9)	
Sugar beets, leaves; summary:								
Maximum			7.64	2.83	1.07	.38	.61	
Minimum			1.01	.39	.26	.08	.31	
Mean			3.28(60)	1.14(60)	.51(59)	.22(60)	.48(20)	
Sugarcane leaves; summary:								
Maximum			1.58	.62		.22	.23	
Minimum			.36	.43		.07	.06	
Mean			1.10(10)	.54(6)	.40(1)	.13(10)	.13(5)	
Sugarcane, tops; summary:								
Maximum			2.65	.44	.17	.31		
Minimum			.46	.02	.13	.10		
Mean			1.83(10)	.21(10)	.14(5)	.17(18)		
Sugarcane, stalks; summary:								
Maximum			1.44	.24	.13	.17	.15	
Minimum			.05	.02	.02	.02	.02	
Mean			.56(87)	.07(43)	.06(34)	.07(96)	.06(34)	

Sunflower, heads minus seeds and husks, mature plant; grown in District of Columbia.		1	9.43	2.49	1.26	.41	.46	592
Sunflower, seed husk, mature plant; grown in District of Columbia		1	.92	.35	.23	.07	.05	592
Sunflower, seed kernel without husk, mature plant; grown in District of Columbia.		1	.96	.21	.40	1.01	.02	592
Sunflower, leaves, head formed, seed undeveloped; grown in Puerto Rico.		7	3.85	3.29	.088	1.08		209
Sunflower, leaves, mature plant; grown in District of Columbia		1	1.62	7.64	3.15	.35	.43	592
Sunflower, stalks, head formed, seed undeveloped grown in Puerto Rico.		8	4.58	1.03	.63	.31		209
Sunflower, stalks, mature plant; grown in District of Columbia		1	3.23	1.72	1.20	.07	.14	209
Sunflower, above-ground portion, cut before bloom; grown in Germany.		1	3.33	2.09	.49	.20	.13	368
Sunflower, above-ground portion, bud appearing on top of plant; Palouse silt loam, Idaho.		6	4.58	2.20	.42	.28	.28	431
Sunflower, above-ground portion, flower 3 inches in diameter, no seed; Palouse silt loam, Idaho.		6	4.20	1.89	.37	.28	.32	431
Sunflower, above-ground portion, cut in full bloom; grown in Germany.		1	2.11	2.06	.50	.18	.14	368
Sunflower, above-ground portion, cut before seed of first bloom was in dough stage; Palouse silt loam, Idaho.		6	4.08	1.80	.37	.27	.26	431
Sunflower, above-ground portion, seeds of first flower in dough stage; Palouse silt loam, Idaho.		6	3.69	1.61	.28	.27	.23	431
Sunflower, above-ground portion, seeds quite hard and rays fallen; Palouse silt loam, Idaho.		6	3.11	1.57	.37	.26	.25	431
Sweetpotatoes, tubers; summary:								
Maximum			1.74	.15	.21	.22		
Minimum			.68	.04	.11	.06		
Mean			1.21(25)	.08(9)	.16(2)	.12(33)	.12(1)	
Sweetclover (*Melilotus alba* Desv.), above-ground portion, very young: Palouse silt loam, Washington.	None	5		1.66		.46		533
Sweetclover (*M. alba*), above-ground portion, flower buds just opening:								
Grown in Canada	do	2	1.88	1.55		.243		200
Palouse silt loam, Washington	do	1		1.19		.46		533
Sweetclover (*M. alba.*), above-ground portion, in full bloom; summary:								
Maximum			1.81	2.64	.47	.41		
Minimum			1.48	.61	.21	.05		
Mean			1.64(3)	1.26(175)	.34(9)	.13(176)		
Sweetclover (*M. alba*), above-ground portion, seeds well filled; grown in Canada.	None	2	1.27	1.36		1.94		200
Sweetclover (*M. alba*), above-ground portion, maturity unknown:								
Bluford silt loam, Illinois	do	3	1.49			.38		40
Shelby loam, Missouri	do	1					.399	237
Hagerstown loam, Pennsylvania		1	2.03	1.19	.293	.227	.70	495
Summary:								
Maximum			2.03	1.53	.35	.39	.70	
Minimum			.60	1.19	.29	.12	.25	
Mean			1.30(10)	1.33(3)	.32(2)	.31(13)	.45((3)	
Tendergreen, above-ground portion:								
Decatur series, Alabama		1		2.59	.09	.97		13x
Norfolk series, Alabama		1		2.38	.06	.74		

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Timothy, above-ground portion, 2–4 inches high; grown in Iowa		3		0.59		0.37		6x
Timothy, above-ground portion, 4–5 inches high; Maury silt loam, Kentucky.		3	2.25	.49		.37		14x
Timothy, above-ground portion, 10–12 inches high; summary		2	1.98	.17		.27		
Timothy, above-ground portion, just beginning to head; summary		2	1.49	.23		.21		
Timothy, above-ground portion, full bloom:								
Maury silt loam, Kentucky		2	1.16	.42		.31		14x
Gloucester stony loam, New Hampshire		1	1.64	.20	0.09	.17	0.09	495
Hagerstown loam, Pennsylvania		1	1.75	.24	.16	.21	.27	
Penn silt loam, Pennsylvania		1	2.08	.26	.15	.24	.19	
Summary:								
Maximum			2.32	.44	.17	.41	.27	
Minimum			.92	.15	.09	.17	.02	
Mean			1.69(8)	.28(7)	.14(5)	.24(8)	.13(5)	
Timothy, above-ground portion, out of bloom, seed formed; grown in Missouri.		1	1.12			.17		565
Timothy, above-ground portion, seed ripe; summary		3	1.58	.16	.07	.17	.16	
Timothy, above-ground portion, seed all in dough; grown in Missouri.		1	.89			.14		565
Timothy, above-ground portion, cut for hay, maturity unknown:								
Tilsit silt loam, Kentucky	M	1	1.46	.28	.17	.14	.17	14x
	ML	1	1.47	.31	.20	.11	.20	
	MPL	2	1.20	.34	.17	.16	.16	
Dunkirk silt loam, New York		2		.48		.57		304
Bridgehampton very fine sandy loam, Rhode Island	PK	1	1.63	.21	.06	.19		19x
	NPK	1	1.14	.15	.04	.14		
	NPKMn	9		.24	.09			
Summary:								
Maximum			2.89	1.02	.38	.60	.32	
Minimum			.79	.04	.03	.08	.07	
Mean			1.79(63)	.39(98)	.14(68)	.21(128)	.14(21)	
Timothy, leaves, cut for hay, maturity unknown:								
Grown in Wales		1		1.31		.19		170
Do		1		.27		.19		
Tobacco, leaves; dark, air-cured type; grown in Kentucky; summary:								
Maximum			3.41	3.52	1.01	.41	1.19	
Minimum			.51	2.91	.93	.21	.40	
Mean			2.31(33)	3.23(5)	.97(4)	.32(9)	.70(21)	
Tobacco, leaves, Burley: summary:								
Maximum			6.16	5.30	.80	.53		
Minimum			1.45	2.59	.25	.19		
Mean			3.56(72)	4.02(18)	.62(14)	.37(18)	.22(1)	

Tobacco, leaves, cigar binder type; summary:								
Maximum			7.08	5.20	1.57	.26	1.06	
Minimum			1.80	2.48	.31	.12	.40	
Mean			5.36(34)	3.72(34)	.93(32)	.21(32)	.73(32)	
Tobacco, leaves, cigar filler type:								
Hagerstown series, Pennsylvania	None	4	3.39			.24		9x
	NK	1	3.46			.21		
	PK	7	3.24			.23		
	NPK	19	3.21			.23		
Summary:								
Maximum			4.96	6.07	.84	.26	.64	
Minimum			1.37	2.67	.45	.17	.46	
Mean			2.75(55)	4.85(24)	.65(20)	.22(41)	.55(10)	
Tobacco, leaves, cigar wrapper type; summary:								
Maximum			7.81	5.51	2.74	.46	.97	
Minimum			3.49	3.23	.44	.21	.68	
Mean			5.90(41)	4.34(40)	1.13(39)	.33(39)	.78(15)	
Tobacco, leaves, dark fired type; summary:								
Maximum			5.13	4.72	.89	.23	.32	
Minimum			3.19	3.60	.57	.14	.28	
Mean			4.36(6)	3.85(6)	.71(5)	.18(5)	.30(2)	
Tobacco, leaves, flue-cured type; summary:								
Maximum			2.97	3.84	.85	.39	1.16	
Minimum			1.31	1.20	.13	.19	.34	
Mean			2.20(67)	2.84(67)	.46(56)	.28(56)	.54(56)	
Tobacco, leaves, type unknown:								
Collington sandy loam, Maryland		5		1.63	.25			201
Summary:								
Maximum			7.00	5.62	1.94	.52	1.03	
Minimum			1.98	1.36	.03	.15	.18	
Mean			4.77(88)	3.51(93)	.81(77)	.29(85)	.64(42)	
Tobacco, dark lugs; grown in Kentucky		4	2.53	2.90	1.00	.21		519, 520
Tobacco, dark trash; grown in Kentucky		4	2.28	2.65	1.12	.20		519, 520
Tobacco, above-ground portion; grown in France		1	5.15			.31	.95	64, 66
Tomato, pulp (whole fruit except seeds):								
Sassafras sandy loam, Maryland	None	2	3.54			.40		556
	N	2	3.48			.39		
	P	2	3.68			.41		
	K	2	4.56			.40		
	NK	2	4.83			.40		
	PK	2	3.70			.49		
	NPK	6	4.48			.45		
	M	2	4.86			.46		
Tomato, fruit:								
Parkwood fine sandy loam, Florida	NPK	26	5.13	.22	.31	.74	.32	5x
Bridgehampton very fine sandy loam, Rhode Island	NP	2	2.54			.36		19x
	NPK	4	3.57			.50		
	NPKMn	6		.12	.17			
Summary:								
Maximum			5.88	.48	.59	.84	.45	
Minimum			1.88	.08	.13	.29	.14	
Mean			4.80(57)	.24(58)	.30(48)	.55(62)	.32(2)	

TABLE 20.—*The principal chemical elements in some important crops*—Continued

Plant or plant part, soil type, and location	Fertilizer used	Analyses	K	Ca	Mg	P	S	Reference No.
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
Turnip, roots:								
Cecil series, Alabama		1		0.16		.06		
Decatur series, Alabama		1		.28		.08		13x
Norfolk series, Alabama		3		.23		.07		
Alton stony loam, Rhode Island	NK	2				.32		
	NPK	2				.34		
Gloucester stony loam, Rhode Island	M	2				.41		
	NK	3				.42		
	NPKL	3				.31		
Miami stony loam, Rhode Island	None	1				.22		
	NK	10				.28		248
	NP	3				.35		
	PK	3				.36		
	NPK	8				.36		
	NKL	3				.33		
	NPKL	6				.39		
	M	3				.49		
Bridgehampton very fine sandy loam, Rhode Island	NKL	8				.26		19x
Summary:								
Maximum			4.70	1.04	0.42	.79	0.78	
Minimum			1.07	.11	.11	.06	.12	
Mean			2.77(97)	.51(87)	.24(48)	.36(238)	.43(5)	
Standard deviation			±.75	±.22		±.15		
Mode			2.60–3.00	.60–.64		.20–.24		
Turnip-tops, edible:								
Bridgehampton very fine sandy loam, Rhode Island	NKL	7				.22		19x
Summary:								
Maximum			4.84	4.75	.95	.82	.36	
Minimum			1.27	1.49	.63	.14	.19	
Mean			3.00(11)	3.28(14)	.80(4)	.39(22)	.27(2)	
Turnip, whole plant:								
Grown in France		1				.848	1.494	66
Grown in Pennsylvania		8		3.00		.369		7x
Vetch, above-ground portions, cut before bloom; variety unknown; grown in Africa.		1	4.34	.69		.32		291
Vetch, above-ground portion, full bloom; variety unknown; summary.		3	2.51	1.48	.43	.33	.28	
Vetch, above-ground portion, cut when pods were forming; grown in Germany.		1	1.70	1.51	.78	.62	.36	368
Vetch, above-ground portion, seeds beginning to ripen; variety unknown; grown in Germany.		1	1.48	1.40	.44	.31	.30	368
Vetch, purple (*Vicia atropurpurea*), above-ground portion, cut for hay; grown in South Carolina.		1		.53	.18	.38		414

Vetch, common (*Vicia sativa* L.) above-ground portion, cut for hay; grown in Massachusetts; summary.		2	2.49	1.33		.36		
Vetch, hairy (*Vicia villosa* Roth) above-ground portion, cut for hay; summary:								
Maximum			3.23	2.05	.27	.68		
Minimum			1.38	.92	.22	.17		
Mean			2.23(8)	1.28(28)	.25(8)	.36(36)		
Vetch, above-ground portion, cut for hay; variety unknown; summary:								
Maximum			2.99	3.39	.35	.86	.20	
Minimum			.81	.58	.07	.14	.05	
Mean			1.67(28)	1.14(36)	.20(28)	.29(32)	.10(23)	
Vetch, straw, cut when seeds were beginning to ripen; grown in Germany.		1	1.44	1.54	.25	.17	.14	368
Vetch, seed; grown in Germany; summary		3	1.11	.12	.15	.53	.14	
Wheat, grain:								
Tilsit silt loam, Kentucky	None	1	.54	.068	.13	.34	.19	14x
	M	1	.52	.049	.14	.35	.21	
	ML	1	.45	.057	.12	.32	.21	
	MLP	2	.48	.047	.16	.44	.20	
Summary:								
Maximum			.62	.122	.29	.54	.29	
Minimum			.29	.005	.09	.15	.10	
Mean			.48(264)	.050(290)	.17(267)	.40(310)	.18(138)	
Standard deviation			±.06	±.021	±.04	±.07	±.05	
Mode			.45-.48	.035-.049	.15-.16	.43-.45	.21-.24	
Wheat, straw:								
Tilsit silt loam, Kentucky	None	1	.75	.19	.11	.09	.26	14x
	M	1	.98	.14	.08	.06	.27	
	ML	1	1.29	.18	.09	.06	.26	
	MLP	2	.94	.18	.13	.07	.28	
Summary:								
Maximum			1.54	.43	.22	.17	.30	
Minimum			.26	.08	.03	.03	.07	
Mean			.85(109)	.23(115)	.10(97)	.08(115)	.17(48)	
Standard deviation			±.24	±.07	±.03	±.03		
Mode			.85-.92	.24-.26	.07-.09	.08-.09		
Wheat, above-ground portion, in flower; grown in France		17					.20	399
Wheat, above-ground portion, grown in France		17					.22	399
Wheat, above-ground portion, milk stage; grown in Washington		10	.21	.11		.15		533, 21x

TABLE 21.—*The minor-element content of some important crops* [1]

[Moisture-free basis]

ARSENIC [2]

Plant or part of plant	Location	Reference No.[2]	Arsenic	Remarks
			Mg./kg.	
Alfalfa, above-ground portion, cut for hay	France	300	0.5	
Alfalfa, above-ground portion	Virginia	594	14.	Hagerstown silt loam. Sample taken under trees sprayed with arsenic. Soil contained 60 p. p. m. of arsenic in first 3 inches.
Almond, edible portion	France	298	.3	
Apple, edible portion	Switzerland	178	.19	
Do	do	178	.07	
Apple, fruit	France	298	.36	
Asparagus, edible portion	do	298	.75	
Banana, edible portion	do	298	.33	
Barley, grain	do	298	.55	
Do	Kansas	594	.1	Soil contained 8 p. p. m. of arsenic.
Beans, garden; edible pods and seeds	Virginia	594	.4	Chester clay loam. Contained 6 p. p. m. of arsenic.
Do	France	298	.20	Two samples.
Beets, leaves	do	300	.61	
Beets, roots	Virginia	594	1.3	Chester clay loam.
Beets, tops	do	594	.2	Do.
Do	New York	594	10.	Soil contained 140 p. p. m. of arsenic. Contaminated by spray.
Cabbage, edible portion	France	298	1.3	
Carrots, roots	do	298	.40	
Do	Virginia	594	.8	Chester clay loam.
Cauliflower, head	France	298	.86	
Celery, entire plant except flower	do	298	2.32	
Celery, stalks	Virginia	594	0.6	Chester clay loam.
Chestnuts, edible portion	France	300	.11	
Clover, red, above-ground portion	do	300	.37	*Trifolium pratense.*
Clover, leaves	Virginia	594	12.	Hagerstown silt loam. Sample collected under trees sprayed with arsenic preparation.
Corn, grain	France	300	.36	
Do	Switzerland	178	.03	
Corn, sweet, edible portion	Virginia	594	.4	Chester clay loam.
Cress, water, edible portion	France	298	2.10	
Endive, above-ground portion	Switzerland	178	.21	
Hazelnuts, edible portion	France	298	.11	
Lettuce, edible portion	do	298	3.87	
Do	Switzerland	178	.43	

Mandarin, edible portion	France	298	.85	
Mushroom, edible portion	do	298	.45	
Oats, above-ground portion, maturity unknown	do	298	.62	
Onions, bulb	Switzerland	178	0.116	
Orange, edible portion	Spain	298	.99	
Parsley, leaves	Virginia	594	.1	Chester clayloam.
Parsnips, roots	do	594	.2	Do.
Peach, edible portion	Switzerland	178	.14	
Peanut, edible portion	do	178	.10	
Do	Virginia	594	.3	Chester clay loam.
Pears, edible portion	Spain	298	.51	
Peas, green, seed	France	298	.15	
Peas, yellow, edible portion	Switzerland	178	.16	
Peas, above-ground portion	France	298	.30	
Peas, pod only	do	298	.52	
Potatoes, tops	do	300	.31	
Potatoes, tubers	Switzerland	178	0.034	
Do	Virginia	594	.2	Chester clay loam.
Pumpkin, fruit	France	298	1.95	
Radish, roots	do	298	1.80	
Rutabaga, roots	Virginia	594	.8	Chester clay loam.
Salsify, roots	France	298	.25	
Spinach, edible portion	do	298	.77	
Do	Switzerland	178	.17	
Turnip, leaves	France	298	1.54	
Turnip, tops	Virginia	594	1.0	Chester clay loam.
Turnip, roots	do	594	.7	Do.
Do	France	298	.83	
Tomato, fruit	Virginia	594	1.0	Chester clay loam.
Vetch, above-ground portion	France	300	.54	
Wheat, grain	Switzerland	178	.15	
Do	Kansas	594	.3	Hayes silt loam. Contained 7 p. p. m. of arsenic 3 samples.

[1] Footnotes 1, 2, and 3 to table 20 (page 93) apply to this table also.

[2] The arsenic data of Jones and Hatch (*307*) have not been included in this compilation. Their data are calculated on the fresh basis, and the moisture content of the fruit is not given.

TABLE 21.—*The minor-element content of some important crops*—Continued

BARIUM [3]

Plant or part of plant	Location	Reference No.	Barium	Remarks
			Mg./kg.	
Alfalfa, above-ground portion, cut for hay	Kentucky	369	78	
Alfalfa, above-ground portion, mature	Missouri	495	130	
Alfalfa, above-ground portion	Virginia	496	1,300	Tatum silt loam. Contained 1,460 p. p. m. of barium.
Alfalfa, above-ground portion, before bloom	Pennsylvania	495	18	Hagerstown loam. Contained 540 p. p. m. of barium.
Alfalfa, above-ground portion, full bloom	do	495	70	Penn silt loam, Contained 470 p. p. m. of barium.
Apple, fruit	New Hampshire	495	3	Gloucester stony loam. Contained 4,750 p. p. m. of barium.
Beans, garden: above-ground portion, pods beginning to form	North Carolina	495	170	Cecil clay. Contained 350 p. p. m. of barium.
Beans, garden; edible green seeds	New Hampshire	495	3	Gloucester stony loam.
Cabbage, head	North Carolina	495	27	Cecil clay.
Carrots, roots	New Hampshire	495	27	Gloucester stony loam.
Clover, crimson; above-ground portion, full bloom	North Carolina	495	107	Cecil sandy loam. Contained 514 p. p. m. of barium
Clover, red; above-ground portion, in bloom	Pennsylvania	495	74	Penn silt loam.
Do	do	495	54	Hagerstown loam.
Clover, red, above-ground portion, mature	New Hampshire	495	54	Gloucester stony loam.
Clover, sweet. *See* sweetclover		495		
Clover, white; above-ground portion, beginning to bloom	Pennsylvania	495	13	Hagerstown loam.
Clover, white, above-ground portion, seeded	Maine	495	72	
Corn, above-ground portion; young	North Carolina	495	63	Norfolk sandy loam. Contained 36 p. p. m. of barium.
Do	South Carolina	495	18	York silt loam. Contained 2,570 p. p. m. of barium.
Corn, grain	Missouri	496	9	Decatur soil. Contained 1,790 p. p. m. of barium.
Corn, stover	Kentucky	369	82	
Cotton, plant, before bloom	North Carolina	495	36	Norfolk sandy loam.
Hemp, above-ground portion	Kentucky	369	21	
Kentucky bluegrass, above-ground portion, in seed	Pennsylvania	495	36	Penn silt loam.
Kentucky bluegrass, above-ground portion, stage of maturity unknown.	Kentucky	369	46	
Lettuce, beginning to seed	Pennsylvania	495	72	Do.
Oats, above-ground portion, milk stage	do	495	18	Do.
Onions, bulb	New Hampshire	495	18	Gloucester stony loam.
Orchard grass	Pennsylvania	495	72	Penn silt loam.
Peas, above-ground portion, in blossom	North Carolina	495	63	Cecil clay.

Potatoes, tubers	New Hampshire	495	5	Gloucester stony loam.
Soybean, seed, mature	Kentucky	369	8	
Soybean, above-ground portion, cut for hay	do	369	29	
Soybean, stems and leaves	Missouri	496	1,090	Decatur soil.
Sweetclover, above-ground portion, before bloom	Pennsylvania	495	27	Hagerstown loam.
Timothy, above-ground portion, in bloom	do	495	36	Penn silt loam.
Do	do	495	27	Hagerstown loam.
Do	New Hampshire	495	45	Gloucester stony loam.
Timothy, above-ground portion, in seed	Maine	495	18	
Tobacco, above-ground portion, before bloom	North Carolina	495	160	Durham sandy loam. Contained 1,002 p. p. m. of barium.
Tobacco, dark, air-cured type; leaves	Kentucky	369	293	5 samples; range 56 to 435.
Tobacco, burley, leaves	do	369	88	2 samples.
Tobacco, burley, stalks	do	369	193	4 samples; range 53 to 400.
Tobacco, dark, air-cured type; stalks	do	369	273	4 samples; range 224 to 400.
Wheat, above-ground portion, mature	North Carolina	495	18	Durham sandy loam.
Do	Pennsylvania	495	18	Penn silt loam.
Wheat, grain	Missouri	496	8	Decatur soil.
Wheat, leaves	do	496	130	Do.
Wheat, stems	do	496	180	Do.

[3] The barium content of locoweed and other weeds and grasses has been reported (*41, 396*). Barium in Brazil nuts (*517, 578*) and in tobacco and other plants (*16*) has been determined, but the moisture content of the materials was not reported.

TABLE 21.—*The minor-element content of some important crops*—Continued

BORON [4]

Plant or part of plant	Location	Reference No.	Analyses	Boron			Remarks
				Maximum	Minimum	Mean	
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Alfalfa, above-ground portion, cut for hay	France	66	2	29	25	27	
Alfalfa, leaves	Washington and Canada	387	11	32	4	15	
Almond, edible portion	California	157	1			26	
Apples, edible portion	Nova Scotia	303	3	13	12	13	
Apple, fruit, immature	New Zealand	21	26	44	4	15	
Apple, fruit, mature			128	76	3	19	Summary (20, 21, 29, 467).
Apple, parings	Nova Scotia	303	3	15	15	15	
Apricot, fruit	California	157	2	52	51	51	
Barley, grain	France	66	1			2	
Beans, garden; edible pods and seeds			7	37	2	17	Summary (120, 553).
Cabbage, edible portion	France	66	1			37	
Carrots, whole plant	do	66	1			25	
Celery, entire plant except flower	do	66	3	15	.05	9	
Cherries, edible portion	California	157	1			42	
Clover, crimson; above-ground portion	France	68	1			70	*Trifolium pratense.*
Clover, red; above-ground portion	do	66	1			36	Do.
Clover, red; flower	Russia	78	1			40	Do.
Clover, red; leaves	do	78	1			57	Do.
Clover, red; stems	do	78	1			28	*T. incarnatum.*
Coffee, bean	Trinidad	156	1			17	
Cowpeas, above-ground portion	Florida	120	3	283	42	190	
Cranberries, edible portion	California	157	2	96	68	82	
Currants, edible portion	do	157	5	58	19	37	
Dandelion, whole plant	France	68	1			80	
Dates, edible portion	California	157	1			14	
Figs	do	157	1			80	
Gooseberries, edible portion	do	157	1			49	
Lupine, leaves	Russia	78	1			9	
Lupine, stems	do	78	1			6	
Lupine, entire flower	do	78	1			39	
Mustard, greens	France	68	2	53	22	38	
Orange, edible portion	California	515	4	38	10	20	
Peach, fruit	do	157	2	52	49	51	

Pear, fruit	do	157	1			19	
Peas, green; edible portion	Netherlands	357	8	7	2	3	
Peas, above-ground portion			2	22	18	20	Summary (68, 553).
Potatoes, tubers	Virginia	120	5	16	2	7	
Potatoes, tops	France	66	2	15	14	14	
Prunes, fruit	California	157	3	7	7	7	
Radish, roots	Florida	120	3	152	17	79	
Rutabaga, roots	New Zealand	488	4	11	7	9	
Rye, above-ground portion, maturity unknown			2	3	.3		Summary (66, 68).
Soybean, seeds, mature	Virginia	120	5	29	6	19	
Soybean, above-ground portion	do	120	5	13	1	8	
Spinach, edible portion	France	68	1			10	
Tobacco, leaves	Russia	78	1			51	
Tobacco, above-ground portion	France	66	1			25	
Tomato, fruit	Netherlands	157	1			191	
Turnip, roots	New Zealand	488	7	8	6	7	
Turnip, whole plant	France	68	1			49	
Wheat, above-ground portion	do	66	1			3	

[4] The analyses of Askew and Thomson (*28*) and of de Long (*147*) showing the relation of the boron content of apples to internal cork have been omitted because they are given on the fresh basis without a statement as to the moisture content.

TABLE 21.—*The minor-element content of some important crops*—Continued

BROMINE [5]

Plant or part of plant	Location	Reference No.	Bromine	Remarks
			Mg./kg.	
Alfalfa, above-ground portion, cut for hay	France	130	6.4	
Do	do	130	1.9	
Artichoke, flower head	do	131	9.8	
Artichoke, Jerusalem. *See* Jerusalem-artichoke				
Artichoke, Japanese; tuber	France	131	6.1	
Apricot, edible portion	do	131	2.8	
Asparagus, edible portion	do	131	20.2	
Banana, edible portion	do	131	5.4	
Barley, grain	do	130	5.5	
Beans, garden; edible pods and seeds	do	130	6.4	
Beets, roots	do	131	5.5	
Do	do	131	3.7	
Cabbage, edible portion	do	131	4.5	
Cantaloup, edible portion	do	131	94.5	
Carrots, roots	do	131	3.9	
Cauliflower, head	do	131	7.3	
Do	do	131	6.7	
Celery, entire plant except flower	do	131	4.7	
Do	do	131	3.8	
Cherries, edible portion	do	131	Tr.	
Corn, grain	do	130	1.7	
Currants, edible portion	do	131	1.7	
Do	do	131	.9	
Figs	do	131	1.8	
Garlic, bulb	do	131	4.4	
Grapes, edible portion	do	131	2.0	
Hemp, plant	do	130	2.2	
Jerusalem-artichoke, tuber	do	131	6.2	
Mandarin, edible portion	do	131	5.3	
Millet, grain	do	130	3.8	
Oats, grain	do	130	3.1	

Onion, bulb	do	131	2.2
Do	do	131	1.0
Orange, edible portion	do	131	3.2
Peach, edible portion	do	131	4.7
Do	do	131	Tr.
Peas, green; edible portion	do	130	2.1
Peas, pods only	do	130	6.3
Potatoes, tubers	do	131	14.3
Do	do	131	2.7
Radish, roots	do	131	9.2
Do	do	131	8.3
Rhubarb, stem	do	131	7.5
Rye, grain	do	130	1.9
Strawberries, edible portion	do	131	7.1
Turnip, edible portion	do	131	8.9
Do	do	131	3.1
Vetch, above-ground portion	do	130	2.1
Watermelon, edible portion	do	131	262

[5] Analyses of bromine in wheat (*286*) and in several fruits and vegetables (*159*) have been reported, but the moisture content of the samples used is not given.

TABLE 21.—*The minor-element content of some important crops*—Continued

CHLORINE [6]

Plant or part of plant	Location	Reference No.	Analyses	Chlorine: Maximum	Chlorine: Minimum	Chlorine: Mean	Remarks
			Number	*Percent*	*Percent*	*Percent*	
Alfalfa, above-ground portion, prebud stage	England	601, 602	17	0.66	0.20	0.43	
Alfalfa, above-ground portion, in bud	do	600, 601, 602	19	.56	.09	.34	
Alfalfa, above-ground portion, one-tenth to one-quarter bloom.			18	.71	.12	.35	Summary.
Alfalfa, above-ground portion, one-half bloom			3	.90	.30	.51	Do.
Alfalfa, above-ground portion, full bloom			9	.93	.25	.49	Do.
Alfalfa, above-ground portion, cut for hay			33	1.74	.01	.88	Do.
Apples, fruit	New Hampshire	495	1			.03	Gloucester stony loam.
Do			2	.06	.03	.04	Summary.
Artichoke, flower head	France	131	1			.38	
Apricot, edible portion	do	131	1			.09	
Barley, grain			29	.60	.05	.17	Summary.
Beans, field; seed			14	.10	.02	.05	Summary. *Phaseolus vulgaris.*
Beans, garden; edible pods and seeds			17	.50	.05	.09	Summary.
Beans, garden; edible hulls	Kentucky	379	1			.05	
Beans, garden; immature seed	do	379	1			.06	
Beans, lima; mature seed	do	379	1			.03	
Beets, roots			19	.71	.11	.22	Do.
Broccoli, edible portion	Maryland	140	3	.89	.78	.85	
Cabbage, edible portion	Florida	5x	1			.46	Coxville soil.
Do	do	5x	8	.60	.39	.44	Leon soil (NPK).
Do	do	5x	2			.42	Leon soil (NPKMn).
Do	do	5x	2			.42	Leon soil (NPKCu).
Do	do	5x	1			.74	Parkwood soil (NPK).
Do	North Carolina	495	1			.85	Cecil clay.
Do			52	1.50	.17	.51	Summary.
Carrots, roots			6	1.50	.23	.52	Do.
Cauliflower, head	France	131	2	.57	.57	.57	
Cauliflower, edible portion	California	140	2	.50	.47	.48	
Celery, edible portion	Florida	5x	3			2.28	Bladen soil.
Do			34	5.28	.12	1.92	Summary.
Cherries, edible portion	France	131	1			tr.	
Clover, alsike; above-ground portion			14	1.40	.15	.78	Summary. *Trifolium hybridum.*
Clover, crimson; above-ground portion	North Carolina	495	1			.37	*T. incarnatum.* Cecil sandy loam.
Do			11	1.19	.07	.63	Summary. *T. incarnatum.*
Clover, red; above-ground portion, mature, with blossoms and seeds.	New Hampshire	495	1			.30	Gloucester stony loam.
Clover, red; above-ground portion, in bloom	Pennsylvania	495	1			.20	*T. pratense.* Hagerstown loam.

Clover, red; above-ground portion	do	495	1			.20	*T. pratense.* Penn silt loam.
Do			12	1.55	.20	.79	Summary. *T. pratense.*
Clover, white; above-ground portion, some blossoms seeded	Maine	495	1			.48	*T. repens.*
Clover, white; above-ground portion			25	1.48	.26	.59	Summary. *T. repens.*
Corn, grain			16	.073	.004	.024	Summary.
Corn, stover	Ohio	192	1			.31	
Corn, sweet; edible portion			16	.17	.027	.045	Summary.
Cowpeas, above-ground portion	Ohio	192	1			.17	
Cowpeas, seeds	do	192	1			.05	
Garlic, bulb	France	131	1			.06	
Hemp, plant	do	131	1			.01	
Horsebeans, forage	Germany	368	1			.09	*Vicia faba.*
Horsebeans, seed	do	368	1			.08	Do.
Horsebeans, straw	do	368	1			.49	Do.
Jerusalem artichoke, tuber	France	131	1			.23	
Kafir, grain	Ohio	192	1			.27	
Kale, edible portion	California	140	1			1.11	Yolo silt loam.
Do	Maryland	140	2	1.20	1.15	1.17	Sassafras sandy loam.
Do	Virginia	140	2	1.02	.96	.99	Norfolk loam.
Do			6	1.20	.71	1.02	Summary.
Kale, marrow stem; above-ground portion	England	600	4	1.79	1.29	1.48	
Kale, thousand-head; above-ground portion	do	600	2	1.11	.90	1.00	
Kentucky bluegrass, above-ground portion, in seed	Pennsylvania	495	1			.44	Penn silt loam.
Kentucky bluegrass, above-ground portion, stage of maturity unknown.	Germany	368	5	.70	.44	.62	
Lettuce, head, outer leaves removed	Florida	5x	13	1.70	1.01	1.30	Leon soil (NPK).
Do	do	5x	3	1.30	1.14	1.26	Leon soil (NPKMn).
Do	do	5x	2			1.24	Leon soil (NPKCu).
Lettuce, head, outer leaves	do	5x	1			1.97	Portsmouth soil (NPK).
Lettuce, edible portion			23	2.18	1.01	1.34	Summary.
Lupine, straw only	Germany	368	3	.68	.21	.41	
Lupine, hulls only	do	368	1			.04	
Lupine, seeds	do	368	3	.12	.02	.09	
Mandarin, edible portion	France	131	1			.36	
Mangel-wurzel, roots	Ohio	193	1			1.38	
Oats, grain			38	.88	.01	.13	Summary.
Oats, straw			21	1.52	.05	.78	Do.
Oats, above-ground portion, mature	Pennsylvania	466	4	.25	.01	.10	
Oats, above-ground portion, cut for hay	Germany	314, 368	9	.82	.20	.52	
Onions, bulb			3	.18	.06	.12	Summary.
Peas, green; edible portion			2	.07	.04	.05	Do.
Peas, seed	Germany	259	3	.20	.03	.09	
Peas, above-ground portion, after bloom	do	259	3	.43	.14	.28	
Peas, pod only	France	130	1			.15	
Peas, field; straw	Germany	259	3	.43	.10	.22	
Potatoes, tubers	Colorado	257	5	.20	.09	.13	Fort Collins loam. No fertilization.
Do	do	257	5	.20	.09	.12	Fort Collins loam (N).
Do	Florida	5x	6	.58	.27	.44	Bladen soil (NPK).
Do	do	5x	1			.58	Bladen soil (NPKMn).
Do	do	5x	1			.52	Bladen soil (NPKCu).
Do	do	5x	4	.35	.18	.23	Coxville soil (NPK).

[6] The summaries were calculated from data compiled from a number of sources.

TABLE 21.—*The minor-element content of some important crops*—Continued

CHLORINE—Continued

Plant or part of plant	Location	Reference No.	Analyses	Chlorine Maximum	Chlorine Minimum	Chlorine Mean	Remarks
			Number	*Percent*	*Percent*	*Percent*	
Potatoes, tubers	Florida	5x	3			0.22	Coxville soil (NPKMn).
Do	do	5x	2			.18	Coxville soil (NPKCu).
Do	do	5x	1			.21	Coxville soil (NPKMnCu).
Do	do	5x	4	0.43	0.20	.26	Leon soil (NPK).
Do	do	5x	1			.39	Norfolk soil (NPK).
Do	New Hampshire	5x	1			.57	Gloucester stony loam.
Do			496	.81	.03	.29	Summary.
Potatoes, tops	Germany	137, 368	16	3.36	.26	2.27	
Prunes, edible portion		192	1			.05	
Redtop, above-ground portion, cut for hay	Wyoming	128	2	.09	.08	.08	
Rye, grain			4	.03	.02	.02	Summary.
Rye, straw			25	.52	.06	.24	Do.
Soybean, leaves	France	335	1			.48	
Soybean, pods	do	335	1			.04	
Soybean, stems	do	335	1			.04	
Soybean, seed, mature	Ohio	192	2	.04	.03	.03	
Spinach, edible portion	Maryland	140	2	.93	.66	.79	Sassafras sandy loam.
Do	Virginia	140	2	.58	.52	.55	Norfolk loam.
Do			6	1.94	.52	.97	Summary.
Strawberries, edible portion	France	131	1			.14	
Sugar beets, roots			8	.92	.06	.46	Summary.
Sugar beets, young leaves	Colorado	606	5	4.68	1.47	2.86	
Sugar beets, leaves, mature	Germany	584	14	.33	.08	.21	
Sugarcane, leaves	Africa	81	1			.21	
Sugarcane, canes			14	.57	.01	.29	Summary.
Sunflower, heads minus seeds and husks	District of Columbia	592	1			1.81	
Sunflower, seed husk	do	592	1			.04	
Sunflower, seed kernel without husk	do	592	1			.01	
Sunflower, leaves	do	592	1			.36	
Sunflower, stalks	do	592	1			.73	
Sunflower, above-ground portion, cut before bloom	Germany	368	1			.72	
Sunflower, above-ground portion, full bloom	do	368	1			.73	
Sunflower, above-ground portion, cut for forage	do	368	3	.05	.04	.05	
Sunflower, leaves and stems	do	368	3	.33	.22	.26	
Sunflower, seeds with husks	District of Columbia	592	1			.02	
Sweetclover, above-ground portion	Pennsylvania	495	1			.37	*Melilotus alba.*
Sweetpotatoes, tuber	Ohio	192	1			.06	

Timothy, above-ground portion, in bloom	New Hampshire	495	1			.50	Gloucester stony loam.
Do	Pennsylvania	495	1			.54	Hagerstown loam.
Do	do	495	1			.71	Penn silt loam.
Timothy, above-ground portion, in seed	Maine	495	1			.59	
Timothy, above-ground portion, cut for hay			9	1.09	.12	.62	Summary.
Tobacco, Burley; leaves			55	.61	.02	.10	Do.
Tobacco, cigar-binder type; leaves			34	1.63	.01	.25	Do.
Tobacco, cigar-filler type; leaves			24	2.29	.10	.60	Do.
Tobacco, cigar-wrapper type; leaves			17	.76	.18	.46	Do.
Tobacco, dark air-cured type; leaves	Kentucky		60	6.51	.05	.85	
Tobacco, dark fired type; leaves			3	1.92	.10	1.26	Summary.
Tobacco, flue-cured type; leaves			67	3.17	.09	.60	Do.
Tobacco, leaves, type unknown	Maryland	110	1			.62	Collington sandy loam.
Do			74	2.13	.04	.74	Summary.
Tobacco, dark lugs	Kentucky	520	19	.62	.04	.22	
Tobacco, dark trash	do	520	18	.95	.04	.25	
Tomato, fruit	Florida	5x	26	.57	.39	.48	Parkwood fine sandy loam (NPK).
Do			35	1.99	.39	.61	Summary.
Turnip, roots			4	1.25	.44	.67	Do.
Turnip, leaves			2	2.98	.89	1.93	Do.
Vetch, above-ground portion, in bloom		368	1			1.85	Do.
Vetch, above-ground portion, seeds beginning to ripen	Germany	368	1			1.47	
Vetch, above-ground portion, maturity unknown	France	130	1			.05	
Vetch, above-ground portion, pods beginning to form	Germany	368	1			1.99	
Vetch, seeds	do	368	3	.12	.07	.09	
Vetch, straw, seeds ripening	do	368	1			.57	
Walnuts, edible portion	California	235	1			.01	
Watermelon, edible portion	France	131	1			1.04	
Wheat, grain			80	.19	.02	.09	Summary.
Wheat, straw			26	.63	.04	.33	Do.

Table 21.—*The minor-element content of some important crops*—Continued

COBALT

Plant or part of plant	Location	Reference No.	Cobalt	Remarks
			Mg./kg.	
Apricot, edible portion	France	61	0.032	
Beans, field; seed	do	61	.011	*Phaseolus vulgaris.*
Buckwheat, grain	do	61	.36	
Cabbage, edible portion	do	60	.07	
Carrots, roots	do	61	.02	
Carrots, leaves	do	61	.31	
Cherries, edible portion	do	61	.005	
Clover, white, above ground-portion	New Zealand	23	4.6	*Trifolium repens.*
Do	do	23	.28	Do.
Coffee, bean	France	61	.002	
Corn, grain	do	61	.011	
Cress, water	do	61	.15	
Figs	do	61	.20	
Oats, grain	do	61	Tr.	
Onions, bulb	do	61	.13	
Pear, pulp	do	61	.18	
Peas, green; edible portion	do	61	.03	
Potatoes, tubers	do	61	.06	
Rice, polished	do	61	.006	
Spinach, edible portion	do	61	.074	
Tomato, fruit	do	61	.096	
Walnuts, edible portion	do	61	.05	
Wheat, grain	do	61	.012	

TABLE 21.—*The minor-element content of some important crops*—Continued

COPPER [7]

Plant or part of plant	Location	Reference No.	Analyses	Copper Maximum	Copper Minimum	Copper Mean	Remarks
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Alfalfa, above-ground portion, cut for hay			8	15	4	9	Summary (166, 373, 14x).
Almond, edible portion			2	13	11	12	Summary (232, 355).
Apples, fruit, mature			3	7	5	6	Summary (232, 355).
Artichoke, flower head	Wisconsin	355	1			20	
Asparagus, edible portion			3	17	7	11	Summary (185, 347, 355).
Banana, edible portion			3	9	8	9	Summary (163, 232, 355).
Barley, grain			12	41	6	16	Summary (166, 220, 232).
Beans, field; seed			12	16	7	11	*Phaseolus vulgaris.* Summary (355, 379, 503).
Beans, garden; edible pod and seeds	Florida	5x	4	20	10	16	St. Lucie soil.
Do			24	20	6	13	Summary (232, 343, 482, 5x).
Beans, garden; edible hulls	Kentucky	379	1			12	
Beans, garden; immature seed	do	379	1			10	
Beans, horse; seed	France	232, 392	2	11	10	10	*Vicia faba.*
Beans, lima; mature seed			3	10	8	9	Summary (355, 379, 503).
Beets, root			15	27	6	10	Summary (129, 232, 355, 482, 8x)
Beets, leaves		355	4	18	9.	12	Summary (355, 482).
Blackberries, fruit	Wisconsin	355	1			10	
Blueberries, fruit	do	355	1			6	
Brazil nut, edible portion		355	1			15	
Broccoli, edible portion			3	37	2	24	Summary (140, 347).
Brussels sprouts, edible portion	Wisconsin	355	1			8	
Butternut, edible portion	do	355	1			12	
Cabbage, edible portion	Florida	5x	1			15	Coxville soil (NPK).
Do	do	5x	8	28	19	22	Leon soil (NPK).
Do	do	5x	2			13	Leon soil (NPKMn).
Do	do	5x	2			26	Leon soil (NPKCu)
Do	do	5x	1			10	Parkwood soil (NPK).
Do			26	28	4	14	Summary (185,355,482,5x)
Cabbage, outer green leaf	England	129	2	5	5	5	
Cabbage, inner green leaf	do	129	2	6	4	5	
Cabbage, center vein of outer leaves	do	129	1			3	
Cabbage, center vein of inner leaves	do	129	2	3	2	2	
Cabbage, center stalk of plant	do	129	1			3	
Cabbage, outermost leaves, mesophyll	Japan	502	5	5	5	5	*Brassica pekinensis* (*B. pe-tsai*).
Cabbage, outermost leaves, veins	do	502	5	4	3	4	Do.
Cabbage, leaves, second layer, mesophyll	do	502	5	4	3	3	Do.
Cabbage, leaves, second layer, veins	do	502	5	3	1	2	Do.
Cabbage, leaves, third layer, mesophyll	do	502	5	4	4	4	Do.

[7] The analyses of Mader and Mader (*390*) of the copper content of potatoes and those of Grendel (*227*) and of van Leeuwen (*342*) were omitted because the moisture content of the material was not given. The data of Vedrode (*573*) have been omitted because of the very high values reported. The work was done in 1896.

TABLE 21.—*The minor-element content of some important crops*—Continued

COPPER

Plant or part of plant	Location	Reference No.	Analyses	Copper			Remarks
				Maximum	Minimum	Mean	
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Cabbage, leaves, third layer, veins	Japan	502	5	3	3	3	*Brassica pekinensis* (*B. pe-tsai.*)
Cabbage, leaves, fourth layer, mesophyll	do	502	5	4	3	4	Do.
Cabbage, leaves, fourth layer, veins	do	502	5	3	3	3	Do.
Cabbage, center	do	502	5	5	4	5	Do.
Cantaloup, edible portion	Wisconsin	355	2	6	6	6	
Carrots, roots			15	18	7	11	Summary (232, 355, 391, 482, 8x).
Carrots, leafy part excepting lower leaves	England	129	2	11	10	10	
Carrots, stalks of leaves	do	129	1			5	
Carrots, yellow part of root	do	129	1			5	
Carrots, red part of root	do	129	1			5	
Cauliflower, edible portion			3	47	16	36	Summary (140, 355).
Celery, edible portion	Florida	5x	3			163	Bladen soil.
Do			30	560	2	238	Summary (232, 355, 5x).
Celery cabbage	Wisconsin	355	1			10	
Cherries, edible portion			2	16	12	14	Summary (232, 355).
Chestnut, edible portion			2	9	5	7	Summary (232, 355).
Citron, edible portion	Puerto Rico	179	1			7	*Citrus medica.*
Clover, alsike; above ground portion	Kentucky	14x	2	7	5	6	*Trifolium hybridum.*
Clover, red; above ground portion	do	14x	5	11	9	10	*T. pratense.* Tilsit silt loam.
Do	do		41	20	6	10	*T. pratense.* (166, 14x).
Clover, red; seeds	do	14x	1			17	*T. pratense.*
Clover, red; foliage	do	14x	1			8	Do.
Coconut, edible portion	Wisconsin	14x	1			11	
Corn, grain			6	17	4	8	Summary (166, 185, 232, 503).
Corn, stover	Kentucky	14x	2	6	3	5	Tilsit silt loam.
Do			16	9	2	5	Summary (166, 14x).
Corn, sweet, edible portion	Wisconsin	355	2	7	6	6	
Cotton, seed	Mississippi	374	1			54	
Cowpeas, seed	Alabama	13x	1			5	Norfolk soil.
Cranberries, edible portion	Wisconsin	355	1			8	
Cress, water, edible portion			2	18	5	12	Summary (232, 355).
Cucumber, fruit	France	232	1			50	
Cucumber, edible portion			2	30	18	24	Summary (343, 355).
Currants, edible portion	Wisconsin	355	1			17	
Dandelion, edible portion	do	355	1			13	
Dates, edible portion			4	5	2	3	Summary (115, 232, 355).
Eggplant, edible portion			4	16	11	13	Summary (355, 482).
Figs		355	1			6	
Gooseberries	Wisconsin	355	1			8	
Grapefruit, edible portion		355	1			5	
Grapes, edible portion			3	10	5	8	Summary (232, 355, 503).

Hickory nuts, edible portion	Wisconsin	355	1			15	
Kafir, grain	do	166	1			8	
Kale, edible portion	California	140	1			24	Yolo silt loam.
Do	Maryland	140	2	56	31	43	Sassafras sandy loam.
Do	Virginia	140	2	39	35	37	Norfolk loam.
Do		140	6	56	24	36	Summary.
Kentucky bluegrass, above-ground portion, young blades	Kentucky	375	1			14	
Kentucky bluegrass, above ground portion, stage of maturity unknown.			3	14	7	10	Summary (166, 373, 381).
Kentucky bluegrass, seeds	Kentucky	375	1			60	
Kohlrabi, edible portion	Wisconsin	355	1			15	
Kumquat, edible portion		355	1			5	
Lemon, fruit		236, 355	3	10	3	5	
Lemon, fruit, seed-free	California	236	9	5	2	3	
Lemon, peel	do	236	2	4	3	4	
Lemon, pulp with seed	do	236	1			5	
Lettuce, head, outer leaves removed	Florida	5x	13			32	Leon soil (NPK).
Do	do	5x	3	33	26	31	Leon soil (NPKMn).
Do	do	5x	2			31	Leon soil (NPKCu).
Do	do	5x	1			18	Leon soil (NPK).
Lettuce, edible portion			45	33	3	19	Summary (343, 347, 355, 411, 482, 5x, 8x).
Lettuce, outer leaves	England	129	2	19	16	17	
Lettuce, inner leaves	do	129	2	26	25	26	
Lettuce, center stalk	do	129	1			13	
Lettuce, leaf	Wisconsin	355	1			11	
Mulberry, fruit	France	185	1			4	
Mushrooms, edible portion	Wisconsin	355	1			62	
Oats, grain			29	51	4	11	Summary (166, 220, 232, 473).
Oats, straw			26	54	3	11	Summary (166, 383, 473).
Olives, fruit	France	232	1			8	
Okra, fruit	South Carolina	482	8	13	6	9	
Onions, bulb			11	24	5	12	Summary (232, 355, 482).
Orange, edible portion	California	236, 355	12	31	1	9	
Orange, fruit			3	22	3	10	Summary (232, 236).
Parsley, edible portion	Wisconsin	355	1			17	
Parsnips, root	do	355	1			7	
Peanut, edible portion	do	355	1			10	
Pear, edible portion			2	13	6	10	Summary (232, 355).
Peas, green, edible portion			9	15	6	9	Summary (129, 185, 232, 355, 391, 392).
Peas, with pods, edible	France	391	2	12	7	10	
Peas, pods only			2	5	3	4	Summary (129, 185).
Peas, black-eyed; seeds	North Carolina	503	1			7	
Pecans, edible portion			1			14	
Peppers, green; edible portion	Wisconsin		1			16	
Pineapple, fruit			1			8	
Pistachio nut, edible portion			1			12	
Plums, edible portion	Wisconsin		1			10	
Potatoes, tubers	Florida	5x	6	26	19	22	Bladen soil (NPK).
Do	do	5x	1			18	Bladen soil (NPKMn).
Do	do	5x	1			24	Bladen soil (NPKCu).
Do	do	x	4	14	9	13	Coxville soil (NPK).

TABLE 21.—*The minor-element content of some important crops*—Continued

COPPER—Continued

Plant or part of plant	Location	Reference No.	Analyses	Copper: Maximum	Copper: Minimum	Copper: Mean	Remarks
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Potatoes, tubers	Florida	5x	3			8	Coxville soil (NPKMn).
Do	do	5x	2			19	Coxville soil (NPKCu).
Do	do	5x	1			13	Coxville soil (NPKMnCu).
Do	do	5x	4	20	7	11	Leon soil (NPK).
Do	do	5x	1			10	Norfolk soil (NPK).
Do	Wisconsin	12x	3	6	4	5	Miami silt loam.
Do			143	24	1	8	Summary (129, 232, 343, 355, 389, 391, 503, 5x, 12x).
Potatoes, tops	England	129	1			11	
Prunes, edible portion			16	9	3	4	Summary (391, 506).
Pumpkin, edible portion	Wisconsin	355	1			4	
Pumpkin, fruit	France	232	1			11	
Quince, edible portion	Wisconsin	355	1			8	
Radish, roots	do	355	1			29	
Rape, above-ground portion	Alabama	13x	1			Tr.	Norfolk soil.
Do	Wisconsin	166	1			8	
Raspberries, fruit	do	355	1			8	
Redtop, above-ground portion, cut for hay	Kentucky	14x	1			5	Dekalb silt loam; no fertilization.
Do	do	14x	1			4	Dekalb silt loam (M).
Do	do	14x	1			4	Dekalb silt loam (ML).
Do	do	14x	1			4	Dekalb silt loam (PL).
Do	do	14x	1			3	Tilsit silt loam; no fertilization.
Do	do	14x	1			4	Tilsit silt loam (NP).
Do	do	14x	1			3	Tilsit silt loam (NPL).
Do	do	14x	13	5	3	4	
Rhubarb, edible portion	Wisconsin	355	1			9	
Rice, brown			2	4	3	3	Summary (355, 380).
Rice, polished			3	6	2	4	Summary (232, 355, 380).
Rutabaga, roots	Wisconsin	355	1			8	
Rye, grain			2	7	6	7	Summary (166, 232).
Rye, straw	Wisconsin	166	1			4	
Salsify, edible portion	do	355	1			11	
Soybean, leaves	Kentucky	372	1			8	
Soybean, seeds, mature	do	372	1			12	
Soybean, seeds, green	Wisconsin	166	1			23	
Soybean, above-ground portion, cut for hay	Kentucky	14x	1			9	Dekalb silt loam; no fertilization.
Do	do	14x	1			9	Dekalb silt loam (ML).
Do	do	14x	2	10	9	9	Dekalb silt loam (MP).
Do	do	14x	2	10	9	9	Dekalb silt loam (MPL).
Do	do	14x	2	10	9	9	Dekalb silt loam (MPKL).
Do	do	14x	1			8	Tilsit silt loam; no fertilization.

Do	do	14x	1			8	Tilsit silt loam (M).
Do	do	14x	2	12	11	11	Tilsit silt loam (MP).
Do	do	14x	3	11	7	9	Tilsit silt loam (MPK).
Do	do	14x	1			8	Tilsit silt loam (ML).
Do	do	14x	2	11	10	10	Tilsit silt loam (MPL).
Do	do	14x	2	7	6	6	Tilsit silt loam (MPKL).
Do			32	12	4	9	Summary (166, 14x).
Spinach, edible portion	Maryland	140	2	45	43	44	Sassafras sandy loam.
Do	Virginia	140	2	73	66	69	Norfolk loam.
Do			40	73	3	15	Summary (140, 232, 347, 355, 392 411, 482, 8x).
Do			34	24	3	9	Summary eliminating results of Davidson and LeClerc (140). (232, 347, 355, 392, 411, 482, 8x.)
Squash, edible portion	South Carolina	482	6	15	11	13	
Strawberries, edible portion			2	8	2	5	Summary (185, 355).
Sugar beets, roots	Wisconsin	166	1			8	
Sugar beets, leaves	do	166	1			6	
Sweetclover, above-ground portion			2	12	9	10	*Melilotus alba.* Summary (166, 14x).
Sweetpotatoes, tubers			11	9	3	4	Summary (482, 503).
Swiss chard, edible portion	Wisconsin	355	1			13	
Tangerine, edible portion	do	355	1			6	
Timothy, above-ground portion, cut for hay	Kentucky	14x	4	7	4	5	Tilsit silt loam.
Do			14	7	2	5	Summary (166, 14x).
Tobacco, leaves	Wisconsin	166	1			17	
Tomato, fruit	Florida	5x	26	19	5	11	Parkwood sandy loam (NPK).
Do			51	34	8	14	Summary (166, 232, 355, 378, 482, 5x).
Tomato, juice and pulp	Italy	349	7	9	5	7	
Tomato, seeds	do	349	7	12	9	10	
Tomato, skins	do	349	7	12	8	9	
Turnip, roots			8	18	4	9	Summary (129, 232, 355, 482).
Turnip, leaves			7	12	6	8	Summary (129, 347, 482).
Vetch, above-ground portion, cut for hay	Wisconsin	166	1			10	
Watermelon, edible portion	do	355	1			9	
Wheat, grain	Kentucky	14x	1			8	Tilsit silt loam; no fertilization.
Do	do	14x	1			6	Tilsit silt loam (M).
Do	do	14x	1			6	Tilsit silt loam (ML).
Do	do	14x	1	5	5	5	Tilsit silt loam (MPL).
Do			108	24	4	9	Summary (220, 232, 381, 391, 543, 581, 1x, 14x).
Wheat, straw	Kentucky	14x	1			3	Tilsit silt loam; no fertilization.
Do	do	14x	1			4	Tilsit silt loam (M).
Do	do	14x	1			3	Tilsit silt loam (ML).
Do	do	14x	2	3	2	2	Tilsit silt loam (PML).
Do			24	5	1	3	Summary (166, 185, 381, 14x).

TABLE 21.—*The minor-element content of some important crops*—Continued

FLUORINE [8]

Plant or part of plant	Reference No.	Location	Fluorine	Plant of part of plant	Reference No.	Location	Fluorine
			Mg./kg.				*Mg./kg.*
Alfalfa, above-ground portion	203	France	56.5	Lentil	203	France	18.0
Apple, pulp	203	do	2.1	Lettuce	404	Austria	1.2
Apple, skin	203	do	27.8	Mustard, black; seeds	203	France	15.8
Apricot, edible portion	203	do	25.0	Mustard, black; leaves	203	do	68.0
Asparagus, young shoot	203	do	79.4	Onions, bulb	404	Austria	3.0
Banana, edible portion	203	do	3.8	Peach, pulp	203	France	39.3
Beans, garden; edible pods and seeds	404	Austria	.6	Pear, pulp	203	do	1.7
Beets, leaves	203	France	134	Potatoes, tuber	203	do	3.0
Buckwheat	203	do	25.3	Radish, root	203	do	20.0
Cabbage, head	203	do	10.8	Rice, polished	203	do	9.4
Carrots, root	203	do	3.4	Spinach, leaves	203	do	30.0
Cauliflower, edible portion	203	do	25.7	Do	404	Austria	1.7
Cherries, pulp and skin	203	do	37.0	Do	404	do	1.3
Cress	203	do	12.0	Strawberries	203	France	14.0
Figs	203	do	19.8	Tomato, fruit	203	do	40.6
Grapes, edible portion	203	do	8.1	Tomato, edible portion	404	Austria	None
Kidney beans, mature seed	203	do	21.0	Turnip	203	France	20.2
Kidney beans, green seed	203	do	2.1	Walnuts, edible portion	203	do	7.8

[8] The fluorine analyses quoted by Steinkoenig (*539*) are those of Gautier and Clausman (*203*) compiled in this table.

IODINE [9]

Plant or part of plant	Location	Reference No.	Analyses	Iodine (parts per billion)			Remarks
				Maximum	Minimum	Mean	
			Number				
Alfalfa, above-ground portion, cut for hay			4	385	69	157	Summary (5, 414).
Apple, fruit			4	340	89	205	Summary (5, 45).
Apple, edible portion	Oregon	363	1			3	
Asparagus, edible portion			7	3, 780	12	1, 168	Summary (153, 258, 365, 481).
Barley, grain			5	124	73	102	Summary (45, 363).
Barley, straw	Germany	45	4	740	286	550	
Beans, field; seed	South Africa	77	13	83	21	57	*Phaseolus vulgaris.*
Beans, garden; edible pods and seeds			32	1, 560	29	579	Summary (5, 45, 258, 363, 385, 404, 587, 7x).
Beets, roots			18	416	8	241	Summary (45, 258, 264, 481, 587).
Beets, leaves			8	1, 435	248	984	Summary (45, 258).
Cabbage, edible portion			85	791	16	218	Summary (5, 45, 258, 364, 445, 481, 587, 604).
Carrots, roots			35	2, 400	2	309	Summary (5, 45, 258, 264, 363, 365, 445, 481, 587, 604).
Celery, edible portion			2	623	14	318	Summary (365, 587).
Cherries, edible portion	Oregon	363	1			33	
Citron, edible portion	Puerto Rico	179	1			26	*Citrus medica* L.
Clover, alsike; above-ground portion	South Carolina	414	1			181	*Trifolium hybridum.*
Clover, red; above-ground portion			23			121	Summary (381, 414). *T. pratense.*
Clover, white, above-ground portion	New Zealand	525	1			5, 590	*T. repens.*
Collards, edible portion	Georgia	274	9	191	34	74	
Corn, grain [10]			21	650	63	177	Summary (377, 548).
Corn, sweet, milk stage	Pennsylvania	7x	10	210	100	130	Hagerstown soil.
Corn, sweet, edible portion			21	250	52	127	Summary (7x, 363, 385).
Cowpeas, above-ground portion	South Carolina	414	7	560	37	167	
Cranberries, edible portion	Massachusetts	416, 417	1			259	
Cress, water, edible portion	England	445	1			626	
Cucumber, edible portion			8	940	44	226	Summary (404, 587, 604).
Figs, edible portion		177	1			69	
Hazelnuts, edible portion	Switzerland	177	1			15	
Lettuce, edible portion			41	6, 740	71	1, 137	Summary (5, 153, 258, 282; 404, 445).
Loganberries	Oregon	363	1			160	
Millet, grain			9	36	.2	10	Summary (3, 4, 548).
Mustard, greens	Oklahoma	258	2	952	169	560	
Oats, grain			13	175	10	57	Summary (45, 363, 604).
Oats, straw	Germany	45	4	764	335	524	
Okra, fruit			3	1, 075	412	697	Summary (258, 365).
Onion, bulb			23	479	46	188	Summary (45, 404, 445).
Parsnips, root	New Zealand	264	2	180	100	140	

[9] Data from the following references have been omitted because the moisture content of the material is not given: 76, 118, 175, 177.
[10] McHargue (*377*) reported 250,000 p. p. b. of iodine in a sample of corn raised in Kentucky, while Adolph (*5*) reported that he found none in a sample raised in Nebraska.

TABLE 21.—*The minor-element content of some important crops*—Continued

IODINE—Continued

Plant or part of plant	Location	Reference No.	Analyses	Iodine (parts per billion)			Remarks
				Maximum	Minimum	Mean	
			Number				
Peach, edible portion			2	192	11	101	Summary (363, 365).
Pear, edible portion			2	15	15	15	Summary (5, 363).
Peas, green, edible portion	California	365	1			9	
Peas, seed	Germany	45	3	120	72	97	
Peas, field, above-ground portion, cut for hay	South Carolina	414	2	1,317	595	956	
Pineapple, fruit	Hawaii	587	1			1,070	
Potatoes, tubers	Pennsylvania	7x	10	446	162	238	Hagerstown soil.
Do			360	446	7	97	Summary (5, 45, 77, 198, 258, 364, 365, 385, 445, 481, 587, 604, 7x, 14x).
Prunes, fruit	Oregon	367	1			5	
Radish, roots	Oklahoma	265	1			994	
Redtop, above-ground portion, cut for hay	Kentucky	386	14			89	
Rice, polished	Manchuria	559	1			40	
Rutabaga, roots	New Zealand	271	4	850	460	615	
Rye, grain			5	133	3	83	Summary (45, 363).
Rye, straw	Germany	46	4	770	292	490	
Soybeans, above-ground portion, cut for hay	South Carolina	423	35	456	50	237	
Spinach			91	48,650	19	9,382	Summary (5, 45, 258, 274, 404, 481, 509, 510, 525, 587, 604).
Do	Germany	45, 509, 510	24	48,650	15,600	26,417	Iodine fertilization.
Sugar beets, roots	do	509, 510, 542, 604	36	423	2	87	
Sugar beets, leaves	do	510, 542, 604	25	2,010	110	425	
Sweetpotatoes, roots			4	115	70	92	Summary (258, 365, 481, 587).
Swiss chard, edible portion	Oklahoma	265	1			515	
Timothy, above-ground portion, cut for hay	Kentucky	386	13			71	
Tomato, fruit			22	660	20	233	Summary (45, 258, 365, 385, 404, 587, **7x**).
Turnip, roots			4	870	223	484	Summary (258, 264).
Turnip, leaves			22	676	111	255	Summary (258, 274).
Turnip, whole plant	Pennsylvania	390	5	2,080	740	1,434	No fertilization.
Do	do	390	5	94,960	19,540	42,304	Fertilized with KI.
Vetch, purple, above-ground portion, cut for hay	South Carolina	414	1			546	
Vetch, hairy, above-ground portion, cut for hay	do	414	1			547	
Vetch, woolly-pod; above-ground portion, cut for hay.	do	414	1			549	
Vetch, monantha; above-ground portion, cut for hay.	do	414	1			328	
Vetch, above-ground portion, cut for hay	do	414	2	330	268	299	Variety unknown.
Wheat, grain			26	168	0	67	Summary (45, 265, 363).
Wheat, straw			5	772	67	455	Summary (45, 381).
Yams, tuber	Hawaii	587	1			173	

IRON [11]

Plant or part of plant	Location	Reference No.	Analyses	Iron: Maximum	Iron: Minimum	Iron: Mean	Remarks
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Alfalfa, above-ground portion, prebud stage	Tennessee	580	3	350	140	247	
Alfalfa, above-ground portion, full bloom			4	1,000	161	428	Summary (58, 580).
Alfalfa, above-ground portion, cut for hay	Pennsylvania	495	1			287	Hagerstown loam.
Do	do	495	1			270	Penn silt loam.
Do	Tennessee	22x	4	343	238	269	Cumberland loam.
Do	do	22x	4	308	217	262	Fullerton silt loam.
Do			19	629	132	275	Summary (373, 495, 522, 580, 14x, 22x).
Almond, edible portion	Wisconsin	319, 455	2	42	42	42	
Apple, fruit, mature			8	38	20	29	Summary (91, 455).
Apple, edible portion			24	69	1	15	Summary (276, 393).
Artichoke, flower head			2	337	69	203	Summary (393, 455).
Apricot, fruit	Wisconsin	455	1			43	
Asparagus, edible portion			5	979	80	337	Summary (347, 393, 455, 457).
Avocado, edible portion			9	575	12	264	Summary (393, 408, 562).
Banana, edible portion			6	72	8	28	Summary (163, 319, 408, 455).
Barley, grain			23	350	14	99	Summary (222, 368, 455, 462, 528).
Beans, field; seed			16	210	79	139	Summary (368, 379, 455). *Phaseolus vulgaris.*
Beans, garden; edible pod and seed	Florida	5x	4	175	125	146	St. Lucie soil.
Do			30	769	125	231	Summary (393, 457, 482, 5x).
Beans, garden; edible hulls	Kentucky	379	1			270	
Beans, garden; immature seed	do	371, 379	6	270	80	131	
Beans, lima; mature seed			3	150	74	112	Summary (379, 455).
Beets, roots	New Hampshire	495	1			104	Gloucester stony loam.
Do			14	280	69	133	Summary (393, 455, 482, 495, 8x).
Beets, leaves			7	1,932	170	795	Summary (393, 413, 455, 457, 482).
Blackberries, fruit	Wisconsin	455	1			63	
Blueberries, fruit	do	455	1			22	
Brazil nut, edible portion	do	455	1			42	
Broccoli, edible portion			2	210	200	205	Summary (347, 393).
Brussels sprouts, edible portion			2	210	177	193	Summary (393, 455).
Buckwheat, grain	Wisconsin	455	1			34	
Buckwheat, above-ground portion, cut in bloom	France	58	1			100	
Bur clover; above-ground portion, early green	California	245	1			120	*Medicago hispida.*
Butternut, edible portion	Wisconsin	455	1			70	

[11] The analyses of Shackleton and McCance (*528*) and of Stiebeling (*552*) have been omitted because the moisture content of the materials is not given.

TABLE 21.—*The minor-element content of some important crops*—Continued

IRON—Continued

Plant or part of plant	Location	Reference No.	Analyses	Iron: Maximum	Iron: Minimum	Iron: Mean	Remarks
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Cabbage, edible portion	Alabama	13x	1			208	Decatur soil.
Do	do	13x	1			180	Hartsell soil.
Do	do	13x	4	290	81	205	Norfolk soil.
Do	Florida	5x	8	200	140	165	Leon soil (NPK).
Do	do	5x	2			147	Leon soil (NPKMn).
Do	do	5x	2			154	Leon soil (NPKCu).
Do	North Carolina	495	1			190	Cecil clay.
Do			67	305	11	95	Summary (393, 455, 456, 457, 482, 495, 5x, 13x)
Cabbage, Chinese, edible portion	Hawaii	113	2	875	202	538	*Brassica pekinensis* (*B. pe-tsai*).
Cabbage, white mustard; edible portion	do	113	2	490	451	470	*B. chinensis*.
Cabbage, Chinese mustard; edible portion	do	113	1			605	*B. juncea*.
Cantaloup, edible portion			7	210	54	168	Summary (393, 455).
Carrots, roots	Rhode Island	19x	8	350	140	192	Bridgehampton very fine sandy loam (NPK).
Do	New Hampshire	495	1			147	Gloucester stony loam.
Do			27	490	49	179	Summary (166, 393, 455, 482, 495, 8x, 19x.)
Carrots, leaves	South Carolina	482	5	765	355	517	
Cashew, mature seed, edible portion	Philippine Islands	393	1			70	
Cauliflower, edible portion			4	280	52	177	Summary (393, 455, 457).
Celery, edible portion	Florida	5x	3			192	Bladen soil.
Do			32	350	110	159	Summary (393, 455, 5x).
Celery cabbage, edible portion	Wisconsin	455	1			100	
Cherries, edible portion			3	140	28	69	Summary (393, 408, 455).
Chestnut, Italian; edible portion	Wisconsin	455	1			63	
Citron, edible portion	Puerto Rico	179	1			61	*Citrus medica*.
Clover, hop; above-ground portion, before bloom	Tennessee	22x	1			516	Maury silt loam. *Trifolium agrarium*.
Clover, hop; above-ground portion, in bloom	do	22x	2	181	133	157	Do.
Clover, hop; above-ground portion	do	22x	1			230	Do.
Clover, hop; leaves	do	22x	1			335	Do.
Clover, hop; stems	do	22x	1			105	Maury silt loam. *Trifolium agrarium*.
Clover, alsike; above-ground portion	Kentucky	14x	2	490	410	450	*T. hybridum*.
Clover, alsike; seeds	do	371	1			517	Do.
Clover, crimson; seeds	do	371	1			29	*T. incarnatum*.
Clover, low hop, above-ground portion, pre-bloom	Tennessee	580	1			517	*T. procumbens*.
Clover, low hop; above-ground portion, in bloom	do	580	1			182	Do.
Clover, low hop, above-ground portion, bloom dying.	do	580	1			133	Do.
Clover, red; above-ground portion	Kentucky	14x	5	190	130	162	Tilsit silt loam. *T. pratense*.
Do			42	1,300	100	305	Summary (524, 14x). *T. pratense*.
Clover, red; seeds	Kentucky	371, 373	2	336	21	178	*T. pratense*.

Clover, red; foliage	do	373	1			364	Do.
Clover, white; above-ground portion	New Zealand	19	18	580	120	322	*T. repens.*
Clover, white; seeds	Kentucky	371	1			20	Do.
Coconut, edible portion			2	44	35	39	Summary (393, 455).
Collards, leaves	Alabama	13x	3	328	219	287	Norfolk soil.
Do	do	13x	1			534	Vaiden soil.
Do			7	534	111	275	Summary (413, 521, 13x).
Corn, grain			4	50	25	37	Summary (393, 455, 528).
Corn, stover	Kentucky	14x	2	188	160	174	Tilsit silt loam.
Do			16	345	94	219	Summary (528, 14x).
Cotton, lint	Mississippi	374	1			190	
Cotton, seed	do	374	1			150	
Cowpeas, seed	Alabama	13x	1			81	Norfolk soil.
Do			3	662	81	399	Summary (113, 13x).
Cranberries, edible portion	Massachusetts	416, 417	1			19	
Cress, water, edible portion			3	1,399	428	929	Summary (113, 393, 455).
Cucumber, edible portion			3	420	109	270	Summary (393, 455).
Dandelion, edible portion	Wisconsin	455	1			516	
Dates, edible portion			3	70	35	49	Summary (115, 455).
Eggplant, edible portion			4	256	45	148	Summary (113, 393, 455, 588).
Endive, edible portion	Philippine Islands	393	1			700	
Figs			2	64	10	37	Summary (408, 455).
Flax, seed			2	118	85	101	Summary (368, 371).
Gooseberries	Wisconsin	455	1			47	
Grapefruit, fruit	Florida	199	2	58	36	47	
Grapefruit, edible portion			2	210	37	124	Summary (393, 455).
Grapes, edible portion			6	112	13	67	Summary (408, 455, 11x).
Hazelnuts, edible portion	Wisconsin	455	1			47	
Hemp, seeds	Kentucky	371	1			210	
Hickory nuts, edible portion	Wisconsin	455	1			24	
Horsebeans, forage	Germany	368	1			280	*Vicia faba.*
Horsebeans, seed	do	368	1			21	Do.
Horsebeans, straw	do	368	1			63	Do.
Kafir, grain	Wisconsin	528	1			39	
Kale, edible portion			2	979	399	684	Summary (113, 393).
Kale, thousand-head; above-ground portion	England	600	1			65	
Kale, narrow stem; above-ground portion	do	600	2	59	43	51	
Kentucky bluegrass, above-ground portion, young blades.	Kentucky	375	1			320	
Kentucky bluegrass, above-ground portion, in seed.	Pennsylvania	495	1			175	Penn silt loam.
Kentucky bluegrass, above-ground portion, state of maturity unknown.			4	425	60	285	Summary (373, 381, 524, 528).
Kentucky bluegrass, seeds	Kentucky	371, 375	2	460	350	405	
Kohlrabi, edible portion			3	420	61	185	Summary (393, 455, 457).
Kumquat, edible portion		455	1			34	
Lemon, peel	Wisconsin	455	1			60	
Lemon, pulp	Philippine Islands	393	1			420	
Lespedeza, above-ground portion, before bloom	Tennessee	22x	4	231	119	154	Clarksville silt loam.
Do	do	22x	13	1,028	259	407	Cumberland loam.
Do	do	22x	1			175	Decatur silt loam.
Do	do	22x	2	552	245	394	Maury silt loam.
Do	do	22x	1			140	Montevallo silt loam.

TABLE 21.—*The minor-element content of some important crops*—Continued

IRON—Continued

Plant or part of plant	Location	Reference No.	Analyses	Iron: Maximum	Iron: Minimum	Iron: Mean	Remarks
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Lespedeza, above-ground portion, early bloom	Tennessee	22x	3	196	133	159	Clarksville silt loam.
Do	do	22x	7	455	119	295	Cumberland loam.
Do	do	22x	3	266	217	240	Maury silt loam.
Lespedeza, above-ground portion, full bloom	do	22x	3	371	133	235	Clarksville silt loam.
Do	do	22x	13	685	252	355	Cumberland loam.
Do	do	22x	2	301	203	252	Dandridge silt loam.
Do	do	22x	1			224	Fullerton silt loam.
Do	do	22x	1			322	Montevallo silt loam.
Lespedeza, above-ground portion, late bloom	do	22x	6	643	112	241	Clarksville silt loam.
Do	do	22x	1			224	Maury silt loam.
Lespedeza, above-ground portion, in seed	do	22x	1			217	Clarksville silt loam.
Do	do	22x	10	979	196	347	Cumberland loam.
Lespedeza, above-ground portion, maturity unknown.	do	22x	1			259	Clarksville silt loam.
Do	do	580	3	231	126	166	Do.
Do	do	22x	28	601	161	292	Cumberland loam.
Do	do	580	17	1,329	182	445	Hartsells silt loam.
Do	do	22x	2	231	203	217	Maury silt loam.
Do	do	580	4	413	217	273	Do.
Lettuce, edible portion	Alabama	13x	1			1,500	Cecil soil.
Do	do	13x	2	780	600	691	Norfolk soil.
Do			27	4,830	65	1,034	Summary (113, 319, 347, 351, 455, 482, 8x, 13x).
Lettuce, leaf	Wisconsin	455	1			334	Bridgehampton very fine sandy loam (NPK).
Mangel-wurzel, roots	Rhode Island	19x	4	210	140	175	
Mangel-wurzel, crown	do	19x	4	699	280	455	Do.
Mangel-wurzel, leaves	do	19x	4	1,259	1,189	1,206	Do.
Millet, grain	Kentucky	371	1			52	
Millet, above-ground portion, fruiting	Philippine Islands	394	1			560	
Millet, Japanese; above-ground portion, cut for hay.	Wisconsin	528	1			59	
Milo, above-ground portion, flowering	Philippine Islands	394	1			420	
Milo, above-ground portion, fruiting	do	394	1			49	
Mulberry, fruit	do	393	1			280	
Mushrooms, edible portion	Wisconsin	455	1			109	
Mustard, greens	Alabama	13x	2	600	300	450	Norfolk soil.
Do			5	858	300	497	Summary (181, 521, 13x).
Mustard, Chinese; leaves	Philippine Islands	393	2	1,540	1,259	1,399	
Mustard, above-ground portion, cut for fodder	Germany	368	2	350	350	350	

Mustard, straw	do	368	1			70	
Oats, grain			34	350	7	79	Summary (222, 368, 371, 455, 528).
Oats, straw			8	370	61	203	Summary (382, 528).
Oats, above-ground portion, flowering stage	France	58	1			50	
Oats, above-ground portion, milk stage	Pennsylvania	495	1			154	Penn silt loam.
Okra, fruit			6	140	72	108	Summary (393, 482).
Onions, bulb			8	265	48	130	Summary (455, 457, 482).
Orange, edible portion			2	70	19	44	Summary (393, 408).
PaPaw, edible portion	Hawaii	408	1			17	*Carica papaya* L.
Do	Philippine Islands	393	3	210	70	117	Do.
Parsley, leaves			3	1, 609	304	1, 154	Summary (319, 393, 455).
Parsnip, root			4	210	46	114	Summary (393, 455, 457).
Peach, edible portion	Philippine Islands	393	1			140	
Peanut, edible portion			3	28	21	24	Summary (393, 455).
Pear, edible portion			2	140	29	84	Summary (393, 455).
Peas, green; edible portion			6	282	70	126	Summary (113, 319, 371, 455).
Pecans, edible portion		455	1			26	
Peppers, green; edible portion	Wisconsin	455	1			68	
Peppers, red; edible portion	do	455	1			72	
Peppers, sweet; fruit	Philippine Islands	393	1			630	*Capsicum annuum* L.
Pineapple, edible portion			4	280	17	144	Summary (393, 408).
Pineapple, fruit		455	1			40	
Pistachio nut, edible portion		455	1			825	
Plums, edible portion			3	140	51	110	Summary (393, 455).
Pomegranate, seeds		455	1			44	
Potatoes, tubers	Florida	5x	6	87	58	75	Bladen soil (NPK).
Do	do	5x	1			83	Bladen soil (NPKMn).
Do	do	5x	1			74	Bladen soil (NPKCu).
Do	do	5x	4	107	75	92	Coxville soil (NPK).
Do	do	5x	3			101	Coxville soil (NPKMn).
Do	do	5x	2			85	Coxville soil (NPKCu).
Do	do	5x	1			94	Coxville soil (NPKMnCu).
Do	do	5x	4	71	40	54	Leon soil (NPK).
Do	do	5x	1			69	Norfolk soil (NPK).
Do	New Hampshire	495	1			28	Gloucester stony loam.
Do			131	363	7	105	Summary (137, 213, 368, 393, 413, 455, 495, 5x, 20x).
Prunes, edible portion	California	506	15	75	38	55	
Quince, edible portion	Wisconsin	455	1			58	
Radish, roots			14	825	97	436	Summary (113, 209, 393, 455).
Rape, above-ground portion	Alabama	13x	1			176	Norfolk soil.
Do			2	244	176	210	Summary (528, 13x).
Rape, above-ground portion, flowering stage	France	58	2	87	81	84	
Rape, seed	Kentucky	371	1			85	
Raspberries, fruit	Wisconsin	455	1			62	
Redtop, above-ground portion, cut for hay	Kentucky	14x	1			130	Dekalb silt loam; no fertilization.
Do	do	14x	1			120	Dekalb silt loam (M).
Do	do	14x	1			160	Dekalb silt loam (ML).
Do	do	14x	1			110	Tilsit silt loam; no fertilization.
Do	do	14x	1			110	Tilsit silt loam (NP).
Do	do	14x	1			110	Tilsit silt loam (NPL).
Do			12	160	56	117	Summary (394, 14x).

TABLE 21.—*The minor-element content of some important crops*—Continued

IRON—Continued

Plant or part of plant	Location	Reference No.	Analyses	Iron Maximum	Iron Minimum	Iron Mean	Remarks
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Redtop, seeds	Kentucky	371	1			160	
Rhubarb, stem			2	559	154	356	Summary (393, 455).
Rice, brown		380	1			76	
Rice, polished			3	32	12	19	Summary (380, 455).
Rutabagas, roots			3	559	56	275	Summary (393, 455).
Rutabagas, leaves	Philippine Islands	393	1			1,389	
Rye, grain	Wisconsin	528	1			57	
Salsify, edible portion	do	455	1			53	
Soybean, leaves	Kentucky	372	1			336	
Soybean, seed, green			41	161	59	101	Summary (113, 409, 528, 603).
Soybean, seed, mature			13	133	57	80	Summary (371, 372, 393).
Soybean, above-ground portion, cut for hay	Kentucky	14x	1			160	Dakalb silt loam; no fertilization.
Do	do	14x	1			140	Dekalb silt loam (ML).
Do	do	14x	2	170	100	135	Dekalb silt loam (MP).
Do	do	14x	2	130	120	125	Dekalb silt loam (MPL).
Do	do	14x	2	150	110	130	Dekalb silt loam (MPKL).
Do	do	14x	1			110	Tilsit silt loam; no fertilization.
Do	do	14x	1			570	Tilsit silt loam (M).
Do	do	14x	2	350	150	250	Tilsit silt loam (MP).
Do	do	14x	3	300	180	250	Tilsit silt loam (MPK).
Do	do	14x	1			130	Tilsit silt loam (ML).
Do	do	14x	2	130	110	120	Tilsit silt loam (MPL).
Do	do	14x	2	350	320	335	Tilsit silt loam (MPKL).
Do			33	570	100	212	Summary (394, 528, 14x).
Spinach, edible portion	Alabama	13x	1			1,319	Cecil soil.
Do	do	13x	2	517	299	408	Norfolk soil.
Do			54	1,750	54	683	Summary (113, 181, 302, 319, 347, 393, 411, 455, 457, 482, 489, 8x, 13x).
Squash, edible portion	South Carolina	482	3	130	70	105	
Strawberries, edible portion			3	267	68	135	Summary (393, 408, 455).
Sudan grass, above-ground portion, before flowering.	Philippine Islands	394	1			70	
Sudan grass, above-ground portion, flowering	do	394	1			140	
Sugar beets, roots	Wisconsin	528	1			53	
Sugar beets, leaves	do	528	1			179	

Sunflower, seeds	Kentucky	371	1			34	
Sweetclover, above-ground portion	do	381	1			130	*Melilotis alba.*
Sweetpotatoes, tubers			18	140	39	70	Summary (393, 482).
Swiss chard, edible portion			3	1,049	473	690	Summary (113, 393, 455).
Tangerine, edible portion	Wisconsin	455	1			44	
Tendergreen, edible portion	Alabama	13x	1			1,415	Decatur soil.
Do	do	13x	1			262	Norfolk soil.
Timothy, above-ground portion, in bloom	New Hampshire	495	1			154	Gloucester stony loam.
Do	Pennsylvania	495	1			238	Hagerstown loam.
Do	do	495	1			287	Penn silt loam.
Timothy, above-ground portion, in seed	Maine	495	1			266	
Timothy, above-ground portion, cut for hay	Kentucky	14x	4	160	110	135	Tilsit silt loam.
Do			14	160	30	116	Summary (528, 14x).
Timothy, seed	Kentucky	371	1			61	
Tobacco, seed	do	371	1			240	
Tomato, fruit	Florida	5x	26	290	87	159	Parkwood fine sandy loam (NPK).
Do			56	800	48	202	Summary (107, 378, 393, 455, 482, 5x).
Turnip, roots	Alabama	13x	3	77	19	57	Norfolk soil.
Do	do	13x	1			92	Cecil soil.
Do	do	13x	1			66	Decatur soil.
Do			9	210	19	92	Summary (368, 393, 455, 13x).
Turnip, tops			7	2,483	140	618	Summary (113, 181, 347, 368, 413, 482, 521).
Vetch, above-ground portion, in bloom	Germany	368	1			280	
Vetch, above-ground portion, seeds beginning to ripen.	do	368	1			629	
Vetch, above-ground portion, cut for hay			2	354	280	317	Summary (166, 368).
Vetch, straw, seeds ripening	Germany	368	1			63	Summary (368, 371).
Vetch, seed			4	85	21	53	
Walnuts, edible portion			3	61	22	37	Summary (393, 455).
Watermelon, edible portion			3	280	17	109	Summary (393, 408, 455).
Wheat, grain	Kentucky	14x	1			140	Tilsit silt loam; no fertilization.
Do	do	14x	1			80	Tilsit silt loam (M).
Do	do	14x	1			90	Tilsit silt loam (ML).
Do	do	14x	2	70	60	65	Tilsit silt loam (MPL).
Do			131	420	28	68	Summary (222, 224, 238, 368, 371, 381, 528, 543, 1x, 14x).
Wheat, straw	Kentucky	14x	1			150	Tilsit silt loam; no fertilization.
Do	do	14x	1			130	Tilsit silt loam (M).
Do	do	14x	1			130	Tilsit silt loam (ML).
Do	do	14x	2	130	120	125	Tilsit silt loam (MLP).
Do			39	630	60	177	Summary (166, 368, 381, 528, 14x).
Yams, tuber	Hawaii	113	1			340	

TABLE 21.—*The minor-element content of some important crops*—Continued

MANGANESE

Plant or part of plant	Location	Reference No.	Analyses	Manganese			Remarks
				Maximum	Minimum	Mean	
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Alfalfa, above-ground portion, prebud stage	Tennessee	580	3	101	29	67	
Alfalfa, above-ground portion, 1/10 bloom	Michigan	507	4	34	24	28	
Alfalfa, above-ground portion, full bloom			8	936	14	155	Summary (58, 253, 507, 580).
Alfalfa, above-ground portion, cut for hay	Pennsylvania	495	1			37	Hagerstown loam.
Do	do	495	1			55	Penn silt loam.
Do	Tennessee	22x	4	54	77	67	Cumberland loam.
Do	do	22x	4	124	70	99	Fullerton silt loam.
Do			32	124	16	60	Summary (80, 306, 373, 495, 580, 585, 14x, 22x).
Alfalfa, leaves	Oregon	306	2	76	45	50	
Alfalfa, stems	do	306	2	13	11	12	
Alfalfa, seeds			4	15	6	10	Summary (306, 371, 373).
Almond, edible portion			2	13	13	13	Summary (299, 461).
Apple, fruit	New Hampshire	495	1			4	Gloucester stony loam.
Do			4	22	1	8	Summary (299, 356, 495).
Artichoke, flower head			2	26	23	24	Summary (299, 461).
Asparagus, edible portion			5	29	12	24	Summary (63, 73, 299, 356).
Banana, edible portion			6	117	7	43	Summary (117, 158, 163, 299, 356, 485).
Barley, grain			12	38	7	19	Summary (73, 138, 356, 368, 485, 528).
Barley, straw	Germany	368	1			7	
Beans, field; mature seed			16	36	14	21	Summary (73, 356, 368, 379, 485). *Phaseolus vulgaris.*
Beans, garden; edible pods and seeds	Florida	5x	4	56	48	51	St. Lucie soil.
Do	Wisconsin	458	2	44	43	43	Boone fine sandy loam.
Do	do	458	3	39	36	38	Carrington silt loam.
Do	do	458	1			36	Colby silt loam.
Do	do	458	1			34	Kennan silt loam.
Do	do	458	1			22	Miami gravelly sandy loam.
Do	do	458	4	51	30	37	Miami silt loam.
Do	do	458	6	57	30	46	Plainfield sand.
Do			43	57	11	36	Summary (299, 421, 458, 461, 482, 5x).
Beans, garden; edible hulls	Kentucky	379	1			39	
Beans, garden; immature seed	do		6	19	16	18	
Beans, lima; mature seed			2	25	12	18	Summary (356, 379).
Beets, roots	New Hampshire	495	1			52	Gloucester stony loam.
Do			20	104	19	54	Summary (73, 356, 413, 421, 482, 485, 495, 585, 8x).
Beets, leaves			5	205	16	139	Summary (300, 482).
Blackberries, fruit	Wisconsin	356	1			37	
Blueberries, fruit	do	356, 461	2	315	122	219	

Brazil nut, edible portion		461	1			10	
Broccoli, edible portion	Maryland	140	3	32	21	26	
Brussels sprouts, edible portion	Wisconsin	356	1			21	
Buckwheat, above-ground portion, cut in bloom	France	58	1			14	
Cabbage, edible portion	Florida	5x	1			34	Coxville soil (NPK).
Do	do	5x	8	35	24	26	Leon soil (NPK).
Do	do	5x	2			38	Leon soil (NPKMn).
Do	do	5x	2			41	Leon soil (NPKCu)
Do	do	5x	1			29	Parkwood soil (NPK).
Do	North Carolina	495	1			49	Cecil clay.
Do	Wisconsin	458	2	11	13	12	Miami silt loam.
Do			68	436	5	31	Summary (65, 299, 356, 421, 458, 482, 485, 495, 585, 5x, 13x).
Cabbage, main rib of leaf	France	63	1			21	
Cabbage, secondary rib of leaf	do	63	1			40	
Cabbage, stalk	do	63	1			63	
Cantaloup, edible portion	Wisconsin	461	1			8	
Carrots, root			19	91	6	31	Summary (299, 356, 421, 482, 485, 495, 585, 8x).
Carrots, leaves			6	199	23	105	Summary (299, 482).
Cauliflower, edible portion			5	27	7	17	Summary (140, 299, 421, 461).
Celery, edible portion	Florida	5x	3			56	Bladen soil.
Do			34	64	8	30	Summary (356, 421, 585, 5x).
Celery cabbage, edible portion	Wisconsin	461	1			23	
Cherries, edible portion	do	356	1			2	
Chestnuts, edible portion			2	56	16	36	Summary (300, 461).
Clover, hop; above-ground portion, before bloom	Kentucky	22x	1			85	Maury silt loam. *Trifolium agrarium.*
Clover, hop; above-ground portion, in bloom	do	22x	2	70	54	62	Do.
Clover, hop; above-ground portion	do	22x	1			85	Do.
Clover, hop; leaves	do	22x	1			116	Do.
Clover, hop; stems	do	22x	1			54	Do.
Clover, alsike; above-ground portion			6	288	20	117	Summary (306, 368, 585, 14x). *T. hybridum.*
Clover, alsike; seeds	Kentucky	371	1			28	*T. hybridum.*
Clover, crimson; above-ground portion, full bloom	North Carolina	495	1			387	Cecil sand loam. *T. incarnatum.*
Clover, crimson; above-ground portion			4	387	24	246	Summary (368, 371, 495, 585). *T. incarnatum.*
Clover, crimson; seed	Kentucky	371	1			29	*T. incarnatum.*
Clover, low hop; above-ground portion, prebloom	Tennessee	580	1			72	*T. procumbens.*
Clover, low hop; above-ground portion, in bloom	do	580	1			58	Do.
Clover, low hop; above-ground portion, bloom dying.	do	580	1			72	Do.
Clover, red; above-ground portion	Kentucky	14x	5	120	60	94	Tilsit silt loam. *T. pratense.*
Clover, red; above-ground portion, mature with blossoms and seeds.	New Hampshire	495	1			465	Gloucester stony loam. *T. pratense.*
Clover, red; above-ground portion, in bloom	Pennsylvania	495	1			287	Hagerstown loam. *T. pratense.*
Clover, red; above-ground portion	do	495	1			542	Penn silt loam. *T. pratense.*
Do			51	542	25	121	Summary (300, 368, 495, 585, 14x). *T. pratense.*
Clover, red; seeds	Kentucky	371, 373	2	38	25	31	*T. pratense.*
Clover, red; foliage	do	373	1			200	Do.
Clover, red; bloom	Oregon	306	2	66	30	48	Do.
Clover, red; leaves	do	306	2	84	40	62	Do.
Clover, red; seeds	do	306	2	12	6	9	Do.

TABLE 21.—*The minor-element content of some important crops*—Continued

MANGANESE—Continued

Plant or part of plant	Location	Reference No.	Analyses	Manganese			Remarks
				Maximum	Minimum	Mean	
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Clover, red; stems	Oregon	306	2	20	15	17	*T. pratense.*
Clover, white; above-ground portion, beginning to bloom.	Pennsylvania	495	1			356	Hagerstown loam. *T. repens.*
Clover, white; above-ground portion, some blossoms seeded.	Maine	495	1			875	*T. repens.*
Clover, white; above-ground portion			3	144	18.5	102	Summary (368, 585). *T. repens.*
Clover, white; seeds	Kentucky	371	1			22	*T. repens.*
Coconut, edible portion	Wisconsin	461	1			25	
Collards, leaves	Alabama	13x	3	295	53	147	Norfolk soil.
Do	South Carolina	413	1			73	
Corn, grain			13	19	5	13	Summary (138, 300, 356, 485, 528).
Corn, stover	Kentucky	14x	2	114	103	108	Tilsit silt loam.
Do			20	270	54	127	Summary (507, 528, 14x).
Corn, sweet; edible portion			2	31	5	18	Summary (413, 461).
Cotton, lint	Mississippi	374	1			190	
Cotton, seed	do	374	1			13	
Cowpeas, seed	South Carolina	413	1			45	
Cranberries, edible portion			2	49	25	37	Summary (416, 417, 461).
Cress, water, edible portion			4	69	25	56	Summary (63, 299).
Cucumber, edible portion			3	48	24	33	Summary (461, 585).
Currants, edible portion	Wisconsin	356	1			4	
Dandelion, edible portion	do	461	1			19	
Dates, edible portion			3	54	2	32	Summary (115, 356).
Eggplant			5	53	15	32	Summary (413, 461, 482).
Endive, edible portion	Wisconsin	461	1			35	
Flax, seed			3	102	38	61	Summary (368, 371).
Gooseberries	Wisconsin	356	1			5	
Grapefruit, fruit	Florida	199	2	5	4	5	
Grapefruit, edible portion	Wisconsin	356	1			Tr.	
Grapes, edible portion	do	356	1			Tr.	
Hazelnuts, edible portion			2	43	33	38	Summary (299, 461).
Hemp, seeds			2	165	34	100	Summary (371, 585).
Horsebeans, seed	Germany	368, 585	2	15	14	14	*Vicia faba.*
Horsebeans, straw	do	368	1			23	Do.
Horsebeans, forage	do	368	1			36	Do.
Kafir, grain	Wisconsin	528	2	16	16	16	
Kale, edible portion	California	140	1			11	Yolo silt loam.
Do	Maryland	140	2	61	60	60	Sassafras sandy loam.
Do	Virginia	140	2	137	66	101	Norfolk silt loam.
Do		140	6	137	11	68	Summary.

Kentucky bluegrass, above-ground portion, young blades.	Kentucky	375	1			80	
Kentucky bluegrass, above-ground portion, in seed.	Pennsylvania	495	1			29	Penn silt loam.
Kentucky bluegrass, above-ground portion, stage of maturity unknown.	Idaho	80	10	107	69	78	Boise sandy loam.
Do			19	216	30	87	Summary (80, 368, 373, 381, 528, 595).
Kentucky blue grass, seeds	Kentucky	371, 375	2	110	85	97	
Kohlrabi, edible portion	Wisconsin	356	1			13	
Kumquat, edible portion		356	1			4	
Lemon, edible portion	France	63	1			3	
Lespedeza, above-ground portion, before bloom	Tennessee	22x	4	147	70	114	Clarksville silt loam.
Do	do	22x	13	302	54	174	Cumberland loam.
Do	do	22x	1			441	Decatur silt loam.
Do	do	22x	2	255	217	236	Maury silt loam.
Do	do	22x	1			116	Montevallo silt loam.
Lespedeza, above-ground portion, early bloom	do	22x	3	418	77	199	Clarksville silt loam.
Do	do	22x	7	232	62	155	Cumberland loam.
Do	do	22x	3	163	132	147	Maury silt loam.
Lespedeza, above-ground portion, full bloom	do	22x	3	147	77	114	Clarksville silt loam.
Do	do	22x	13	232	54	143	Cumberland loam.
Do	do	22x	2	163	70	116	Dandridge silt loam.
Do	do	22x	1			178	Fullerton silt loam.
Do	do	22x	1			240	Montevallo silt loam.
Lespedeza, above-ground portion, late bloom	do	22x	3	225	93	173	Cumberland loam.
Do	do	22x	1			108	Maury silt loam.
Lespedeza, above-ground portion, in seed	do	22x	1			85	Clarksville silt loam.
Do	do	22x	10	364	101	199	Cumberland loam.
Lespedeza, above-ground portion, maturity unknown.	do	22x	1			62	Clarksville silt loam.
Do	do	580	3	331	86	178	Do.
Do	do	22x	28	217	54	97	Cumberland loam.
Do	do	580	17	317	58	124	Hartsell silt loam.
Do	do	22x	2	263	178	221	Maury silt loam.
Do	do	580	4	223	130	185	Do.
Lettuce, edible portion	Alabama	13x	1			89	Cecil soil.
Do	do	13x	2	211	198	204	Norfolk soil.
Lettuce, head, outer leaves removed	Florida	5x	13	209	141	185	Leon soil (NPK).
Do	do	5x	3	389	302	355	Leon soil (NPKMn).
Do	do	5x	2			292	Leon soil (NPKCu).
Do	do	5x	1			174	Portsmouth soil (NPK).
Lettuce, edible portion			44	523	15	196	Summary (140, 299, 356, 413, 482, 485, 585, 5x, 8x, 13x).
Lettuce, leaf	Wisconsin	461	1			167	
Lupine, yellow; seeds	Netherlands	585	1			678	
Mandarin, edible portion	France	63, 299	2	3	2	2	
Millet, grain	Kentucky	371	1			17	
Millet, straw	Africa	485	1			25	
Millet, German, above-ground portion, cut for hay.	Michigan	507	6	135	94	121	
Millet, Japanese, above-ground portion, cut for hay.	Rhode Island	19x	1			30	Bridgehampton very fine sandy loam (PKCaMg).
Do	Wisconsin	528	1			36	

TABLE 21.—*The minor-element content of some important crops*—Continued

MANGANESE—Continued

Plant or part of plant	Location	Reference No.	Analyses	Manganese			Remarks
				Maximum	Minimum	Mean	
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Mushrooms, edible portion			2	42	7	25	Summary (299, 461).
Mustard, greens	Alabama	13x	2	160	150	155	Norfolk soil.
Mustard, seeds	France	63	2	39	27	33	
Mustard, above-ground portion, cut for fodder	Germany	368	2	144	144	144	
Mustard, straw	do	368	1			72	
Oats, grain			16	76	23	51	Summary (73, 138, 356, 371, 528, 585).
Oats, straw			12	1,656	4	733	Summary (368, 382, 485, 528).
Oats, above-ground portion, flowering stage	France	58	1			5	
Oats, above-ground portion, milk stage	Pennsylvania	495	1			116	Penn silt loam.
Oats, above-ground portion, maturity unknown	France	299	1			50	
Oats, above-ground portion, cut for hay			6	280	72	166	Summary (368, 507).
Okra, fruit	South Carolina	482	5	62	36	48	
Onions, bulb			16	96	2	26	Summary (63, 73, 356, 421, 482, 485, 585).
Orange, edible portion	France	63, 299	2	3	3	3	
Parsley, edible portion	Wisconsin	356	1			80	
Peanut, edible portion			2	16	2	9	Summary (356, 485).
Pear, edible portion			2	4	2	3	Summary (299, 356).
Peas, edible portion	Wisconsin	458	1			22	Boone fine sandy loam.
Peas, edible portion, all sizes	do	458	3	20	10	13	Carrington silt loam.
Do	do	458	2	17	17	17	Miami fine sandy loam.
Do	do	458	7	25	10	15	Miami silt loam.
Peas, green, edible portion			34	25	4	12	Summary (299, 356, 357, 371, 413, 458, 485).
Peas, seed			3	12	4	9	Summary (73, 306, 585).
Peas, above-ground portion	France	299	1			15	
Peas, pods only	Africa	485	1			27	
Do	France	299	1			22	
Peas, field; stems	Oregon	306	1			14	
Peas, field; blooms	do	306	1			21	
Peas, field; leaves	do	306	1			38	
Peas, field; pods	do	306	1			21	
Pecans, edible portion		461	1			36	
Peppers, green, edible portion	Wisconsin	461	1			19	
Peppers, red, edible portion	do	356	1			18	
Pineapple, fruit		356	1			134	
Pistachio nut, edible portion		356	1			7	
Plums, edible portion	Wisconsin	461	1			6	
Pomegranate, seeds		356	1			9	
Potatoes, tubers	Colorado	257	5	31	15	23	Fort Collins stony loam; no fertilization.
Do	do	257	5	31	8	22	Fort Collins stony loam (N).
Do	Florida	5x	6	21	5	14	Bladen soil (NPK).
Do	do	5x	1			42	Bladen soil (NPKMn).

Do	do	5x	1			40	Bladen soil (NPKCu).
Do	do	5x	4	17	10	14	Coxville soil (NPK).
Do	do	5x	3			31	Coxville soil (NPKMn).
Do	do	5x	2			38	Coxville soil (NPKCu).
Do	do	5x	1			40	Coxville soil (NPKCuMn).
Do	do	5x	4	11	7	10	Leon soil (NPK).
Do	do	5x	1			11	Norfolk soil (NPK).
Do	New Hampshire	495	1			8	Gloucester stony loam.
Do	Wisconsin	12x	3	7	5	7	Miami silt loam.
Do			205	94	4	19	Summary (79, 257, 356, 368, 413, 421, 485, 495, 5x, 12x, 20x).
Potatoes, tops	Germany	368	4	108	86	99	
Prunes, edible portion	California	506	15	7	4	6	
Pumpkin, edible portion	Wisconsin	461	1			4	
Pumpkin, fruit	France	299	1			13	
Quince, edible portion	Wisconsin	356	1			Tr.	
Radish, roots			2	45	14	29	Summary (63, 297, 461).
Radish, flesh without skin	France	63	3	21	11	15	
Rape, above-ground portion, maturity unknown	Alabama	13x	1			43	Norfolk soil.
Rape, above-ground portion, flowering	France	58, 299	3	77	46	65	
Rape, above-ground portion, maturity unknown			2	51	43	47	Summary (528, 13x).
Rape, seed	Kentucky	371	1			38	
Raspberries, fruit	Wisconsin	461	1			46	
Redtop, above-ground portion, cut for hay	Kentucky	14x	1			330	Dekalb silt loam; no fertilization.
Do	do	14x	1			310	Dekalb silt loam (M).
Do	do	14x	1			110	Dekalb silt loam (ML).
Do	do	14x	1			120	Dekalb silt loam (PL).
Do	do	14x	1			370	Tilsit silt loam; no fertilization.
Do	do	14x	1			510	Tilsit silt loam (NP).
Do	do	14x	1			180	Tilsit silt loam (NPL).
Do			25	510	79	226	Summary (80, 128, 14x).
Redtop, seeds		371	1			510	
Rhubarb, edible portion	Wisconsin	461	1			31	
Rice, brown			2	28	18	23	Summary (380, 485).
Rice, polished			4	14	10	12	Summary (373, 380, 461, 485).
Rutabaga, roots	Wisconsin	421, 461	2	10	8	9	
Rye, grain			7	157	32	100	Summary (138, 528).
Salsify, root			2	27	12	20	Summary (297, 461).
Sorghum, above-ground portion, cut for hay	Michigan	507	10	210	82	131	
Soybean, leaves	Kentucky	372	1			160	
Soybean, seeds, green	Wisconsin	528	1			29	
Soybean, seeds, mature	Kentucky	371, 372	11	41	21	28	
Soybean, above-ground portion, cut for hay	do	14x	1			200	Dekalb silt loam; no fertilization.
Do	do	14x	1			62	Dekalb silt loam (ML).
Do	do	14x	2	280	170	225	Dekalb silt loam (MP).
Do	do	14x	2	88	64	75	Dekalb silt loam (MPL).
Do	do	14x	2	64	45	54	Dekalb silt loam (MPKL).
Do	do	14x	1			130	Tilsit silt loam; no fertilization.
Do	do	14x	1			160	Tilsit silt loam (M).
Do	do	14x	2	155	120	137	Tilsit silt loam (MP).
Do	do	14x	3	130	88	104	Tilsit silt loam (MPK).
Do	do	14x	1			68	Tilsit silt loam (ML).
Do	do	14x	2	97	87	92	Tilsit silt loam (MPL).

TABLE 21.—*The minor-element content of some important crops*—Continued

MANGANESE—Continued

Plant or part of plant	Location	Reference No.	Analyses	Manganese			Remarks
				Maximum	Minimum	Mean	
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Soybean, above-ground portion, cut for hay	Kentucky	14x	2	100	90	95	Tilsit silt loam (MPKL).
Do			32	280	45	126	Summary (528, 14x).
Spinach, edible portion	Alabama	13x	1			48	Cecil soil.
Do	do	13x	2	290	244	267	Norfolk soil.
Do	Maryland	140	2	694	84		Sassafras sandy loam.
Do	Rhode Island	19x	1			52	Bridgehampton very fine sandy loam; no fertilization.
Do	do	19x	1			103	Bridgehampton very fine sandy loam (Mn).
Do	do	19x	8	56	10	36	Bridgehampton very fine sandy loam (NPK).
Do	do	19x	8	120	10	66	Bridgehampton very fine sandy loam (NPKMn).
Do	Virginia	140	2	70	65	67	Norfolk loam.
Do			76	694	10	101	Summary (73, 140, 207, 299, 356, 411, 421, 481, 485, 566, 585, 8x, 13x, 19x).
Squash, edible portion	South Carolina	482	6	28	19	24	
Strawberries, edible portion			2	40	6	23	Summary (63, 356).
Sugar beets, roots	Wisconsin	528	1			206	
Sugar beets, leaves, mature	Michigan	507	21	79	11	25	
Sugar beets, leaves	Wisconsin	528	1			712	
Sunflower, seeds	Kentucky	371	1			23	
Sunflower, above-ground portion, cut before bloom.	Germany	368	1			72	
Sunflower, above-ground portion, bud appearing on top of plant.	Idaho	431	6	1,066	778	852	Palouse silt loam.
Sunflower, above-ground portion, flower 3 inches in diameter.	do	431	6	1,268	490	773	Do.
Sunflower, above-ground portion, full bloom	Germany	368	1			72	
Sunflower, above-ground portion, cut before seed of first bloom was in dough stage.	Idaho	431	6	1,253	864	1,015	Palouse silt loam.
Sunflower, above-ground portion, seeds of first flower in dough stage.	do	431	6	1,224	576	818	Do.
Sunflower, above-ground portion, seeds quite hard and rays fallen.	do	431	6	1,138	634	807	Do.
Sweetclover, above-ground portion	Pennsylvania	495	1			186	Hagerstown loam. *Melilotus alba.*
Do			2	186	50	118	Summary (495, 14x). *M. alba.*
Sweetpotatoes, tubers			11	28	3	11	Summary (413, 482, 485).
Swiss chard, edible portion	Wisconsin	356	1			93	
Tangerine, edible portion	do	356	1			3	

Tendergreen, edible portion	Alabama	13x	1			497	Decatur soil.
Do	do	13x	1			189	Norfolk soil.
Timothy, above-ground portion, in bloom	New Hampshire	495	1			58	Gloucester stony loam.
Do	Pennsylvania	495	1			34	Hagerstown loam.
Do	do	495	1			36	Penn silt loam.
Timothy, above-ground portion, in seed	Maine	495	1			104	
Timothy, above-ground portion, cut for hay	Kentucky	14x	4	110	70	82	Tilsit silt loam.
Do			28	165	11	86	Summary (80, 128, 254 528,585, 14x).
Timothy, seed	Kentucky	371	1			72	
Tobacco, cigar wrapper type, leaves	Connecticut	10, 42	38	2, 262	70	657	
Tobacco, leaves, type unknown	do	43	19	1, 729	144	701	
Tobacco, seed	Kentucky	371	1			70	
Tomato, fruit	Florida	5x	26	58	43	51	Parkwood fine sandy loam (NPK).
Do			47	98	18	46	Summary, (378, 461, 482, 5x).
Turnip, roots	Alabama	13x	1			5	Cecil soil.
Do	do	13x	1			21	Decatur soil.
Do	do	13x	3	65	12	31	Norfolk soil.
Do			17	56	5	19	Summary (48, 63, 297, 368, 413, 461, 485, 585, 13x).
Turnip, tops			11	900	36	185	Summary (63, 297, 368, 370, 482).
Vetch, above-ground portion, in bloom	Germany	368	1			72	
Vetch, above-ground portion, seeds beginning to ripen.	do	368	1			144	
Vetch, above-ground portion, cut for hay			3	106	27	54	Summary (166, 300, 368).
Vetch, above-ground portion, pods forming	Germany	368	1			360	
Vetch, straw, seeds ripening	do	368	1			14	
Vetch, seed			4	72	14	34	Summary (368, 371).
Walnuts, edible portion			2	33	19	26	Summary (299, 356).
Watermelon, edible portion	Wisconsin	356	1			2	
Wheat, grain	Kentucky	14x	1			60	Tilsit silt loam; no fertilization.
Do	do	14x	1			70	Tilsit silt loam (M).
Do	do	14x	1			50	Tilsit silt loam (ML).
Do	do	14x	2	70	50	60	Tilsit silt loam (MPL).
Do			109	260	5	49	Summary (73, 138, 255, 341, 368, 371, 381, 485, 528, 543, 585, 14x).
Wheat, straw	Kentucky	14x	1			60	Tilsit silt loam; no fertilization.
Do	do	14x	1			90	Tilsit silt loam (M).
Do	do	14x	1			60	Tilsit silt loam (ML).
Do	do	14x	2	80	70	75	Tilsit silt loam (MPL).
Do			30	150	22	60	Summary (166, 368, 381, 528, 14x).
Yams, tuber	Africa	485	1			2	

TABLE 21.—*The minor-element content of some important crops*—Continued

NICKEL

Plant or part of plant	Location	Reference No.	Nickel	Remarks	Plant or part of plant	Location	Reference No.	Nickel	Remarks
			Mg./kg.					*Mg./kg.*	
Apricots, edible portion	France	61	0.64		Oats, grain	France	61	0.45	
Beans, field; seed	do	61	.59	*Phaseolus vulgaris.*	Onions, bulb	do	61	.16	
Buckwheat, grain	do	61	1.34		Pear, pulp	do	61	1.30	
Cabbage, edible portion	do	60	3.3		Peas, green, edible portion	do	61	2.25	
Carrots, roots	do	61	.29		Potatoes, tubers	do	61	.25	
Do	do	61	.21		Rice, polished	do	61	.02	
Carrots, leaves	do	61	1.83		Soybeans, seed	Kentucky	372	3.92	
Cherries, edible portion	do	61	.50		Spinach, edible portion	France	61	2.37	
Coffee, bean	do	61	.38		Tomato, fruit	do	61	.15	
Corn, grain	do	61	.14		Walnuts, edible portion	do	61	.60	
Cress, water	do	61	.50	*Nasturtium officinale.*	Wheat, grain	do	61	.35	
Figs	do	61	1.20						

SELENIUM[12]

Plant or part of plant	Location	Reference No.	Selenium	Remarks
			Mg./kg.	
Alfalfa	Colorado	104	3	
Do	Utah	104	100	Sandy loam. Contained 0.3 p. p. m. of selenium.
Do	Colorado	104	0	Soil contained 1 p. p. m. of selenium.
Do	Various Western States	104	2	Average of 17 samples, omitting the sample from Utah.
Aster, wild; young	South Dakota	100	2, 670	Boyd clay. Contained 6 p. p. m. of selenium.
Aster, wild	do	100	60	Alluvial clay. Contained 2 p. p. m. of selenium.
Do	do	100	5	Boyd clay. Contained 3 p. p. m. of selenium.
Do	Nebraska	100	1, 210	Boyd clay loam. Contained 2.5 p. p. m. of selenium.
Do	do	100	12	Boyd clay loam. Contained 7 p. p. m. of selenium.
Astragalus racemosus	do	101	5, 560	Niobrara clay. Contained 7 p. p. m. of selenium.
Do	do	101	920	Niobrara clay. Contained 1 p. p. m. of selenium.
Do	do	101	70	Pierre clay. Contained 0.7 p. p. m. of selenium.
Do	do	101	970	Do.
Do	do	101	1	Niobrara stony clay loam. Contained 1 p. p. m. of selenium.
Russian thistle	Various Western States	100, 101	9	Average of 89 samples. 75 percent of the plants examined contained from 1 to 15 p. p. m. of selenium.
Vetch, two-groove poison	Colorado	104	1, 380	Pierre clay. Contained 3 p. p. m. of selenium.
Wheat, grain	Small plot in South Dakota	493	26	Soil contained from 3 to 16 p. p. m. of selenium.
Do	Various countries	493	0. 5	29 samples. Range 0.1 to 1.9 p. p. m. of selenium.

[12] In this table there are listed a few representative samples of selenium contents of some plants grown in seleniferous and nonseleniferous areas. For more complete lists the reader is referred to the literature cited.

TABLE 21.—*The minor-element content of some important crops*—Continued

SODIUM [13]

Plant or part of plant	Location	Reference No.	Analyses	Sodium in moisture-free material: Maximum	Minimum	Mean	Remarks
			Number	*Percent*	*Percent*	*Percent*	
Alfalfa, above-ground portion, prebud stage	England	601	7	0.18	0.02	0.12	
Alfalfa, above-ground portion, in bud	do	600, 601	13	.33	.07	.22	
Alfalfa, above-ground portion, 1/10 to 1/4 bloom			18	.36	.02	.16	Summary.
Alfalfa, above-ground portion, 1/2 bloom			3	.22	.12	.16	Do.
Alfalfa, above-ground portion, full bloom			4	.16	.04	.06	Do.
Alfalfa, above-ground portion, cut for-hay			38	1.76	.09	.43	Do.
Apples, fruit	New Hampshire	495	1			.01	Gloucester stony loam.
Do			3	.12	.01	.07	Summary.
Barley, grain			33	.15	.03	.07	Do.
Beans, field; seed			15	.38	.01	.10	Summary. *Phaseolus vulgaris.*
Beans, garden; edible pod and seed			2	.19	.01	.10	Summary.
Beans, garden; edible hulls	Kentucky	379	1			.12	
Beans, garden; immature seed	do	379	1			.19	
Beans, lima; mature seed	Kentucky	379	1			.03	
Beets; roots			28	3.78	.04	.74	Summary.
Beets; leaves	Netherlands	294	20	3.76	.87	2.13	
Broccoli, edible portion	Maryland	140	3	.81	.40	.54	
Buckwheat, above-ground portion, cut in bloom	France	58	1			.01	
Buckwheat, above-ground portion, past bloom	Massachusetts	214	1			.28	
Cabbage, edible portion	North Carolina	495	1			.18	Cecil clay.
Do			4	.38	.02	.15	Summary.
Canada bluegrass, above-ground portion	Netherlands	292	7	.13	.05	.08	
Carrots, roots			11	2.88	.07	1.61	Do.
Cauliflower, edible portion	California	140	2	.64	.60	.62	
Celery, edible portion	Florida	5x	3			2.32	Bladen soil.
Do	do	5x	30	3.49	1.18	2.21	
Clover, alsike, above-ground portion			17	.58	.13	.46	Summary. *Trifolium hybridum.*
Clover, crimson; above-ground portion, full bloom	North Carolina	495	1			.08	Cecil sandy loam. *T. incarnatum.*
Clover, crimson; above-ground portion			11	.80	.08	.39	Summary. *T. incarnatum.*
Clover, red; above-ground portion	Kentucky	14x	5	.24	.10	.17	Tilsit silt loam. *T. pratense.*
Clover, red; above-ground portion, mature with blossoms and seeds.	New Hampshire	495	1			.01	Gloucester stony loam. *T. pratense.*
Clover, red; above-ground portion, in bloom	Pennsylvania	495	1			.07	Hagerstown loam. *T. pratense.*
Clover, red, above-ground portion	do	495	1			.08	Penn silt loam. *T. pratense.*
Do	Rhode Island	19x	2	.10	.10	.10	Narragansett stony loam. *T. pratense.*
Do			55	.85	.01	.21	Summary. *T. pratense.*
Clover, white; above-ground portion, some blossoms seeded.	Maine	495	1			.09	*T. repens.*
Clover, white; above-ground portion			34	.80	.07	.41	Summary. *T. repens.*

Coconut, kernel, without milk	Australia	39	1			.03	
Corn, grain			18	.125	.001	.048	Summary.
Corn, sweet; edible portion			17	.82	.06	.16	Do.
Cotton, lint			3	.05	.02	.03	Do.
Cotton, seed			3	.71	.01	.31	Do.
Cowpeas, above-ground portion; full bloom	South Carolina	359	1			.09	
Cowpeas, above-ground portion; pods forming	do	359	1			.17	
Cowpeas, above-ground portion; pods formed	do	359	1			.03	
Cowpeas, above-ground portion; first pods beginning to turn yellow.	Missouri	514	1			.11	
Cowpeas, above-ground portion	Ohio	193	1			.72	
Cowpeas, seeds	do	193	1			.30	
Horsebeans, forage	Germany	368	1			.19	*Vicia faba.*
Horsebeans, seed	do	368	1			.01	Do.
Horsebeans, straw	do	368	1			.30	Do.
Kafir, grain	Ohio	193	1			.07	
Kale, edible portion	California	140	1			1.01	Yolo silt loam
Do	Maryland	140	2	.83	.83	.83	Sassafras sandy loam.
Do	Virginia	140	2	.77	.70	.73	Norfolk loam.
Do			6	1.01	.70	.85	Summary.
Kale, marrow stem; above-ground portion	England	600	4	.38	.16	.25	
Kale, thousand-head; above-ground portion	do	600	2	.16	.10	.13	
Kentucky bluegrass; above-ground portion, young blades.	Kentucky	375	1			.24	
Kentucky bluegrass, above-ground portion, past bloom.	Massachusetts	214	2	.14	.06	.10	
Kentucky bluegrass; above-ground portion, in seed	Pennsylvania	495	1			.15	Penn silt loam.
Kentucky bluegrass, above-ground portion; stage of maturity unknown.			12	.27	.01	.11	Summary.
Kentucky bluegrass, seeds	Kentucky	375	1			.25	
Lettuce, edible portion		140	1			.55	
Lupine, straw only	Germany	368	3	.55	.24	.42	
Lupine, hulls only	do	368	1			.15	
Lupine, seeds	do	368	1	.16	.10	.13	
Mangel-wurzel, roots	Ohio	193	1			.72	
Oats, grain			36	.23	.01	.09	Do.
Oats, straw			49	2.02	.06	.53	Do.
Oats, above-ground portion, mature	Pennsylvania	466	5	.07	.03	.05	
Oats, above-ground portion, cut for hay	Germany	314, 368	9	.36	.01	.17	
Onions, bulb			2	.09	.07	.08	Do.
Parsnips, root			2	.04	.01	.02	Do.
Peas, seed	Germany	323	1			.03	
Potatoes, tubers	Colorado	257	5	.35	.01	.08	Fort Collins loam; no fertilization.
Do	do	257	5	.38	.01	.10	Fort Collins loam (N).
Do	Florida	5x	6	.31	.17	.22	Bladen soil (NPK).
Do	do	5x	1			.20	Bladen soil (NPKMn).
Do	do	5x	1			.15	Bladen soil (NPKCu).
Do	do	5x	4	.23	.17	.11	Coxville soil (NPK).
Do	do	5x	3			.16	Coxville soil (NPKMn).
Do	do	5x	2			.22	Coxville soil (NPKCu).

[13] The summaries were calculated from data compiled from a number of sources.

TABLE 21.—*The minor-element content of some important crops*—Continued

SODIUM—Continued

Plant or part of plant	Location	Reference No.	Analyses	Sodium in moisture-free material: Maximum	Sodium in moisture-free material: Minimum	Sodium in moisture-free material: Mean	Remarks
			Number	*Percent*	*Percent*	*Percent*	
Potatoes, tubers	Florida	5x	1			0.18	Coxville soil (NPKCuMn).
Do	do	5x	4	0.23	0.15	.19	Leon soil (NPK).
Do	do	5x	1			.14	Norfolk soil (NPK).
Do	New Hampshire	495	1			.04	Gloucester stony loam.
Do			188	.38	.01	.10	Summary.
Potatoes, tops	Germany	137, 368	16	1.18	.13	.50	
Prunes, edible portion			13	.28	.04	.15	Do.
Rape, above-ground portion, flowering	France		3	.41	.32	.36	
Rape, seed	do	64	1			.01	
Redtop, above-ground portion, cut for hay	Kentucky	14x	1			.057	Dekalb silt loam; no fertilization.
Do	do	14x	1			.103	Dekalb silt loam (M).
Do	do	14x	1			.116	Dekalb silt loam (ML).
Do	do	14x	1			.044	Dekalb silt loam (LP).
Do	do	14x	1			.057	Tilsit silt loam; no fertilization.
Do	do	14x	1			.116	Tilsit silt loam (NP).
Do	Rhode Island	19x	1			.06	Bridgehampton very fine sandy loam (PK).
Do	do	19x	1			.03	Bridgehampton very fine sandy loam (NPK).
Do			33	.12	.03	.07	Summary.
Rice, paddy	Hawaii	561	7	.19	.06	.10	
Rice, brown			18	.11	.06	.09	Do.
Rice, polished		380	1			.06	Do.
Rice, straw	Hawaii	561	7	.70	.09	.31	
Rutabaga, roots			2	.48	.22	.35	Do.
Rye, grain			4	.08	.01	.04	Do.
Rye, straw			31	.27	.04	.13	Do.
Sorghum, green stalk	Texas	240	1			.57	
Sorghum, green head and stalk	do	240	1			.25	
Soybean, leaves	France	335	1			.01	
Soybean, pod	do	335	1			.11	
Soybean, stems	do	335	1			.05	
Soybean, hulls and vines	South Carolina	359	1			.07	
Soybean, above-ground portion, full bloom	do	359	1			.02	
Soybeans, seed, mature			6	.61	.14	.24	Do.
Soybeans, above-ground portion, cut for hay	Kentucky	14x	1			.34	Dekalb silt loam; no fertilization.
Do	do	14x	1			.12	Dekalb silt loam (ML).
Do	do	14x	2	.13	.09	.11	Dekalb silt loam (MP).
Do	do	14x	2	.04	.04	.04	Dekalb silt loam (MPL).
Do	do	14x	2	.10	.04	.07	Dekalb silt loam (MPKL).

Do	do	14x	1			.05	Tilsit silt loam; no fertilization.
Do	do	14x	1			.13	Tilsit silt loam (M).
Do	do	14x	2	.06	.06	.06	Tilsit silt loam (MP).
Do	do	14x	3	.12	.06	.08	Tilsit silt loam (MPK).
Do	do	14x	1			.03	Tilsit silt loam (ML).
Do	do	14x	2	.07	.07	.07	Tilsit silt loam (MPL).
Do	do	14x	2	.14	.11	.12	Tilsit silt loam (MPKL).
Do			32	.34	.03	.10	Summary.
Spinach, edible portion	Maryland	140	2	2.37	1.62	1.99	Sassafras sandy loam.
Do	Virginia	140	2	.99	.70	.84	Norfolk loam.
Do			11	2.37	.34	1.42	Summary.
Sugar beets, roots			8	.76	.26	.47	Do.
Sugar beets, young leaves	Colorado	606	5	4.81	3.96	4.35	
Sugar beets, leaves, mature	Germany	584	14	.65	.52	.56	
Sugarcane, leaves			4	1.45	.11	.84	Do.
Sugarcane, canes			33	.60	.01	.25	Do.
Sunflower, heads minus seeds and husks	District of Columbia	592	1			.06	
Sunflower, seed husk	do	592	1			.02	
Sunflower, seed kernel without husk	do	592	1			.03	
Sunflower, leaves	do	592	1			.17	
Sunflower, stalks	do	592	1			.28	
Sunflower, above-ground portion, cut before bloom	Germany	368	1			1.00	
Sunflower, above-ground portion, full bloom	do	368	1			.77	
Sunflower, flower, cut for forage	do	368	3	.12	.05	.08	
Sunflower, leaves and stems, cut for forage	do	368	3	.08	.07	.07	
Sunflower, seeds with husks	District of Columbia	592	1			.03	
Sweetclover, above-ground portion	Pennsylvania	495	1			.07	Hagerstown loam. *Melilotus alba.*
Do			4	.12	.06	.09	Summary. *M. alba.*
Sweetpotato, tuber	Ohio	192	1			.06	
Timothy, above-ground portion, in bloom	New Hampshire	495	1			.01	Gloucester stony loam.
Do	Pennsylvania	495	1			.02	Hagerstown loam.
Do	do	495	1			.01	Penn silt loam.
Do	North Dakota	278	2	.81	.33	.57	
Timothy, above-ground portion, in seed	Maine	495	1			.07	
Timothy, above-ground portion, cut for hay	Kentucky	14x	4	.35	.15	.24	Tilsit silt loam.
Do	Rhode Island	19x	2	.03	.03	.03	Bridgehampton very fine sandy loam.
Do			19	.41	.01	.18	Summary.
Tobacco, burley; leaves	Virginia	141	1			.15	
Tobacco, cigar binder type; leaves			32	3.47	1.24	2.08	Summary.
Tobacco, cigar wrapper type; leaves	Massachusetts	251	1			2.08	
Tobacco, dark fired type; leaves	Virginia	141	2	.28	.14	.21	
Tobacco, leaves, type unknown			19	1.31	.01	.25	Summary.
Tobacco, above-ground portion	France	62, 64	2	.58	.01		
Tomato, fruit	Florida	5x	26	.50	.11	.22	Parkwood fine sandy loam (NPK).
Do			39	.87	.11	.26	Summary.
Turnip, roots			39	3.75	.18	1.51	Do.
Turnip, leaves			3	1.81	.55	1.14	Do.
Vetch, above-ground portion, in bloom	Germany	368	1			.53	
Vetch, above-ground portion, seeds beginning to ripen	do	368	1			.49	
Vetch, above-ground portion, pods beginning to form	do	368	1			.53	
Vetch, straw, seeds ripening	do	368	1			.11	
Vetch, seeds	do	368	3	.07	.03	.04	
Walnuts, edible portion	California	235	5	.22	.13	.15	

TABLE 21.—*The minor-element content of some important crops*—Continued

SODIUM—Continued

Plant or part of plant	Location	Reference No.	Analyses	Sodium in moisture-free material			Remarks
				Maximum	Minimum	Mean	
			Number	*Percent*	*Percent*	*Percent*	
Wheat, grain	Kentucky	14x	1			.13	Tilsit silt loam; no fertilization.
Do	do	14x	1			.12	Tilsit silt loam (M).
Do	do	14x	1			.15	Tilsit silt loam (ML).
Do	do	14x	2	.12	.10	.11	Tilsit silt loam (MPL).
Do			100	.27	.01	.07	Summary.
Wheat, straw	Kentucky	14x	1			.19	Tilsit silt loam; no fertilization.
Do	do	14x	1			.07	Tilsit silt loam (M).
Do	do	14x	1			.20	Tilsit silt loam (ML).
Do	do	14x	2	.22	.08	.15	Tilsit silt loam (MPL).
Do			48	.30	.01	.14	Summary.

TITANIUM [14]

Plant or part of plant	Location	Reference No.	Titanium	Remarks
			Mg./kg.	
Alfalfa, above-ground portion, cut for hay	France	67	3.6	
Almond, edible portion	do	67	1.3	
Apple, fruit	do	67	.9	
Do	Germany	204	4.0	
Barley, grain	France	67	.9	
Beans, field; seed	do	67	1.5	*Phaseolus vulgaris.*
Beets, roots	do	67	8.0	
Do	Germany	204	11.0	
Beets, leaves	France	67	15.0	
Do	Germany	204	42.0	
Buckwheat, grain	France	67	3.0	
Buckwheat, straw	do	67	6.6	
Cabbage, leaves	do	67	1.5	
Do	do	67	1.2	
Cabbage, heart	do	67	.9	
Cabbage, red	Germany	204	5.0	
Carrots, roots	France	67	4.6	
Carrots, leaves	do	67	30.0	

Cherries, edible portion	do	67	Tr.	
Clover, white; above-ground portion	do	67	3.0	*Trifolium repens.*
Coffee, bean	do	67	4.8	
Corn, grain	do	67	1.4	
Dandelion, edible portion	do	67	6.0	
Dates, edible portion	do	67	.6	
Endive, above-ground portion	do	67	4.0	
Garlic, bulb	do	67	6.0	
Grapes, edible portion	do	67	4.2	
Hazelnuts, edible portion	do	67	.5	
Lemon, fruit	do	67	1.5	
Lettuce, outer leaves	do	67	27.0	
Lettuce, center leaves	do	67	7.0	
Oats, grain	do	67	1.3	
Onions, bulb	do	67	9.3	
Orange, fruit	do	67	.6	
Parsnips, root	do	67	1.9	
Peach, edible portion	do	67	8.0	
Peach, fruit	Germany	204	2.0	
Peanut, edible portion	France	67	.3	
Peas, green, edible portion	do	67	.8	
Peas, above-ground portion	do	67	4.8	
Potatoes, tubers	do	67	1.8	
Prunes, edible portion	do	67	.7	
Radish, root	do	67	8.0	
Rape, above-ground portion, flowering	do	67	3.9	
Rice, polished	do	67	Tr.	
Rye, grain	do	67	.8	
Spinach, edible portion	do	67	12.0	
Strawberries, edible portion	do	67	48.0	
Turnip, roots	do	67	6.0	
Turnip, leaves	do	67	36.0	
Vetch, seed	do	67	3.3	
Walnuts, edible portion	do	67	Tr.	
Wheat, grain	do	67	.9	
Wheat, above-ground portion	do	67	6.0	

[14] Terlikowski and Gornicki (*552*) determined titanium in a number of cereals and grasses and in alfalfa, but they did not give the moisture content of the plants.

TABLE 21.—*The minor-element content of some important crops*—Continued

ZINC [15]

Plant or part of plant	Location	Reference No.	Analyses	Zinc: Maximum	Zinc: Minimum	Zinc: Mean	Remarks
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Alfalfa, above-ground portion, full bloom	France	58	1			14	
Alfalfa, above-ground portion, cut for hay			4	112	14	57	Summary (57, 373, 14x).
Almond, edible portion	France	57	1			21	
Apple, fruit	do	57	2	9	3	6	
Apricots, edible portion	do	57	1			3	
Asparagus, edible portion	do	57	1			52	
Banana	do	57	1			9	
Barley, grain	do	57	1			21	
Beans, field; seed			10	56	23	35	Summary (57, 379). *Phaseolus vulgaris.*
Beans, garden; edible pods and seeds	France	57	1			8	
Beans, garden; edible hulls	Kentucky	379	1			53	
Beans, garden; immature seed	do	379	1			46	
Beans, lima; mature seed	do	379	1			46	
Beets, roots	France	57	2	69	25	47	
Buckwheat, grain	do	57	1			12	
Buckwheat, above-ground portion, cut in bloom	do	58	1			15	
Cabbage, leaves	do	56	2	33	15	24	
Carrots, roots	do	57	1			10	
Carrots, leaves	do	57	1			26	
Cauliflower, edible portion	do	57	1			25	
Cherries, edible portion	do	57	1			6	
Chestnut, edible portion	do	57	1			4	
Clover, alsike; above-ground portion	Kentucky	14x	2	70	50	60	*Trifolium hybridum.*
Clover, red; above-ground portion	do	14x	5	60	30	44	Tilsit silt loam. *T. pratense.*
Do	do	14x	40	70	24	43	Do.
Clover, red; seeds	do	14x	1			76	Do.
Clover, red; foliage	do	14x	1			80	Do.
Coconut, edible portion	France	57	1			17	
Corn, grain	do	57	1			20	
Corn, stover	Kentucky	14x	2	13	9	11	Tilsit silt loam.
Do	do	14x	15	80	5	27	
Cotton, seed	Mississippi	374	1			320	
Cress, water; edible portion	France	57	1			84	
Cress, garden; edible portion	do	56	1			101	
Cucumber, fruit	do	57	1			44	
Dandelion, edible portion	do	56, 57	2	101	98	99	
Dates, edible portion	do	57	1			4	
Endive, above-ground portion	do	57	1			7	

Figs	do	57	2	8	5	7	
Flax, seed	do	57	1			20	
Garlic, bulb	do	57	1			32	
Grapes, edible portion	do	57	1			2	
Hazelnuts, edible portion	do	57	1			10	
Hemp, seeds	do	57, 301	2	90	43	67	
Jerusalem-artichoke, tuber	do	57	1			11	
Kentucky bluegrass, above-ground portion, young blades.	Kentucky	375	1			170	
Kentucky bluegrass, above-ground portion, stage of maturity unknown.			2	28	17	23	Summary (373, 381).
Kentucky bluegrass, seeds	Kentucky	375	1			360	
Lettuce, head	France	57	1			105	
Lettuce, green leaf	do	56	1			119	
Lettuce, etiolated leaf	do	56	1			50	
Mandarin, edible portion	do	57	1			7	
Millet, grain	do	57	1			20	
Mushrooms, edible portion	do	57	1			44	
Mustard, seed	do	301	1			22	
Oats, grain	do	57	1			22	
Oats, straw			8	193	4	83	Summary (57, 382).
Oats, above-ground portion, flowering stage	France	58	1			25	
Onions, bulb	do	57	1			100	
Orange, edible portion	do	57	1			12	
Peach, edible portion	do	57	1			2	
Pear, edible portion	do	57	1			9	
Peas, edible portion	do	57	1			48	
Pineapple, fruit	do	57	1			20	
Pomegranate, fruit, center	do	57	1			12	
Potatoes, tubers	do	57	2	14	11	12	
Prunes, edible portion	do	57	1			2	
Pumpkin, edible portion	do	57	1			44	
Radish, roots	do	57	1			23	
Rape, above-ground portion, flowering	do	58	2	50	50	50	
Redtop, above-ground portion, cut for hay	Kentucky	14x	1			10	Dekalb silt loam, no fertilization.
Do	do	14x	1			20	Dekalb silt loam (M).
Do	do	14x	1			20	Dekalb silt loam (ML).
Do	do	14x	1			60	Dekalb silt loam (PL).
Do	do	14x	1			10	Tilsit silt loam; no fertilization.
Do	do	14x	1			10	Do.
Do	do	14x	1			20	Tilsit silt loam (NP).
Do	do	14x	1			30	Tilsit silt loam (NPL).
Do	do	14x	13	60	10	23	
Rhubarb, stem	France	57	1			22	
Rice, brown		380	1			30	
Rice, polished			3	28	3	13	Summary (57, 373, 380).
Rutabaga, root	France	57	1			29	
Rye, grain	do	57	1			13	
Rye, straw	do	57	1			25	
Salsify, root	do	57	1			35	
Sorghum, grain	do	57	1			14	

[15] The zinc analyses of Berckner (*70*) have been omitted because no moisture data are given.

TABLE 21.—*The minor-element content of some important crops*—Continued

ZINC—Continued

Plant or part of plant	Location	Reference No.	Analyses	Zinc Maximum	Zinc Minimum	Zinc Mean	Remarks
			Number	*Mg./kg.*	*Mg./kg.*	*Mg./kg.*	
Soybean, leaves	Kentucky	372	1			110	
Soybean, seeds, mature	do	372	1			18	
Soybean, above-ground portion, cut for hay	do	14x	1			44	Dekalb silt loam; no fertilization.
Do	do	14x	1			21	Dekalb silt loam (ML).
Do	do	14x	2	30	27	28	Dekalb silt loam (MP).
Do	do	14x	2	34	29	31	Dekalb silt loam (MPL).
Do	do	14x	2	40	32	36	Dekalb silt loam (MPKL).
Do	do	14x	1			34	Tilsit silt loam; no fertilization.
Do	do	14x	1			50	Tilsit silt loam (M).
Do	do	14x	2	61	40	50	Tilsit silt loam (MP).
Do	do	14x	3	50	30	38	Tilsit silt loam (MPK).
Do	do	14x	1			32	Tilsit silt loam (ML).
Do	do	14x	2	40	33	36	Tilsit silt loam (MPL).
Do	do	14x	2	60	50	55	Tilsit silt loam (MPKL).
Do	do	14x	31	80	27	42	Summary.
Spinach	France	56, 57	2	121	67	94	
Strawberries, edible portion	do	57	1			4	
Sunflower, seeds	do	57	1			19	
Sweetclover, above-ground portion	Kentucky	14x	1			50	*Melilotus alba.*
Sweetpotatoes, tuber	France	57	1			5	
Timothy, above-ground portion, cut for hay	Kentucky	14x	4	60	40	50	Tilsit silt loam.
Do	do	14x	13	60	30	42	
Tomato, fruit			2	67	12	39	Summary (57, 378).
Turnip, roots	France	57	1			18	
Turnip, leaves	do	57	1			33	
Vetch, seed	do	57	1			27	
Walnuts, edible portion	do	57	1			24	
Wheat, grain	Kentucky	14x	1			60	Tilsit silt loam; no fertilization.
Do	do	14x	1			80	Tilsit silt loam (M).
Do	do	14x	1			70	Tilsit silt loam (ML).
Do	do	14x	2	90	70	80	Tilsit silt loam (MPL).
Do			27	100	19	63	Summary (57, 67, 381, 543, 551, 14x).
Wheat, straw	Kentucky	14x	1			20	Tilsit silt loam; no fertilization.
Do	do	14x	1			20	Tilsit silt loam (M).
Do	do	14x	1			10	Tilsit silt loam (ML).
Do	do	14x	2	20	20	20	Tilsit silt loam (MPL).
Do	do		24	25	7	17	Summary (57, 381, 14x).