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Chemical Analyses of Iowa Soils for Phosphorus, Nitrogen and Carbon: a Statistical Study

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SOILS SUBSECTION

AGRONOMY SECTION

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SUMMARY

1. Data concerning the phosphorus, nitrogen and carbon content of Iowa soils, as published in the various Iowa Soil Survey reports, have been assembled, summarized and analyzed statistically for the purpose of characterizing the various soil types for the state as a whole.

2. The mean phosphorus, nitrogen and carbon content of each soil type is recorded, and the variability within the types is pointed out.

3. In spite of the variability within soil types, the differences among types, in most cases, were found to be significant or highly significant. Certain soil types were found to be similar in their phosphorus, nitrogen and carbon content, but significantly different from other soils.

4. In general, surface soils contained larger quantities of phosphorus, nitrogen and carbon than subsoils.

5. Dark colored loess soils contained larger quantities of phosphorus, nitrogen and carbon than light colored loess soils.

6. Fine textured soil types contained larger quantities of phosphorus, nitrogen and carbon than the coarser textured types of the same series or of different series. A high or low phosphorus, nitrogen or carbon content, however, seems to be a series characteristic entirely apart from the textural influence. This appears to be related to the topography and native vegetation factors.

7. The loess soils as a group do not differ from the drift soils either in their phosphorus, nitrogen or carbon content nor in their carbon-nitrogen ratio. The bottomland soils, however, contain significantly larger amounts of phosphorus, nitrogen and carbon than the terrace soils, but the two groups do not differ in their carbon-nitrogen ratio. The terrace and bottomland soils as a group contain significantly larger quantities of phosphorus and nitrogen than the loess and drift soils, but the difference in carbon is hardly large enough to be significant. There is little, if any, difference in the carbon-nitrogen ratio.

8. The mean carbon-nitrogen ratio for all soils of Iowa was found to be 12.15 :1, but the largest number of soils had a ratio slightly lower, the mode of the frequency distribution curve being at 12 :1.

9. The close relation between the nitrogen and carbon content of Iowa soils is shown by the high correlation coefficients, which were found to be 0.95 for the drift soils and 0.93 for the loess soils.

10. Although the temperature and humidity factors are of primary importance in determining the nitrogen and carbon content of soils, it appears that within the comparatively narrow range of variation of these factors within the state of Iowa, the factors of topography, soil texture and type of vegetation have been of greatest importance in the differentiation of soil types.

11. In general, the results of this study support the soil type concept now in use in soil classification.

Chemical Analyses of Iowa Soils for Phosphorus, Nitrogen and Carbon: a Statistical Study[1]

By R. H. Walker and P. E. Brown[2]

The Iowa soil survey was begun in 1913 for the purpose of mapping, classifying and determining the pedological and fertility characteristics of Iowa soils. In connection with this work chemical analyses have been made to determine the phosphorus, nitrogen and carbon content of representative samples of the various soil types mapped. Analyses of the soils of each county have been published in their respective soil survey reports and data now are available for the soils in 77 counties.

It is the chief purpose of the study reported here to assemble all of the analytical data on the various soil types as given in the county soil survey reports, and analyze them for the state as a whole in an attempt to characterize the soils with respect to their content of phosphorus, nitrogen and organic carbon. The average content of these constituents in the different soil types was estimated in order that correlations with other soil characteristics might be studied, and also that a more definite basis for estimating the productivity of the various soils and for making recommendations for their proper management might be established.

It has long been established that there is a direct relation between the inherent productivity of soils and their content of the essential plant nutrients. Although this relationship may not hold in the case of the current productivity of a particular soil, it is bound to appear over a period of years and the total plant nutrient content is one of the factors determining the permanence of soil fertility.

The entire quantity of any of the nutrient elements in soils is never in a form available for the use of growing plants. In fact the percentage of nutrients available in the soil at any particular time is usually rather low. But from the unavailable nutrients the available forms are constantly being produced by the biological, chemical and physical processes. Proper soil management and treatment may encourage the production of available nutrients from the unavailable forms to such an ex-

[1] Project 228 of the Iowa Agricultural Experiment Station.

[2] The authors are indebted to the various members of the staff who have assisted in taking the soil samples and in making the chemical analyses during the progress of the Iowa soil survey. Appreciation is also expressed for the suggestions and criticisms offered by Prof. George W. Snedecor of the Statistical Laboratory.

tent that there may seem to be no relation between the total supply and the quantity available for the nutrition of plants. The quantity of plant nutrients made available in a soil over a period of years, however, is dependent mainly upon the total content of these constituents in the soil.

METHODS

At the completion of the soil survey field work in all of the counties, samples of the surface, subsurface and subsoil of each soil type in the county were sent to the soils laboratory for analysis. The chemical analyses reported here were made on these samples.

The more extensive soil types in each county were sampled in three different areas where they were typically developed. The minor soil types were sampled in only one location in each county. The samples were taken with care in order that they would be entirely representative of the types and in order that there would not be any abnormal condition in the samples owing to previous treatments of the area or to peculiarities of the soil in the particular location. In all cases the samples were taken from cultivated fields. This was done because, except in rare cases, it was found impossible to locate virgin areas representative of the types from which samples could be obtained.

Inasmuch as the soil survey and study of soil types were carried on for some time before the development of the present method of characterizing soil types the samples were taken, as in the earlier work, at definite depths from the surface. This method was continued throughout the work. The surface samples were taken from 0 to 6⅔ inches; the subsurface samples from 6⅔ to 20 inches; and the subsoil samples from 20 to 40 inches. The surface samples corresponded more or less closely to what is known as the A horizon. The subsurface samples, in most cases, were probably a mixture of the soil of the A and B horizons. For this reason the data obtained from the study of the subsurface samples were not considered here. The subsoil samples were somewhat representative of the C horizon, or the parent material from which the A and B horizons have been developed through the soil-forming processes. The data obtained in the chemical analysis of the subsoil samples of the upland drift and loess soils were included in this study, but the results on the terrace and bottomland subsoils were omitted.

In this study attention was centered largely upon the data obtained from the analyses of the surface soils of the state.

The chemical determinations for phosphorus, nitrogen, and total and inorganic carbon were made according to the method of the Association of Official Agricultural Chemists (2). The organic carbon was estimated by deducting the quantity of inorganic carbon from the total carbon.

These determinations were made over a period of 20 years, and a number of different analysts have worked on the project. All have used the same methods, however. Determinations have been made for phosphorus and nitrogen on duplicate portions of each soil sample after grinding and mixing. The total carbon determinations were usually made on only one portion of each sample, but in many cases these analyses were also made in duplicate. A study of the data from the duplicate determinations has shown that the error resulting from the variance of portions of individual samples is extremely low and that they may be considered as two observations of the same thing. There is ample justification from the statistical viewpoint for using either determination alone, or an average of the duplicates. This indicates the comparatively small degree of error in the chemical determinations that have been made, but it does not lessen the desirability of making determinations on duplicate portions of the samples. In this work the averages of the duplicate determinations have been used in the analysis of the data.

In order to make the desired comparisons and yet give full consideration to the variability between samples of individual soil types from different locations, it was necessary to employ statistical methods. In most instances the analysis of variance

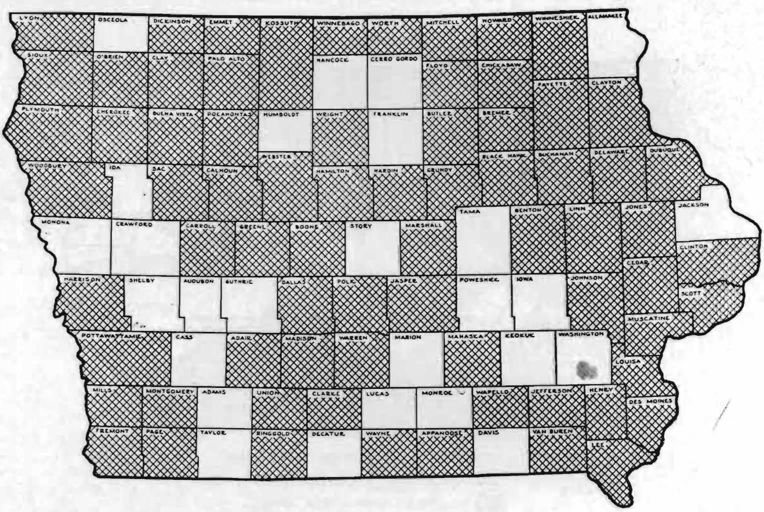

Fig. 1. Cross hatching indicates counties from which data were available for the phosphorus, nitrogen and carbon contents of Iowa soils.

method was used (18). In other cases Student's "t test" for the significance of mean differences, and correlation methods (25) were employed.

At the time this study was initiated data giving the phosphorus, nitrogen and organic carbon content of the soils of the state were available for 72 counties. These counties are well distributed over the state, as shown in fig. 1.

Reference to the soil area and the soil type maps of the state in figs. 2 and 3 shows that the counties from which samples were taken are well distributed among the various soil areas, and also that the principal soil type groups were adequately sampled for this study. Many of the individual soil types, and particularly the more extensive ones, occur in several of the counties and samples were taken in each county. For example, Carrington loam was sampled in 36 counties, O'Neill loam in 30, Waukesha silt loam in 40, and Wabash silt loam in 58 counties.

On the other hand, some of the soil types had been mapped in only one county, hence data on chemical analyses were available for only one sample. Usually these soils were of relatively little importance from the standpoint of total area, although they may be of considerable importance on individual farms. The Clarion fine sand, Dodgeville sandy loam and LaCrosse sandy loam are representative of this group of soils.

It is obvious that data on the chemical composition of a soil which has been sampled from 20 to 40 different counties would give a better idea of the variability within the type and would

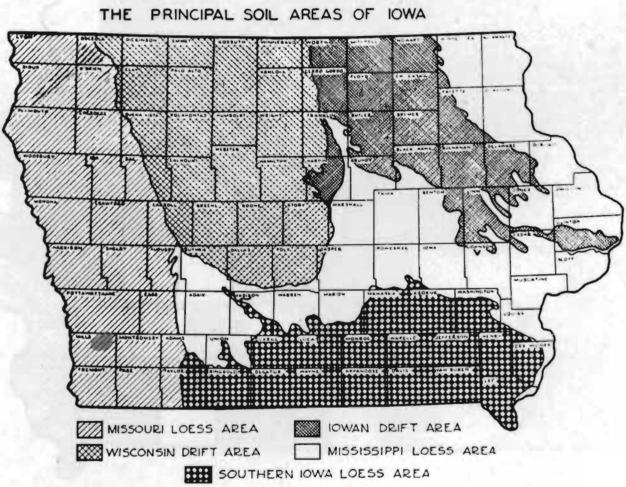

Fig. 2. The location of the principal soil areas of Iowa.

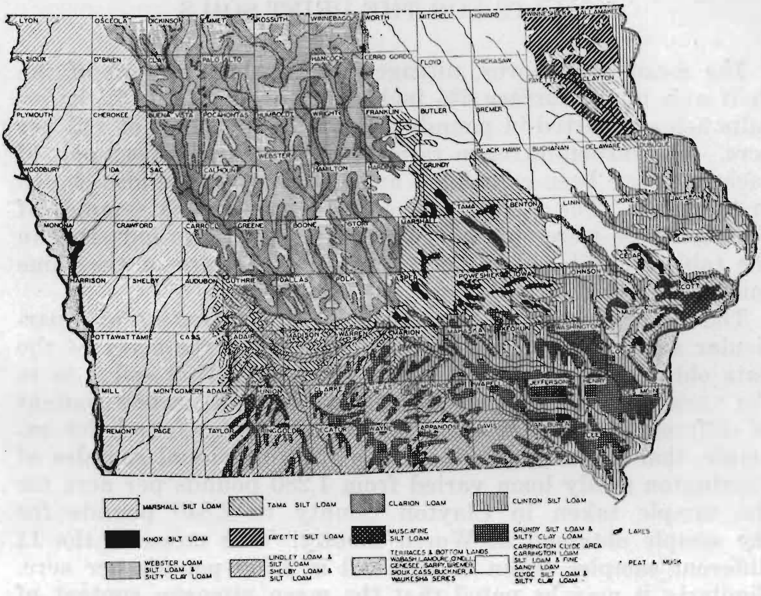

Fig. 3. The location of the principal soil types of Iowa.

offer a more reliable basis upon which to make comparisons between types than one which has been sampled in only one or two locations. The data reported here are entirely adequate for the characterization of most of the soils of the state with respect to their phosphorus, nitrogen and carbon content, and particularly for the more important or extensive soils. The data for the less extensive or minor types cannot be considered so satisfactory but they were included as they have proved to be of some interest.

Reference may be made to the soil survey reports for the individual counties (20) (4) for information concerning the chemical composition of the soil types in any particular county. In this work, however, the data from the individual counties were combined and summarized on the soil type basis for the state as a whole.

It has been convenient in this study to arrange the soils into three groups on the basis of their geological origin and location, namely: drift soils, loess soils and terrace and bottomland soils.

RESULTS FOR THE DRIFT SOILS

The mean phosphorus, nitrogen and carbon content of the drift soils in the surface 6⅔ inches is shown in table 1, the results being reported in pounds per 2 million pounds of soil per acre. The carbon-nitrogen ratios for the individual samples of each soil have been calculated and their means are also shown in the table. The number of counties from which samples of each soil type were obtained for this study is also indicated in the table. Similar data for the subsoil samples of the same soils are shown in table 2.

The mean phosphorus, nitrogen and carbon content of a particular soil, as shown in table 1, provides a summary of the data obtained from the individual samples of that soil. As to the variability of the phosphorus, nitrogen or carbon content of different samples of a particular soil, it was found, for example, that the nitrogen content of the individual samples of Carrington sandy loam varied from 1,280 pounds per acre for the sample taken in Clayton County to 2,840 pounds for the sample obtained in Worth County. The mean of the 11 different samples taken of this soil is 2,000 pounds per acre. Similarly it may be noted that the mean nitrogen content of Webster loam is 5,681 pounds per acre, whereas the individual samples varied from 4,360 pounds per acre in Greene County to 8,200 pounds in Sac County. The standard deviation has been computed for representative types of the drift soils and recorded in table 3. This table also shows the coefficient of variability. These values serve to indicate the extent and character of the variability of the individual observations about the mean.

In view of the large variability of the phosphorus, nitrogen and carbon content of different samples within soil types, it seemed desirable to determine whether or not the differences between types as indicated by the means were significant.

DeTurk (6) made a somewhat similar study on three soil types in Illinois. He states that "the extreme range of values indicated by individual analyses would completely obliterate all chemical boundary lines between soil types." He adds further that, "a study of the means, while it shows in general the differences between types, does not give a reliable indication of the existence or non-existence of boundary lines between types with respect to chemical composition." In making this study, however, DeTurk considered only the range between the extremes of the data and it is doubtful if due consideration was given to the character of the variability. For example, it is possible that the extremes for different types may overlap, but at the same time the majority of the values, as indicated by the standard deviation, may fall into sufficiently different ranges to warrant a differentiation of the types.

TABLE 1. THE MEAN PHOSPHORUS, NITROGEN AND CARBON CONTENT OF THE DRIFT SOILS OF IOWA.

Pounds per acre of 2 million pounds of surface soil; 0—6 2/3 inches.

Soil type	Number of samples	Phos-phorus	Nitrogen	Carbon	C:N ratio
Carrington sand	2	800	550	8,000	14.05
Carrington fine sand	2	750	850	11,500	14.50
Carrington very fine sandy loam	1	700	600	8,000	14.10
Carrington sandy loam	11	864	2,000	25,000	12.50
Carrington fine sandy loam	21	895	2.133	26,380	12.54
Carrington loam	36	1,147	3,756	44,300	12.24
Carrington loam (steep phase)	6	1,117	3,383	43,000	12.97
Carrington loam (rolling phase)	1	1,100	3,900	46,000	11.70
Carrington silt loam	24	1,288	4,606	53,580	11.66
Clarion fine sand	1	1,600	2,200	28,000	12.60
Clarion sandy loam	1	1,100	2,800	32,000	11.30
Clarion fine sandy loam	6	1,100	3,083	38,670	12.28
Clarion loam	19	1,205	4,368	48,840	11.22
Clarion loam (rolling phase)	5	1,180	4,160	47,800	11.60
Clarion loam (shallow phase)	1	900	2,600	29,000	11.20
Clarion loam (steep phase)	5	1,060	2,840	43,000	18.48
Clarion silt loam	7	1,257	4,986	60,570	12.18
Clyde silt loam	14	1,642	7,157	80,070	12.50
Clyde silty clay loam	17	1,735	7,929	91,290	11.72
Conover silt loam	2	700	2,150	27,000	12.45
Dickinson loamy sand	1	500	900	8,300	9.40
Dickinson sandy loam	5	1,060	1,860	27,600	14.54
Dickinson loamy fine sand	1	900	800	26,000	32.00
Dickinson fine sandy loam	10	870	2,310	32,000	16.19
Dickinson loam	8	1,175	3,475	36,620	10.80
Dodgeville sandy loam	1	600	1,700	23,000	13.80
Dodgeville loam	5	1,080	4,060	37,600	9.96
Dodgeville silt loam	7	1,043	4,357	49,140	11.24
Dodgeville silt loam (shallow phase)	1	1,000	3,900	51,000	12.90
Floyd silt loam	5	1,540	6,420	81,800	13.32
Lakeville sandy loam	1	1,300	4,300	36,000	8.50
Lindley sand	1	1,000	700	8,000	11.50
Lindley fine sand	6	733	782	10,830	14.37
Lindley sandy loam	4	600	850	9,250	10.43
Lindley fine sandy loam	9	789	1,733	21,330	12.44
Lindley very fine sandy loam	2	1,000	2,550	31,000	12.65
Lindley loam	21	852	2,033	24,470	11.86
Lindley silt loam	19	847	2,226	26,840	12.20
Pierce sandy loam	4	1,025	2,775	28,500	12.55
Pierce fine sandy loam	2	1,400	4,950	53,500	11.35
Pierce loam	2	1,100	3,400	43,500	12.75
Rogers silt loam	3	2,033	17,330	235,670	14.40
Roseville silt loam	1	500	3,000	29,000	9.90
Shelby loamy fine sand	1	400	900	8,000	8.60
Shelby sandy loam	1	600	1,200	7,000	6,10
Shelby fine sandy loam	4	725	2,300	23,750	10.02
Shelby loam	17	965	3,023	34,765	11.58
Shelby silt loam	6	883	3,150	35,170	10.98
Thurston loamy sand	1	1,000	900	12,000	12.70
Thurston sandy loam	3	1,000	1,600	20,000	13.53
Thurston loam	1	1,000	1,900	23,000	12.00
Webster loam	16	1,244	5,681	66,190	11.82
Webster silt loam	6	1,567	8,633	102,000	12.23
Webster silty clay loam	19	3,084	4,158	54,890	14.35
Webster clay loam	8	1,788	6,762	82,620	12.50
Weighted average for all soils		1,215	3,720	45,742	12.34

TABLE 2. THE MEAN PHOSPHORUS, NITROGEN AND CARBON CONTENT OF THE DRIFT SOILS OF IOWA.

Pounds per acre of 6 million pounds of subsoil; 20—40 inches.

Soil type	Number of samples	Phos-phorus	Nitrogen	Carbon	C:N ratio
Carrington sand	2	1,600	850	12,000	15.75
Carrington fine sand	2	1,400	1,800	21,500	11.45
Carrington very fine sandy loam	1	1,300	1,000	19,000	18.50
Carrington sandy loam	11	1,900	2,310	25,090	12.15
Carrington fine sandy loam	21	2,019	2,576	33,520	13.24
Carrington loam	36	2,200	3,703	41,440	11.93
Carrington loam (steep phase)	6	2,450	2,617	34,000	14.56
Carrington loam (rolling phase)	1	2,000	2,900	20,000	7.10
Carrington silt loam	24	2,271	3,892	39,670	10.61
Clarion fine sand	1	5,000	1,700	26,000	15.40
Clarion sandy loam	1	2,700	2,520	24,870	9.87
Clarion fine sandy loam	6	2,700	2,567	39,830	15.40
Clarion loam	19	2,763	3,774	45,580	14.56
Clarion loam (rolling phase)	5	2,800	3,150	22,750	7.15
Clarion loam (shallow phase)	1	2,700	2,000	15,000	7.40
Clarion loam (steep phase)	5	3,160	3,360	24,200	18.50
Clarion silt loam	7	3,457	3,871	42,860	12.71
Clyde silt loam	13	2,554	3,234	34,714	10.87
Clyde silty clay loam	17	3,238	4,205	49,705	11.83
Conover silt loam	2	2,000	2,550	30,000	11.55
Dickinson loamy sand	1	1,200	500	7,000	15.20
Dickinson sandy loam	5	1,900	2,020	22,000	10.52
Dickinson loamy fine sand	1	1,700	1,200	18,000	14.70
Dickinson fine sandy loam	10	1,850	2,990	24,800	9.43
Dickinson loam	8	2,375	2,375	22,880	11.59
Dodgeville sandy loam	1	1,200	3,200	35,000	10.90
Dodgeville loam	2	2,181	3,365	50,393	14.65
Dodgeville silt loam	5	1,960	4,740	54,000	11.66
Dodgeville silt loam (shallow phase)	1	1,900	3,700	40,000	11.00
Floyd silt loam	5	2,540	1,900	20,200	7.88
Lakeville sandy loam	1	2,400	3,500	8,000	2.30
Lindley sand	1	1,700	780	7,935	10.17
Lindley fine sand	6	1,200	1,033	13,000	16.97
Lindley sandy loam	4	1,450	1,625	14,500	10.85
Lindley fine sandy loam	9	2,078	2,000	16,220	9.79
Lindley very fine sandy loam	2	2,300	2,100	29,500	13.50
Lindley loam	21	2,195	1,971	23,619	13.37
Lindley silt loam	19	2,215	2,084	19,789	10.47
Pierce fine sandy loam	2	3,200	1,700	19,000	11.10
Pierce loam	2	2,600	3,500	30,000	8.70
Rogers silt loam	3	4,333	43,133	457,330	10.60
Roseville silt loam	1	300	1,300	12,000	9.20
Shelby loamy fine sand	1	500	4,300	——	——
Shelby sandy loam	1	1,100	1,300	13,000	10.00
Shelby fine sandy loam	4	1,675	3,375	28,500	8.58
Shelby loam	17	2,170	2,817	28,940	10.59
Shelby silt loam	6	1,316	2,950	28,000	9.76
Thurston loamy sand	1	1,400	1,200	10,000	8.80
Thurston sandy loam	3	2,567	2,867	20,670	11.23
Thurston loam	1	1,400	600	13,000	21.00
Webster loam	16	2,544	4,219	45,750	10.66
Webster silt loam	6	3,183	5,150	79,670	14.27
Webster silty clay loam	19	3,084	4,158	54,890	14.35
Webster clay loam	8	3,150	3,112	36,620	13.47
Weighted average for all soils		2,373	3,691	37,700	11.49

TABLE 3. THE MEAN, STANDARD DEVIATION AND COEFFICIENT OF VARIABILITY OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF REPRESENTATIVE DRIFT SOILS OF IOWA.

Code: P and N ÷ 100; C ÷ 1,000.

Soil type	Number of determinations	Phosphorus			Nitrogen			Carbon		
		Mean	Standard deviation	Coefficient of variability	Mean	Standard deviation	Coefficient of variability	Mean	Standard deviation	Coefficient of variability
Carrington sandy loam	11	864	157	18.1	2,000	506	25.3	25,000	7,670	30.0
Clarion loam	19	1,205	297	24.6	4,368	1,040	23.8	48,840	10,980	22.4
Webster loam	16	1,244	253	20.3	5,681	1,137	20.0	66,190	13,520	20.4
Carrington silt loam	24	1,288	225	17.4	4,604	932	20.2	53,580	11,490	21.4
Clyde silty clay loam	17	1,735	404	23.2	7,929	2,320	29.2	91,290	29,800	32.6
Webster silty clay loam	19	3,084	868	28.1	4,158	2,316	55.6	54,890	30,120	54.8
All drift soils (55 types)	384	1,215	610	50.2	3,720	2,290	61.5	45,742	31,700	69.3

Bizzell (3) studied the chemical composition of New York soils and among other things he reported the nitrogen and phosphorus content for 101 soils. There was a wide variation in chemical composition between samples of one type taken from different localities, and the variations were frequently greater than the differences between averages of different types. He concluded that in total nitrogen and phosphorus the types are neither distinct nor are the soils within each type closely similar. Owing to the relatively small number of samples in most of the soil types, no attempt was made to analyze the data statistically, as it was considered impossible to give a satisfactory mathematical expression to this variation.

Walker (24) studied the chemical composition of Louisiana soils and came to the conclusion that there are usually wider variations within a given series or class than there are between averages of series or classes.

In analyzing the data for the drift soils of Iowa, the results obtained from all of the individual samples within a soil type were employed; hence all of the variability within types was given full consideration. The results are shown in table 4.

Before making the analysis the figures reported in the soil survey reports were coded by dividing the pounds per acre of phosphorus and nitrogen by 100 and the pounds per acre of carbon by 1,000. The mean square figures shown in the analysis of variance tables were not decoded, but wherever the means for phosphorus, nitrogen or carbon content are shown, as in tables 1, 2, 11, etc., the figures are decoded and the values shown are of the proper magnitude.

There are 384 individual samples of soil distributed among

TABLE 4. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF THE VARIOUS TYPES OF DRIFT SOILS OF IOWA.

Code: P and N ÷ 100; C ÷ 1,000

Source of variation	Degrees of freedom	Mean square			
		Phosphorus	Nitrogen	Carbon	C:N ratio
Surface: 0 to 6 2/3 inches					
Total	383	37	526	977	18
Between soil types	54	190**	2,496**	5,279**	26*
Within soil types	329	12	203	272	17
Subsoil: 20 to 40 inches					
Total	370	71	1,673	2,250	55
Between soil types	52	380**	8,216**	11,419**	135**
Within soil types	318	21	602	754	41

*Significant difference
**Highly significant difference

the 55 types considered in this analysis. The data of table 4 indicate that in spite of the large variability within types the differences among types are highly significant. This is true for the phosphorus, nitrogen and carbon content of both the surface and subsoil samples. The variability of the samples is not great enough to conceal the actual differences among the type means for these constituents.

The above conclusions apply to the drift soil types as a whole, and not to the difference between any two soil types that may be singled out for direct comparison. In order to make an independent comparison of two soils it would be necessary to make a "t test" of the mean difference. For example, in comparing the Clarion and Webster silt loams in their nitrogen contents it may be observed from table 1 that the means are 4,986 and 8,633 pounds per acre, respectively. The mean difference is 3,647 pounds which was found to be significant. Hence the difference in nitrogen content of these two soils is real and cannot be accounted for on the basis of random sampling.

Similarly the Carrington silt loam and Webster silt loam with mean nitrogen contents of 4,606 and 8,633 pounds per acre, respectively, are found to be highly significantly different. On the other hand, the mean difference between the Carrington and Clarion silt loams is only 380 pounds of nitrogen per acre, which is not significant. Thus it is shown that although the analysis of variance in table 4 indicates that there are real and significant differences among types, certain soils may not differ materially in nitrogen, phosphorus or carbon.

The Clarion and Webster soils of the Wisconsin Drift area probably were similarly supplied with phosphorus, nitrogen and carbon when they were laid down by the glacier. Owing to the topographic position of the Webster soils, however, and their occurrence in somewhat depressed and poorly-drained locations, they have supported a greater abundance of plant growth than the Clarion soils which are rolling in topography and naturally well drained. The rate of organic matter decomposition also has been less in the wetter soils, and these two conditions have favored a larger accumulation of organic matter which is shown by the higher content of carbon and nitrogen. Furthermore, the topographic conditions have favored the leaching of nutrients from the higher-lying Clarion soils and their accumulation in the depressed areas of Webster soils. Similar comparisons may be made of the Carrington and Clyde soils of the Iowan Drift area. The mean contents of phosphorus, nitrogen and carbon of the Clyde soils are higher and apparently significantly higher in most cases, than in the rolling Carrington soils.

Soils having considerably smaller mean phosphorus, nitrogen and carbon contents than those referred to above are the Shelby and Lindley loams of southern Iowa. These soils may have contained quite different amounts of phosphorus, nitrogen and carbon than the soils of northern Iowa when they were laid down by glacial action, but in addition to that they have been subjected to somewhat different environmental conditions during the period of soil formation. They are older soils; they have been formed under conditions of greater rainfall, and in general they are steeper in topography than the soils of northern Iowa previously referred to.

COMPARISON OF SURFACE AND SUBSOILS

A number of investigators have found that the percentage content of nitrogen and carbon is considerably less in the subsoil than it is in the surface layer. Naturally the differences in phosphorus content have not been so pronounced as those for nitrogen and carbon. The data recorded in table 1 show the pounds of the various constituents per acre to a depth of 6⅔ inches which is considered to be equivalent to 2,000,000 pounds of soil. The data representing the subsoils recorded in table 2 are based on a soil depth from 20 to 40 inches below the surface, or a layer three times the thickness of the surface layer. In order to make a direct comparison of the content of the surface and subsoil horizons of these soils, therefore, it would be necessary first to divide the figures for the subsoils by 3. The composition of both soil layers would then be expressed on the basis of pounds per 2 million pounds of soil. In this way a comparison may be made between the surface and subsoil layers of any soil type. In the case of the Webster loam for example, the mean phosphorus, nitrogen and carbon content of the surface soil, as shown in table 1, is 1,244, 5,681, and 66,190 pounds per acre, whereas the corresponding values for the subsoil when calculated to an equivalent basis would be 848, 1,406 and 15,250 pounds per acre, respectively. In order to make a more generalized comparison between the two soil layers the mean content for all the soil types in the drift group was computed and found to be 1,215, 3,720, and 45,742 pounds, whereas for the subsoils the corresponding figures were 791, 1,230, and 12,566 pounds, respectively.

It is apparent from these means that there is a real difference in the nitrogen and carbon content of the two horizons, and this is to be expected. It is in the surface horizon that organic matter has accumulated from plant remains during the ages through which the soils have developed.

It also appears that the difference in phosphorus content in the two horizons is significant. It seems reasonable to assume that the phosphorus content of the surface and subsoil layers was practically the same when the soil material was deposited by glacial action. It follows, therefore, that factors must have been in operation since that time to increase the phosphorus content of the surface layer, or to decrease it in the subsoil, or both. This change may be explained, undoubtedly, on the basis of the assimilation of phosphorus by plant roots in the subsoil, and the subsequent translocation of a portion of it to the stems and leaves of the plants. Thus as organic matter accumulated in the surface soil there was also an accumulation of phosphorus in this soil horizon, although to a lesser degree than in the case of nitrogen and carbon.

THE INFLUENCE OF TEXTURE

It has been commonly recognized that the total plant nutrient content of soils varies widely with the texture. In order to determine whether or not this is true for the drift soils of Iowa the data of table 1 were studied further.

The relationship of texture to composition within a single series is shown in table 5. In this table the available classes of soils belonging to the Carrington series are listed according to their increasing degree of fineness of texture, and their corresponding phosphorus, nitrogen and carbon contents are shown. It is evident that there is a rather definite and consistent relationship between the texture of the soil and the content of these constituents.

The limitations of this type of comparison are not to be overlooked. In the first place the comparison has been confined to a small group of similar soils. This objection may be met by

TABLE 5. THE AVERAGE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF SOIL TYPES OF DIFFERENT CLASSES OF THE CARRINGTON SERIES.

Soil types ranked in order of texture	Pounds per acre		
	Phosphorus	Nitrogen	Carbon
Carrington sand	800	550	8,000
Carrington fine sand	750	850	11,500
Carrington sandy loam	864	2.000	25,000
Carrington fine sandy loam	895	2,133	26,380
Carrington loam	1,147	3,756	44,300
Carrington silt loam	1,288	4,606	53,580

analyzing the data from a larger number of soils. This has been done and the results are reported below. Another objection is the fact that the type designation, although it is an expression of the texture, is not a very specific designation. For example there is some range of texture among soils that fall into the loam class. If a single mathematical expression could be used to express the specific texture of a soil it would be much easier to make a correlation between texture and composition and the results would more nearly approach the ideal. Russell and McRuer (15) used the hygroscopic coefficient as an expression of soil texture in their studies. Unfortunately in the work reported here no data are available to provide a single value expression of soil texture.

In order to overcome partially the limitations pointed out, and make more reliable comparisons of the phosphorus, nitrogen and carbon content of the various textural groups, a statistical analysis was made for the individual soils within the groups, and then comparisons were made between groups. The textural groups studied, and the soils included in each group are shown in table 6. This table also gives the low and high means for the various constituents for the soils within each textural group.

In the first place an analysis of variance was made of the data for the soils listed in each textural group. These analyses are recorded in table 7.

It was found that in the group of sandy loam soils the different types differ among themselves significantly or highly significantly in phosphorus, nitrogen and carbon. They also differ in carbon-nitrogen ratio. The fine sandy loam soils differ significantly in nitrogen and carbon-nitrogen ratio, but the differences in their phosphorus and carbon contents are not sufficiently large to be significant. The various types within the loam, silt loam, silty clay loam, and clay loam classes differ significantly in content of all constituents in all cases.

In general, it appears that the different soils within a specific textural group differ among themselves in content of phos-

TABLE 6. THE HIGH AND LOW MEAN NITROGEN, PHOSPHORUS AND CARBON CONTENT OF TEXTURAL GROUPS OF DRIFT SOILS USED IN TEXTURAL COMPARISONS.

Textural group	Soil type	No. of samples	Phosphorus low	Phosphorus high	Nitrogen low	Nitrogen high	Carbon low	Carbon high
Sandy loams								
	Thurston	3	—	—	—	—	—	—
	Pierce	4	—	—	—	—	—	—
	Carrington	11	—	—	—	3,756	—	44,300
	Dickinson	5	—	1,175	—	—	—	—
	Lindley	4	600	—	850	—	9,250	—
Fine sandy loams								
	Shelby	4	725	—	—	—	—	—
	Carrington	21	—	—	—	—	—	—
	Clarion	6	—	1,100	—	3,083	—	38,670
	Dickinson	10	—	—	—	—	—	—
	Lindley	9	—	—	1,733	—	21,330	—
Loams								
	Shelby	17	—	—	—	—	—	—
	Carrington (steep phase)	6	—	—	—	—	—	—
	Clarion (rolling phase)	5	—	—	—	—	—	—
	Clarion (steep phase)	5	—	—	—	—	—	—
	Clarion	19	—	—	—	—	—	—
	Carrington	36	—	—	—	—	—	—
	Dodgeville	5	—	—	—	—	—	—
	Dickinson	8	—	—	—	—	—	—
	Lindley	21	852	—	2,033	—	24,476	—
	Webster	16	—	1,244	—	5,681	—	66,190
Silt loams								
	Webster	6	—	—	—	—	—	—
	Rogers	3	—	2,033	—	17,330	—	235,670
	Clarion	7	—	—	—	—	—	—
	Carrington	24	—	—	—	—	—	—
	Dodgeville	7	—	—	—	—	—	—
	Conover	2	700	—	2,150	—	—	—
	Clyde	13	—	—	—	—	—	—
	Floyd	5	—	—	—	—	—	—
	Lindley	19	—	—	—	—	26,842	—
	Shelby	2	—	—	—	—	—	—
Silty clay loams and clay loam	Clyde s.c.l.	17	1,735	—	—	7,962	—	91,940
	Webster s.c.l.	19	—	3,084	4,158	—	54,890	—
	Webster c.l.	8	—	—	—	—	—	—

phorus, nitrogen and carbon. In view of this fact the question then arises whether or not the differences between the means of groups are sufficiently large to be significant in spite of the variability within the various groups.

To answer this question the data were analyzed by the analysis of variance with the results shown in table 8. It may be noted that the mean square within soil types is considerably less than that between textural groups in the case of phosphorus, nitrogen and carbon. Just the opposite is true for the carbon-nitrogen ratio. These results may be interpreted to mean that the observed differences in the means of the phosphorus, nitrogen and carbon content of the textural groups of soils are real and of sufficient magnitude that they are not obscured by the variability within the types of the various textural groups. In

TABLE 7. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF DIFFERENT SOIL TYPES IN THE TEXTURAL GROUPS OF DRIFT SOILS LISTED IN TABLE 6.

Code: P and N ÷ 100; C ÷ 1,000.

Source of variation	Degrees of freedom	Mean square			
		Phosphorus	Nitrogen	Carbon	C:N ratio
Sandy loams					
Between soil types	4	14.9*	196**	263**	16.1**
Within soil types	22	5.1	38	77	2.5
Fine sandy loams					
Between soil types	4	11.7	171*	342	417.9**
Within soil types	45	5.6	62	178	53.8
Loams					
Between soil types	9	25.5**	1,497**	1,919**	29.5*
Within soil types	116	7.0	102	129	12.3
Silt loams					
Between soil types	9	104.2**	3,830**	15,022**	4.1
Within soil types	76	7.1	395	435	11.7
Silty clay loams and clay loam					
Between soil types	2	969.4**	6,030**	6,338**	30.5
Within soil types	40	47.2	516	742	15.9

*Significant
**Highly significant

TABLE 8. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF THE SOIL TYPES OF THE TEXTURAL GROUPS OF DRIFT SOILS SHOWN IN TABLE 6.

Code: P and N ÷ 100; C ÷ 1,000.

Source of variation	Degrees of freedom	Mean square			
		Phosphorus	Nitrogen	Carbon	C:N ratio
Between textural groups	4	1,574**	12,848**	21,707**	11.0
Within soil types	327	21	390	780	23.1

**Highly significant

view of this conclusion it appears from the data of table 6 that the soils classified in the finer textural groups contain significantly larger amounts of phosphorus, nitrogen and carbon than the soils of coarser texture. This general relationship is illustrated by the graph in fig. 4 where the mean phosphorus, nitrogen and carbon content of the various textural groups is shown.

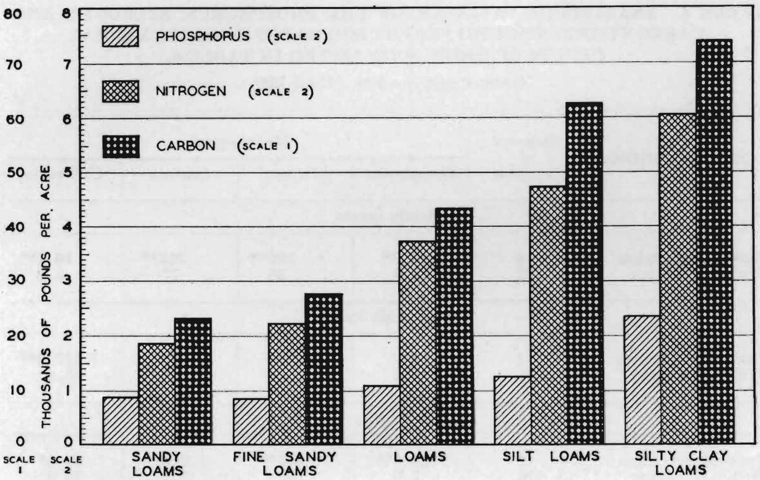

Fig. 4. The mean phosphorus, nitrogen and carbon content of various textural groups of drift soils.

The graph also indicates that the correlation between texture and nitrogen and carbon content is probably larger than it is between texture and phosphorus content. The results of this analysis show that the soils of different texture either contained different amounts of phosphorus before they were acted upon by the weathering processes or, owing to their textural differences, they have lost phosphorus at different rates through drainage, crop removal or other means, or the present difference in phosphorus content may be the resultant of both of these factors. In the case of nitrogen and carbon, however, the situation is somewhat different. Considerable amounts of each of these elements have been added to the soil from outside sources during the process of soil formation. The nitrogen content has undoubtedly been increased as a result of the growth and the fixation of atmospheric nitrogen by the nitrogen fixing bacteria of the soil. The carbon content has been increased through the photosynthetic process and the subsequent accumulation of organic debris in the soil. The comparative phosphorus, nitrogen and carbon contents of the surface and subsoils substantiate these conclusions. Hence the results of table 8 indicate that the soil texture has had a real influence either on the factors tending toward an increase or a decrease in soil nitrogen and carbon, or on both.

Walker (24) did not find this type of relationship between soil texture and the content of phosphorus and nitrogen for Louisiana soils. In his studies on 67 samples of 27 soil types he found rather wide variations between extremes in phosphorus and nitrogen content but he concluded that the results were so uniform for most of the soils that the averages for each series or textural group were practically the same. No attempt was made to analyze the data statistically.

On the other hand, in their studies on Nebraska soils, Russell and McRuer (16) concluded that texture is the outstanding factor determining nitrogen content in any soil type, and since all soil types show considerable variation in texture, they exhibit a corresponding variation in nitrogen content.

In studying the chemical composition of the soils of New York, Bizzell (3) arranged them on the basis of fineness of division or texture, beginning with the coarsest and ending with the finest textural group. He found that nitrogen and potassium have a distinct tendency to increase with an increase of fineness of the soil. Phosphorus, magnesium and sulfur exhibhibited the same general trend, although the differences were not so pronounced. These observations are in complete agreement with those reported here.

Some question may arise as to the significance of the differences between two closely related textural groups. Inasmuch as there is a natural continuity of textural change from the coarsest to the finest textured soil in the field without sharp lines of demarcation appearing such as have been artificially and arbitrarily set up in the laboratory, and also since the method of establishing soil class as used in the field by the soil surveyor is not one of specific measurement, it is natural that borderline cases may be interpreted differently by different observers. This is a possible source of error in this type of comparison and it serves to emphasize the fact that if absolute measurements of soil texture were available the relationship of texture to composition would undoubtedly be more pronounced.

Another possible explanation of the fact that statistically significant differences in phosphorus, nitrogen and carbon content may not occur between two specific textural groups whereas there would be differences between other groups, lies in the fact that the actual difference in texture between the two groups may be very slight. The sandy loam and fine sandy loam groups, for example, may be much more closely related in specific texture, if it were possible to make such a measurement, than the fine sandy loam and loam classes, or the loam and silt loam classes.

COMPARISON OF SOILS OF UNIFORM TEXTURE

A convenient and interesting comparison of the various soils as affected by factors other than texture may be obtained by ranking those soils of a certain textural class according to their content of phosphorus, nitrogen and carbon. This has been

TABLE 9. LOAM SOILS IN THE DRIFT AREAS RANKED IN ORDER OF INCREASING PHOSPHORUS, NITROGEN AND CARBON CONTENT.

Rank	Phosphorus	Nitrogen	Carbon
1	Lindley	Thurston	Thurston
2	Shelby	Lindley	Lindley
3	Thurston	Shelby	Shelby
4	Dodgeville	Pierce	Dickinson
5	Pierce	Dickinson	Dodgeville
6	Carrington	Carrington	Pierce
7	Dickinson	Dodgeville	Carrington
8	Clarion	Clarion	Clarion
9	Webster	Webster	Webster

TABLE 10. SILT LOAM SOILS IN THE DRIFT AREAS RANKED IN ORDER OF INCREASING PHOSPHORUS, NITROGEN AND CARBON CONTENT.

Rank	Phosphorus	Nitrogen	Carbon
1	Roseville	Conover	Lindley
2	Conover	Lindley	Conover
3	Lindley	Roseville	Roseville
4	Dodgeville	Dodgeville	Dodgeville
5	Clarion	Carrington	Carrington
6	Carrington	Clarion	Clarion
7	Floyd	Floyd	Clyde
8	Webster	Clyde	Floyd
9	Clyde	Webster	Webster
10	Rogers	Rogers	Rogers

done for the loam and silt loam soils and the results are shown in tables 9 and 10, respectively. The mean phosphorus, nitrogen and carbon contents of these soils, as recorded in table 1, have been employed in making this classification.

The relative phosphorus, nitrogen and carbon content of the various soils is shown in these tables. It may be noted that soils which rank high in one constituent have a tendency to have approximately the same ranking in the other two constituents. The same tendency appears for the low ranking soils.

It may also be observed from these tables that the series which rank the highest in the various constituents in one texture also tend to rank high in other textural classes. The same observation may be made for the low ranking soils. In other words, a high or low phosphorus, nitrogen or carbon content seems to be a series characteristic entirely apart from the textural influence. It is only natural that this should be the case for it is the individual and combined characteristics of soils, other than texture, that differentiate them into series.

Undoubtedly the soil-forming processes that have operated on soils of similar inherent characteristics to produce types having entirely different acquired characteristics have also had a profound influence upon their phosphorus, nitrogen and carbon content. Indeed the content of phosphorus, nitrogen and carbon of a soil is an important characteristic of that soil, and it is reflected either directly or indirectly in other profile characteristics. The fact that significant differences occur in the phosphorus, nitrogen and carbon contents of soil types, and also between series of similar classes, is strong evidence in support of the soil type theory of soil classification. In other words the chemical analysis of soils supports and substantiates the differentiation of soils into series and classes in the field by the soil surveyor. Although this is true in general when a large number of soils is considered, it should not be misinterpreted to mean that it may be possible to differentiate soils merely by making analyses for their phosphorus or nitrogen content. It must be kept in mind that the phosphorus or nitrogen content of a soil is only one of its many characteristics, and that a knowledge of one character cannot be used to determine the other characters. There is a close relationship, however, between this characteristic and the others that are employed in differentiating soils.

RESULTS FOR THE LOESS SOILS

The mean phosphorus, nitrogen and carbon content of the loess soils of Iowa is shown in table 11. In order to indicate the extent of the variability within types in this group of soils, the standard deviation of the phosphorus, nitrogen and carbon for three of the more important soils and for the loess soils as a whole has been computed and is shown in table 12. From this table it appears that the loess soils show approximately the same degree of variability as the drift soils. For example, the nitrogen content of the Tama silt loam varied from 3,360 pounds per acre in the sample from Fayette County to 6,010 pounds in the sample from Marshall County. The mean is 4,269 pounds per acre, and the standard deviation is 700 pounds, which is 16.3 percent of the mean. Somewhat larger variability is indicated for the nitrogen content of the Clinton and Marshall silt loams and for the loess soils as a group. The variability in the phosphorus and carbon content of these soils is also indicated by the data of table 12.

As in the case of the drift soils an analysis of variance of the data for all of the individual samples of each soil has been made for the purpose of determining whether the variability within soils is so large as to obscure differences between types. The results of this analysis are shown in table 13.

It was found that the variance within types was considerably and significantly less than that between types in the case of phosphorus, nitrogen and carbon for the surface samples. Hence the differences between means of types are highly significant. There is no significant difference, however, between

TABLE 11. THE PHOSPHORUS, NITROGEN, AND CARBON CONTENT OF THE LOESS SOILS OF IOWA.

Soil type	Number of samples	Surface Soil: 0—6 2/3 inches				Subsoil: 20—40 inches			
		Phosphorus	Nitrogen	Organic carbon	C:N ratio	Phosphorus	Nitrogen	Organic carbon	C:N ratio
Afton silty clay loam	1	1,200	7,000	74,000	10.50	3,100	8,500	67,000	7.90
Clinton sand	1	500	800	12,000	14.30	1,000	1,000	12,000	12.40
Clinton fine sand	4	875	750	9,750	12.45	2,025	1,125	15,500	13.25
Clinton loamy fine sand	1	600	500	8,000	14.20	2,100	700	8,000	10.50
Clinton fine sandy loam	4	750	1,075	14,750	13.90	2,175	3,225	38,250	11.55
Clinton very fine sandy loam	4	825	2,050	21,000	10.40	2,375	2,575	19,500	8.32
Clinton silt loam	36	1,019	2,506	30.030	12.05	2,958	2,542	25,420	10.61
Clinton silt loam (steep phase)	3	1,200	1,900	21,660	11.57	2,866	2,300	20,333	9.53
Edina silt loam	1	1,200	3,500	38,000	10.80	2,400	4,400	49,000	11.10
Fayette sand	1	500	300	5,000	13.30	1,800	800	9,000	10.60
Fayette fine sand	1	600	1,200	16,000	14.10	1,800	300	2,700	9.00
Fayette very fine sandy loam	1	800	2,200	29,000	13.10	3,200	1,400	17,000	12.00
Fayette silt loam	7	943	2,300	25,580	11.17	2,685	3,128	23,850	7.86
Fayette silt loam (steep phase)	1	500	1,300	12,000	9.70	2,500	5,100	23,000	4.50
Grundy silt loam	19	1,268	4,253	53,630	12.70	2,374	4,505	51,100	11.43
Grundy silty clay loam	7	1,229	4,971	62,710	12.54	2,200	3,786	50,140	13.37
Grundy clay loam	3	1,533	4,800	57,330	12.37	2,700	3,667	63,000	15.87
Knox silt loam	6	1,283	2,117	19,500	9.25	4,050	2,150	19,830	9.13
Marcus silt loam	1	1,300	6,000	62,000	10.40	3,500	10,100	64,000	6.30
Marion silt loam	7	957	2,229	26,860	12.07	2,557	2,657	23,860	9.40
Marshall silt loam	14	1,329	4,029	43,860	11.22	3,443	5,314	47,360	9.83
Marshall silt loam (level phase)	3	1,800	5,600	66,000	11.73	1,800	5,600	66,000	11.73
Marshall silt loam (shallow phase)	4	1,350	3,575	38,750	11.75	3,800	3,175	27,750	8.88
Muscatine silt loam	13	1.400	4,415	51,846	11.62	2,653	4,531	45,461	10.36
Muscatine silty clay loam	2	1,500	4,750	61,500	12.90	4,100	3,800	90,500	28.30
Putnam silt loam	6	1,150	3,083	36,330	11.90	2,367	4,100	42,170	10.22
Scott silt loam	2	1,350	3,550	41,500	11.75	2,500	3,350	35,500	10.55
Tama sand	1	500	400	6,200	14.70	1,300	—	13,000	—
Tama loamy fine sand	1	1,000	2,100	33,000	16.00	2,400	1,900	17,000	8.60
Tama silt loam	29	1,237	4,210	48,000	11.45	2,763	4,526	50,368	10.90
Tama silt loam (rolling phase)	1	1,100	3,000	40,000	13.00	1,300	2,200	34,000	15.80
Tama silt loam (shallow phase)	4	1,075	3,350	37,000	10.90	2,525	3,975	35,750	9.58
Tama silt loam (light colored phase)	4	975	2,650	33,500	17.00	2.225	4,825	32,500	7.18
Weighted average		1,436	3,201	37,109	11.75	2,725	3,741	38,156	10.59

TABLE 12. THE MEAN, STANDARD DEVIATION AND COEFFICIENT OF VARIABILITY OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF REPRESENTATIVE LOESS SOILS OF IOWA.

Code: P and N÷100; C÷1,000.

Soil types	Number of determinations	Phosphorus			Nitrogen			Carbon		
		Mean	Standard deviation	Coefficient of variability	Mean	Standard deviation	Coefficient of variability	Mean	Standard deviation	Coefficient of variability
Tama silt loam	29	1,248	277	22.2	4,269	700	16.3	48,860	854	17.0
Clinton silt loam	36	1,019	221	21.6	2,506	623	24.8	30,030	789	26.0
Marshall silt loam	14	1,329	120	9.0	4,029	1,070	26.5	43,860	1,020	23.0
All loess soils (36 types)	229	1,435	793	55.3	3,201	1,185	37.0	37,108	1,617	43.6

TABLE 13. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF THE LOESS SOILS OF IOWA.

Code: P and N÷100; C÷1,000.

Source of variation	Degrees of freedom	Mean square			
		Phosphorus	Nitrogen	Carbon	C:N ratio
Surface: 0—6 2/3 inches					
Total	229	63	140	261	9.7
Between soil types	35	309**	862**	1,288**	9.5
Within soil types	194	18	10	76	9.8
Subsoil: 20 to 40 inches					
Total	191	78	357	423	18.8
Between soil types	32	156**	1,098**	1,315**	34.6**
Within soil types	159	63	208	243	15.6

**Highly significant difference.

types with respect to their carbon-nitrogen ratio.

In the case of the subsoil samples the variance within types was considerably less than that between types for each of the constituents and also for carbon-nitrogen ratio. Hence it may be concluded that the subsoils of the various types are significantly different in their phosphorus, nitrogen and carbon content and also in their carbon-nitrogen ratio. This may be interpreted as meaning that these soils were endowed originally with different amounts of these constituents, or that there has been infiltration into them from the A and B horizons of certain soils or losses by drainage from others.

In comparing the surface samples against the subsoil samples it is necessary again to reduce the data to a uniform basis and it is convenient to make the computation on the basis of pounds of phosphorus, nitrogen or carbon per 2 million pounds of soil. In the surface samples of Clinton silt loam the mean phosphorus, nitrogen and carbon content, respectively, is 1,019, 2,506, and 30,030 pounds per 2 million pounds of soil, whereas in the subsoil the corresponding figures are 986, 847, and 8,473 pounds. A similar situation is shown by the means for the Marshall silt loam where the mean phosphorus, nitrogen and carbon content of the surface soils is 1,329, 4,029 and 63,860 pounds, respectively, while for the subsoils the corresponding values are 1,148, 1,771 and 15,787 pounds per 2 million of soil. It is evident that there is a larger percentage of phosphorus, nitrogen and also of carbon in the surface than in the subsoil samples of the loess soils just as was shown earlier to be the case with the drift soils. Although it is not surprising that the surface soils are richer in nitrogen and carbon it is rather interesting to find that they also are richer in phosphorus.

RELATION OF SOIL COMPOSITION TO SOIL COLOR

A rather wide range of color variation is exhibited by the loess soils of Iowa. The lightest colored soil of all those mapped in the state is the Marion silt loam. This soil in the virgin state has a very light gray layer in the lower portion of the A horizon, whereas the upper portion is somewhat darkened by the accumulated organic matter. In cultivated fields, however, where the light gray layer has been turned up in the plowing process the entire soil has an unusually light color. This soil occurs in areas of rather rough topography and under forest conditions. The Clinton silt loam is another comparatively light colored soil that has developed under forest conditions. It is rather variable in color, ranging from a light gray in areas adjacent to the Marion soils to a light or even a dark brown in other areas. Somewhat lighter in color than most of the Clinton soils are the Fayette soils of northeastern Iowa. In other respects these two soils are very similiar in the surface layer, both having developed under a forest growth. The Knox soils that occur along the Missouri River bluffs are also rather light colored as compared with the other soils of the state.

The darker colored loess soils have developed under prairie grasses rather than under forest conditions. Among this group may be listed soils of the Marshall, Tama, Muscatine and Grundy series. The Grundy and Muscatine soils are somewhat darker in color than the Marshall and Tama. There is also appreciable variability in the depth of the color in the latter two soils.

In analyzing the data for the phosphorus, nitrogen and carbon content of these soils it seemed desirable to determine whether or not the various light colored soils differed significantly among themselves, whether the dark colored soils differed from each other, and whether there is a significant differ-

TABLE 14. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF FOUR TYPES OF LIGHT COLORED SOILS AND FOUR TYPES OF DARK COLORED SOILS.

Code: P and N÷100; C÷1,000.

Source of variation	Degrees of freedom	Mean square			
		Phosphorus	Nitrogen	Carbon	C:N ratio
Light colored soils, Clinton, Marion, Fayette and Knox silt loams					
Between types	3	15.98*	38.6	211*	14.39*
Within types	52	5.23	39.4	65	3.10
Dark colored soils, Marshall, Tama, Muscatine and Grundy silt loams					
Between types		2.12	24.6	259*	8.02*
Within types		6.79	61.4	81	2.69

*Significant difference.

ence in composition between the light colored soils as a group and the dark colored soils as a group. Hence the data for the Clinton, Marion, Fayette and Knox silt loams were analyzed and the results are shown in table 14. It is found that these soils differ significantly in their phosphorus and carbon contents but not in their nitrogen content. They also show a significant difference in carbon-nitrogen ratio.

Similarly the data for the Marshall, Tama, Muscatine and Grundy silt loams were analyzed and the results are also shown in table 14. These soils do not show a significant difference in phosphorus or nitrogen content but they are different in carbon content and in carbon-nitrogen ratio. These results may be interpreted to mean that the various soils were probably somewhat similarly supplied originally with phosphorus, nitrogen and carbon, but that due to the different conditions under which they have developed, such as topography, rainfall, temperature, etc., they have become distinctly different in chemical

TABLE 15. THE t TEST OF THE MEAN DIFFERENCES BETWEEN THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF LIGHT AND DARK COLORED LOESS SILT LOAM SOILS.

Dark soils: Marshall, Tama, Muscatine and Grundy silt loams.
Light soils: Clinton, Marion, Fayette and Knox silt loams.

	Phosphorus	Nitrogen	Carbon	C:N ratio
Mean—dark soils	1,294	4,250	49,650	11.78
Mean—light soils	1,030	2,403	27,940	11.64
Mean difference	264	1,847	21,710	0,14
t value	5.47**	14.14**	13.72**	0.43

**Highly significant difference.
t = Mean difference/standard error of the mean difference.

characteristics, particularly in carbon content, for this is the constituent that is influenced to the greatest extent by the type of vegetation.

The results of testing whether there is a significant difference between the light and dark colored soils as groups are shown in table 15. It may be seen that the dark colored soils are richer in all three constituents and that the difference between the two groups is highly significant in each case. There is no difference, however, in the carbon-nitrogen ratio of the two groups. This substantiates, by chemical analyses on a large scale, the observations by farmers for many years that the darker colored soils are the more fertile.

COMPARISON OF LOESS SILT LOAMS

Inasmuch as most of the loess soils have a silt loam texture, it was not possible to make a study of the influence of texture on composition within this group of soils. In order to show the combined effects of all other profile differential factors on the different soils the various series of the silt loam class have been ranked according to their increasing phosphorus, nitrogen and carbon content and the ranking is shown in table 16.

It is apparent that in general, soils having a high content of one constituent are also high in the other two. One notable exception to this generalization is the Knox soil. It has a relatively high phosphorus content but the lowest content of nitrogen and carbon of all the soils in the group. This condition may be explained by the fact that although this soil was probably as well supplied with these constituents originally as the adjacent and closely related Marshall soils, it has a characteristic topography which has prevented the growth of all but a very sparse vegetation while the topograhy of the other soils has permitted a dense growth of grass or trees and brush. This

TABLE 16. SILT LOAM SOILS OF LOESS ORIGIN RANKED IN ORDER OF INCREASING PHOSPHORUS, NITROGEN AND CARBON CONTENT.

Rank	Phosphorus	Nitrogen	Carbon
1	Fayette	Knox	Knox
2	Marion	Marion	Fayette
3	Clinton	Fayette	Marion
4	Putnam	Clinton	Clinton
5	Edina	Putnam	Putnam
6	Tama	Edina	Edina
7	Grundy	Scott	Scott
8	Knox	Marshall	Marshall
9	Marcus	Grundy	Tama
10	Marshall	Tama	Muscatine
11	Scott	Muscatine	Grundy
12	Muscatine	Marcus	Marcus

has prevented the accumulation of organic matter, and, of course, of organic carbon and nitrogen in the surface soil. This is an illustration of the influence topography may have on the quantity of nitrogen and carbon a soil may contain.

RESULTS FOR THE TERRACE AND BOTTOMLAND SOILS

The mean phosphorus, nitrogen and carbon content of the various terrace and bottomland soils is shown in table 17. It may be observed that these soils exhibit a wide range of composition. For example the lowest mean nitrogen content is 440 pounds per acre in the case of the Sarpy very fine sand, and the highest mean nitrogen content is 8,720 pounds in the case of the Fargo clay. This range includes all the mineral soils but does not take into consideration the peat and muck soils which have considerably larger mean nitrogen contents than even the Fargo clay as is shown in the table. The mean phosphorus content varies from 457 pounds per acre in the Sarpy sand to 2,745 in the Judson fine sandy loam.

It should also be noted that several of these soils have been sampled in only a few counties or, in some cases, in only one. Obviously the latter soils have not been sampled sufficiently to obtain a reliable indication of their composition. Most of them are restricted to rather small areas, and in many cases they occur to the extent of only a few acres in one or more counties. Although they may be of considerable importance on an individual farm they are not of great importance as compared with the major soil types of the state. In making an analysis of variance of the data representing the terrace and bottomland soils, those soils that have been sampled in less than three counties were omitted from the study. The analysis for the more extensive soils of this group is summarized in table 18. In this analysis 567 individual samples of soil, representing 42 types, were considered. The results are practically the same as those obtained in the analysis of the data from the drift and loess soils.

RELATIONSHIP OF TEXTURE TO COMPOSITION

Inasmuch as there is considerable variability in texture among the terrace and bottomland soils, an excellent opportunity is afforded for comparing the composition of soils of various textural groups. Hence soils of sandy loam, fine sandy loam, loam, silt loam and silty clay loam texture have been considered. The soils belonging to these textural groups are shown in table 19, which also shows the lowest and highest mean phosphorus, nitrogen and carbon content for each textural group.

TABLE 17. THE MEAN PHOSPHORUS, NITROGEN, AND CARBON CONTENT OF THE TERRACE AND BOTTOMLAND SOILS OF IOWA.

Pounds per acre in the surface 6 2/3 inches.

Soil type	Number of samples	Phos-phorus	Nitrogen	Carbon	C:N ratio
Benoit loam	1	1,037	5,600	55,568	9.92
Benoit silt loam	1	1,575	8.160	14,466	1.77
Bertrand loam	1	848	1,460	16,934	11.59
Bertrand silt loam	3	821	1,640	17,775	11.38
Bremer fine sandy loam	1	1,060	1,980	25,120	12.68
Bremer loam	10	1,482	4,640	55,262	12.04
Bremer silt loam	33	1,600	5,130	60,090	12.04
Bremer silty clay loam	22	1,436	5,682	65,910	11.97
Bremer clay	3	2,480	5,826	69,635	12.01
Buckner coarse sand	1	880	660	7,840	11.87
Buckner sand	2	2,446	2,412	14,008	6.20
Buckner fine sand	9	959	1,356	15,135	11.94
Buckner loamy sand	1	592	840	13,104	15.60
Buckner loamy fine sand	1	1,723	3,360	43,789	13.03
Buckner gravelly sandy loam	1	1,190	1,900	18,800	9.89
Buckner coarse sandy loam	1	1,080	1,860	4,246	2.28
Buckner sandy loam	6	999	1,722	20,738	12.55
Buckner fine sandy loam	13	1,092	2,102	20,949	10.34
Buckner very fine sandy loam	2	808	1,861	18,560	9.26
Buckner loam	15	1,333	3,400	41,130	12.08
Buckner loam (colluvial phase)	1	1.020	2,860	31,480	11.00
Buckner silt loam	8	1,615	4,159	48,937	12.08
Buckner silt loam (colluvial phase)	2	1,963	4,202	51,284	12.28
Calhoun silt loam	18	1,366	3,220	38,220	12.15
Cass sand	2	900	500	11,570	22.68
Cass sandy loam	11	1,200	2,590	29,540	11.85
Cass fine sandy loam	8	1,137	1,900	23,370	12.64
Cass very fine sandy loam	2	1,757	2.820	28,238	10.36
Cass loam	14	1,550	4,692	49,420	10.83
Cass silt loam	9	1,600	4,422	62,645	16.88
Cass silty clay loam	6	1,816	3,800	44,830	11.98
Cass silty clay	2	1,450	3,850	39,326	10.10
Cass clay	1	1,709	4,240	41,042	9.67
Chariton silt loam	8	1,325	3,912	44,870	11.36
Davenport sandy loam	1	880	1,350	18,700	13.85
Davenport clay loam	1	1,508	4,360	47,611	10.91
Davenport silt loam	1	1,210	3,640	23,450	6.44
Davenport silty clay loam	3	1,233	4,700	52,073	10.83
Fargo loam	2	1,241	6,520	78,309	12.14
Fargo silt loam	3	2,245	8,052	160,360	14.64
Fargo silty clay loam	11	1,800	8,418	91,090	11.25
Fargo clay	1	2,020	8,720	91,373	10.47
Genesee fine sandy loam	4	1,036	2,098	22,573	11.25
Genesee very fine sandy loam	4	825	1,650	16,253	10.64
Genesee silt loam	11	1,254	2,536	28,540	11.21
Genesee silty clay loam	2	1,272	2,560	26,021	10.07
Hancock silt loam	2	1,975	3,090	36,052	11.68
Hancock fine sandy loam	1	1,198	1,840	13,742	7.46
Hancock very fine sandy loam	2	1,467	2,552	33,462	12.33
Hancock loam	2	1,225	4,455	45,400	10.24
Hancock very fine sandy loam (shallow)	1	1,306	1,880	18,336	9.75
Hancock fine sand (shallo phase)	1	1,171	1,080	13,843	12.81
Hancock silty clay	1	1,900	4,380	52,428	11.96
Jackson silt loam	14	1,092	2,771	31,140	11.23
Judson silt loam	12	1,588	4,130	48,427	11.91
Judson silt loam (light colored)	1	2,300	3,880	46,340	11.94
Judson loamy sand	2	962	1,020	9,823	9.72
Judson fine sandy loam	1	2,745	3,360	58,248	17.33
Judson loam	3	1,582	3,780	44,314	11.70
La Crosse sandy loam	1	1,697	1,880	18,898	10.05
Lamoure loam	6	1,533	4,913	71,834	11.34
Lamoure silt loam	7	1,924	6,330	87,092	14.38
Lamoure silt loam (colluvial phase)	1	1,220	7,460	78,100	10.46
Lamoure silty clay loam	22	1,725	7,550	79,567	10.77
Lamoure clay loam	1	1,124	3,390	29,126	8.59

TABLE 17. (Continued)

Soil type	Number of samples	Phos-phorus	Nitrogen	Carbon	C:N ratio
Lamoure silty clay	2	2,006	4,100	49,512	13.00
Lamoure clay	2	1,642	2,540	30,981	12.27
Millsdale silt loam	1	1,623	4,760	55,896	11.74
Millsdale fine sandy loam	1	956	2,360	25,415	10.76
Millsdale loam	5	1,464	3,488	47,036	14.43
O'Neill sand	2	1,372	2,628	27,560	11.33
O'Neill fine sand	3	999	917	10,662	13.72
O'Neill loamy fine sand	1	740	1,840	21,840	11.86
O'Neill coarse sandy loam	2	1,262	1,497	19,185	12.65
O'Neill fine sandy loam	13	1,272	3,414	38,234	11.14
O'Neill sandy loam	15	1,040	2,346	28,070	12.39
O'Neill loam (deep phase)	1	1,104	3,680	37,352	10.15
O'Neill loam (light colored phase)	1	741	1,480	17,884	12.08
O'Neill loam	30	1,274	3,728	43,191	11.82
O'Neill silt loam	2	1,126	3,110	36,973	12.03
Osgood very fine sand	1	1,220	1,340	10,670	7.96
Plainfield sand	1	431	260	5,177	19.91
Plainfield loamy fine sand	1	552	1,072	22,520	21.00
Plainfield sandy loam	3	828	1,400	16,835	12.15
Plainfield fine sandy loam	3	609	1,140	14,379	13.25
Plainfield loam	2	804	1,550	19,447	12.78
Ray silt loam	2	1.400	1.920	26,483	14.05
Sarpy sand	1	457	600	7,630	12.72
Sarpy fine sand	3	967	1,005	9,221	14.08
Sarpy very fine sand	1	840	440	10,300	25.75
Sarpy loamy sand	1	840	1,400	17,920	12.80
Sarpy sandy loam	1	1,090	1,290	17,915	13.88
Sarpy fine sandy loam	8	1,217	1,511	20,500	14.46
Sarpy very fine sandy loam	8	1,250	1.537	15,250	10.14
Sarpy loam	3	1,917	2,737	32,057	11.64
Sarpy silt loam	11	1,555	3,079	37,105	12.05
Sarpy silt loam (deep phase)	1	1,764	1,680	18,813	11.19
Sarpy silty clay loam	2	1,504	3,025	34,980	11.55
Sarpy silty clay loam (deep phase)	1	1,684	2,080	20,257	9.73
Sioux fine sandy loam	2	1,097	3,400	45,459	13.60
Sioux loam	9	1,301	3,026	47,223	11.76
Sioux silt loam	1	1,239	4,920	46,059	9.36
Sparta fine sand	1	552	540	5,781	10.70
Wabash stony silt loam (colluvial)	1	1,347	4,440	53,212	11.98
Wabash fine sandy loam	8	1,329	2,474	29,875	12.29
Wabash very fine sandy loam	2	1,535	3,540	40,438	11.25
Wabash loam	38	1,523	4,808	54,394	11.64
Wabash silt loam	58	1,562	4,808	58,642	12.57
Wabash silt loam (colluvial phase)	18	1,422	4,010	48,395	11.99
Wabash silt loam (gray subsoil phase)	2	1,594	5,030	50,888	10.06
Wabash silt loam (heavy phase)	1	1,522	8,246	103,350	12.53
Wabash silty clay loam	44	1,770	5,747	67,880	12.46
Wabash clay loam	4	1,655	4,375	53,180	11.84
Wabash silty clay	7	1,821	4,298	51,758	12.22
Wabash clay	7	1,774	4,369	52,771	12.05
Waukesha sandy loam	2	970	2,568	31,827	12.38
Waukesha fine sandy loam	1	1,266	2,182	25,960	12.00
Waukesha loam	18	1,343	3,454	41,157	11.89
Waukesha silt loam	40	1,457	4.359	52,940	12.65
Meadow	1	1,640	3,600	47,547	13.20
Peat	3	1,805	37,112	538,803	14.34
Muck	8	1,844	25,775	342,184	13.21
Muck & peat	1	2,504	27,100	412,444	15.21
Weighted average of all soils		1,451	4,134	49,478	12.18

TABLE 18. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF THE TERRACE AND BOTTOMLAND SOILS OF IOWA.

Code: P and N ÷ 100; C ÷ 1,000.

Source of variation	Degrees of freedom	Mean square			
		Phosphorus	Nitrogen	Carbon	C:N ratio
Total	566	18.4	422	642	13.8
Between soil types	41	74.6**	2,514**	3,923**	14.3
Within soil types	525	14.0	259	386	13.8

**Highly significant difference.

NOTE: This analysis has been restricted to those soils which have been sampled in three or more counties, and it does not include those terrace and bottomland soils for which only one or two analyses are available.

TABLE 19. THE HIGH AND LOW MEAN PHOSPHORUS, NITROGEN AND CARBON CONTENT OF TEXTURAL GROUPS OF CERTAIN TERRACE AND BOTTOMLAND SOILS.

Textural group	Soil type	No. of samples	Phosphorus		Nitrogen		Carbon		C:N ratio
			Low	High	Low	High	Low	High	
Sandy loams	*Mean*		1,062		2,234		26,285		12.23
	Buckner	6	—	—	—	—	—	—	—
	Cass	11	—	1,200	—	2,590	—	29,540	—
	O'Neill	15	—	—	—	—	—	—	—
	Plainfield	3	828	—	1,400	—	16,838	—	—
Fine sandy loams	*Mean*		1,158		2,289		26,192		11.91
	Buckner	13	—	—	—	—	—	—	—
	Cass	8	—	—	—	—	—	—	—
	Genesee	4	—	—	—	—	—	—	—
	O'Neill	13	—	—	—	3,414	—	38,234	—
	Plainfield	3	609	—	1,140	—	14,379	—	—
	Sarpy	8	—	—	—	—	—	—	—
	Wabash	8	—	1,329	—	—	—	—	—
Loams	*Mean*		1,430		4,124		48,251		11.80
	Bremer	10	—	—	—	—	—	—	—
	Buckner	15	—	—	—	—	—	—	—
	Cass	14	—	—	—	—	—	—	—
	Judson	3	—	—	—	—	—	—	—
	Lamoure	6	—	—	—	4,913	—	71,834	—
	Millsdale	5	—	—	—	—	—	—	—
	O'Neill	30	1,274	—	—	—	—	—	—
	Sarpy	3	—	1,917	2,737	—	32,057	—	—
	Sioux	9	—	—	—	—	—	—	—
	Wabash	38	—	—	—	—	—	—	—
	Waukesha	18	—	—	—	—	—	—	—
Silt loams	*Mean*		1,498		4,205		52,384		12.54
	Bertrand	3	821	—	1,640	—	17,775	—	—
	Bremer	33	—	—	—	—	—	—	—
	Buckner	8	—	—	—	—	—	—	—
	Calhoun	18	—	—	—	—	—	—	—
	Cass	9	—	—	—	—	—	—	—
	Chariton	8	—	—	—	—	—	—	—
	Fargo	3	—	2,245	—	8,052	—	160,360	—
	Genesee	11	—	—	—	—	—	—	—
	Jackson	14	—	—	—	—	—	—	—
	Judson	12	—	—	—	—	—	—	—
	Lamoure	7	—	—	—	—	—	—	—
	Sarpy	11	—	—	—	—	—	—	—
	Wabash	58	—	—	—	—	—	—	—
	Waukesha	40	—	—	—	—	—	—	—
Silty clay loams	*Mean*		1,704		5,876		67,744		12.02
	Bremer	22	—	—	—	—	—	—	—
	Cass	6	—	1,816	3,800	—	44,830	—	—
	Davenport	3	1,233	—	—	—	—	—	—
	Fargo	11	—	—	—	8,418	—	91,090	—
	Lamoure	22	—	—	—	—	—	—	—
	Wabash	44	—	—	—	—	—	—	—

TABLE 20. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF SOIL TYPES COMPOSING TEXTURAL GROUPS OF TERRACE AND BOTTOMLAND SOILS.

Code: P and N ÷ 100; C ÷ 1,000.

Source of variation	Degrees of freedom	Mean square			
		Phosphorus	Nitrogen	Carbon	C:N ratio
Sandy loams					
Between soil types	3	8.78	176	203	0.77
Within soil types	31	6.36	111	125	6.96
Fine sandy loams					
Between soil types	6	21.25	478**	532**	17.45
Within soil types	50	10.81	71	113	20.75
Loams					
Between soil types	10	25.78	574*	856*	51.58
Within soil types	140	14.69	290	394	43.86
Silt loams					
Between soil types	13	64.29**	1,859**	4,387**	34.32
Within soil types	220	13.13	180	448	20.90
Silty clay loams					
Between soil types	5	29.68	2,066**	1,897**	5.57
Within soil types	84	19.71	579	469	8.38

*Significant.
**Highly significant.

TABLE 21. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF CERTAIN TEXTURAL GROUPS OF TERRACE AND BOTTOMLAND SOILS.

Code: P and N ÷ 100; C ÷ 1,000.

Source of variation	Degrees of freedom	Mean square			
		Phosphorus	Nitrogen	Carbon	C:N ratio
Between textural groups	4	413**	14,868**	20,491**	14.6
Within soil types	562	15	320	501	13.9

**Highly significant.

In the first place a study was made to determine whether or not the individual soil types within a textural group differed significantly in their content of phosphorus, nitrogen and carbon. The results of this study are presented in table 20.

In view of the fact that the soils of most of the textural groups differ among themselves in nitrogen and carbon content,

TABLE 22. TERRACE AND BOTTOMLAND LOAM SOILS RANKED IN ORDER OF DECREASING PHOSPHORUS, NITROGEN, AND CARBON CONTENT.

Rank	Phosphorus	Nitrogen	Carbon
1	O'Neill	Sarpy	Sarpy
2	Sioux	Sioux	Buckner
3	Buckner	Buckner	Waukesha
4	Waukesha	Waukesha	O'Neill
5	Millsdale	Millsdale	Judson
6	Bremer	O'Neill	Millsdale
7	Wabash	Judson	Sioux
8	Lamoure	Bremer	Cass
9	Cass	Cass	Bremer
10	Judson	Wabash	Wabash
11	Sarpy	Lamoure	Lamoure

whereas most of them do not differ significantly in their phosphorus content, it is important to determine whether or not the soils of the various textural groups as a whole differ in their content of phosphorus, nitrogen or carbon. The analysis designed to answer this question is shown in table 21. It appears that the variance of the phosphorus, nitrogen and carbon content between the various textural groups is significantly larger than that within groups. Such a difference is not indicated for the carbon-nitrogen ratio, however. The mean phosphorus, nitrogen and carbon content for the various textural groups is shown by the graph in fig. 5.

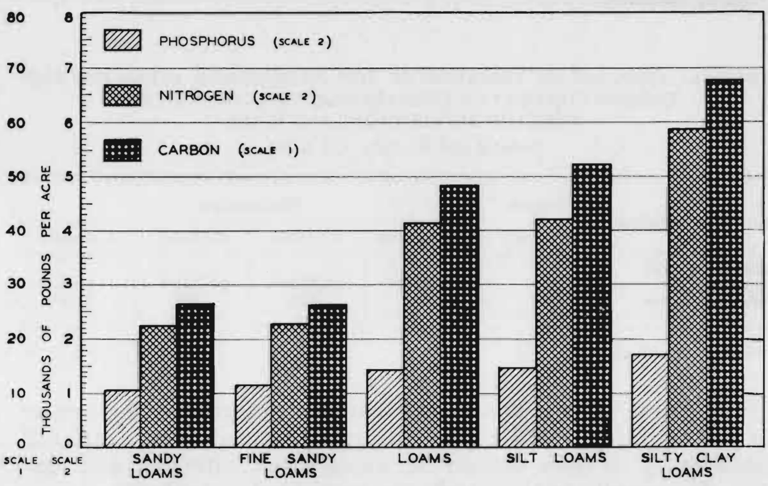

Fig. 5. The mean phosphorus, nitrogen and carbon content of various textural groups of terrace and bottomland soils.

These conclusions agree with those obtained in the analysis of the drift soils on a textural basis. They point out the close relationship of texture to content of phosphorus, nitrogen and carbon in soils. Furthermore, they lend support to the statement made by Russell and McRuer (16) that "texture is the outstanding factor determining nitrogen content in any soil type." In this study a great variety of soils was considered: soils that had widely different inherent characteristics, and soils that had developed widely different profile characteristics as a result of their environment, and yet they showed a marked relationship between texture and composition. It is believed that there would be a rather high degree of correlation between these two factors if it were possible to express the texture of the soils in numerical form. This, however, as was pointed out earlier, is not possible with the data available.

COMPARISON OF SOILS OF UNIFORM TEXTURE

In order to eliminate, insofar as possible, the influence of texture on composition of these soils, and yet obtain a relative idea of their content of phosphorus, nitrogen and carbon, all those soils of the loam class have been ranked in order of their decreasing content of these constituents and the ranking is shown in table 22. A similar ranking for the soils of silt loam texture is shown in table 23. Such a ranking would undoubtedly be of considerable aid in making a fertility rating of these soils.

COMPARISON OF UPLAND AND TERRACE AND BOTTOMLAND SOILS

In order to present a more generalized picture of the phosphorus, nitrogen and carbon content of the soils of the state as

TABLE 23. TERRACE AND BOTTOMLAND SILT LOAMS RANKED IN ORDER OF INCREASING PHOSPHORUS, NITROGEN, AND CARBON CONTENT.

Rank	Phosphorus	Nitrogen	Carbon
1	Bertrand	Bertrand	Bertrand
2	Jackson	Genesee	Genesee
3	Genesee	Jackson	Jackson
4	Chariton	Sarpy	Sarpy
5	Calhoun	Calhoun	Calhoun
6	Waukesha	Chariton	Chariton
7	Sarpy	Judson	Judson
8	Wabash	Buckner	Buckner
9	Judson	Waukesha	Waukesha
10	Cass	Cass	Wabash
11	Bremer	Wabash	Bremer
12	Buckner	Bremer	Cass
13	Lamoure	Lamoure	Lamoure
14	Fargo	Fargo	Fargo

TABLE 24. THE MEAN PHOSPHORUS, NITROGEN, AND CARBON CONTENT OF THE SOILS OF IOWA.
(pounds per acre, 0 to 6 2/3 inches)

	Loess soils	Drift soils	Terrace soils	Bottomland soils	All soils
No. of samples	230	384	318	249	1,181
Phosphorus	1,436	1,215	1,384	1,537	1,372
Nitrogen	3,201	3,720	3,983	4,327	3,818
Carbon	37,109	45,742	47,232	52,345	45,854
C:N ratio	11.75	12.34	11.98	12.44	12.15

TABLE 25. ANALYSIS OF VARIANCE OF THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF GEOLOGICAL GROUPS OF SOILS IN IOWA.
Geological groups: Loess, Drift, Terrace, and Bottomland Soils.
Code: P and N ÷ 100; C ÷ 1,000.

Source of variation	Degrees of freedom	Mean square			
		Phosphorus	Nitrogen	Carbon	C:N ratio
Total	1,180	34.3	412.9	697.6	16.6
Between geological groups	3	642.2**	5,450.8**	9,564.3**	29.6
Within geological groups	1,177	32.9	400.0	674.96	16.6

**Highly significant.

TABLE 26. THE t TEST OF THE MEAN DIFFERENCES BETWEEN THE PHOSPHORUS, NITROGEN, AND CARBON CONTENT OF GEOLOGICAL GROUPS OF SOILS IN IOWA.

	Phosphorus	Nitrogen	Carbon	C:N ratio
Loess + Drift	M_1 = 1,291	3,508	42,303	12.06
Terrace + Bottomland	M_2 = 1,451	4,134	49,478	12.18
	t = 4.78**	5.35**	4.72**	0.50
Loess	M_1 = 1,436	3,201	37,109	11.75
Drift	M_2 = 1,215	3,720	45,742	12.34
	t = 2.52*	3.09**	3.96**	1.73
Terrace	M_1 = 1,384	3,983	47,232	11.98
Bottomland	M_2 = 1,537	4,327	52,345	12.44
	t = 3.80**	1.98*	2.28*	0.9

*Significant difference.
**Highly significant difference.
t = Mean difference/standard error of the mean difference.

a whole the means for the drift, loess, terrace and bottomland soils and for all the soils of the state as a whole are shown in table 24. Certain differences between groups may be observed in this table. The test for the significance of the differences is shown in table 25.

Although the means for the various groups were found to be different, it would be of interest to know which ones differ from the others. Table 26 shows the results of testing the mean differences. The loess soils as a group contain significantly more phosphorus, and less nitrogen and carbon than the drift soils, but they are not significantly different in carbon-nitrogen ratio. The bottomland soils contain significantly larger amounts of phosphorus, nitrogen and carbon than the terrace soils, but the two groups do not differ in carbon-nitrogen ratio. When the terrace and bottomland soils as a group were compared with the drift and loess soils as a group, it was found that the terrace and bottomland soils contain significantly larger amounts of phosphorus, nitrogen and carbon. There is no significant difference in carbon-nitrogen ratio between the two groups.

CARBON-NITROGEN RATIO

Numerous investigations have shown a rather close relationship between the carbon and nitrogen content of soils, and the conclusion has been drawn that the ratio of carbon to nitrogen tends to approach 10:1. The explanation for this has been pointed out by Waksman (21) (22), Stewart (19), Sievers and Holtz (17) and others. The characteristics of the decomposition process have been investigated by Waksman (22) and his associates.

Brown and O'Neal (5) reported the C:N ratio of Carrington loam in Iowa to be about 12 or 13 to 1 in most instances but in some cases it was much wider. The ratio for Tama silt loam was as low as 10 in some cases but most of the samples examined had a ratio near 12 or 13. Stewart (19) found the C:N ratio of brown silt loam soils of Illinois to be 12.1. Alway and McDole (1) found it to be somewhat below 11.6 in cultivated chernozem soils of Nebraska, and later Rost and Alway (15) found the ratio in Minnesota drift forest soils to be 11.6 and in drift prairie soils to be 12.3 and 12.4.

Leighty and Shorey (10) have reported data from 176 samples of soil from 63 locations in 12 states which show that the C:N ratio is quite variable and, with a few exceptions, is widest in surface soil and becomes narrower at lower levels.

Sievers and Holtz (17) found a C:N ratio ranging from 12.5 to 14.0 in virgin Palouse silt loam and 9.4 to 12.0 in similar soils that have been cropped from 35 to 40 years. These investigators point out the fact that the C:N ratio in virgin soils rarely, if ever, reaches the narrowest ratio compatible with active decomposition of organic matter by microorganisms for there is a continuous return of plant residues having a wider ratio and also because soil conditions are rarely optimum for decomposition for any considerable period of time. In cultivated soils, however, where little effort is made to return crop residues to the soil and where conditions are made favorable for the decomposition of organic matter, this ratio may become rapidly narrower and thus approach the theoretical minimum.

McLean (13) determined the C:N ratio for 50 British soils and 16 foreign soils. The ratio for the British soils varied from 6.5 to 13.5 and the average was 10.2 ± 0.3, whereas the ratio for the foreign soils varied from 2.0 to 23.0. It was observed that the ratios of soils, whether high or low in organic matter, from limited areas were approximately constant. It was also found that the ratios of arable soils do not differ appreciably from those of grassland soils, although the percentages of carbon and nitrogen were slightly higher in the latter.

McKibbin (12) found a mean C:N ratio of 21.3 for 25 upland podzols, 22.6 for 11 lowland podzols, 15.9 for 16 brown earths, 14.2 for 17 sandy clays and 15.2 for 17 heavy clays. Within each group there was considerable variability in the ratio between soils.

Hosking (7) found that the C:N ratio of Australian soils varied not only over wide areas, but also in very restricted ones, both in virgin and cultivated country. In the Australian black earths, a major grassland soil, the range for the ratios is very restricted, varying only from 13.5 to 18.3 in the surface soils, the modal frequency occurring at the mean 16.2. The ratio for the podzolized soils was somewhat more variable, the values ranging from 10 to 24.8 with a theoretical maximum frequency of 16.1. The mean ratio for the gray and brown zonal type of soils was 10.3, whereas, in the semi-desert gray soils the range covered by the ratios was from 6.3 to 9.8.

Remezov (14) computed the C:N ratio of 164 Russian soils representing 7 zonal types. As was pointed out by Hosking his figures are remarkably low throughout for all soil types and bear comparison with no other figures. It was also pointed out by Hosking that the wet combustion method used by Remezov did not give complete oxidation of the carbon in all cases, and his data therefore cannot be compared with those obtained by the complete combustion methods. Waksman and Hutchings (23) have also indicated that the discrepancies between their results and those of Remezov may be traced to the fact that the latter investigator subtracted the nitrogen found in the humus in the form of amides and amino acids from the total nitrogen and calculated the differences as protein, whereas other investigators have based their calculations upon the total organic nitrogen.

Waksman and Hutchings (23) found a progressive narrowing of the C:N ratio as one proceeds from the podzols, to chernozems, chestnut soils and to the serozems. The podzols studied were characterized by a rather wide ratio; the chernozems had a ratio of about 10; and the serozems were characterized by a ratio of about 6. The work of these investigators in connection with the characteristics of the organic matter or humus associated with the C:N ratio for the different zonal soil types, has contributed much to our understanding of the carbon-nitrogen relationships in soils.

Lunt (11) has shown that the C:N ratio is higher for forest soils than for field soils.

Jenny (8) (9) concluded that the C:N ratio of the soil organic matter becomes narrower with increasing temperature. Under low temperature the nitrogen content of the soil approaches the nitrogen content of the vegetation and consequently the C:N ratio of the soil tends to become as wide as that of the undecomposed organic material. On the other hand, it was concluded that the C:N ratio does not vary with the humidity factors in the temperate region. Its average value is about 11.3 for the soils between Colorado and New Jersey along the 11° C. isotherm (51 to 53° F.) and is nearly the same both in timber (10.9) and grassland soils (11.6); the same is true in the subtropical region in the states of Texas, Louisiana, and Mississippi where the annual temperature ranges from 64 to 68° F.

In analyzing the carbon and nitrogen data for the various soils of Iowa the carbon-nitrogen ratio was computed in each sample of soil. The means for the various types are shown in tables 1, 11 and 18.

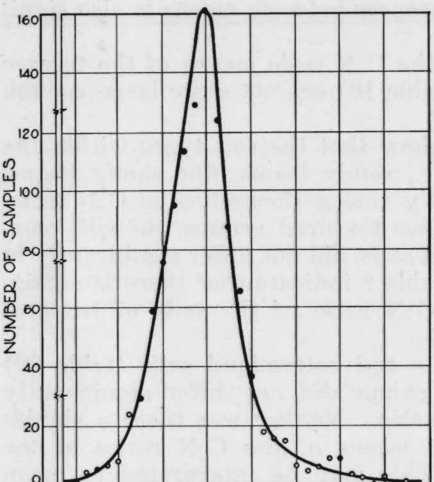

Fig. 6. Frequency distribution of carbon-nitrogen ratio for Iowa soils.

The graph in fig. 6 shows the frequency distribution of the C:N ratios for all of the individual soil samples except for two that were too small for the graph, which were 4.1 and 5.1, respectively, and also for 15 that were too large, ranging from 23 to 62 each with a different ratio.

The frequency classes covered the C:N ratio values varying within 0.5 unit, and they were so arranged that the midpoint of the class would be either a half or a whole number. For example one class included all items falling within the range 10.3 to and including 10.7 and the mid-point was 10.5; the next class ranged from 10.8 to 11.2 with the mid-point at 11.0. The mid-points of the frequency classes were used in plotting the graph in fig. 6.

It may be noted that the largest number of samples had a C:N ratio within the frequency class of 11.8 to 12.2 with 12 as the mid-point. The mean C:N ratio, however, was 12.15 or slightly higher than the modal frequency. This may be explained readily by the fact that there was an appreciable number of samples with a rather wide C:N ratio, which caused the mean to be slightly higher than the mode.

It is of interest that only a rather small percentage of the total number of samples had a ratio below 8 or above 15. Those samples having ratios beyond these values are indeed unusual and undoubtedly represent some peculiar soil condition.

In table 4 it was shown that there was a significant difference in C:N ratio in the surface and subsoil samples of the soils of drift origin. Reference to table 1 shows that the mean ratio for all drift soils is 12.34, and that in those cases where the soil type has been more widely sampled the mean ratio more nearly approaches the mean for the entire group. The variation of the ratio for the individual samples within a soil type is not shown in table 1 but this has been considered in the analysis of variance.

An analysis of the ratios for the loess soils, both surface and subsoil, shows that the differences between means is also signicant.

The differences between the C:N ratio means of the terrace and the bottomland soils (table 18) are not quite large enough to be significant.

The analyses in table 7 show that the soil types within the coarser textured groups, i.e., sandy loams, fine sandy loams, and loams, differ significantly among themselves in C:N ratio, whereas the types in the finer textured groups, the silt loam, silty clay loam and clay loam soils, did not differ significantly in this respect. The data of table 8 indicate that there is no significant difference in the C:N ratio of the soils of textural groups considered as a whole.

In the case of the terrace and bottomland soils (table 20) the types within textural groups did not differ significantly among themselves in C:N ratio. Neither was there a significant difference between the means of the C:N ratios of the textural groups studied. This may be interpreted to mean that the terrace and bottomland soils as a whole may be expected to approach homogeneity in C:N ratio as nearly as do individual types. Or in other words, individual soil types may be expected to be as heterogeneous with respect to C:N ratio as the terrace and bottomland soils as a whole. Furthermore it indicates that no definite relationship exists between the C:N ratio of these soils and their texture.

The data of table 14 show that there are significant differences between the C:N ratio means for soils in the light and also in the dark colored groups. In the light colored group the mean ratios are 12.05, 11.17, 9.25 and 12.07, respectively, for the Clinton, Fayette, Knox and Marion silt loams. In the dark colored group the mean ratios are 12.70, 11.22, 11.62 and 11.45 respectively for the Grundy, Marshall, Muscatine and Tama silt loams. Although the differences between these means are not large they are significant. It may be noted that there was appreciably less variability in C:N ratio within soil types in the loess group than in the drift or terrace and bottomland group, hence smaller mean differences are required to indicate real differences between types. When the light colored soils as a group are compared with the dark colored soils (table 15) the somewhat wider range of ratios serves to obscure the differences between groups. The results indicate that the C:N ratio mean of 11.78 for the dark soils is not significantly larger than that of 11.64 for the light soils.

In order to obtain a somewhat broader view of the relation between carbon and nitrogen in these soils, the quantities of nitrogen have been plotted against the quantities of carbon. The data for the drift soils, with a few exceptions, are shown by the scatter diagram in fig. 7. The regression equation for the data in this graph was computed to be

$$C = 11.11N + 2{,}177$$

and the straight line corresponding to this equation has been superimposed upon the scatter diagram. Furthermore the correlation coefficient between carbon and nitrogen was computed to be 0.95, a highly significant value.

The data points excluded from this graph and the accompanying correlation analysis are: First, those representing 11 samples of soils of the Webster, Clyde and Rogers series whose carbon and nitrogen values are so large that it was impracticable to represent them on the graph; second, those representing 6 samples of soil whose carbon-nitrogen ratios were over 30 and therefore obviously in error. By leaving out these 17 data the intercept value in the regression equation, 11.11, which is an average carbon-nitrogen ratio for all the data included in the analysis, is somewhat less than the average for all the drift soils given in table 24. It is probable that the lower carbon-nitrogen ratio, 11.11, more nearly approaches the average condition for the great majority of the drift soils.

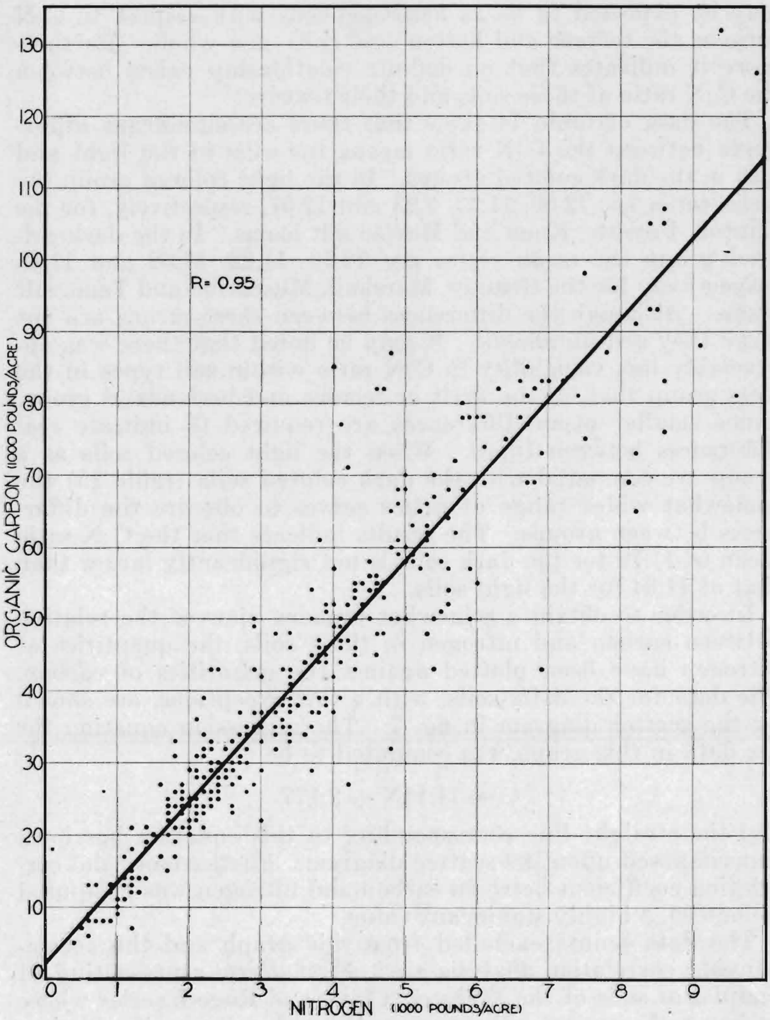

Fig. 7. Scatter diagram and regression line showing the relationship of carbon to nitrogen in the drift soils of Iowa.

A similar scatter diagram was drawn for the loess soils and it is shown in fig. 8. The equation for the line is

$$C = 11.05N + 2{,}246$$

and the correlation coefficient for the quantities of carbon and nitrogen is 0.93. In this case, as with the drift soils, a few sam-

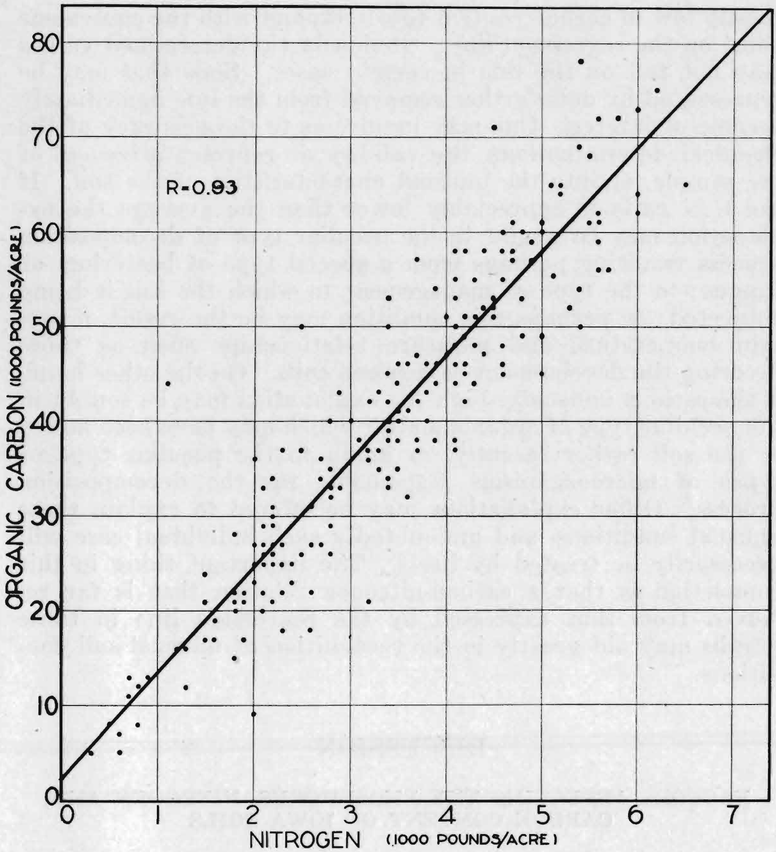

Fig. 8. Scatter diagram and regression line showing the relationship of carbon to nitrogen in the loess soils of Iowa.

ples of soil whose carbon-nitrogen ratio was obviously abnormal have been excluded from the analysis, and thus a lower average value was obtained than the one shown in table 24.

These graphs show a very definite relationship between the carbon and nitrogen content of the loess and drift soils of Iowa. Furthermore this relationship seems to be fairly constant, irrespective of whether the quantities of carbon and nitrogen in the soil are low or high.

The regression line in these diagrams may be of considerable value in interpreting the results of carbon and nitrogen determinations on these types of soil in the future. The straight line serves as sort of a moving average for both carbon and nitrogen content. For example, if a soil is found to be rather low in nitrogen content, it should, under normal conditions, be sufficiently low in carbon content to correspond with the equivalent point on the regression line. Obviously the determined values may not fall on the line in certain cases. Soils that may be represented by dots farther removed from the line immediately become of interest. One may inquire as to the accuracy of the chemical determinations, the validity or representativeness of the sample, or into the unusual characteristics of the soil. If the C:N ratio is appreciably lower than the average the explanation may be sought in the peculiar type of decomposition process resulting perhaps from a special type of bacterium or fungus; to the type of management to which the soil is being subjected; or perhaps this condition may be the result of certain temperature and moisture relationships such as those favoring the development of serozem soils. On the other hand, if the ratio is unusually high the explanation may be sought in the peculiar type of organic matter which may have been added to the soil rather recently, or again to the peculiar type or types of microorganisms responsible for the decomposition process. Other explanations may be offered to explain these unusual conditions, and undoubtedly each individual case will necessarily be treated by itself. The important thing in this connection is that a carbon-nitrogen relation that is far removed from that expressed by the regression line in these graphs may aid greatly in the recognition of unusual soil conditions.

DISCUSSION

FACTORS AFFECTING THE PHOSPHORUS, NITROGEN AND CARBON CONTENT OF IOWA SOILS

It is apparent that many forces have had a part in determining the phosphorus, nitrogen and carbon content of the soils of Iowa. Undoubtedly the content of the original rock and organic material from which the soils have been formed has had some influence on their present composition. An analysis of the data presented in this bulletin, however, seems to indicate that other factors have had a much greater influence in this connection.

Russell and McRuer (16) pointed out that the nitrogen content of Nebraska soils varies with the rainfall and topography, level types containing more nitrogen than rolling types under the same precipitation, probably because of the difference in the effectiveness of rainfall in such cases.

Probably the most outstanding contributions on this subject have been made by Jenny (8) who has ingeniously studied the functional relationships of the nitrogen content of soils and climatic factors. In the first place, he has shown that in the semi-arid, semi-humid and humid regions of the United States a correlation exists between the mean annual temperature and the average total nitrogen content of upland prairie and timber soils and of terrace and bottomland soils. The nitrogen content of soils was found to decrease exponentially with an increase in temperature. In general, for every 10° C. decline in mean annual temperature, the average nitrogen content of the soil was found to increase two to three times. In the second place, Jenny (9) found the average nitrogen content of grassland soils to increase logarithmically with the humidity factors. It was also observed that the nitrogen-humidity factor relationship is a discontinuous one, consisting of two separate curves, one for grassland soils and one for timber soils, thus indicating an interaction between the effects of forest development itself and the humidity factors.

The temperature and humidity factors therefore have had a major role in determining the nitrogen and carbon content of the soils of Iowa. The effects undoubtedly have been direct and also indirect. They have been direct in that the total amount of nitrogen that may have been accumulated in Iowa soils has been definitely limited by the mean annual temperature and the humidity factors, which embrace the mean annual rainfall and the precipitation-evaporation ratio. Fortunately the combined effects of these factors have permitted rather large accumulations of nitrogen and carbon in Iowa soils, and undoubtedly they have played a major role in the development of our highly fertile soils.

On the other hand they have had a marked indirect effect on the nitrogen and carbon content of Iowa soils as a result of their interaction with the topographic, textural and vegetative conditions under which these soils have developed. A study of the data presented in this bulletin will show a rather definite relationship between the nitrogen, and carbon content, and also of the phosphorus content, of these soils and their topographic characteristics. For example, under the discussion of the drift soils it was shown that the difference between the mean composition of the Clarion and Webster silt loams, and between the Carrington and Clyde silt loams, was real and highly significant. This difference is not one of texture, as soils of the same texture have been compared. A knowledge of the important characteristics of these soils leads to the assumption that the primary force responsible for their differentiation is that of topograhy. Such a comparison may be made for many Iowa soils. The rolling upland soils in general have better underdrainage than the soils of level to flat topography. As a result plant nutrients have been leached from the more rolling lands of higher topographic position and they have been allowed to accumulate in the lower and more nearly flat lands. Futhermore, the terrace and bottomland soils have received deposits from the richer surface horizon of the upland soils and in this way they have developed a significantly higher phosphorus, nitrogen and carbon content than the upland soils as was shown by the data previously presented. Thus it may be concluded that as an interacting force, along with the temperature and humidity factors, the topography of the land has played an important role in determining the present phosphorus, nitrogen and carbon content of the soils of Iowa.

Similarly the texture of the soils of Iowa has had considerable influence in differentiating them with respect to their content of phosphorus, nitrogen and carbon. This has been definitely shown by the data presented. Under given humidity and temperature factors there has undoubtedly been a larger loss of plant nutrients from the coarser textured soils, and particularly those of rolling to steep topography, than from the finer textured soils. As a result, the soils of finer texture that have developed under otherwise uniform conditions now contain large quantities of phosphorus, nitrogen and carbon.

The vegetative factor also has had considerable influence in differentiating the soils of Iowa. In the discussion of the results of the loess soils it was shown that the light colored soils contain significantly smaller amounts of these constituents than dark colored soils of similar texture. The light colored soils have developed in the main under forest conditions, whereas the dark colored soils have developed under grassland or prairie conditions. Although it is not supposed that the type of vegetation has been the sole differential factor in this case, it has undoubtedly played a major role along with topography and perhaps certain other less important factors. Similarly, other cases might be cited to illustrate the effects of the type of vegetation on the nutrient content of soils.

In general, it may be concluded therefore that the topographic characteristics of the land, the texture or fineness of the soil, and the type of vegetation under which the soil has developed, have all played important secondary roles in determining the phosphorus, nitrogen and carbon content of the soils of Iowa. In fact, owing to the comparatively uniform temperature and humidity factors within the boundaries of the state, and also to the great variability of the soils within the state especially in topography and texture, the temperature and humidity factors may well be removed from consideration and it may be concluded that the topography, texture and type of vegetation have been the predominant factors in the differentiation of soils within the state in content of phosphorus, nitrogen and carbon. The latter conclusion would not be warranted, however, for soils occurring in an area having a wider range of mean annual temperature and humidity factors.

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