Chemical and Mineralogical Characteristics of Selected Indiana Soils[1]

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Abstract

Chemical and mineralogical characteristics of 48 selected Indiana soils representative of many of the major soil series in the state were determined. Data for soils were grouped into 7 textural classes and average values for the classes were obtained for each parameter measured. The amount of organic C, total N, ammonium fixing capacity, total P, total S, and cation exchange capacity in soils tended to decrease as soil texture became coarser. The proportion of quartz, vermiculite, and amorphous material in the clay fraction, the proportion of organic C extractable with pyrophosphate and hot water, and the proportion of total P present as inorganic P in soils increased as soil texture became coarser. The clay fraction of the Indiana soils studied contained higher proportions of micaceous (illite) and chlorite-like minerals than other constituents. A substantial proportion of the total N in soils is fixed NH_4-N with the heavier-textured soils possessing relatively high NH_4 fixing capacities, i.e. 100 ug NH_4-N/g. The organic C:N:S:P ratio is very constant in Indiana soils averaging 11:1:1.5:0.15. There were close relationships between clay content and organic C, total N, total P, and total S in soils. The mica content of soils was closely related to fixed ammonium content, cation exchange capacity, and ammonium fixing capacity.

Agronomists are often asked to make recommendations on nitrogen, phosphorus, and potassium fertilizer application rates for Indiana soils. They are often asked specific questions concerning various fertilizer management practices and, in recent times, they are asked to calculate application rates for animal, municipal and industrial wastes which may be effectively applied to various soils in the state. Arriving at suitable recommendations requires detailed knowledge of the characteristics of the soil involved. Typically, to make an accurate recommendation, it is necessary for the agronomist to travel to the site, take soil samples, and have the samples characterized. In many cases, the time required for sample collection and analysis is lengthy, and thus, a general knowledge of the mineralogical and chemical properties of Indiana soils would allow rapid evaluation of management alternatives.

Some relevant data on Indiana soils are contained in the soil survey reports developed for each county; however, many of the characteristics of the soil which are needed for use in making management recommendations are not available in soil survey bulletins. Therefore, our research group initiated a study of the chemical and mineralogical characteristics of Indiana soils representing many of the major soil series within the state. The objectives of this study were: (1) to obtain detailed information on the chemical and mineralogical composition of many of the major soil series in Indiana, (2) to group the soils studied into seven textural classes and attempt to generalize some of the observed characteristics of each class, and (3) to determine

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the interrelationships between various soil components. The latter objective is important because in the case of a soil where limited data is available, it may be appropriate to relate what is known about the composition to other parameters for which we have no information. The authors realize that it is difficult to group data for soil properties because of the inherent variability in soils belonging to a given textural class. However, to make the data obtained suitable for publication grouping of soils by textural classes was necessary. Data for individual soils studied may be obtained directly from the authors.

Materials and Methods

The surface soils (0-20 cm) used in this investigation were collected by Wischmeier and Mannering (10) during studies to evaluate the erodibility of Indiana soils. These studies involved determination of soil physical properties, but relatively little data was obtained on chemical and mineralogical properties. To expand the textural range and soil slope conditions covered in this study, additional soils were collected from throughout Indiana to supplement those used by Wischmeier and Mannering. All samples were obtained from sites which had been cropped for many years and identification relative to soil series was provided by soil survey personnel. All soils were air-dried, ground to pass an 80-mesh sieve, and stored in sealed plastic bags until use.

Twenty two chemical and mineralogical properties were determined for each of the soils included in this study. Clay, silt, and sand were measured by the pipet method outlined by Kilmer and Alexander (4). Kaolinite, inorganic amorphous material, montmorillonite, mica, quartz, chlorite, vermiculite, pyrophosphate extractable C and hot water extractable C were determined by procedures outlined by Roth, Nelson, and Römkens (8). Organic C was determined by the method of Mebius (5). Total N was estimated by the method of Nelson and Sommers (7). Fixed ammonium N was measured by the method of Silva and Bremner (9). Organic N was calculated as the difference between total N and fixed ammonium N. Total P was determined by the method of Sommers and Nelson (10). Organic P was estimated by the method of Mehta *et al.* (6). Inorganic P was calculated as the difference between total P and organic P. Total S was determined by procedures outlined by Bardsley and Lancaster (1). Cation exchange capacity was measured by the method of Edwards (2). Ammonium fixing capacity was determined by the difference in fixed ammonium N before and after treating 1 gram of soil with 1000 μg of ammonium N for a period of 24 hours at 22C.

Results and Discussion

Table 1 presents data on the average particle size distribution in Indiana soils belonging to seven textural classes. Since the basic criteria for grouping soils was particle size distribution, the data obtained are characteristic for the textural classes included in the study.

TABLE 1. *Particle size distribution in Indiana soils as related to textural classification.*

Textural class	No. of soils	Particle size distribution*		
		Clay	Silt	Sand
		%	%	%
Silty clay loam	4	36.5±1.9	49.8±5.6	8.0±5.5
Clay loam	2	24.5±0.7	34.5±7.8	28.5±0.7
Silt loam	24	16.1±3.2	66.4±7.1	13.3±8.8
Loam	9	17.2±2.4	43.2±5.3	36.1±5.9
Sandy loam	6	9.3±2.5	25.5±6.0	61.7±5.0
Loamy sands	3	4.0±1.0	9.3±1.2	85.3±1.2

* Values given are averages and standard deviations for the soils making up each textural class.

The average distribution of inorganic materials present in the clay fraction of Indiana soils belonging to seven textural classes is presented in Table 2. Surprisingly, the clay fraction of Indiana soils is rich in micaceous and chlorite-like minerals relative to kaolinite and montmorillonite. These findings are somewhat different from those of White *et al.* (12) who observed that Indiana surface soils contain substantial proportions of quartz and kaolinite in addition to mica, and different from those of Fehrenbacher *et al.* (3) who reported that loess soils from southwestern Indiana contain considerable montmorillonite. Other clay materials make up substantial proportions of the clay minerals in the soils studied, with the exception of vermiculite ($< 10\%$ of the total clay minerals). It is interesting to note that the proportions of inorganic amorphous material, quartz, and vermiculite tended to increase as the clay content of the soils studied decreased. The proportion of mica present in the clay fraction of Indiana soils tended to decrease as the sand content of the soils increased. The proportion of kaolinite, montmorillonite and chlorite-like minerals present in the clay fractions of Indiana soils studied was not related to soil textural class.

Table 3 presents data on the average organic C content and forms of organic C in Indiana soils belonging to seven textural classes. The average organic C concentration for the soils in each textural class and the standard deviation of C contents for soils within classes are presented. It is interesting to note that the coefficient of variation

TABLE 2. *Distribution of inorganic materials in the clay fraction of Indiana soils as related to textural class.*

Textural class	No. of soils	Mica	Koal-inite	Amorp. material	Montmor-illonite	Quartz	Chlorite	Vermic-ulite
	— — — — — —			% of clay fraction		— — — — — —		
Silty clay loam	4	45.8	9.2	6.1	6.7	7.5	19.4	5.3
Clay loam	2	37.1	8.2	6.5	13.9	9.0	22.4	2.9
Silt loam	24	21.1	16.1	14.3	14.9	10.6	19.3	3.7
Loam	9	34.5	9.9	12.3	12.3	11.7	15.8	3.5
Sandy loam	6	28.0	12.9	12.9	8.6	12.9	15.1	9.6
Loamy sand	3	20.0	15.0	15.0	10.0	17.5	15.0	7.5

TABLE 3. *Organic C content and forms of organic C in Indiana soils as related to textural class.*

Textural class	No. of soils	Organic C*	Org C forms: Pyrosphosphate ext.	Org C forms: Hot water ext.
		%	— — % of org C — —	
Silty clay loam	4	2.260±1.012	22.6	3.7
Clay loam	2	1.375±0.488	20.0	3.3
Silt loam	24	1.103±0.269	27.6	4.1
Loam	9	1.492±0.570	26.9	4.1
Sandy loam	6	1.197±0.637	39.4	7.0
Loamy sand	3	0.573±0.240	34.0	4.5

* Values given are averages and standard deviations for the soils making up each textural class.

for data on organic C content varied from 30 to 50%. This finding suggests that organic C contents of soils within a given textural class is not extremely variable because differences in organic C contents were greater between soils of varying textural classes than for soils within a given textural class. The amount of organic carbon present in the Indiana soils studied tended to decrease as the texture of the soils becomes coarser. However, some poorly-drained, coarse textured soils contained substantial organic C.

The proportion of organic C extractable with sodium pyrophosphate varied from 20 to 39% for the soils studied. The proportion of organic C in soils extractable with pyrophosphate tended to increase as soils become coarser in texture. This finding suggests that even though coarser-textured soils tend to have low amounts of C, the organic C present in these soils may be effective in promoting aggregation and may be readily available for decomposition by microorganisms. The latter point is important because decomposition of soil organic matter releases significant amounts of N, P, and S for plant growth. The fraction of soil organic matter extractable with pyrophosphate appears to be more active in binding inorganic materials into aggregates than other soil organic matter fractions. The proportion of organic C extractable with hot water varied from 3.3 to 7% within the textural classes studied. There was a tendency for the proportion of organic C extracted by hot water to increase as soil texture became coarser.

Hot water extracts polysaccharides, an organic C fraction which has been implicated in promoting aggregation and improving soil structure. These findings would suggest that coarser-textured Indiana soils may have the potential to be well aggregated due to pyrophosphate-extractable and water-soluble organic materials even though the absolute amount of organic carbon in these soils is relatively low.

The average total N contents, NH_4^+ fixing capacities, and forms of N in soils studied belonging to seven textural classes is given in Table 4. Within a given textural class, the coefficient of variation for total N content varied from 20 to 40%. The total N contents of Indiana soils tended to decrease as soils became coarser in texture.

TABLE 4. *Total N content, ammonium fixing capacity, and forms of N in Indiana soils as related to textural class.*

Textural class	No. of soils	Total N	NH_4^+-fixing capacity*+	N forms in soil: Fixed NH_4^+-N	Org N
		ppm	ug NH_4^+-N/g soil	— % of total N —	
Silty clay loam	4	2297±883	160(439)	13.6(854)	86.4
Clay loam	2	1420±424	108(441)	17.7(1024)	82.3
Silt loam	24	1205±254	24(149)	10.5(783)	89.5
Loam	9	1360±436	25(145)	11.2(884)	88.8
Sandy loam	6	1168±490	16(172)	6.2(774)	93.8
Loamy sand	3	563±154	2(50)	4.6(650)	95.4

* Values in parenthesis are ug NH_4^+-N fixed per gram of clay.
+ Values in parenthesis are ug fixed ammonium N per gram of clay.

Likewise, the NH_4^+ fixing capacity of silty clay loam soils was much higher than that of silt loams or sandy soils. In fact, the NH_4^+ fixing capacity of silt loams, loams, sandy loams and loamy sands was extremely low (i.e., less than 25 μg NH_4^+-N fixed/g soil). It is interesting that the NH_4^+ fixing capacity, when expressed as μg of NH_4^+-N fixed per g of clay, is much higher in silty clay loams and clay loam soils than in coarser-textured soils. The ammonium fixing capacity of the clay fraction of loamy sand soils is only 50 μg of NH_4^+ -N/g clay.

Data on forms of N in soils studied indicate that fixed NH_4^+-N constitutes a substantial proportion of the total N present in loam, silt loam, clay loam and silty clay loam soils. In the two clay loam soils, 17.7% of the total N was present as fixed NH_4^+-N. Compared to values for other midwestern soils, a very high proportion of the total N in Indiana soils is present as fixed NH_4^+-N. Even in coarse-textured soils, from 5 to 6% of the total N was present as fixed NH_4^+-N. These findings are significant because unlike other forms of N in soils, microbial activity does not release fixed NH_4^+ for plant uptake. Expressing the fixed ammonium content of soils on the basis of clay demonstrated that clay loam soils have an average of 1024 μg NH_4^+-N/g clay. Similar expressions for other soil textural classes illustrated that the fixed ammonium content of soil clays varied from 650 to 884 μg NH_4^+-N/g clay. The proportion of total N in soils which was organic tended to increase as soil textures became coarser. This finding was expected since the proportion of total N present as fixed ammonium in heavy-textured soils was much higher than that of coarse-textured soils.

Table 5 presents data on the average P content and forms of P. As expected, the total P concentration tended to be higher in heavier-

TABLE 5. *Total P content and forms of phosphorus in Indiana soils as related to textural class.*

Textural class	No. of soils	Total* P	Phosphorus Forms Organic P	Inorganic P
		ppm	— % of total P —	
Silty clay loam	4	705± 40	44.1	55.9
Clay loam	2	588±230	22.1	77.9
Silt loam	24	424±137	36.3	63.7
Loam	9	433±211	31.9	68.1
Sandy loam	6	301± 76	30.9	69.1
Loamy sand	3	340± 50	19.4	80.6

* Values given are averages and standard deviations for the soils making up each textural class.

textured soils and there was a tendency for total P content to decrease as soil texture became coarser. This finding is to be expected because soil P is normally associated with organic matter and clay and data presented previously have indicated that both clay content and organic matter content are lower in coarser-textured Indiana soils as compared to silty clay loam, clay loam, and silt loam soils. The proportion of total P present as organic P tended to be higher in heavier-textured soils as compared to coarser-textured soils. Conversely, the proportion of total P present as inorganic P tended to be higher in lighter-textured soils as compared to heavier-textured soils. This finding is important because it suggests that those soils which are low in total P contain P forms which are most readily available for plant growth (i.e., inorganic P forms), whereas those soils which are high in total P contain a lower proportion as inorganic P. Therefore, it can be concluded that most of the soils studied contain appreciable amounts of phosphorus in inorganic forms which will serve as a source of plant-available P for the years to come.

Table 6 gives data on the average total S content, cation exchange capacity (CEC) and organic C:N:S:P ratios of Indiana soils. All of the Indiana soils studied had appreciable concentrations of total S (i.e.,

TABLE 6. *Total S content, cation exchange capacity, and organic C:N:S:P ratios of Indiana soils as related to textural class.*

Textural class	No. of soils	Total S	Cation exc. cap.*	Org C:Org N:Org S:Org P
		ppm	me/100 g	
Silty clay loam	4	1905±106	35.0± 0.1(95.9)	12.1:1:1.5:0.24
Clay loam	2	1755± 7	29.9±10.0(122.0)	11.6:1:1.5:0.11
Silt loam	24	1386±140	12.1± 2.9(75.2)	10.2:1:1.3:0.14
Loam	9	1390±136	13.9± 6.3(80.8)	12.4:1:1.3:0.13
Sandy loam	6	1125±139	7.9± 3.4(84.9)	8.9:1:1.2:0.10
Loamy sand	3	1032±159	4.2± 0.9(105.0)	12.1:1:2.3:0.15

* Values in parenthesis are me of cation exchange capacity per 100 g of clay. It should be noted that a substantial portion of total exchange capacity resides in soil organic matter.

greater than 1000 ppm). It was also interesting to note that the coefficient of variation for total S within soil textural classes was from 1 to 15%. This would suggest that the S content of the soils studied was relatively uniform within a given textural class. The total S content of soils was highest in heavier-textured soils and decreased as soil texture becomes coarser. This finding is expected because most of the total S in soils is associated with soil organic matter, and it has been shown previously that the organic matter content of the soils studied was considerably higher in heavier-textured soils than in lighter-textured soils.

The average CEC of Indiana soils varied from 4.2 to 35 me per 100 grams over the textural classes studied. The CEC values decreased markedly as the sand content of the soils increased. Heavier-textured soils contained markedly higher CEC values than did coarser-textured soils. When CEC was expressed as me per 100 grams of clay, there was little difference in the values over the soil textural classes studied. However, soils belonging to the clay loam class had higher CEC per gram of clay than did soils belonging to any other textural class. It is important to recognize that a substantial portion of the CEC of the clay fraction is due to organic matter associated wih the inorganic constituents.

Organic C:N:S:P ratios were calculated to evaluate the consistency of soil organic matter composition over the textural classes. It is interesting to note that the average C:N:S:P ratio in soil organic matter was extremely consistent (average 11:1:1.5:0.15) within the textural classes studied. Only silty clay loam soils contained an abundance of organic P relative to C, N, and S in organic matter, whereas loamy sand soils were enriched in organic S. The fact that these ratios are constant over the wide range of soil types studied, suggest that a measurement of one parameter, such as organic C or organic N, would allow an investigator to estimate the composition of organic matter in any Indiana soil developed under similar conditions. The consistency of this ratio also indicates that cropping has resulted in proportional decreases in C, N, S, and P in the soil during the time net decomposition of soil organic matter has occurred.

All data on soil chemical and mineralogical analyses were subjected to linear correlation analysis. Table 7 presents a summary of correlations involving clay, mica, and organic carbon contents with other chemical properties of Indiana soils. Due to the relatively large number of soils studied, correlation coefficients (r) of greater than 0.35 are sufficient for significance ($p=0.05$). In addition to the positive correlations summarized in Table 7, a large number of other statistically significant correlations were obtained; however, they were not considered useful relationships for understanding soil differences.

The expected interaction between clay and soil organic matter is readily apparent from the correlations between clay, organic C, total N, total P and total S. These relationships are due to: (1) the stabilizing influence of clay on the rate of residue decomposition and thus the resultant organic matter content; (2) the main constituents of soil

TABLE 7. *Summary of correlations involving clay content, mica content, and organic C content with other chemical properties of Indiana soils.*

Correlation parameters	No. of soils	Correlation Coefficient (r)
Clay with Organic C	48	+0.54
Clay with Total N	48	+0.64
Clay with Total P	42	+0.53
Clay with Total S	42	+0.85
Clay with Fixed NH_4^+-N	48	+0.78
Clay with CEC	42	+0.79
Clay with NH_4^+ Fixing Cap.	44	+0.78
Mica with Fixed NH_4^+-N	42	+0.94
Mica with CEC	42	+0.82
Mica with NH_4^+ Fixing Cap.	39	+0.84
Mica with Organic C	42	+0.41
Mica with Total N	42	+0.47
Organic C with Total N	48	+0.94
Organic C with Organic N	48	+0.95
Organic C with Total P	42	+0.50
Organic C with Organic P	42	+0.57
Organic C with Total S	42	+0.27
Organic C with Pyrophosphate Sol. C	42	+0.76
Organic C with Hot H_2O Sol. C	42	+0.76

organic matter are C, N, P and S; (3) C, N, P and S in soil organic matter are present in nearly consistent ratio proportions. Numerous other studies have demonstrated the close relationships between these soil components. A result of the clay-organic matter association is the correlation with CEC. Negative charges originating from isomorphous substitution in clays and C, N, P and S functional groups in organic matter are responsible for the CEC of soils.

Clay content was also related to fixed NH_4^+-N content and NH_4^+ fixing capacities of the soils studied. This finding was expected because clay minerals such as illite and vermiculite are responsible for fixing NH_4^+ in soils and previous work (D. W. Nelson, Purdue University, unpublished data) has established that greater than 95% of the fixed NH_4^+-N in soils is present in the clay fraction.

Correlation data suggests that the micaceous mineral fraction is responsible for the fixed NH_4^+ content and the NH_4^+ fixing capacities of soils studied. These findings are to be expected because the only soils minerals having the capacity to fix NH_4^+ are mica and vermiculite. The vermiculite content of the soils studied was quite low. The cation exchange capacity was also directly related to the micaceous mineral content of the soils studied suggesting that a substantial proportion of the exchange capacity of these soils reside with the mica component. The organic C and total N contents of Indiana soils were not strongly related to soil mica content suggesting that soil organic matter is not predominately associated with the mica component of soil clays.

The organic C content was directly related to the amounts of total N and organic N present in Indiana soils. This finding has been reported in many studies of other soils in the United States. The total P and organic P contents of the samples studied were not strongly related to the organic C concentration in Indiana soils. It is surprising that there was not a good correlation between organic C and organic P content of the soils because both are components of soil organic matter. The finding that the organic P content of soils is variable in relation to the organic C content suggests that organic P is not accumulated in fixed proportion to the amount of organic C incorporated during soil organic matter synthesis. There was no relationship between the amount of organic C and total S present in Indiana soils. This finding is very difficult to understand because in excess of 95% of the total S in soils is present in organic form. The amount of pyrophosphate soluble-C and hot water soluble-C were directly related to the amount of organic C present in the soil, suggesting that a given proportion of the organic C is extractable with sodium pyrophosphate and with hot water. This finding suggests that similar types of organic matter components are present in most Indiana soils.

Conclusions

The following conclusions may be drawn from this study: (1) Indiana soils have a reasonably uniform clay mineralogy and the < 2 micron fraction of Indiana soils contain higher proportions of micaceous and chlorite-like clays as compared to other minerals, (2) the organic matter contents of Indiana soils are directly related to soil texture; heavier-textured soils have proportionately more soil organic matter than do coarser-textured soils. The organic matter present in Indiana soils is apparently uniform in composition because the ratios of organic C:N:S:P are very consistent over all textural classes, (3) Indiana soils generally have low NH_4^+ fixing capacities except for silty clay loams and clay loam soils where NH_4^+ fixing capacities greater than 100 μg NH_4^+-N/g soil are common, (4) Indiana soils have a larger proportion of total N present as fixed NH_4^+-N than other soils of the humid cornbelt, (5) the total C content of Indiana soils is reasonably high suggesting minimal probability for need of S fertilization, (6) the cation exchange capacity of heavier-textured soils exceeds 30 me/100 g and decreases proportionately as the clay and organic C contents decrease, (7) the micaceous mineral content is closely related to the fixed NH_4^+ content, the CEC, and the NH_4^+ fixing capacity, (8) the amounts of organic C, total N, total P, and total S are positively correlated with the clay content of Indiana soils.

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