PARALLELISM OF THE SOILS developed ON THE GRAY DRIFTS IN MINNESOTA.

By

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INTRODUCTION.

The whole of the state of Minnesota, with the exception of a very small area in the extreme southeastern corner, has, at one time or another been glaciated (23 p. 16). The study of the mantle of till left behind by the receding ice has shown that this deposit is the result of successive glaciations, some of the ice sheets having radiated from centers east of Jones Bay, designated the Labradorian, and the others from north or northwest of Minnesota, referred to as Keewatin centers. While some of the ice sheets from different centers may have been contemporaneous, or the one may have followed almost immediately after the other, in most cases each of the advances of ice after the first was so widely separated in time from its immediate predecessor that under the milder climate prevailing the earlier deposit had soils developed upon it and drainage channels fully formed. The succeeding invasion then planed off the hilltops, filled up the valleys and buried the remaining portion of the earlier drift sheet. In those cases where one of the later ice sheets did not extend as far as the earlier an opportunity is offered for a comparison of the soils formed on the two.

The drift material carried into the state and left behind by the melting ice was picked up between the center from which the glacier radiated and the northerly borders of Minnesota as well as along its course across the state. In the case of the later ice sheets glacial debris left by the earlier invasions was to a greater or less extent incorporated in the mass of fresh material brought by the advancing ice, a factor which complicates the comparison mentioned above. This mantle of glacial material constitutes the parent rock of most of the soils of Minnesota.

Glacial History of Minnesota.

From eleven to thirteen successive stages of the glacial period are generally recognized as applying to the United States (13, p. 383). These are represented below, the most recent (XIII) being given first and the oldest last (I).

XIII - The Champlain sub-stage (marine).
XII - The glacio-lacustrine sub-stage.
XI - The Later Wisconsin, the sixth advance.
X - The fifth interval of deglaciation, as yet unnamed.
IX - The Earlier Wisconsin, the fifth invasion.
VIII - The Peorian, the fourth interglacial interval.
VII - The Iowan, the fourth invasion.
VI - The Sangamon, the third interglacial interval.
V - The Illinoian, the third invasion.
IV - The Yarmouth, or Buchanan, the second interglacial interval.
III - The Kansan, or second invasion now recognized.
II - The Aftonian, the first known interglacial interval.
I - The sub-Aftonian, or Jerseyan, the earliest known invasion.

There is some doubt as to the existance of an Iowan. The late Professor Calvin and members of the Iowa Geological Survey have regarded this as a distinct stage of glaciation but little older than the Wisconsin. Leverett (22 p. 282) was at first inclined to regard this as possibly of Illionoian age but has later come to consider it as part of the Kansan. In this case the Sangamon and the Peorian interglacial intervals would be identical. In the present thesis the views of Leverett are accepted.

Of the six glacial invasions five crossed what are now the borders of this state (22, p. 248 ff; 13, p. 382 ff.) The first of these was the pre-Kansan or Nebraskan which corresponds to the sub-Aftonian. This radiated from the Keewatin field and covered the greater part of the state but none of it is now naturally exposed in Minnesota, it having been entirely buried by the following invasions. It is encountered only in the deeper wells.

The second ice sheet to reach the state, the Kansan or Old Gray Drift, (Fig. 1), also radiated from the Keewatin field, covering every part of the state either previously or subsequently glaciated. It is still exposed in parts of Dakota, Rice, Dodge, Olmstead, Goodhue, Mower, Fillmore, Pipestone and Rock counties. Its presence in the two counties named last was not recognized by glacial geologists at the time when the field work for this study was carried out.

The Illinoian, or Old Red Drift, the third to reach the state covered only a small area in Washington county and the greater part of Dakota county. It came from a Labradorian center and over-rode the Kansan.

The fourth advance of the ice into Minnesota, the Early Wisconsin or Young Red Drift, approached from the northeast and covered a considerable area to the west and southwest of Lake Superior (Fig. 1). The two red drifts crossing highly ferruginous rock formations gathered up portions of these and, consequently, the soils developed upon them show a distinctly red color.

The fifth ice sheet, the Late Wisconsin, or Late Gray Drift, radiated from a Keewatin center north or slightly to the northwest and covered a much larger portion of the state (Fig. 1) than either of its immediate predecessors. This younger formation in contrast to the Old Gray Drift is characterized by numerous lakes and poorly drained areas which the deposits older than the Young Red Drift do not possess. Fully developed drainage lines are to be found only where they were formed by the out-rushing water from the melting ice.

In addition to the Keewatin or DesMoines Lobe of the Late Wisconsin there was the contemporaneous Superior Lobe, in which the ice advancing up the bed of Lake Superior spread to the north, northeast, east and southeast. The till, almost free of limestone, was derived from crystalline rocks and, like the Illinoian and Early Wisconsin in Minnesota, has a red color. As it did not extend as far as the border of the DesMoines Lobe, it is not included in the present study.

Each period of glaciation was separated from the succeeding one by an interglacial interval which, in some cases, was very long, probably much longer than has elapsed since the Late Wisconsin. The successive stages appear to have become shorter, the earlier being much longer than the later ones, (13 p. 382).

Soil Formation.

Soil is to be defined as the superficial weathered layer of the solid earth-crust, the last including not only solid rocks but also unconsolidated formations such as loess, dune-sands, glacial deposits and deposits of plant remains. Soils are variously defined, according to whether the particular writer is viewing them as the habitat of plants - the botanical viewpoint, or as simply the superficial geological formation - the geological viewpoint. Accordingly the depth of the superficial layer includes, under the general designation "soil", varies from writer to writer, the geologist often placing this higher than the botanist. The latter will consider it to extend, at least, as deep as the roots penetrate, and the former as deep as the influence of percolating water, aided more or less by organisms or their products, may have affected the composition of the parent rock.

As the common farm crops in southern Minnesota derives both their mineral constituents and their moisture chiefly from the first three feet and almost exclusively from within the first five feet, and as most of them draw more or less upon the third foot for these, the whole of the first three foot section is to be considered as well within the soil zone. For this reason a study of the soil should include sections to at least this depth.

The surface three feet or so of a freshly exposed lake-bed, a recently formed sand-dune, or a till-plain or terminal moraine just exposed by a retreating glacier, is not to be considered as soil but as the parent rock upon which soils may be developed by combined agencies of living organisms and the products resulting on the death of these, percolating or ascending waters charged with carbonic acid, soluble salts and organic compounds.

The form of alteration in the parent rock, induced by the soil forming agencies, will depend upon the vegetative covering, the temperature, the precipitation, the rate of evaporation, level of ground water, the perviousness of the parent rock to decending water and the water retaining capacity of the superficial portion of this. The vegetative covering, in its turn, is largely determined by the character of the parent rock or of the soil developed upon this, together with the climate. Hence, the character of the parent rock and the climate of the region in which it happens to be exposed will determine the relative importance of the role of the various soil making agencies and hence, the character of the resulting soil.

"Within only recent years has it come to be recognized, first through the work of Dakutschajew and Sibertzew in Russia, that in general the character of the soil is much more dependent upon the climate of the region in which it is found than upon the character of the rock from which it has been derived, or upon the manner of its formation. Thus a granite may weather to produce a soil very similar to that developed upon a wind-laid silt loam or a lacustral clay when all three have been exposed for a sufficient length of time to the same climate, while all will be quite distinct in character from the soils that would have resulted under a radically different climate". (2, p. 199).

Accordingly, as the climate of the earth shows a zonal distribution, the soil, unlike any other geological formation, also shows a zonal distribution, similar zones appearing in regular order on the different continents and in both hemispheres (15, map 2) as we pass from the equator poleward, or, in a tropic or temperate region, ascend a high mountain (16, p. 343). Thus, desert soils in the United States resemble desert soils in Africa or Asia and the prarie soils of United States the Chernosem of European Russia and Siberia (16, p. 286; 2, p. 231; 4, p. 423) and the pampas soils of Argentine (16, p.44 and 114). If one but knows the climate of a region the general character of the soils can be predicted.

Where the character of the parent rock, its chemical composition or its physical properties, have been such as to leave upon the resulting soil an impression not overshadowed by the climate the soil is, according to Glinka, to be designated Endodynamomorphic but otherwise as Ektodynamomorphic (16, p. 35; 27, p. 559). It is with the latter group of soils that the present study is concerned and these may be divided into six classes.

1. Soils formed where the mean temperature is high and the precipitation very high or fairly high.

The most of the organic material decays rapidly, causing a low content of organic matter in the soil, and the salts resulting from this and the weathering of silicates are completely leached out. The silicic acid derived from the weathering of ilicates and alumino-silicates is leached out along with the alkali and alkali earth etals, leaving behind, in addition to the quartz, the alumina, ferric oxide and titanium xide.

The laterites (tile colored soils, 10, p.440) of the moister and the Red Earths the drier portions of the tropics belonging to this class. The yellow soils of southern ance (27, p. 600) and Japan are related to the Red Earths, the removal of the silica ing characteristic of only the later stages as in the Laterites, in which the concentra-on has, in various places, proceded so far as to make this soil serve as a source of tallic iron, really a low grade ore.

II. Soils where the precipitation is lower and the temperature much lower, as er Northwestern and Western Europe and the United States east of the Mississippi river.

The soluble salts are leached out, the carbonates removed from the upper layer, a certain amount of iron transported from the upper to the lower layers (27, p. 554). y part of the organic matter is lost rapidly thus permitting a comparatively large unt in ther upper layers. In the colder moister regions there result podsols, character-ically a whitish or gray horizon near the surface with concentration of iron at a ater depth and a markedly acid reaction. Along with the iron, manganese, calcium, nesium, potassium and sodium more or less phosphoric acid is leached out of the upper ers, this being redeposited with the iron and manganese at a lower horizon (15 p.78).

Where the temperature is higher, brown earths or gray forest soils develop, se showing less translocation of iron and little or none of phosphoric acid.

Both the true podsols and the brown or gray forest soils develop under forest ditions.

III. Soils where the precipitation, evaporation, temperature and topographical itions cause a grassland vegetation to hold its own agains t the forest.

The abundant growth of grasses exhausts the soil moisture supply and causes layed decomposition of these with the result that the organic matter content of the l is high. The plants, being chiefly annuals, biennials, or shortlived perennials, fre-tly contribute both root and stem, as well as leaf, to the soil forming agencies and the organic matter is increased as deeply as the roots penetrate. Alkali salts are removed and carbonates largely leached out of the upper layer to be deposited, for the most part, in the zone of maximum penetration. Gypsum is redeposited at a still lower level, if at all. Alkali salts and carbonates resulting from the action of carbon dioxide upon the silicates behave like the original soluble salts and carbonates, the resulting silicic acid remaining in the upper layers (2, p. 315). The soils include the Black Earth or chernozem of Russia and the black and part of the brown prarie soils of the United States and Canada (21, p. 207 and 338).

IV. Soils of the semi-arid or arid regions with a short grass or desert vegetation

The content of organic matter is lower than in the preceding group. Little or no percolation occurs. The movement of mineral constituents is confined to a concentration of carbonate and soluble salts just beyond or near the root tips in the drier portions and to removal of only the soluble salts in the moister . This condition is found on the Great Plains of the United States and Canada and on the Steppes of Russia (16, p. 132).

V. Soils formed under excess of moisture, the upper soil horizon or both this and the lower being saturated with water the most of the time.

Organic matter being unable to decay accumulates, iron is present largely as ferrous salts, and pyrites is formed. Where there is no outlet for the water evaporation will cause accumulation of gypsum and carbonates near the surface if these are present in surrounding higher lying soils. Peat, muck, marsh meadow, and swamp soils belong to this group.

VI. Alkali soils.

These form in both the chernozem and dry zones in places where water accumulates periodically and then escapes by evaporation, there being little or no loss by seepage or run-off (18, p. 103), or where water rises from a water table close to the surface and evaporates so rapidly that the percolation following rains does not counter-balance the ascent of soluble salts.

Area selected for study.

Rice county in southeastern Minnesota offered the best site in the state for a study of the influence of the age of a glaciation upon the character of the soils. The earliest glaciation from which any till remains uncovered by later deposits, the Kansan, covered the whole of what is now included in the county boundaries while the most recent of all the glaciations, the Late Wisconsin, covered only the western two-thirds and no intervening ice sheet had entered the county except possibly the Early Wisconsin at the very edge on the north(Fig. 1). A long period of time including several epochs of glaciation as well as long interglacial periods, in which floras and faunas were developed, elapsed between the two. Both glaciers radiated from Keewatin centers and accordingly brought along with them similar material, the chief characteristic of which was an abundant supply of limestone fragments.

Thus we have in Rice county exposed side by side, soils developed on the oldest exposed and on the very youngest of the glacial formations, both of which have been subjected to the same climatic conditions and other soil forming agencies since the melting of the last ice-sheet.

For such a study it is highly desirable to be able to compare soils formed under different vegetation conditions, e. g., forest soils on the earlier drift with forest soils on the later and natural grassland soils on the former with natural grassland soils on the latter. Rice is the only county in which this is possible, the other counties in which the two selected drifts occur side by side being south of the limit of the forest (Fig. 2).

Further, for Rice county there was available a detailed soil survey by the United States Bureau of Soils made in 1909 and published in 1911 (11) while Leverett kindly made a detailed demarkation of the boundary of the Late Wisconsin glaciation within the county, this having not yet been reported in printed form.

In the survey by the Bureau of Soils the two drifts exposed on the surface were identified, and the line dividing them recognized (11, p. 21 - 23), Leverett having personally indicated the boundaries to the soil surveyors. Fourteen types of soil are shown, of which three of the most widely distributed, viz: Carrington silt loam, Fargo silt loam, and Carrington loam have representative areas on both glacial drifts. No attempt was made by the United States Bureau of Soils surveyors to differentiate types in respect to the two drifts although it is states (p. 21) that "the limestone from which much of this drift (Kansan) is derived, has long since given way to the agencies of weathering and only the more resistant rocks are left, whereas in the Wisconsin drift limestone and shales in addition to numerous cherty and crystalline rocks are very common".

Thus an exceptional opportunity was presented to determine whether the soil classification used by the United States Bureau of Soils properly recognizes differences between soils on different drifts, to study any differences in the mechanical, chemical and petrographical composition caused by the difference in age and the consequent longer continued leaching on one than on the other; to classify them according to their development in view of the climatic influences to which they have been exposed, and to compare them with the same types found elsewhere.

Types chosen for study.

Only four soil types are involved in the present study. A soil type as the term is employed by the U. S. Bureau of Soils (12, p. 11) in its surveys is the unit of classification and should include all soils that are alike agriculturally or as nearly alike as it is possible to determine by field methods. The type name results from combining the class name (loam, silt loam, clay, etc.) of the surface material with the series name (Fargo, Carrington, etc.). The class is determined by the texture of the surface soil, as decided upon the field by the experienced surveyor and later confirmed in the laboratory by mechanical analysis of typical samples. Some 15 different classes are recognized.

The series name expresses all the properties of the type except the texture of the surface stratum, the portions encountered by tillage implements, and hence must indicate the color and content of organic matter in both surface soil and subsoil, the subsoil profile, the topography, the origin and the mode of formation and prominent chemical differences insofar as they are likely to affect agricultural practice. A series includes all the types that differ only in the texture of the surface stratum. The total number of series so far recognized in the United States by the Bureau of Soils amounts to about 600 and of type to a little in excess of 1650.

The soils of the Carrington series are derived from the weathering of the glacial drift. The loam occupies the rolling uplands, is generally well drained and was originally nearly all covered with deciduous forest - the Big Woods. The silt loam is found almost only in upland portions of the originally prairie part of the county. Its drainage on the Kansan is much poorer than that of the Carrington loam, but on the Wisconsin the drainage is good. Boulders occur in small numbers on both the Carrington types, some being very large.

The Carrington loam is described (11, p.22-23) as "a brownish black or yellowish brown silty loam, 12 to 24 inches deep, grading into a heavy yellow clay, which usually exceeds a depth of 15 feet. The texture of the surface soil is for the most part uniform, but the color and depth are variable. A depth of 15 inches is more typical than either of the extremes. There are few stone fragments in the material to a depth of 3 feet, though these increase in quantity with depth."

The Carrington silt loam (11, p.26) is "a grayish-black or black heavy silty loam, with a depth of 15 inches, grading into a drab or brownish silty clay which at about 24 inches is underlain by dark yellow clay. The soil is generally uniform in texture and has a high content of organic matter."

The Fargo silt loam is described (11, p. 32) as "a black clay or silty clay loam from 10 to 15 inches deep, grading into a dull-colored clay which at 20 to 30 inches changes to a yellow and gray plastic clay. Beneath this there usually occurs a thin layer of sand, sandy clay or gravel. In the southeast corner of the county the Fargo silt loam occupies a part of the original plain of the Kansan drift, but elsewhere it is a bottom-land type. The topography is generally level but is characterized by very gentle slopes as it approaches sloughs and streams. The areas are generally poorly drained and water is often found within the 3-foot section in the bottoms.

The soil material along the sloughs has been washed from the higher slopes and has accumulated faster than the sluggish streams can remove it. Some of the type, however, is lacustrine in origin, having been deposited in shallow basins or ponds. A very small part of it can be attributed to stream and river oferflows." Originally it was almost exclusively grass-land.

Marshall loam, in more recent counties surveyed designated Marshall silt loam is derived from the weathering of loess deposits (11, p. 35). The surface soil is a yellowish brown or brown silty loam to 6 or 12 inches, under which is a compact yellow silty loam and under this, at a depth varying from 24 to 36 inches, a loose incoherent silty material lighter in color. The loess deposit varies from a few inches to 15 feet in thickness and in this county is underlain by glacial material.

The mechanical composition of typical samples from the county reported by Burke and Kolbe (11) is given in table 1. The great amount of time consumed by a mechanical analysis prevents it being extensively employed in survey work. Certain physical constants, viz; the hygroscopic coefficient and the moisture equivalent, are

Table I.

Mechanical composition of typical samples from
Rice County, as reported by Burke and Kolbe.

Stratum	Fine gravel percent	Coarse sand percent	Medium sand percent	Fine sand percent	Very fine sand percent	Silt percent	Clay percent	Computed Moist. equiv. By B & S[1] formula	By A & R[2] formula
Carrington loam.									
Soil	0.7	4.0	5.1	13.8	9.9	49.0	17.3	29.7	27.1
Subsoil	1.1	6.4	6.7	16.8	14.4	36.5	17.6	27.4	24.5
Carrington silt loam.									
Soil	0.0	1.2	1.6	2.8	18.8	62.3	12.9	27.7	27.1
Subsoil	.0	2.3	2.2	3.8	30.9	39.7	20.8	31.3	27.3
Fargo silt loam.									
Soil	0.0	3.3	4.2	9.4	4.9	65.0	13.1	28.4	28.0
Subsoil	1.9	6.2	7.0	15.6	10.1	39.8	19.0	29.5	26.5
Marshall loam.									
Soil	0.1	1.7	4.6	12.1	10.6	50.5	20.5	33.2	28.6
Subsoil	.0	1.5	4.9	10.0	38.9	26.4	17.9	25.7	24.3
Lower Subsoil	.0	1.0	5.0	13.3	25.0	42.4	13.2	24.1	24.6

1. Briggs and Shantz

2. Alway and Russell

dependent upon the mechanical composition and express in a single valued term the relative fineness of texture, while they are readily determined. Briggs and McLane (6, p.20-21) and Briggs and Shantz (8, p. 73) have proposed the formulas - Hygroscopic coef. = 0.0007 sand + 0.082 silt + 0.39 clay. Moisture equivalent = 0.02 sands + 0.22 silt + 1.05 clay. Alway and Rost (4, p. 410) have pointed out that no one formula will do for all soils but that as an approximation the above will serve. For loessial soils, such as the Marshall silt loam, they have developed a more suitable formula.

Hygroscopic coef. = 0.0005 coarser fractions + 0.07 very fine sand + 0.082 silt + 0.39 clay.

Similarly Alway and Russel (5 p. 842) from the same soils have developed a formula: Moisture equivalent = 0.14 sands + 0.27 silt + 0.53 clay.

Previous Comparisons.

A limited amount of data upon the relation of the chemical composition of glacial soils to the age of the drift upon which they occur is already available, but none of the studies were made under conditions so favorable as those existing in Rice county. Hopkins and Pettit (20) in Illinois, Brown (9) in Iowa, and McMiller (25) in Minnesota have each reported a study.

Hopkins and Pettit's study was based upon Leverett's drift survey of Illinois, in which six glacial formations had been mapped. A considerable number of samples were collected from three depths on each, 0-7, 7-20, and 20-40 inches, and subjected to analysis for nitrogen, carbon, potassium and phosphorus. The averages for the different drift sheets are summarized in table 2.

As the glacial soils of Illinois are generally covered by a layer of loess from 3 to 10 feet or more in depth (20 p.193) the samples were not of till but of the overlying mantle, and the age of the latter is not definitely related to that of the former. Hopkins and Pettit appear to have assumed that after each glaciation the freshly exposed till became quickly covered with its mantle of loess derived from the till sheet a portion of which it covered, and that the loess deposited on the later till sheets was

Table 2.

Relation of composition of Illinois soils to age of drift as shown by data of Hopkins.

Glaciation	Nitrogen 0-7" %	Nitrogen 7"-20" %	Nitrogen 20"-40" %	Phosphoric acid 0-7" %	Phosphoric acid 7"-20" %	Phosphoric acid 20"-40" %	Potash 0-7" %	Potash 7"-20" %	Potash 20"-40" %
A. Undulating prairie lands, with silt loam soil.									
Lower Illinoian	.144	.080	.054	.096	.086	.092	1.49	1.61	1.68
Middle Illinoian	.218	.145	.057	.133	.110	.092	1.93	1.87	1.80
Upper Illinoian	.242	.162	.057	.138	.120	.106	1.97	1.94	1.97
Pre - Iowan	.215	.116	.066	.136	.117	.129	2.05	2.17	2.05
Iowan	.246	.128	.059	.140	.110	.106	1.97	1.98	1.99
Early Wisconsin	.252	.164	.057	.136	.115	.100	2.17	2.18	2.35
Late Wisconsin	.337	.172	.060	.161	.113	.101	2.70	2.89	3.20
B. Flat prairie lands with clay loam soil.									
Middle Illinoian	.270	.154	.050	.163	.130	.115	1.91	1.92	1.90
Upper Illinoian	.338	.184	.052	.193	.154	.140	1.78	1.82	1.92
Early Wisconsin	.392	.180	.058	.232	.177	.138	2.10	2.15	2.22
Late Wisconsin	.445	.227	.053	.214	.163	.149	2.24	2.36	2.51
C. Timbered uplands, with silt loam soil.									
Lower Illinoian	.107	.054	.041	.108	.115	.122	1.91	2.01	1.99
Middle Illinoian	.093	.049	.047	.094	.087	.108	2.00	1.96	1.98
Upper Illinoian	.100	.047	.038	.096	.092	.124	2.09	2.17	2.01
Pre - Iowan	.119	.057	.040	.096	.101	.131	2.23	2.28	2.04
Iowan	.096	.053	.041	.103	.113	.149	2.15	2.14	2.10
Early Wisconsin	.094	.047	.041	.099	.092	.101	1.96	2.05	2.08
Late Wisconsin	.114	.068	.054	.092	.080	.092	2.86	3.34	4.33

derived chiefly from these and did not affect the soils of the earlier glaciations. In default of satisfactory evidence of this it is doubtful what, if any, importance we are to attach to their data in connection with the present question. It should be pointed out that Hopkins and Pettit's investigation was not planned to answer the question, but to determine the general character of Illinois soils, their data being reported by glaciations, and these in order of age, in order to bring out what relation, if any, existed between age and chemical composition. While they report no physical constants their omission is not so serious as the soils alluded to in table 2 were all silt loams or clay loams of loessial origin.

The composition does not appear definitely associated with the age of the drift except that the Late Wisconsin soils are in general richer in potash than those of the earlier formation. In the case of the prairie soils there is some relation but in the timber uplands none. Hopkins and Pettit explain the latter on the assumption that erosion keeps a comparatively fresh and unleached stratum constantly near the surface.

Brown (9) in a recent study of Iowa soils very similar in conception to that of Illinois compares Late Wisconsin drift soils with the Kansan drift soils lying just to the east (He following the practice of Iowa geologists designates as Iowan the drift sheet which Leverett regards as an integral part of the Kansan). Like Hopkins and Pettit he divides his soil column into three sections, soil 0-6-2/3 inches, subsurface soil 6-2/3 - 20 inches, and subsoil 20 - 40 inches. He reports neither any physical constants of his samples nor the soil types from which they were taken, most of them probably being taken from unsurveyed counties.

The Late Wisconsin soils were collected from three diferent counties - Clay, Kossuth and Boone and the Kansan from six different counties - Cerro Gordo, Floyd, Bremer, Blackhawk, Buchanan and Delaware. Thus the most easterly of his Kansan fields was about 200 miles east of his most westerly Late Wisconsin field.

A summary of his data is reported in table 3. He finds the Late Wisconsin soils much richer in total lime, from 60 to 1100 per cent, in all three levels while the carbonates differ little except in the lower level, where on the later drift they are

Table 3.

Difference in composition of Iowa soils on Kansan (or Iowan) and Late Wisconsin drifts, as shown by data of Brown.

Depth Inches	Nitrogen Kansan per cent	Nitrogen Late Wis. per cent	Phosphoric acid Kansan per cent	Phosphoric acid Late Wis. per cent	Potash Kansan per cent	Potash Late Wis. per cent
0 - 6.6	.226	.273	.147	.160	1.33	1.72
6.6 - 20	.142	.200	.126	.126	1.44	1.67
20 - 40	.056	.071	.097	.124	1.45	1.55

Depth Inches	Lime Kansan per cent	Lime Late Wis. per cent	Carbon Dioxide Kansan per cent	Carbon Dioxide Late Wis. per cent	Frequency of acidity Kansan per cent	Frequency of acidity Late Wis. per cent
0 - 6.6	0.63	1.33	0.018	0.025	90	12
6.6 - 20	0.63	1.01	0.015	0.035	66	0
20 - 40	0.58	6.02	0.016	2.970	70	0

abundant. An acid reaction is usually found in all three levels on the Kansan but only rarely on the Late Wisconsin and then only in the surface foot. On the latter, the total potash was much higher in the first two sections and slightly so in the third while nitrogen was considerably higher in all three levels. The total phosphoric acid averaged higher in both the first and third sections on the Late Wisconsin while the subsurface showed no differente.

McMiller (25) in an investigation of the soils of the most southerly tier of counties in Minnesota, begun in the autumn of 1913 and almost completed before the appearance of the Brown report; conducted a somewhat parallel study. It differed in general conception from the former in that only virgin fields, and these on till plains and terminal moraines, were selected; the sampling was in three one-foot sections, five fields being dealt with in each county. The proportion of gravel and a physical constant, the moisture equivalent, are reported for every sample, thus permitting a ready recognition of the general character of the soil and even the identification of the soil type.

Five of McMiller's fields were on the Kansan, all these being near Spring Valley and on Carrington loam, and 24 on the Late Wisconsin, four near Albert Lea, five near Wells, five near Fairmont, five near Jackson, five near Worthington and five near Adrian. These 24 fields were distributed among five different types, Carrington loam, Carrington silt loam, Fargo silt loam, Fargo clay loam, and Barnes silt loam. When the averages for the five fields near Spring Valley are compared with those for the three on the same soil type near Albert Lea, the most easterly Late Wisconsin fields, they being about 50 miles to the west, no great differences in properties are shown (table 4), but when the averages of all the Late Wisconsin fields are compared with those of the five Kansan the differences are more similar to those found by Brown.

Table 4.

Comparison of Carrington loam at Spring Valley, on the Kansan, with that at Albert Lea, on the Late Wisconsin, from McMiller's data.

h	Coarser fragments		Moisture equivalent		Nitrogen	
pt	Kansan per cent	Late Wis. per cent	Kansan per cent	Late Wis. per cent	Kansan per cent	Late Wis. per cent
	0.47	0.00	23.8	23.1	.190	.220
2	1.28	0.53	19.6	21.1	.076	.118
3	1.49	0.89	16.6	20.6	.030	.063

	Total phosphoric acid		Total Potash		Carbon dioxide	
1	.15	.15	1.85	1.83*	.05	.05
2	.09	.10*	1.77	1.94*	.03	.05
3	.09	.15*	1.57	1.90*	.01	.05

verage of four fields, including one on Carrington silt loam.

FIELD WORK

Selection of Fields.

The three types mentioned above, viz. the Carrington silt loam, an upland prairie type, the Fargo silt loam, a lowland prairie type, and the Carrington loam, a forest type, were selected for study on both drifts.

The fields representing these types on the Kansan are located in the township of Wheeling in the eastern part of the county with the exception of one just over the north line of this (Fig. 3). Fields of Carrington silt loam and Fargo silt loam sampled on the Late Wisconsin are located in the townships of Warsaw and Morristown in the southwestern part of the county, while those of Carrington loam on this drift were selected in the townships of Walcott and Cannon City, none being far distant from the city of Faribault.

The Marshall loam, a type developed upon loessial material derived entirely from pre-Wisconsin drifts and confined to the Kansan side of the dividing line, was studied in addition to the three just mentioned.

In selecting the individual fields it was the aim to secure those in as nearly their virgin condition as it was possible to obtain. This is extremely important since, as has recently been pointed out by Glinka (16 p. 96), the formation of soil horizons which are within reach of the plow is not uncommon. Not a single entire field of upland prairie was found. So, in the case of the Carrington silt loam the task of locating suitable tracts from which to take samples was difficult. Since they were so easily brought under the plow, it is not surprising that entire fields still in an actually virgin condition on this type are no longer to be found. At the time of the field work a few of the original settlers were still living and these were able to give much valuable information. Each field was selected only after consultation with the oldest settlers in the neighborhood and a more or less complete history of the field had been obtained. Thus in the case of one field, IV on the Marshall silt loam, an old settler living within half a mile had cleared off the brush and plowed the adjacent field in 1858 and had seen it every year since. Practically all the samples taken on the Carrington silt loam were from along line fences or beside roadways which it seems certain had never been plowed.

In the case of the Fargo silt loam virgin fields were not quite so

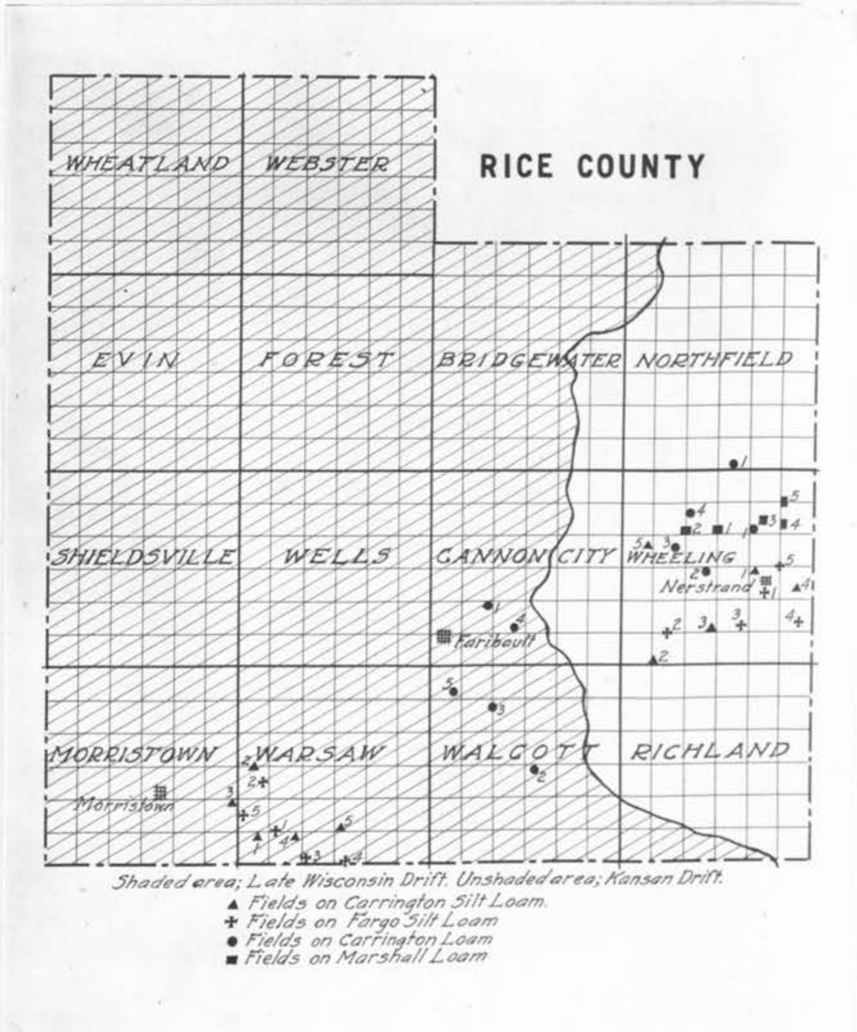

Fig. 3.

Map of Rice County, showing the position of the two drifts and the fields sampled on each.

difficult to find. On the Kansan, two rather poorly drained meadows formed two of the fields, roadways two others, and a line fence border the fifth, while on the Late Wisconsin all were from line fence borders or beside roadways. The two meadows fields mentioned were both plowed a few days after the samples were taken.

Satisfactory fields on the Carrington loam were comparatively easy to locate, the required number of forested areas properly distributed being easily found.

On the Marshall loam, three of the five fields sampled were forested. The sets of samples for the other two were taken, in one case, along a line fence and in the other by the side of a roadway, neither of which, within the recollection of old settlers in the neighborhood, had ever been plowed. Land adjacent to the last two, however, had been cleared of the forest for many years and given over to mixed farming. We will refer to these two as "cleared fields".

In the case of each type an effort was made to locate the five fields so that no two would be less than a mile apart and usually this was found possible. On the Marshall loam three of the fields were a little less than this distance apart.

Method of Sampling.

Five fields (Fig. 3) on each of the types chosen on the two drifts were selected and from each one of these, two sets of samples were taken, the samples of each set being composites from ten borings made approximately 10 yards apart and to a depth of 3 feet. The surface foot was taken in two 6-inch sections so that samples from 4 different depths were obtained, viz: 1-6, 7-12, 13-24 and 25-36 inches. Two augers, one 2.0 and the other 1.5 inches in diameter, were used in the work, the larger being employed to take the surface section and to enlarge the hole preparatory to taking the lower sections with the smaller. Care was taken to prevent the samples from the lower sections being contaminated with soil from the upper part of the hole. The composites of ten borings are designated "Set 1 samples" and "Set 2 samples" while the composites made up in turn from these, and so representing twenty borings, are referred to as the "field samples". The so-called "drift samples" for each type were secured by combining equal weights of the "field samples", and so are composites from 100 borings scattered over a considerable territory.

EXPERIMENTAL.

A - Relative Fineness of Texture.

1 - Proportion of coarser fragments.

When taking samples the fragments larger than 2 mm. in diameter, which were brought up by the auger were included in the sample. In cases where a boulder an inch in diameter or larger obstructed the way a new boring was made. No attempt was made to ascertain the amount of coarse gravel or of rock fragments still larger. On glaciated areas such as these this would vary considerably from place to place and its determination would involve the handling of large amounts of soil and subsoil in the field.

The percentage of the coarser material, as above defined, and the average weight of the fragments (tables 5 to 12) were determined in the samples taken in the different fields. They also serve as a rough indication of the varying amounts of coarse gravel and boulders present in the different sections and on the two drifts.

<u>Carrington silt loam.</u> On the Kansan, the average percentages found for the three foot section in the different fields are very similar while the variation between the amounts found in the corresponding sections are not radically different. The maximum is found, as would be expected, in the third foot-section, little difference existing between the quantities in the two upper foot-sections. The average for all sections of the 5 fields is 0.51 per cent.

The percentages found for the Late Wisconsin are on the average 280 per cent higher than those for the Kansan. It is evident from this that the processes of weathering are the more advanced on the older deposit. An examination of the particles shows that shales, limestones, and cherty rocks are much more abundant on the younger formation, having practically disappeared from the older.

For this type the average weight (table 6) of the gravel particles brought up by the auger is very uniform, showing little variation from field to field

Table 5.

Coarse gravel in the different sections from the five fields on Carrington silt loam.

Depth Inches	Field I per cent	Field II per cent	Field III per cent	Field IV per cent	Field V per cent	Average for 5 fields per cent
			1. Kansan.			
1 - 6	0.06	0.52	0.23	0.15	0.12	0.22
7 - 12	0.04	0.68	0.33	0.21	0.50	0.35
13 - 24	0.13	0.37	0.31	0.13	0.14	0.22
25 - 36	1.08	0.77	1.15	1.06	1.15	1.04
Average 1 - 36*	0.42	0.56	0.55	0.46	0.53	0.51
			2. Late Wisconsin			
1 - 6	0.17	1.18	1.00	1.03	0.99	0.88
7 - 12	0.51	1.08	1.25	1.38	0.98	1.04
13 - 24	1.32	0.91	2.83	1.91	2.38	1.87
25 - 36	1.94	2.85	3.44	2.59	4.32	3.03
Average 1 - 36	1.20	1.63	2.46	1.90	2.56	1.95

* To secure the averages for the 3 foot-sections the percentages from the two 6-inch sections were averaged and this result, in turn averaged with the two lower sections. This procedure was followed for all tables reported hereafter.

Table 6.

Average weight of coarse gravel particles in the different sections from the five fields on Carrington silt loam.

Depth Inches	Field I grams	Field II grams	Field III grams	Field IV grams	Field V grams	Average for five fields grams
			1. Kansan			
1 - 6	.022	.022	.043	.020	.018	.025
7 - 12	.019	.031	.043	.020	.064	.035
13 - 24	.017	.020	.031	.016	.023	.021
25 - 36	.043	.021	.044	.024	.032	.033
Average 1 - 36	.027	.022	.039	.020	.032	.028
			2. Late Wisconsin			
1 - 6	.020	.045	.037	.026	.065	.039
7 - 12	.018	.032	.024	.031	.027	.026
13 - 24	.024	.010	.027	.028	.031	.024
25 - 36	.020	.023	.027	.022	.027	.024
Average 1 - 36	.021	.024	.028	.026	.035	.027

or from drift to drift.

Fargo silt loam. The general distribution (table 7) of coarser fragments is much the same as on Carrington silt loam, there being a maximum in the third foot and on the average only 25 per cent as many on the Kansan as on the later formation. On the former, three fields, I, III and V, show little or no coarse gravel in the surface foot while only one, II, showed an amount as great as 1.0 per cent in the lower section. On the Late Wisconsin the range is from 0.23 per cent to 4.38 per cent with an average of 1.50 per cent for the three foot-sections on the five fields.

The average weights for the gravel particles (table 8) are quite similar both from field to field and on the two drifts. The second foot-section from field III on the Kansan shows the highest average weight of any sample tested, this being due to the inclusion of several stones which were larger than those one is ordinarily able to bring up with the auger.

Carrington loam. On both drifts (table 9) the variation from field to field is much greater than with the two other types. However, the maximum amount is found, with the exception of fields IV and V on the Kansan, in the third foot. On this drift the average for the five fields is somewhat higher than that on the Late Wisconsin, the opposite of what was found true for the two other types. This is caused by the exceptionally high percentages for the third foot of fields I, II and III on the older drift. The topography of this type, as mentioned above (p. 11) is the most rolling of any sampled and accordingly is the most apt to be strongly erroded so that it is not unlikely that much of top soil on these three fields has been carried away leaving the less weathered subsoil nearer the surface.

An examination of the minerals in the third foot-section on the two drifts showed that on the Kansan considerably larger quantities of trap rocks and iron minerals (limonite, magnetite, etc.,), were present than on the Late Wisconsin, while on the latter a higher percentage of quartz, light colored quartzite, chert and shales was observed, no trace of the two last named rocks being found on the Kansan.

Table 7.

Coarse gravel in the different sections from the five fields on Fargo silt loam.

Depth Inches	Field I per cent	Field II per cent	Field III per cent	Field IV per cent	Field V per cent	Average for 5 fields per cent
			1. Kansan			
1 - 6	0.00	0.35	0.00	0.00	0.00	0.07
7 - 12	0.00	0.17	0.00	0.70	0.07	0.19
13 - 24	0.00	0.16	0.20	0.27	0.36	0.20
25 - 36	0.36	2.21	0.17	0.85	0.82	0.88
Average 1 - 36	0.12	0.88	0.12	0.49	0.40	0.40
			2. Late Wisconsin			
1 - 6	0.67	0.23	0.64	0.58	0.46	0.52
7 - 12	1.00	0.23	1.06	1.44	0.83	0.91
13 - 24	0.94	0.79	1.51	4.28	0.68	1.64
25 - 36	1.65	1.06	2.07	4.38	1.57	2.15
Average 1 - 36	1.14	0.69	1.48	3.22	0.96	1.50

Table 8.

Average weight of coarse gravel particles in the different sections on Fargo silt loam.

Depth Inches	Field I grams	Field II grams	Field III grams	Field IV grams	Field V grams	Average for 5 fields grams
			1. Kansan			
1 - 6	.000	.011	.000	.000	.000	.002
7 - 12	.000	.020	.011	.049	.017	.019
13 - 24	.000	.017	.193	.030	.024	.053
25 - 36	.046	.029	.028	.081	.044	.046
Average 1 - 36	.015	.020	.075	.045	.025	.036
			2. Late Wisconsin			
1 - 6	.025	.027	.023	.020	.014	.022
7 - 12	.025	.019	.014	.022	.018	.020
13 - 24	.023	.025	.017	.051	.015	.026
25 - 36	.030	.020	.018	.025	.020	.023
Average 1 - 36	.026	.023	.018	.032	.017	.023

Table 9.

Coarse gravel in the different sections from the five fields on Carrington loam.

Depth Inches	Field I per cent	Field II per cent	Field III per cent	Field IV per cent	Field V per cent	Average for 5 fields per cent
			1. Kansan			
1 - 6	0.93	0.33	0.53	0.03	2.03	0.77
7 - 12	1.02	0.31	0.63	0.13	0.03	0.42
13 - 24	2.52	1.28	1.93	0.19	0.02	1.19
25 - 36	6.22	6.48	8.24	0.04	0.08	4.21
Average 1 - 36	3.23	2.69	3.58	0.10	0.38	2.00
			2. Late Wisconsin			
1 - 6	0.47	1.07	0.64	1.79	0.46	0.89
8 - 12	0.94	0.75	0.27	1.65	0.26	0.77
13 - 24	1.52	1.70	1.10	4.25	0.18	1.75
26 - 36	1.81	2.93	2.90	4.92	1.98	2.91
Average 1 - 36	1.34	1.85	1.48	3.63	0.94	1.83

Table 10.

Average weight of coarse gravel particles in the different sections from the five fields on Carrington loam.

Depth Inches	Field I grams	Field II grams	Field III grams	Field IV grams	Field V grams	Average for 5 fields grams
			1. Kansan			
1 - 6	.020	.026	.020	.009	.035	.022
7 - 12	.020	.024	.026	.035	.014	.024
13 - 24	.033	.033	.038	.037	.017	.032
25 - 36	.043	.039	.050	.016	.027	.035
Average 1 - 36	.032	.032	.037	.025	.023	.030
			2. Late Wisconsin			
1 - 6	.019	.031	.035	.026	.036	.029
7 - 12	.021	.025	.020	.021	.015	.020
13 - 24	.021	.030	.023	.033	.017	.025
25 - 36	.021	.030	.033	.030	.025	.028
Average 1 - 36	.021	.029	.028	.029	.022	.026

The average weight of the gravel particles (table 10) for the three foot sections is very similar for all fields on the Late Wisconsin and for fields IV and V on the Kansan. The average weight for the other fields, I, II and III, on the latter, is slightly higher, due to the heavier particles found in the third foot-section. This, likewise, indicates that the surface material has been erroded leaving the less weathered portion close to the surface in these three fields.

Marshall loam. This type has developed on a loessial formation and accordingly it would not be expected to carry many, if any, fragments coarser than 2 mm. The thickness of the deposit might have an influence on the number of these since, in case it were shallow, burrowing animals and insects could easily carry upward a sufficient amount of the underlying till to modify to a certain degree the mechanical, if not the chemical composition of the soil (21, p. 90-91).

On one field, I (table 11) and in the first set of another, III, the till was encountered in the third foot-section, Set 2, of the latter field being evidently entirely on the till since it carried as high a percentage of coarse fragments as any field on the Carrington loam. The amounts found in the two sets on this field are given below.

Depth Inches	Set 1 per cent	Set 2 per cent
1 - 6	.14	2.25
7 - 12	.14	.51
13- 24	.13	3.50
25- 36	3.99	10.17

The large area of this kind of soil west of Nerstrand, upon which fields I and III are located, is very shallow (11, p.36), while that to the north and east, upon which sites for fields II, IV and V were selected, appears to have a greater thickness and accordingly is more representative of this type. Few, if any, fragments were found in the samples from the three fields last mentioned.

Table 11.

Coarse gravel in the different sections from the five fields on Marshall loam.

Depth Inches	Field I per cent	Field II per cent	Field III per cent	Field IV per cent	Field V per cent	Average for 5 fields per cent
			1. Kansan			
1 - 6	0.06	0.05	1.19	0.00	0.00	0.24
7 - 12	0.02	0.02	0.32	0.02	0.00	0.07
13 - 24	0.48	0.00	1.81	0.01	0.00	0.46
25 - 36	1.92	0.05	7.08	0.00	0.00	1.81
Average 1 - 36	0.81	0.03	3.21	0.01	0.00	0.81

Table 12.

Coarse gravel in the different sections. The data are the averages for the five fields reported in tables 5, 7, 9 and 11.

Depth Inches	Carrington silt loam Kansan per cent	Carrington silt loam Late Wis. per cent	Fargo silt loam Kansan per cent	Fargo silt loam Late Wis. per cent	Carrington loam Kansan per cent	Carrington loam Late Wis. per cent	Marshall loam per cent
1 - 6	0.22	0.88	0.07	0.52	0.77	0.89	0.24
7 - 12	0.35	1.04	0.19	0.91	0.42	0.77	0.07
13 - 24	0.22	1.87	0.20	1.64	1.19	1.75	0.46
25 - 36	1.04	3.03	0.88	2.15	4.21	2.91	1.81
Average 1 - 36	0.51	1.95	0.40	1.50	2.00	1.83	0.81

Table 13.

Average weight of coarse gravel particles in the different sections. The data are the averages for the five fields reported in tables 6, 8, and 10.

Depth Inches	Carrington silt loam: Kansan grams	Carrington silt loam: Late Wis. grams	Fargo silt loam: Kansan grams	Fargo silt loam: Late Wis. grams	Carrington loam: Kansan grams	Carrington loam: Late Wis. grams	Marshall loam grams
1 - 6	.025	.039	.002	.022	.022	.029	.012
7 - 12	.035	.026	.019	.020	.024	.020	.009
13 - 24	.021	.024	.053	.026	.032	.025	.015
25 - 36	.033	.024	.046	.023	.035	.028	.022
Average 1 - 36	.028	.027	.036	.023	.030	.026	.016

iscussion. The average percentages of coarser fragments are higher on the soils on the ansan than on those of the Late Wisconsin with exception of the third foot-section of he Carrington loam. The explanation of this exception appears to lie in that, on three ields, errasion has removed the surface material and thus left the less-weathered portion earer to the surface than it is ordinarily found. The larger amount of coarser particles n the younger formation is due to a less advanced degree of weathering than on the older rift. This same fact is demonstrated by the amount of softer rocks (limestones, shales nd cherty material) found on the two drifts, these on the older formation having practically tirely given way to the processes of weathering to a depth greater than three feet.

Glacial material was encountered in the third foot on two fields of Marshall am but on the other three the thickness of the loess deposit was sufficient to be characteric.

The average weight of the gravel particles found in the three-foot section, was ch the same from type to type and from drift to drift, that of those found on the Kansan ng slightly the higher than that of those on the Late Wisconsin, the difference being atest on the Fargo silt loam.

2. Texture of fine-earth.

As the most satisfactory method of ascertaining the similarity in texture the fine-earth of the samples used in this study the determination of the moisture ivalent (7) was selected. The relation of this to the mechanical composition and er physical constants has been discussed by various authors as mentioned above.

The moisture equivalents of the samples in the two sets from each field were rmined (tables 15 to 18). The data in table 15, the first part of table 16, and those for ld I in the first part of table 17, are the means of duplicate determinations, the others ng derived from single determinations. The concordance of duplicate determinations may illustrated by the results from the 136 samples mentioned, only two showing a difference ter than unity. Another illustration is afforded by the data in table 19.

ington silt loam. On the Kansan Drift, this type showed (table 15) very little variation

Table 15.

Moisture equivalents of samples taken on the two drifts from representative fields of Carrington silt loam.

Depth	Field I			Field II			Field III			Field IV			Field V			Average for
Inches	Set 1	Set 2	Av.	Set 1	Set 2	Av.	Set 1	Set 2	Av.	Set 1	Set 2	Av.	Set 1	Set 2	Av.	5 fields.
							1. Kansan									
1 - 6	33.4	33.2	33.3	27.2	27.5	27.3	32.3	33.5	32.9	28.4	29.1	28.7	30.8	31.4	31.1	30.6
7 -12	30.6	32.7	31.7	27.7	28.2	27.9	32.5	31.8	32.1	27.9	28.2	28.0	31.1	30.3	30.7	30.1
13-24	27.7	29.5	28.6	27.9	26.8	27.3	29.9	29.1	29.5	26.6	26.0	26.3	28.6	29.1	28.8	28.1
25-36	23.4	24.3	23.8	24.1	25.3	24.7	26.7	25.2	25.9	23.0	22.1	22.5	22.2	25.2	23.7	24.1
Average 1 - 36	27.7	28.9	28.3	26.5	26.6	26.5	29.7	28.9	29.3	25.9	25.6	25.7	27.2	28.4	27.8	27.5
							2. Late Wisconsin									
1 - 6	35.1	35.6	35.3	28.1	28.9	28.5	23.1	29.3	26.2	29.8	27.8	28.8	29.0	29.2	29.1	29.6
7 -12	34.1	36.0	35.0	23.4	25.3	24.3	19.8	28.7	24.2	28.8	27.8	28.3	28.2	25.7	26.9	27.7
13 -24	33.2	33.4	33.3	19.2	24.1	21.6	19.6	25.5	22.5	27.5	26.0	26.7	24.7	24.3	24.5	25.7
25 -36	33.3	35.3	34.3	20.4	23.8	22.1	20.6	25.7	23.1	26.2	26.6	26.4	23.5	23.3	23.4	25.9
Average 1 - 36	33.7	34.8	34.2	21.8	25.0	23.4	20.5	26.7	23.6	27.7	26.8	27.2	25.6	25.1	25.3	26.7

from set to set within the same field and are but slightly greater from field to field, the latter being the most marked in the two sections from the surface foot where there was the greatest variation also in the percentage of organic matter (6, p. 18). The highest value, 33.5, was found in the surface section and the lowest, 22.1, in the third foot.

On the Late Wisconsin the variation from field to field was no greater than on the Kansan, but in field III the first set averaged only 20.5 and the second 26.7 compared with 34.8 for set 2 from Field I. The latter field differs markedly from the four others on this drift and shows the highes value of all the fields sampled on this type, those for the four sections, ranging only from 33.3 to 35.3. The averages for the five fields on the two drifts are very similar.

Fargo silt loam. On the Kansan (table 16) this type shows little variation either within the same field or from field to field but on the Late Wisconsin there is a somewhat wider variation in both. The range is from 23.1 found in the subsoil to 52.5 in the surface. The averages for the surface 6-inch sections on the two drifts show a marked difference, that for the Kansan being 45.9 compared with 35.9 on the other. This, in all probability, is due to the larger amount of organic material in the former (6, p. 18) as indicated by the percentages of nitrogen (table 57) and volatile matter (table 52). On the Kansan the nitrogen rises to .786 per cent as compared with .445 on the Late Wisconsin, while, on the former, the volatile matter is 20.34 per cent as compared with 11.68 per cent on the latter.

Carrington loam. There is considerable variation in texture within the individual fields and from field to field (table 17) on the Kansan, this being more pronounced in the third foot, suggesting that at this depth, disintegration has not proceeded as far on the younger drift. On the Late Wisconsin, the variation within the same field and from field to field is not so great. Burke and Kolbe (11, p.22) in describing this type state that "the texture of the surface soil is for the most part uniform, but the color and depth are variable. Areas of minimum depth apparently have resulted from erosion, those of maximum depth representing more probably the natural conditions".

Moisture equivalents of samples taken on the two drifts from representative fields of Fargo silt loam.

Depth	Field I			Field II			Field III			Field IV			Field V.			Average for
Inches	Set 1	Set 2	Av.	Set 1	Set 2	Av.	Set 1	Set 2	Av.	Set 1	Set 2	Av.	Set 1	Set 2	Av.	5 fields
1. Kansan																
1 - 36	44.2	45.3	44.7	45.5	45.5	45.5	39.2	42.7	40.9	52.5	51.7	52.1	49.4	43.6	46.5	45.9
7 - 12	38.8	36.9	37.8	38.0	38.5	38.2	36.1	37.4	36.7	35.4	38.3	36.8	38.9	34.3	36.6	37.2
13- 24	31.1	28.8	29.9	29.2	30.6	29.9	31.6	32.3	31.9	29.8	30.2	30.0	29.0	28.3	28.6	30.1
25- 36	25.6	23.1	24.3	24.1	24.9	24.5	26.6	28.4	27.5	26.1	25.7	25.9	24.2	22.4	23.3	25.1
Average 1 - 36	32.7	31.1	31.8	31.7	32.5	32.1	31.9	33.6	32.7	33.3	33.6	33.4	32.4	29.9	31.1	32.2
2. Late Wisconsin																
1 - 6	42.7	38.3	40.5	35.8	33.2	34.5	38.0	32.7	35.3	31.3	36.9	34.1	34.0	36.2	35.1	35.9
7 -12	38.9	34.8	36.8	27.5	27.2	27.3	40.0	35.0	37.5	29.4	31.0	32.2	32.0	32.7	32.3	32.8
13-24	35.6	35.6	35.6	27.2	26.1	26.6	38.1	33.2	35.6	26.7	27.1	26.9	26.8	26.7	26.7	30.3
25-36	37.2	33.0	35.1	26.7	28.9	27.8	33.2	21.8	32.5	27.8	24.8	26.3	29.0	23.1	26.0	29.5
Average 1 - 36	37.9	35.0	36.4	28.5	28.4	28.4	36.8	32.9	34.8	28.3	28.6	28.4	29.6	28.1	28.8	31.4

Table 17.

Moisture equivalents of samples taken on the two drifts from representative fields of Carrington loam.

Depth Inches	Field I Set 1	Field I Set 2	Field I Av.	Field II Set 1	Field II Set 2	Field II Av.	Field III Set 1	Field III Set 2	Field III Av.	Field IV. Set 1	Field IV. Set 2	Field IV. Av.	Field V Set 1	Field V Set 2	Field V Av.	Average for 5 fields.
1. Kansan																
1 - 6	27.9	24.2	26.0	23.6	25.3	24.4	22.0	25.8	23.9	28.6	26.9	27.7	20.5	25.2	22.8	24.8
7 - 12	24.2	21.4	22.8	21.6	20.3	20.9	20.2	22.3	21.2	23.4	24.4	23.9	19.2	22.8	21.0	22.0
13-24	24.4	20.6	22.5	23.4	22.3	22.8	19.5	23.4	21.4	25.7	25.9	25.8	19.7	21.2	20.4	22.6
25 -36	22.9	16.4	19.6	13.9	16.8	15.3	11.3	20.0	15.7	17.3	20.9	19.1	13.3	16.5	14.9	16.9
Average 1 - 36	24.4	19.9	22.2	20.0	20.6	20.2	17.3	22.5	19.9	23.0	24.1	23.6	17.6	20.6	19.1	21.0
2. Late Wisconsin																
1 - 6	24.7	26.3	25.5	24.5	23.7	24.1	24.1	22.6	23.3	20.5	22.0	21.2	25.6	29.9	27.7	24.4
7 -12	19.0	19.0	19.0	21.2	21.2	21.2	19.8	20.4	20.1	16.5	18.2	17.3	23.8	26.8	25.3	20.6
13-24	18.9	21.7	20.3	24.1	24.8	24.4	21.2	20.4	20.8	17.4	19.2	18.3	24.6	26.9	25.7	21.9
25-36	18.8	20.9	19.8	22.7	23.7	23.2	19.0	17.8	18.4	17.4	19.2	18.3	22.2	23.9	23.0	20.5
Average 1 - 36	19.8	21.6	20.8	23.2	23.6	23.4	20.7	19.9	20.3	17.8	19.5	18.6	23.8	26.4	25.1	21.6

It is to be observed that the moisture equivalent is in most cases higher for the second foot-section than for the 6-inch section above this. The organic matter in forest soils, such as the Carrington loam, is low even in the surface six inches and a lack of this coupled with the translocation of clay particles downward into the second foot may account for this rather regular variation. The averages range from 24.8 in the surface section to 16.9 in the subsoil.

Marshall loam. On this type (table 18) considerable variation within fields II and IV is shown and especially great differences between set I from field II and set 2 from field IV, the former averaging 16.3 and the latter 27.6 or nearly 70 per cent higher. To eliminate all opportunity for differences in speed of the centrifuge, etc., to be the cause of this, the corresponding samples from these two fields were run side by side (table 19). It will be seen that these agree very closely with the first determinations. So great a variation either within the same field or between the different fields on this type was not anticipated. From its loessial origin, a texture more uniform than that on a type developed on the till was to have been expected. In fields IV and V the moisture equivalents for the different sections are distinctly higher than in the three other fields. The area in which the former two are located while originally on the very fringe of the forest has, for many years, been clear even of brush and the fields on both sides of this "fencerow" field kept under mixed farming conditions, which has permitted an accumulation of organic matter similar to that which would accrue under prairie conditions. While this might account for the greater moisture holding capacity in the surface foot it could not explain the variation in the lower sections.

Discussion. The averages for the five fields on the different types (table 20) show little variation from drift to drift. On the Kansan the Fargo silt loam appears to have a finer texture in the two upper sections than in the corresponding ones on the Late Wisconsin. This is probably due to a higher content of organic matter on the former.

The Carrington loam shows a more pronounced variation in texture from drift to drift than is found with the other types, this being greatest in the third foot-section. However, the averages for the five fields on the two drifts are very similar.

Table 18.

Moisture equivalents of samples taken on the Kansan from representative fields of Marshall loam.

Depth Inches	Field I Set 1	Field I Set 2	Field I Av.	Field II Set 1	Field II Set 2	Field II Av.	Field III Set 1	Field III Set 2	Field III Av.	Field IV. Set 1	Field IV. Set 2	Field IV. Av.	Field V Set 1	Field V Set 2	Field V Av.	Average for 5 fields.
1 - 6	23.8	24.1	23.9	18.9	22.3	20.6	24.2	23.4	23.8	27.0	30.5	28.7	30.0	29.8	29.9	25.4
7 -12	21.3	21.5	21.4	16.3	20.7	18.5	21.4	19.5	20.4	25.3	30.2	27.7	28.1	29.2	28.6	23.3
13-24	24.7	22.3	23.5	16.0	20.2	18.1	22.9	20.2	21.5	23.5	27.9	25.7	26.0	25.9	25.9	22.9
25-36	17.6	18.7	18.1	15.2	18.0	16.6	15.6	12.4	14.0	22.0	24.7	23.3	23.1	24.3	23.7	19.1
Average 1 - 36	21.6	21.3	21.4	16.3	19.9	18.1	20.4	18.0	19.2	23.9	27.6	25.7	26.0	26.6	26.3	22.1

Table 19.

Moisture equivalents of samples from two fields of Marshall loam.

Depth Inches	Field II, Set 1. Det. 1	Det. 2	Av.	Field IV, Set 2. Det. 1	Det. 2	Av.
1 - 6	18.5	17.8	18.2	30.3	30.4	30.3
7 - 12	16.0	16.5	16.3	30.0	30.4	30.2
13- 24	15.9	15.5	15.7	28.2	27.9	28.0
25- 36	15.7	15.1	15.4	25.1	25.5	25.3

To obtain the true moisture equivalent a correction for the coarse gravel would need to be made but this does not affect the actual water hold capacity since the rock fragments neither increase or decrease the amount of water held by the fine-earth.

The uniformity in texture on the same type on both drifts shows that the U. S. Bureau of Soils surveyors were fully justified in their classification. Other differences are not so apparent in the field and are brought out only by a laboratory investigation.

The moisture equivalents, computed from the mechanical analyses (table 1.) by formulas proposed by Briggs and Shantz (8, p. 73) and Alway and Russel (5, p. 842), do not agree satisfactorily, although the values found by the latter for the two cleared fields on the Marshall loam resemble very closely those found by direct determination. This is to be expected since Alway and Russel developed their formula for only loessial soils and as they have pointed out (5, p. 843), different formulas would be required for other soil types. The most marked difference between the computed and actual values is found with the surface soil on the Fargo silt loam where the former is much too low.

Table 20.

Moisture equivalents of samples from the different types on the two drifts. The data are averages for the five fields reported in tables to .

Depth Inches	Carrington silt loam Kansan	Carrington silt loam Late Wis.	Fargo silt loam Kansan	Fargo silt loam Late Wis.	Carrington loam Kansan	Carrington loam Late Wis.	Marshall loam
1 - 6	30.6	29.6	45.9	35.9	24.8	24.4	25.4
7 - 12	30.1	27.7	37.2	32.8	22.0	20.6	23.3
13- 24	28.1	25.7	30.1	30.3	22.6	21.9	22.9
25- 36	24.1	25.9	25.1	29.5	16.9	20.5	19.1
Average 1- 36	27.5	26.7	32.2	31.4	21.0	21.6	22.1

B. Lime Supply.

1. Carbonates.

The carbonate contained in the field samples was determined as carbon dioxide (tables 21 to 23) by absorbtion in caustic potash, all determinations with the exception of some 10 or 12 being made singly. However, a check on the accuracy of individual analyses was furnished by the determination of the amount in the drift samples which were prepared by compositing equal weights of the five field samples. The average of the data for the five fields should then agree closely with the amount obtained for the corresponding drift sample. The general agreement of these may be seen from the last two columns in the tables.

Carrington silt loam. The amount of carbon dioxide (table 21) on the Kansan is practically negligible and varies but little from field to field, the average of the three foot-sections of the different fields falling between 0.051 and 0.062 with an average for all five of 0.057.

On the Late Wisconsin two fields, I and IV, show similar small percentages but of the other three fields two show an appreciable amount in the second and third foot-sections, while one, V, shows a similar high content in only the third foot. The maximum amount reaches 3.14 per cent in the third foot of field III.

From the data it is evident that the carbonate on the Kansan has been leached out to a depth greater than three feet. The same is true for two out of five fields on the Late Wisconsin but in general the leaching on the latter has not progressed nearly so far.

It is to be observed that the amounts reported for the first 6-inch sections are higher than those for the second. This, in all probability, is an unavoidable experimental error due to the hydrolysis of some of the organic matter in the course of the determination.

Fargo silt loam. On this type (table 22), the amount of carbon dioxide in the soils on the Kansan varies considerably from field to field, in two, I and IV, there being no more than in the Carrington silt loam on the same drift while the remaining three

Table 21.

Carbon dioxide in the different sections
from the five fields on Carrington silt loam.

Depth Inches	Field I percent	Field II percent	Field III percent	Field IV percent	Field V percent	Av. for 5 fields percent	Composite percent.
			I. Kansan				
1 - 6	0.084	0.052	0.068	0.108	0.072	0.077	0.080
7 - 12	0.088	0.076	0.080	0.076	0.092	0.082	0.088
13 -24	0.045	0.056	0.075	0.064	0.046	0.057	0.060
25 -36	0.031	0.035	0.036	0.016	0.024	0.034	0.033
Average 1 - 36	0.054	0.052	0.062	0.057	0.051	0.057	0.059
			2. Late Wisconsin				
1 - 6	0.112	0.112	0.048	0.044	0.064	0.076	0.072
7 - 12	0.066	0.042	0.047	0.070	0.034	0.052	0.049
13- 24	0.064	0.172	0.348	0.026	0.040	0.130	0.134
25- 36	0.060	1.565	3.136	0.026	0.544	1.066	1.057
Average: 1 - 36	0.071	0.605	1.177	0.036	0.211	0.420	0.417

Table 22.

Carbon dioxide in the different sections from the five fields on Fargo silt loam.

Depth Inches	Field I percent	Field II percent	Field III percent	Field IV percent	Field V percent	Av. for 5 fields percent.	Composite percent
			1. Kansan				
1 - 6	0.096	-	0.096	0.140	0.924	0.314	0.296
7 - 12	0.060	0.080	0.072	0.088	0.672	0.194	0.201
13- 24	0.038	0.064	0.028	0.006	0.160	0.059	0.064
25- 36	0.080	0.490	1.000	0.008	2.562	0.828	0.840
Average: 1 - 36	0.065	-	0.371	0.043	1.173	0.380	0.384
			2. Late Wisconsin				
1 - 6	2.230	0.080	0.094	0.097	0.068	0.511	0.485
7 - 12	2.410	0.056	0.108	0.064	0.064	0.540	0.570
13- 24	2.500	0.036	0.080	0.034	0.010	0.530	0.536
25- 36	3.990	0.108	0.036	1.034	0.020	1.037	1.040
Average: 1 - 36	2.937	0.071	0.072	0.383	0.032	0.697	0.701

ields have an appreciable amount in the third foot-section. In all four sections in ield V the content is comparatively high.

On the Late Wisconsin field I is the most abundantly supplied with carbonate f all 35 fields sampled, the amount ranging from 2.23 per cent in the surface to 3.99 er cent in the third foot.

Subsequent to the collection and analysis of samples from this field, it was establishe hat although there appeared, on first inspection, to be a drainage outlet lower than the lowes oint in the tract, in reality this outlet was some feet higher, the field thus forming a arge "pot-hole". The drainage water accumulated in the lower part of the basin and some of his evaporating left behind the mineral constituents leached from the surrounding uplands, hus bringing about a concentration of these. Since the drift was so well supplied with imestone it is not surprising that the carbonate content of the soils from this field is o high.

Of the four other fields, IV is the only one having an appreciable quantity in the third foot-section, the others averaging less than 0.1 per cent for the three feet.

In general, with this type, the proportion is greater on the Kansan than on the Late Wisconsin, the average of the five fields on the latter being high only because of the large amount in field I.

Carrington loam. The quantity of carbonate in Carrington loam soils (table 23) varies very little from field to field and is practically the same on both drifts, the leaching having carried this beyond the third foot on the younger as well as the older drift.

Discussion. The averages for the five fields on the different types on the two drifts are shown in table 24. On the Late Wisconsin the average amounts of carbon dioxide in the three foot sections are higher than the Kansan with the exception of those for the Carrington loam where they are the same for both drifts. On the older formation, the carbonates have been leached out to a depth greater than three feet on the two Carrington series. No serious leaching has taken place on the Fargo silt loam on either drift. On the Late Wisconsin an appreciable amount is found in the third foot on the Carrington silt loam but practically all has been leached out of the first three feet on the Carrington loam.

Table 23.

Carbon dioxide in the different sections from the five fields on Carrington loam.

Depth Inches	Field I percent	Field II percent	Field III percent	Field IV percent	Field V percent	Av. for 5 fields percent	Composite percent
				I. Kansan			
1 - 6	0.066	0.048	0.072	0.088	0.086	0.072	0.092
7 - 12	0.062	0.048	0.052	0.052	0.056	0.054	0.044
13- 24	0.032	0.084	0.006	0.064	0.080	0.053	0.032
25- 36	0.046	0.076	0.020	0.056	0.060	0.051	0.040
Average 1 - 36	0.047	0.069	0.029	0.063	0.071	0.056	0.047
				2. Late Wisconsin			
1 - 6	0.110	0.112	0.062	0.056	0.072	0.082	0.100
7 - 12	0.086	0.044	0.076	0.040	0.056	0.061	0.064
13- 24	0.048	0.036	0.040	0.044	0.044	0.042	0.052
25- 36	0.026	0.050	0.036	0.108	0.042	0.052	0.044
Average 1 - 36	0.057	0.055	0.048	0.067	0.050	0.055	0.059

Table 24.

Carbon dioxide in the different sections. The data are averages for the five fields reported in tables 21 to 23.

Depth Inches	Carrington silt loam		Fargo silt loam		Carrington loam	
	Kansan per cent	Late Wis. per cent	Kansan per cent	Late Wis. per cent	Kansan per cent	Late Wis. per cent
1 - 6	0.077	0.076	0.314	0.511	0.072	0.082
7 - 12	0.082	0.052	0.194	0.540	0.054	0.061
13- 24	0.057	0.130	0.059	0.530	0.053	0.042
25- 36	0.034	1.066	0.828	1.037	0.051	0.052
Average 1 - 36	0.057	0.420	0.380	0.697	0.056	0.055

Field V on the Kansan and field I on the Late Wisconsin, on the Fargo silt loam, show a carbonate content radically different from the four other fields on their respective drifts. This is an instance of an important constituent differing widely from the majority of soils on the type and brings out clearly the fact that samples from one field cannot be assumed to be representative of the type in any given area.

2. Reaction with litmus.

The reaction of both sets of samples from each field was tested with litmus paper. In this method, strips of sensitive red and blue litmus paper were placed in direct contact with the soil to be tested, the latter moistened with distilled water and after a half hour the reaction noted.

Carrington silt loam. On the Kansan the soils of this type (table 25) are all acid while on the Late Wisconsin the acidity is less general, the lower two sections being neutral or alkaline in field II and in set 1 of field III. The third foot in the second set of field V is also alkaline.

Fargo silt loam. Nearly all of the soils on the Kansan (table 26) are neutral or alkaline, the second set from field III being the only one of the ten sets in which the reaction is acid for all four sections. On the Late Wisconsin the acidity is more marked, approximately half of the samples being neutral or alkaline and half acid. Field V on the Kansan and field I on the Late Wisconsin show both sets alkaline in all sections. In all other cases this reaction is confined to the second and third foot-sections.

Carrington loam. On the Kansan (table 27) every sample reacted acid to litmus, while on the Late Wisconsin all were acid with the exception of the surface foot in three sets.

Marshall loam. All the samples on this type (table 28) were acid with the exception of the second and third foot-sections of set 1 field II.

Discussion. The reaction toward litmus shows the soils of the two Carrington series, on the Kansan to be more acid than on the Late Wisconsin, while on the Fargo silt loam the opposite is true. The samples of Marshall loam were practically all acid.

Table 25.

Acidity as found by the litmus method. Samples taken from five fields on Carrington silt loam.

Depth Inches	Field I Set 1	Field I Set 2	Field II Set 1	Field II Set 2	Field III Set 1	Field III Set 2	Field IV Set 1	Field IV Set 2	Field V Set 1	Field V Set 2
					1. Kansan					
1 - 6	acid	acid	acid	acid	acid	acid	neut.	neut.	acid	neut.
7 - 12	acid	acid	acid	acid	acid	acid	acid	acid	acid	acid
13- 24	acid	acid	acid	acid	acid	acid	acid	acid	acid	acid
25- 36	acid	acid	acid	acid	acid	acid	acid	acid	acid	acid
					2. Late Wisconsin					
1 - 6	acid	acid	acid	acid	acid	acid	acid	acid	acid	acid
7 - 12	acid	neut.	acid	acid	acid	neut.	acid	acid	acid	acid
13- 24	acid	acid	neut.	neut.	neut.	acid	acid	acid	acid	acid
25- 36	acid	acid	alk.	alk.	alk.	acid	acid	acid	acid	alk.

Table 26.

Acidity as found by the litmus method. Samples taken from five fields on Fargo silt loam.

Depth	Field I		Field II		Field III		Field IV		Field V	
Inches	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
	1. Kansan									
1 - 6	neut.	neut.	-	neut.	neut.	acid	neut.	neut.	alk.	alk.
7 - 12	acid	acid	neut.	neut.	acid	acid	neut.	neut.	alk.	alk.
13- 24	neut.	alk.	alk.	neut.	neut.	acid	alk.	alk.	alk.	alk.
25- 36	alk.	alk.	alk.	alk.	alk.	acid	alk.	alk.	alk.	alk.
	2. Late Wisconsin									
1 - 6	alk.	alk.	acid	acid	acid	acid	acid	acid	acid	acid
7 - 12	alk.	alk.	acid	acid	acid	acid	acid	acid	acid	neut.
13- 24	alk.	alk.	neut.	acid	acid	acid	acid	alk.	acid	acid
25- 36	alk.	alk.	alk.	neut.	acid	acid	alk.	alk.	neut.	neut.

Table 27.

Acidity by the litmus method. Samples taken from five fields on Carrington loam.

Depth	Field I		Field II		Field III		Field IV		Field V	
Inches	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
					1. Kansan					
1 - 6	acid	acid	acid	acid	acid	acid	acid	acid	acid	acid
7 - 12	acid	acid	acid	acid	acid	acid	acid	neut.	acid	acid
13- 24	acid	acid	acid	acid	acid	acid	acid	acid	acid	acid
25- 36	acid	acid	acid	acid	acid	acid	acid	acid	acid	acid
					2. Late Wisconsin					
1 - 6	neut.	neut.	acid	acid	acid	neut.	acid	neut.	acid	acid
7 - 12	acid	neut.	acid	acid	acid	acid	acid	neut.	acid	acid
13- 24	acid	acid	acid	acid	acid	acid	acid	acid	acid	acid
25- 36	acid	acid	acid	acid	acid	acid		acid	acid	acid

Table 28.

Acidity by the litmus method. Samples taken from five fields of Marshall loam.

Depth Inches	Field I Set 1	Field I Set 2	Field II Set 1	Field II Set 2	Field III Set 1	Field III Set 2	Field IV Set 1	Field IV Set 2	Field V Set 1	Field V Set 2
1 - 6	acid	acid	acid	acid	acid	acid	acid	acid	neut.	acid
7 - 12	acid	acid	acid	acid	acid	acid	acid	acid	acid	acid
13- 24	acid	acid	alk.	acid	acid	acid	acid	acid	acid	acid
25- 36	acid	acid	alk.	acid	acid	acid	acid	acid	acid	acid

3. Reaction as determined by the Truog method.

The reaction of the two sets of samples from each field was also tested by the Truog method (30), the results being reported in tables 29 to 32.

Carrington silt loam. The acidity of soils on this type (table 29) is more marked on the Kansan than on the Late Wisconsin. On the former there is little variation from field to field or between the two sets within the same field and in most cases the acidity is as great in the third foot-section as in the surface six-inches. On the Late Wisconsin there is in general a decrease from the surface downward, and little variation from field to field.

Fargo silt loam. There is very little difference in the degree of acidity (table 30) on the two drifts. A slightly higher degree of acidity is shown in the surface foot on the Late Wisconsin while the second and third foot-sections on both drifts are practically all neutral.

Carrington loam. This type like the Carrington silt loam, in general, shows a more marked degree of acidity on the Kansan (table 31) than on the Late Wisconsin but on the former appears to be slightly less acid in the third foot than the upper sections.

On the Late Wisconsin the gradual decrease in acidity from the surface downward found with the Carrington silt loam is not to be observed. In fields IV and V the acidity is slightly less in the third foot than in the upper sections. The degree of acidity shown by this type on the Kansan averages higher than on any other type. This type, likewise, has the coarsest texture of those studied, and the resulting increased readiness with which the leaching took place may account for the marked degree of acidity on the later drift.

Marshall loam. The acidity (table 32) of the soils from the forest fields, I, II and III, is on the average slightly higher than that from the prairie fields. Little difference in acidity from the surface downward is indicated except in field II, where it decreases.

Discussion. The soils on the Kansan with both the Carrington series show a more marked degree of acidity than on the younger drift, while on the Fargo silt loam little difference is shown.

On the Marshall loam the three forested fields show a slightly higher degree of acidity than the cleared fields.

Table 29.

Acidity of Carrington silt loam soil as indicated by the Truog method.

Depth Inches	Field I Set. 1	Field I Set. 2	Field II Set. 1	Field II Set. 2	Field III Set. 1	Field III Set. 2	Field IV Set. 1	Field IV Set. 2	Field V Set. 1	Field V Set. 2
1. Kansan										
1 - 6	med.	med.	med.	str.	med.	med.	str.	med.	med.	med.
7 -12	med.	sl.	med.	med.	med.	med.	str.	med.	med.	sl.
13 -24	v.str.	med.	med.	med.	str.	str.	v.str.	v.str.	str.	str.
25 -36	med.	v.sl.	sl.	med.	sl.	med.	med.	str.	sl.	med.
2. Late Wisconsin										
1 - 6	sl.	med.	sl.	v.sl.	sl.	med.	med.	med.	med.	med.
7 -12	med.	sl.	v.sl.	v.sl.	sl.	med.	med.	sl.	sl.	sl.
13 -24	v.sl.	sl.	v.sl.	neut.	neut.	med.	sl.	sl.	v.sl.	sl.
25 -36	sl.	neut.	neut.	neut.	neut.	sl.	v.sl.	v.sl.	v.sl.	neut.

neut. - neutral; v.sl - very slight; sl. - slight; med. - medium; str. - strong; v. str. - very strong.

Table 30.

Acidity of Fargo silt loam soil as indicated by the Truog method.

Depth Inches	Field I Set 1	Field I Set 2	Field II Set 1	Field II Set 2	Field III Set 1	Field III Set 2	Field IV Set 1	Field IV Set 2	Field V Set 1	Field V Set 2
1. Kansan										
1 - 6	sl.	sl.	neut.	neut.	sl.	med.	neut.	neut.	neut.	neut.
7 - 12	sl.	v.sl.	neut.	neut.	v. sl.	med.	neut.	neut.	neut.	neut.
13 - 24	neut.	neut.	neut.	neut.	neut.	sl.	neut.	neut.	neut.	neut.
25 - 36	neut.	neut.	neut.	neut.	neut.	v.sl.	neut.	neut.	neut.	neut.
2. Late Wisconsin										
1- 6	neut.	neut.	med.	med.	med.	med.	sl.	sl.	sl.	v.sl.
7-12	neut.	neut.	v.sl.	med.	sl.	v.sl.	sl.	v.sl.	sl.	v.sl.
13-24	neut.	neut.	neut.	v.sl.	v.sl.	neut.	v.sl.	neut.	v.sl.	neut.
25-36	neut.	neut.	neut.	neut.	neut.	neut.	neut.	neut.	neut.	neut.

neut. - neutral; v. sl. - very slight; sl. - slight; med. - medium; str. - strong; v. str. - very strong.

Table 31.

Acidity of Carrington loam soil as indicated by the Truog method.

Depth Inches	Field I Set 1	Field I Set 2	Field II Set 1	Field II Set 2	Field III Set 1	Field III Set 2	Field IV Set 1	Field IV Set 2	Field V Set 1	Field V Set 2
1. Kansan										
1 - 6	sl.	str.	str.	str.	str.	str.	str.	str.	med.	med.
7 -12	sl.	str.	str.	str.	med.	med.	med.	str.	med.	str.
13- 24	v.sl.	med.	str.	med.	str.	str.	med.	med.	str.	v.str.
25 -36	v.sl.	sl.	v.sl.	v.sl.	v.sl.	str.	sl.	v.sl.	med.	str.
2. Late Wisconsin										
1 - 6	sl.	v.sl.	sl.	sl.	med.	med.	sl.	v.sl.	str.	med.
7 -12	sl.	v.sl.	sl.	sl.	str.	med.	sl.	v.sl.	med.	sl.
13 -24	med.	sl.	sl.	sl.	str.	str.	sl.	v.sl.	med.	sl.
25 -36	str.	sl.	sl.	sl.	med.	sl.	v.sl.	neut.	sl.	sl.

neut. - neutral; v. sl. - very slight; sl. - slight; med. - medium; str. - strong; v. str. - very strong.

Table 32.

Acidity of Marshall loam soil as indicated by the Truog method.

Depth Inches	Field I Set 1	Field I Set 2	Field II Set 1	Field II Set 2	Field III Set 1	Field III Set 2	Field IV Set 1	Field IV Set 2	Field V Set 1	Field V Set 2
					Kansan					
1 - 6	Str.	Med.	v.sl.	str.	v.str.	str.	med.	med.	med.	str.
7 -12	str.	str.	v.sl.	med.	v.str.	str.	v.sl.	sl.	med.	med.
13-24	str.	med.	neut.	med.	v.str.	v.str.	med.	med.	str.	med.
25-36	med.	v.sl.	neut.	sl.	v.str.	str.	med.	v.sl.	med.	sl.

neut. - neutral; v. sl. - very slight; sl. - slight; med. - medium; str. - strong; v. str. - very strong.

4. Coloration of ammonia solution.

The intensity of coloration of the ammonia extract as an indication of the degree of acidity (33) was tested on only the two upper sections, the smaller amounts of organic matter present in the two lower sections precluding the use of this method. Twenty grams of air-dry soil were treated with 250 cc. of 4 per cent ammonia, well shaken and allowed to stand for 8 days when portions were drawn off and compared with a standard solution in a colorimeter. The standard solution was made up from one of the soil extracts which had been drawn off from what appeared to be the darkest in the series. A column of this solution 11.7 cm. high shut out all the light coming through an aperature 1 cm. in diamter from a new 25 Watt Mazda lamp when tested in a dark room. The standard was made by diluting 100 cc. of this solution to 190 cc. with distilled water. In comparing the test solutions with the standard a column of the former 10 cm. in height was employed and the data reported in tables 33 and 34 are the heights in centimeters of columns of standard required to exactly equalize this. All solutions were brown in color, there being none of the black color often obtained in the determination of humus (matière noire of Grandeau).

On the second day after starting the extraction eight of the solutions ranging in color from dark to light and representing the different types were selected and comparisons with the standard were made daily in order to determine when the increase in depth of color ended. The results are shown in table 33. During the seventh day but little increase in the depth of color occured. Then all solutions were shaken and on the next day they were compared with the standard. The eight test solutions showed a slight increase in the depth of color over the previous day, undoubtedly due to the last shaking.

There is considerable variation within the same field and from field to field on all types and on both drifts (table 34), this being least pronounced on the Carrington silt loam. On the Kansan the soils on all three types are more acid than the corresponding ones on the Late Wisconsin.

Table 33.

Proportional amounts of coloring matter extracted by ammonia from day to day.

Time of extraction days	Kansan				Late Wisconsin			
	1	2	3	4	1	2	3	4
2	10	8	2	-	9	-	-	-
3	-	-	-	-	9	5	4	2
4	13	12	-	-	11	6	5	2
5	14	13	3	1	11	6	5	2
6	16	14	3	2	12	6	5	2
7	17	14	3	2	12	7	5	2
8	19	16	4	2	14	7	7	3

Table 34.

Intensity of coloration of ammonia extracts.

Depth Inches	Field I Set 1	Field I Set 2.	Field I Av.	Field II Set 1	Field II Set 2	Field II Av.	Field III Set 1	Field III Set 2	Field III Av.	Field IV Set 1	Field IV Set 2	Field IV Av.	Field V Set 1	Field V Set 2	Field V Av.	Average for 5 fields.
A. Carrington silt loam.																
1. Kansan																
1 - 6	12	13	12	11	12	11	13	13	13	16	18	17	15	12	13	13
7 -12	9	8	8	12	10	11	10	8	9	13	12	12	11	10	11	10
Average: 1 - 12	11	10	10	11	11	11	11	10	11	14	15	14	13	11	12	11
2. Late Wisconsin																
1 - 6	12	12	12	7	7	7	7	9	8	9	10	9	13	14	13	10
7 - 12	9	7	8	5	2	3	2	6	4	8	6	7	7	5	6	6
Average: 1 - 12	10	9	10	6	4	4	4	7	6	8	8	8	10	9	9	8
B. Fargo silt loam.																
1. Kansan																
1 - 6	20	17	18	-	8	8	13	14	13	9	8	8	5	3	4	10
7 -12	5	4	4	1	2	1	3	5	4	8	12	10	1	0	1	4
Average: 1 - 12	12	10	11	1	5	5	8	9	8	8	10	9	3	1	2	6

2. Late Wisconsin.

1 - 6	3	3	3	7	7	7	9	9	9	7	6	6	8	9	8	6
7 - 12	1	1	1	1	4	2	9	7	8	2	2	2	3	3	3	3
Average: 1 - 12	2	2	2	4	5	4	9	8	8	4	4	4	5	6	5	4

C. Carrington Loam.

1. Kansan

1 - 6	8	16	12	19	16	17	16	13	14	15	11	13	13	14	13	14
7 - 12	4	9	6	4	4	4	2	1	1	3	5	4	2	4	3	4
Average: 1 - 12	6	12	9	11	10	10	9	7	8	9	8	8	7	8	8	9

2. Late Wisconsin

1 - 6	10	7	8	10	7	8	22	14	18	15	7	11	17	12	14	12
7 - 12	5	1	3	1	1	1	10	8	9	3	1	2	5	6	5	2
Average: 1 - 12	7	4	5	5	4	4	16	11	13	9	4	6	11	9	10	7

D. Marshall loam.

1. Kansan

1 - 6	15	12	13	5	11	8	17	21	19	13	19	16	13	11	12	14
7 - 12	1	2	1	2	2	2	3	4	3	7	10	8	6	6	6	4
Average: 1 - 12	7	7	7	3	6	5	10	12	11	10	14	12	9	8	9	9

5. Comparison of indications obtained by different methods.

Comparison of indications obtained by Truog and litmus methods. There is a great similarity between the indications obtained by the Truog and the litmus methods as carried out in the present study. For the most part, the reactions are the same if, in the Truog test, we indicate any degree of acidity simply "acid" and if those reacting alkaline to litmus be classed with the neutral ones. The discrepancies are, in the main, between samples which show only a slight acidity by the Truog method, most of these being neutral to litmus.

It is of interest that the soils happened to be tested with litmus after they had been arranged in order of their color (p. 106) so that soils from the different sets, fields, types and drifts were permisciously inter-mingled and it was only after the reaction had been determined and recorded and the data reassembled that the first intimation of the relation of reaction to type and drift was obtained.

Comparison of reaction by the Truog method and the carbonate content. A relation between the degree of acidity shown by Truog's test and the carbonate content as shown by the percentage of carbon dioxide (tables 21 to 23) may be pointed out. Where the content of carbon dioxide is above 0.11 per cent no acidity is shown. In the case of surface soils there seems to be no doubt but that some organic matter is hydrolyzed during the course of the carbon dioxide determination with the evolution of CO_2 and the percentage thus raised slightly. Hence, it appears safe to assume that the showing of even a very slight acidity by the Truog test indicates that carbonates in any form are either lacking or present in so small an amount as to be of no consequence.

Comparison of reaction by litmus method with the carbonate content. Since the litmus method agrees so well with those obtained by the Truog test the same general agreement between the reaction shown by it and the carbonate content would be expected, and this is found to be true.

Comparison of indications furnished by the litmus, Truog, and ammonia methods. The results obtained by the ammonia method agree only in a very general way with those found by the Truog and litmus methods. Between the degree of acidity from field to eld as shown by the ammonia method, on one hand, and the Truog and litmus methods on the her, there is no relation. Now does it appear possible to select any arbitrary number of its of color to correspond with any certain degree of acidity when this is established by e Truog method.

6. Relation of calcareousness to texture.

The variation in texture of the soil from the four types used in this study, as expressed y the moisture equivalents (table 20) varies rather widely, the highest average being 32.2 nd the lowest 21.0. Each type was found to have practically the same texture on both drifts. o, any difference in the amount of calcium carbonate between soils from any one type on the wo drifts must be due, not to difference in texture and hence, in the rate of percolation, ut to the age of the drift.

One relation between the texture and calcareousness should be pointed out. The Fargo ilt loam, which on both drifts, has the finest texture, still has carbonate in the surface ix inches. The Carrington silt loam, next finest in texture, has carbonate present in he second and third foot-sections on the Late Wisconsin but none on the Kansan, while the arrington loam, which has the coarsest texture of all the types studied, shows no carbonate in the first three feet on either drift, the leaching having carried it below this level even on the more recent formation. However, it should be borne in mind that the first named type has the most imperfectly developed natural drainage and the last the best, the Carrington silt loam occupying an intermediate position.

7. Relation of calcareousness to age of drift.

As pointed out above the texture of the soil on each of the three types is quite uniform from drift to drift. Hence, any difference in the amount of carbonate must be attributed to the difference in the age of the drifts. In the samples from the Fargo silt loam carbonate is found on both drifts and so far as the amounts are concerned no difference in the leaching is shown. On the Carrington loam the carbonate has been leached out of the first three feet on both drifts so that it is only in the soils from the Carrington silt loam that any relation between the calcareousness of the soil and the age of the drift is apparent. In the soils from this type on the Kansan no carbonate is found above the three foot level but on the Late Wisconsin it occurs, in the majority of fields, in the third foot-section and in some instances, in the second, indicating that on the other drift the leaching has proceeded farther than on the younger

C. Inorganic Constituents.

1. Methods of chemical analysis.

The drift samples from the three glacial types were subjected to a complete or rock analysis. In the case of the individual field samples, determinations of only carbon dioxide and phosphoric acid was made.

The methods of analysis employed were those used in the laboratory of the United States Geological Survey (19) except in the case of phosphoric acid. In determining this extremely important constituent by the method used in that laboratory such discordant results were obtained that the main investigation was halted until a satisfactory method for the determination of total phosphoric acid could be developed. The author (28) has already published an account of this subsidiary investigation.

The method for the determination of phosphoric acid thus developed is briefly as follows: One gram of dry soil is weighed into a platinum dish of appropriate size and ignited in the muffle at dull red heat a sufficient length of time to insure the complete oxidation of the organic matter. After cooling, 10 cc. of distilled water, 10.cc. of nitric acid and 5 cc. of hydrofluoric acid are added, the mixture well stirred, and the contents of the dish evaporated on the steam bath until approximately 5 cc. remain, when an additional 5 cc. of hydrofluoric acid are added, the mixture again well stirred, and the evaporation continued to complete dryness. Evaporation with small quantities of nitric acid is repeated two or three times. After the final evaporation the residue is dried at 110° C. in the air-bath for an hour or two, in order, as Washington (32 p.163) states, "to render insoluble any silica which might otherwise come down with the phosphorus". When cool the residue is taken up with 3 cc. of concentrated nitric acid and 7 cc. of distilled water, boiled gently for a few minutes, and after cooling somewhat, is filtered and washed; the phosphorus in the filtrate is precipitated with ammonium molybdate, and finally weighed as magnesium pyrophosphate. With soils poor in phosphorus a larger sample of soil should be taken and the amounts of the reagents proportionally increased.

It was later ascertained that if about 15 cc. of boiling hot water be added after treating the residue with 3 cc. of nitric acid and the contents of the dish stirred and set aside for 5 or 10 minutes, instead of bringing this to boiling, the time of filtering could be considerably shortened without lessening the accuracy of the method.

The general scheme for the determination of the other inorganic constituents is briefly outlined in the following sentences: One gram of dry soil was weighed into a 25 cc. platinum crucible and ignited in the muffle at a dull red heat for a sufficient length of time to destroy all organic matter, when it was removed, cooled and weighed. The difference between this and the original weight gives the <u>volatile matter.</u>

The ignited soil was then fused with five grams of sodium carbonate and the melt digested some time with hot water, acidified with hydrochloric acid and finally evaporated to dryness. This was extracted with warm dilute hydrocloric acid and the residue filtered off, dried, ignited and weighed. It was then treated with hydrofluoric acid, evaporated to dryness, ignited and again weighed, the difference between the two weights giving the amount of <u>silica.</u>

In the filtrate the sesquioxides of iron, aluminum, phosphorus and titanium were precipitated with ammonia, filtered off, placed in the same crucible with traces of these left from the silica, dried, ignited and weighed. The combined oxides were fused with potassium pyrosulphate, the melt dissolved in water to which a few cubic centimeters of sulphuric acid had been added, filtered, and the residue ignited, weighed and evaporated with hydrofluoric acid. It was then ignited and again weighed, the loss in weight representing a last trace of silica included in the combined oxides, this being added to the amount first obtained.

In the filtrate from the pyrosulphate fusion the <u>iron</u> was reduced with hydrogen sulphide and treated with permanganate and the <u>titanium</u> determined colorimetrically in this solution after the faint permanganate tint had disappeared. The phosphorus was determined in a separate sample as described above. When the amounts of iron, titanium and phosphorus were deducted from the amount of combined oxides the quantity of alumina was obtained.

In the filtrate from the sesquioxide precipitation, the lime was thrown down with ammonium oxalate and subsequently determined by titration with permanganate.

The magnesia was precipitated in the filtrate after the removal of the lime and finally weighed as magnesium pyrophosphate.

The potash and soda were determined by the Lawrence Smith method (29).

The analytical data are the averages of concordant duplicate determinations.

The inorganic constituents in the various soil types on the different drifts are shown in tables 35 to 37. To make evident the variations in individual constituents these are dealt with separately in later tables.

Table 35.

Composition of Carrington silt loam.

	1 - 6 inches per cent	7 - 12 inches per cent	13 - 24 inches per cent	25 - 36 inches per cent	Av. 1 - 36 inches per cent
			1. Kansan		
SiO_2	69.59	71.02	72.45	75.14	72.63
Al_2O_3	11.09	11.35	11.96	11.89	11.69
Te_2O_3	3.55	3.81	4.40	4.78	4.29
MgO	0.81	0.84	0.85	0.93	0.87
CaO	1.13	1.14	1.02	0.93	1.03
Na_2O	1.26	1.36	1.37	1.29	1.32
K_2O	1.76	1.84	1.90	1.87	1.86
TiO_2	0.64	0.64	0.64	0.70	0.66
P_2O_5	0.23	0.20	0.15	0.13	0.16
CO_2	0.08	0.09	0.06	0.03	0.06
Volatile matter	10.52	8.58	6.07	3.73	6.45
			2. Late Wisconsin		
SiO_2	72.89	73.62	75.24	73.65	74.05
Al_2O_3	10.46	10.87	11.35	12.13	11.38
Fe_2O_3	2.99	3.21	3.42	3.81	3.44
MgO	0.72	0.74	0.88	1.21	0.94
CaO	1.24	1.18	1.24	2.08	1.51
Na_2O	1.39	1.35	1.33	1.31	1.33
K_2O	1.66	1.74	1.86	1.87	1.80
TiO_2	0.50	0.52	0.54	0.53	0.53
P_2O_5	0.18	0.17	0.14	0.11	0.14
CO_2	0.07	0.05	0.13	1.06	0.42
Volatile matter	9.38	7.80	5.34	2.99	5.64

Table 36.

Composition of Fargo silt loam.

	1 - 6 inches per cent	7 - 12 inches per cent	13 - 24 inches per cent	25 - 36 inches per cent	Av. 1 - 36 inches per cent
			1. Kansan		
SiO_2	59.05	65.81	71.71	73.41	69.18
Al_2O_3	10.29	11.46	12.43	12.28	11.86
Fe_2O_3	3.37	3.79	4.21	4.14	3.98
MgO	1.02	1.06	1.21	1.49	1.25
CaO	2.34	2.08	1.55	1.92	1.89
Na_2O	1.31	1.48	1.45	1.59	1.48
K_2O	1.57	1.64	1.83	1.86	1.76
TiO_2	0.60	0.66	0.73	0.72	0.69
P_2O_5	0.31	0.24	0.19	0.18	0.21
CO_2	0.30	0.20	0.06	0.84	0.38
Volatile matter	20.34	12.12	5.41	2.19	7.94
			2. Late Wisconsin.		
SiO_2	68.08	70.42	72.02	71.97	71.08
Al_2O_3	10.18	10.62	11.57	12.54	11.50
Fe_2O_3	3.21	3.21	3.68	3.95	3.61
MgO	1.07	1.08	1.23	1.51	1.27
CaO	1.97	1.84	1.86	2.16	1.97
Na_2O	1.18	1.29	1.27	1.18	1.23
K_2O	1.60	1.68	1.71	1.75	1.70
TiO_2	0.60	0.60	0.60	0.60	0.60
P_2O_5	0.23	0.18	0.15	0.11	0.16
CO_2	0.49	0.57	0.54	1.04	0.70
Volatile matter	11.68	9.61	6.43	4.40	7.16

2. Silica.

The silica (table 38) is quite uniformly distributed on the two drifts, the amounts differing slightly, however, from type to type. The lowest averages are those for the Fargo silt loam and the highest those for the Carrington loam. On the Kansan, the former, in the first 6-inch section shows only 59.05 per cent but this does not appear so strange when we take into consideration the fact that this soil carried over 20 per cent of volatile matter. On the Kansan, the maximum appears in the lowest section while on the Late Wisconsin it is reached in the second foot or the lower half of the first.

Thus the soils on the older drift are somewhat the richer in silica and the maximum amount is found at a lower level.

3. Iron.

The iron is reported as ferric oxide in table 39. The distribution is quite uniform from type to type and from drift to drift. On the Kansan, all three types show a higher content than on the Late Wisconsin, and, on the latter, the average percentages are almost identical. The difference between drifts is greatest on the Carrington silt loam where, in the second and third foot-sections, it amounts to 1.0 per cent, and least on the Carrington loam, which exhibits a remarkable parallelism in the case of practically all other constituents. On the Kansan, the maximum on two of the three types is shown in the second foot-section while on the Late Wisconsin it is found in the third foot.

Thus the distribution of iron is the opposite of that of the silica.

4. Alumina.

The total alumina (table 40) is very uniformly distributed on the two drifts as well as from type to type, on the Kansan showing a minimum of 9.50 per cent and a maximum of 12.43 per cent and, on the Late Wisconsin, a range from 9.52 to 12.54 per cent.

Table 38.

Silica in the different sections.

	Carrington silt loam		Fargo silt loam		Carrington loam	
Depth Inches	Kansan per cent	Late Wis. per cent	Kansan per cent	Late Wis. per cent	Kansan per Cent	Late Wis. per cent
1 - 6	69.59	72.89	59.05	68.08	75.69	76.34
7 - 12	71.02	73.62	65.81	70.42	77.05	77.37
13- 24	72.45	75.24	71.71	72.02	74.95	76.26
25- 36	75.14	73.65	73.41	71.97	78.23	76.98
Average: 1 - 36	72.63	74.05	69.18	71.08	76.52	76.70

Table 39.

Ferric oxide in the different sections.

Depth Inches	Carrington silt loam		Fargo silt loam		Carrington loam	
	Kansan percent	Late Wis. percent	Kansan percent	Late Wis. percent	Kansan percent	Late Wis. percent
1 - 6	3.55	2.99	3.37	3.21	2.93	2.82
7 - 12	3.81	3.21	3.79	3.21	3.41	3.32
13- 24	4.40	3.42	4.21	3.68	4.23	3.93
25- 36	4.78	3.81	4.14	3.95	4.04	3.96
Average 1 - 36	4.29	3.44	3.98	3.61	3.61	3.65

Table 40.

Alumina in the different sections.

Depth Inches	Carrington silt loam		Fargo silt loam		Carrington loam	
	Kansan percent	Late Wis. percent	Kansan percent	Late Wis. percent	Kansan percent	Late Wis. percent
1 - 6	11.09	10.46	10.29	10.18	9.50	9.52
7 - 12	11.35	10.87	11.46	10.62	10.54	10.66
13- 24	11.96	11.35	12.43	11.57	12.01	11.81
25- 36	11.89	12.13	12.28	12.54	10.46	11.77
Average 1 - 36	11.69	11.38	11.86	11.50	10.83	11.22

In the vertical distribution the maximum, as in the case of the ferric oxide, is to be found, on the Kansan, in the second foot and, on the Late Wisconsin, in the third foot, the opposite of what was found for silica. The percentages in the upper sections are not as large as those in the lower ones, which is to be explained by the downward translocation of colloidal clay.

The similarity in the alumina content on the two drifts is evident from the averages for the three-foot sections on all three types, viz., 11.46 per cent on the Kansan and 11.37 per cent on the Late Wisconsin.

5. Titanium.

The titanium (table41) is very uniformly distributed on the two drifts, and on the three types as well. The amounts found on the Kansan are slightly higher in all cases than those found on the Late Wisconsin, thus resembling the alumina in distribution.

Table 41.

Titanium in the different sections.

Depth Inches.	Carrington silt loam Kansan per cent	Carrington silt loam Late Wis. per cent	Fargo silt loam Kansan per cent	Fargo silt loam Late Wis. per cent	Carrington loam Kansan per cent	Carrington loam Late Wis. per cent
1 - 6	0.64	0.50	0.60	0.60	0.68	0.60
7 - 12	0.64	0.52	0.66	0.60	0.73	0.60
13 - 24	0.64	0.54	0.73	0.60	0.69	0.58
25 - 36	0.70	0.53	0.72	0.60	0.60	0.58
Average 1 - 36	0.66	0.53	0.69	0.60	0.67	0.59

Table 37.

Composition of Carrington loam.

	1 - 6 inches per cent	7 - 12 inches per cent	13 - 24 inches per cent	25 - 36 inches per cent	Av. 1 - 36 inches per cent
			1. Kansan		
SiO_2	75.69	77.05	74.95	78.23	76.52
Al_2O_3	9.50	10.54	12.01	10.46	10.83
Fe_2O_3	2.93	3.41	4.23	4.04	3.81
MgO	0.70	0.71	0.94	0.78	0.81
CaO	1.06	0.92	0.97	1.02	0.99
Na_2O	1.46	1.42	1.38	1.41	1.41
K_2O	1.72	1.76	1.82	1.65	1.74
TiO_2	0.68	0.73	0.69	0.60	0.67
P_2O_5	0.23	0.18	0.18	0.15	0.18
CO_2	0.09	0.04	0.03	0.04	0.06
Volatile matter	6.41	3.73	3.32	2.66	3.68
			2. Late Wisconsin		
SiO_2	76.34	77.37	76.26	76.98	76.70
Al_2O_3	9.52	10.66	11.81	11.77	11.22
Fe_2O_3	2.82	3.32	3.93	3.96	3.65
MgO	0.60	0.67	0.84	0.85	0.77
CaO	1.09	0.97	0.95	1.07	1.02
Na_2O	1.41	1.42	1.40	1.42	1.41
K_2O	1.86	1.99	1.96	1.76	1.88
TiO_2	0.60	0.60	0.58	0.58	0.59
P_2O_5	0.19	0.15	0.14	0.14	0.15
CO_2	0.10	0.06	0.05	0.04	0.06
Volatile matter	6.71	4.15	3.77	2.89	4.03

6. Lime.

The total lime (table 42 pt.1) varies almost directly with the carbon dioxide. On the Carrington silt loam the amount in the first three sections is practically the same on both drifts, varying between 1.0 and 1.25 per cent. In the third foot, however, the quantity on the Late Wisconsin is more than twice as great, reaching 2.08 per cent as compared with 0.93 per cent on the Kansan.

On the Fargo silt loam there is not a wide difference between the amounts of this constituent in the different sections on either drift, and the average for the three feet is 1.89 per cent in the case of the Kansan and 1.97 per cent in that of the Late Wisconsin.

The amount of lime in the different sections of Carrington loam is remarkably similar, the difference between on the two drifts for any given level being no greater than that between duplicate determinations on the same sample. All calcium compounds at all readily soluble, have evidently been leached out of this type to a depth greater than three feet.

The amount of lime in the form of carbonate was computed from the carbon dioxide content (table 42 pt. 2). On the Carrington silt loam, only in the second and third foot-sections of the Late Wasconsin is any appreciable quantity shown. On the Fargo silt loam the second foot-section on the Kansan is the only one to show a deficiency in this, while with the Carrington loam on both drifts the carbonate has been leached out to a depth greater than three feet.

By deducting the lime as carbonate from the total amount, the quantity in the form of silicate is secured (table 42, pt. 3). On the two prairie types, this decreases from the surface downward. On the forest type, the Carrington loam, the first and fourth sections show like amounts, while the intervening two are alike and show somewhat smaller amounts.

Discussion. With one exception the amount of total lime in the surface section is greater than in the second. Plant roots feeding in the lower levels carry the constituent into the aerial parts which on death and decay leave behind in the surface

Table 42.

Lime in the different sections.

Depth Inches	Carrington silt loam Kansan per cent	Carrington silt loam Late Wis. per cent	Fargo silt loam Kansan per cent	Fargo silt loam Late Wis. per cent	Carrington loam Kansan per cent	Carrington loam Late Wis. per cent
			1. Total			
1 - 6	1.13	1.24	2.34	1.97	1.06	1.09
7 - 12	1.14	1.18	2.08	1.84	0.92	0.97
13- 24	1.02	1.24	1.55	1.86	0.97	0.95
25- 36	0.93	2.08	1.92	2.16	1.02	1.07
Average 1 - 36	1.03	1.51	1.89	1.97	0.99	1.02
			2. Lime as carbonate (computed from CO_2 content)			
1 - 6	0.10	0.10	0.40	0.65	0.09	0.10
7 - 12	0.10	0.07	0.25	0.69	0.07	0.08
13- 24	0.07	0.16	0.08	0.68	0.07	0.05
25- 36	0.04	1.36	1.06	1.33	0.06	0.07
Average 1 - 36	0.07	0.53	0.49	0.89	0.07	0.07
			3. Lime as silicate			
1 - 6	1.03	1.14	1.94	1.32	0.97	0.99
7 - 12	1.04	1.11	1.83	1.15	0.85	0.89
13- 24	0.95	1.08	1.47	1.18	0.90	0.90
25 -36	0.89	0.72	0.86	0.83	0.96	1.00
Average 1 - 36	0.96	0.97	1.27	1.08	0.92	0.95

layer this translocated line.

On the Kansan, the two Carrington series have lost the more readily soluble lime compounds to a depth of more than three feet. On the Late Wisconsin the Carrington silt loam still retains a considerable amount in the third foot section, but with the Carrington loam the leaching has been as extensive as on the Kansan.

The poorly drained condition of the Fargo silt loam has prevented any serious leaching on this type. This is well illustrated by table 42 part 2, which shows every section well supplied with carbonate with the exception of the second foot on the Kansan.

On the Kansan, lime in the form of carbonate has been leached out to a depth greater than three feet with both the Carrington silt loam and the Carrington loam. On the Late Wisconsin the same is true for the latter type but there is still an appreciable quantity in the third foot-sections of the former.

On each type the average amount of lime as silicate is very similar on both drifts with the exception of the Fargo silt loam where it is slightly the higher on the Kansan. There is a general decrease in the amount of this from the surface downward on the prairie types, while on the forest type there is but little difference in its vertical distribution.

7. Magnesia.

There is very little difference between the amounts of magnesia (table 43) found on the two drifts on any given type. The largest amount is found, as in the case of lime, on the Fargo silt loam, the averages being, respectively, 1.25 per cent for the Kansan and 1.27 per cent on the Late Wisconsin. The averages for the Carrington loam are slightly lower than those for the Carrington silt loam, the latter being 0.87 per cent and 0.94 per cent for the two drifts.

The ratio of total lime to magnesia (table 44, pt. 1) falls between 1.0 and 1.8, averaging 1.4 for the 3-foot sections on all types. It is very similar for each type on both drifts, the greatest difference being shown on the Carrington silt loam where, on the Kansan, it is 1.2 as compared with 1.5 on the Late Wisconsin. The optimum ratio varies with different plants (26) but in general the lime must equal or exceed the magnesia if the most satisfactory cultural results are to be obtained (24, p. 33).

Table 43.

Magnesia in the different sections.

Depth Inches	Carrington silt loam Kansan percent	Late Wis. percent	Fargo silt loam Kansan percent	Late Wis. percent	Carrington loam Kansan percent	Late Wis. percent.
1 - 6	0.81	0.72	1.02	1.07	0.70	0.60
7 - 12	0.84	0.74	1.06	1.08	0.70	0.67
13- 24	0.85	0.88	1.21	1.23	0.94	0.84
25- 36	0.93	1.21	1.49	1.51	0.78	0.85
Average: 1 - 36	0.87	0.94	1.25	1.27	0.81	0.77

Table 44

Relation of lime to magnesia in the different sections.

Depth Inches	Carrington silt loam Kansan	Carrington silt loam Late Wis.	Fargo silt loam Kansan	Fargo silt loam Late Wis.	Carrington loam Kansan	Carrington loam Late Wis
	1. Ratio of total lime to magnesia					
1 - 6	1.4	1.7	2.3	1.8	1.5	1.8
7 - 12	1.3	1.6	2.0	1.7	1.3	1.4
13- 24	1.2	1.4	1.3	1.5	1.0	1.1
25- 36	1.0	1.6	1.3	1.4	1.3	1.3
Average 1 - 36	1.2	1.5	1.6	1.6	1.2	1.3
	2. Ratio of lime as silicate to magnesia.					
1 - 6	1.2	1.5	1.9	1.2	1.4	1.6
7 - 12	1.2	1.5	1.7	1.0	1.2	1.3
13- 24	1.1	1.2	1.2	.9	1.0	1.0
25- 36	.9	.6	.5	.5	1.2	1.2
Average 1 - 36	1.1	1.1	1.2	.8	1.2	1.2

On both prairie types the ratio of the portion of the lime in the form of silicate to magnesia (table 44, pt. 2) decreases from the surface downward, as was the case with the amounts of lime in the form of silicate on these, while on the forest type it decreases through the first three sections, rising slightly again in the third foot. On both drifts the average ratio for each type is very similar with the exception of the Fargo silt where that for the Kansan is the higher.

Discussion. The amounts of magnesia found on the two drifts are very similar, the averages for the three foot sections on the Kansan and the Late Wisconsin respectively being 0.98 per cent and 0.99 per cent. Considerable variation from type to type is shown, the Fargo silt loam carrying the most and the Carrington loam the least.

The ratio of total lime to magnesia is slightly the higher on the Late Wisconsin, this being due to its higher proportion of the former constituent.

The average ratio of lime as silicate to magnesia is very similar on both drifts with the exception of that for the Fargo silt loam on the Late Wisconsin where it is somewhat the lower. The maximum ratio in every instance, is found in the surface section while the minimum is found in the third foot except on the Carrington loam where it appears in the second foot section.

8. Phosphoric acid.

The phosphoric acid (tables 45 to 48) was determined in all the field samples by the modification of Washington's method described above (page 69). Averages from these give the data for the drift samples (table 49).

Carrington silt loam. On this type (table 45) there is shown, in general, a decrease from the surface downward, a distribution characteristic of prairie soils (3). The amount found on the Kansan is slightly higher than that on the Late Wisconsin, the general average for the former being 0.165 per cent compared with 0.141 for the latter. The distribution from field to field is very regular.

Fargo silt loam. While somewhat larger amounts of phosphoric acid are found in the soils of this type (table 46), the same observations as to its distribution apply. The difference in the amounts found on the two drifts are, however, much greater, the average for the

Table 45.

Phosphoric acid in the different sections from the five fields on Carrington silt loam.

Depth Inches	Field I percent	Field II percent	Field III percent	Field IV percent	Field V percent	Average for five fields percent
			1. Kansan			
1 - 6	0.245	0.220	0.258	0.214	0.204	0.228
7 - 12	0.200	0.223	0.220	0.191	0.188	0.204
13- 24	0.159	0.165	0.147	0.137	0.147	0.151
25- 36	0.140	0.143	0.127	0.102	0.134	0.129
Average 1 - 36	0.174	0.176	0.171	0.147	0.159	0.165
			2 Late Wisconsin			
1 - 6	0.204	0.182	0.172	0.175	0.178	0.182
7 - 12	0.210	0.151	0.153	0.172	0.156	0.168
13- 24	0.156	0.108	0.144	0.147	0.118	0.135
25- 36	0.102	0.104	0.121	0.143	0.096	0.113
Average 1 - 36	0.155	0.126	0.142	0.154	0.127	0.141

Table 46.

Phosphoric acid in the different sections from the five fields on Fargo silt loam.

Depth Inches	Field I percent	Field II percent	Field III percent	Field IV percent	Field V percent	Average for five fields percent.
			1. Kansan			
1 - 6	0.290	-	0.255	0.363	0.338	0.311
7 - 12	0.246	0.223	0.207	0.264	0.283	0.243
13- 24	0.169	0.182	0.162	0.207	0.210	0.186
25- 36	0.179	0.172	0.168	0.201	0.175	0.179
Average 1 - 36	0.206	-	0.187	0.240	0.232	0.214
			2. Late Wisconsin			
1 - 6	0.239	0.229	0.219	0.220	0.216	0.225
7 - 12	0.185	0.156	0.213	0.179	0.185	0.184
13- 24	0.146	0.172	0.188	0.134	0.115	0.151
25- 36	0.118	0.099	0.121	0.112	0.111	0.112
Average 1 - 36	0.159	0.154	0.175	0.148	0.142	0.156

nsan being 0.214 per cent compared with 0.156 per cent for the Late Wisconsin. The rmer shows the higher content in all four levels. It is to be noted that the decrease the amounts found in the third foot-section on the Kansan is not nearly so great as on he younger drift.

arrington loam. In the soils on this type (table 47) neither the distribution from the urface downward nor that from field to field is as regular as was the case on the two rairie types. The averages for the five fields on the two drifts show a general decrease rom the surface downward although on the Late Wisconsin they are, below the first 6-inch ection, practically the same. The general average for the Kansan is slightly the higher, eing 0.177 per cent as compared with 0.151 per cent for the Late Wisconsin.

arshall loam. The phosphoric acid in soils from the still forested fields, I, II and III, (table 48) show the same irregularity as those on the other forest type; the Carrington loam. The cleared fields, IV and V, are in general more like those on the prairie types, he amounts being considerably higher than those found on the other three. As pointed out above (p.32), the thickness of loessial deposit on the three forested fields is not great, the till being encountered in the third foot on two of them so that it is not improbably that these have been somewhat modified. The cleared fields, on the other hand, appear to be more typical of this type, the thickness of the deposit here being sufficient to remove any chance of inter-mixing with boulder clay from below.

Discussion. The averages for the five fields from the different types on the two drifts are shown in table 49. The amounts found on the Kansan, are on each type and in every field, greater than those on the Late Wisconsin. The vertical distribution on the prairie types, viz; the Carrington silt loam and the Fargo silt loam, shows a steady decrease from the surface downward while that on the forest types is irregular.

9. Potash.

The potash (table 50) is fairly uniform for each type on the two drifts, the averages for the three foot-sections, with the exception of those for the Carrington loam, being practically the same. On the Late Wisconsin the latter type shows slightly higher amounts, averaging 1.88 per cent compared with 1.74 on the older drift. However, if the

Table 47.

Phosphoric acid in the different sections
from the five fields on Carrington loam.

Depth Inches	Field I percent	Field II perdent	Field III percent	Field IV percent	Field V percent	Average for five fields percent
			1. Kansan			
1 - 6	0.236	0.216	0.220	0.280	0.213	0.233
7 - 12	0.182	0.160	0.178	0.223	0.156	0.180
13- 24	0.150	0.162	0.194	0.197	0.178	0.176
25- 36	0.124	0.159	0.134	0.188	0.143	0.150
Average 1 - 36	0.161	0.170	0.176	0.212	0.168	0.177
			2. Late Wisconsin			
1 - 6	0.213	0.175	0.207	0.162	0.213	0.194
7 - 12	0.178	0.140	0.159	0.115	0.143	0.147
13- 24	0.162	0.147	0.147	0.131	0.128	0.143
25- 36	0.162	0.162	0.110	0.131	0.137	0.140
Average 1 - 36	0.173	0.155	0.147	0.133	0.148	0.151

Table 48.

Phosphoric acid from the different sections from the five fields on Marshall loam.

Depth Inches	Field I percent	Field II percent	Field III percent	Field IV percent	Field V percent	Average for 5 fields per cent
1 - 6	0.167	0.143	0.172	0.226	0.223	0.186
7 - 12	0.153	0.146	0.147	0.207	0.207	0.172
13- 24	0.124	0.124	0.153	0.162	0.178	0.148
25- 36	0.114	0.159	0.153	0.172	0.166	0.153
Average 1 - 36	0.132	0.142	0.155	0.183	0.186	0.160

Table 49.

Phosphoric acid in the different sections.
The data are the averages for the five fields
reported in tables   to   .

	Carrington silt loam		Fargo silt loam		Carrington loam		Marshall loam
Depth Inches	Kansan percent	Late Wis. percent	Kansan percent	Late Wis. percent	Kansan percent	Late Wis. percent	Kansan percent
1 - 6	0.228	0.182	0.311	0.225	0.233	0.194	0.186
7 - 12	0.204	0.168	0.243	0.184	0.180	0.147	0.172
13-24	0.151	0.135	0.186	0.151	0.176	0.143	0.148
25-36	0.129	0.113	0.179	0.112	0.150	0.140	0.153
Average 1 - 36	0.165	0.141	0.214	0.156	0.177	0.151	0.160

mounts found in the 15 fields on each drift are averaged the percentage is the same in both cases, viz; 1.79.

The percentages found for the surface section are, in every case, lower than those found for the second, while the amounts in the three lower sections, except those on the Carrington loam, are very similar. On the type just mentioned, the third foot-section carries on both drifts a smaller amount than any of those above it.

10. Soda.

On the two Carrington series the soda (table 51) is very uniform for both drifts, showing little variation either between the different sections or from the surface downward. With the Fargo silt loam on the Kansan the amounts are distinctly the higher, averaging 1.48 per cent as compared with 1.23 per cent for the younger drift. The widest range in distribution from the surface downward is shown by the same fields where it varies from 1.31 per cent in the surface to 1.59 per cent in the third foot.

Table 50.

Potash in the different sections.

Depth Inches	Carrington silt loam Kansan per cent	Carrington silt loam Late Wis. per cent	Fargo silt loam Kansan per cent	Fargo silt loam Late Wis. per cent	Carrington loam Kansan per cent	Carrington loam Late Wis. per cent
1 - 6	1.76	1.66	1.57	1.60	1.72	1.86
7 - 12	1.84	1.74	1.64	1.68	1.76	1.99
13- 24	1.90	1.86	1.83	1.71	1.82	1.96
25- 36	1.87	1.87	1.86	1.75	1.65	1.76
Average 1 - 36	1.86	1.80	1.76	1.70	1.74	1.88

Table 51.

Soda in the different sections.

Depth	Carrington silt loam		Fargo silt loam		Carrington loam	
	Kansan	Late Wis.	Kansan	Late Wis.	Kansan	Late Wis.
Inches	per cent	per cent	per cent	per cent	per cent	per cent
1 - 6	1.26	1.39	1.34	1.18	1.46	1.41
7 - 12	1.36	1.35	1.48	1.29	1.42	1.42
13- 24	1.37	1.33	1.45	1.27	1.38	1.40
25- 36	1.29	1.31	1.59	1.18	1.41	1.42
Average: 1 - 36	1.32	1.33	1.48	1.23	1.41	1.41

D - Organic Constituents.

Volatile matter.

The volatile matter which in the present instance includes the organic matter and water of constitution is reported in table 52. There is very little difference in the amounts found on the two drifts when the comparison is made between the various sections on the two types of the Carrington series but a very wide one is observed when the surface six-inch section of the Fargo silt loam is taken into consideration. On the Kansan this rises to 20.34 per cent as compared with 11.68 percent on the Late Wisconsin.

The course of the streams before the Late Wisconsin glaciation was in a general southwesterly direction but the ice and later the drift material left behind blocked the previously existing drainage channels and forced the water to find outlets to the southeast. Before these new channels were fully developed the drainage was very incomplete and undoubtedly large areas were covered by standing water part of the season. The surface material carried by the water from the surrounding high lands was thus deposited in the lowlands. Organic material accumulated through the growth of dense lowland vegetation and the deposition of the remains of these. Little or no peat was formed on this drift.

On the Late Wisconsin the poorly drained areas were not as numerous as on the older formation and such as existed were more in the form of "pot holes" in which the conditions for the formation of peat were favorable so that in most instances we have the Fargo silt loam as narrow band between the low lying peat areas and the upland soil. Further, the high land did not have the black surface soil which remained on the unglaciated Kansan from the as yet unnamed inter-glacial interval preceding the Late Wisconsin and hence, the eroded material accumulated in the lower lying areas was not so rich in organic matter.

Table 52.

Valatile matter in the different sections.

Depth Inches	Carrington silt loam		Fargo silt loam		Carrington loam	
	Kansan percent	Late Wis. percent	Kansan percent	Late Wis. percent	Kansan percent	Late Wis. percent
1 - 6	10.52	9.38	20.34	11.68	6.41	6.71
7 - 12	8.58	7.80	12.12	9.61	3.73	4.15
13- 24	6.07	5.34	5.41	6.43	3.32	3.77
25- 36	3.73	2.99	2.19	4.40	2.66	2.89
Average 1 - 36	6.45	5.64	7.94	7.16	3.68	4.03

Nitrogen.

Nitrogen was determined on both sets of samples from each field by the Gunning modification of the Kjeldahl method. The normal variation in upland fields shows a decrease from the surface downward, this being especially regular in the case of prairie fields (2, p. 219).

Carrington silt loam. Considerable variation within the same field and from field to field is shown on both drifts (table 53). The average amounts on the two drifts are very similar.

It is to be observed that in the second and third foot-sections the differences between the two sets from the same field and between the field samples are as great as, if not greater than, in the sections of the surface foot where a difference in compactness and accordingly a difference in density (2, p. 219) might account for it.

Fargo silt loam. As with the Carrington silt loam, the nitrogen varies considerably from field to field and within a few of the individual fields (table 54). An extraordinary range is shown in field IV on the Kansan where it varies from slightly over 1.0 per cent in the surface to .028 per cent in the subsoil.

There is a wide difference in the amounts of nitrogen found in the surface foot on the two drifts, those on the Kansan being, on the average, 76 per cent the higher in the surface six inches and 52 per cent the higher in the second section. The conditions mentioned above (page   ) under which the soils of this type were developed furnish an explanation for this difference, the accumulation of organic matter and nitrogen being parallel.

The average amount of nitrogen found in the second and third foot-sections on the two drifts are, on the other hand, quite similar.

Carrington loam. The amounts of nitrogen found in a forest type are naturally not as high as those found on the prairie types. The variation (table 55) within the same field and from field to field as well as the distribution from the surface downward are much the same. There is little difference between the averages for

Table 53.

Nitrogen in the different sections from the five fields on Carrington silt loam.

Depth	Field I			Field II			Field III			Field IV			Field V.			Average for 5 fields
	Set 1	Set 2	Av.	Set I	Set 2	Av.	Set I	Set 2	Av.	Set I	Set 2	Av.	Set I	Set 2	Av.	
Inches	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
I. Kansan																
1 - 6	.474	.442	.458	.306	.331	.318	.379	.400	.389	.341	.383	.362	.427	.353	.390	.383
7 - 12	.251	.350	.300	.272	.274	.273	.292	.291	.291	.248	.283	.265	.338	.324	.331	.292
13- 24	.094	.201	.147	.147	.182	.164	.204	.159	.181	.160	.138	.149	.176	.199	.187	.166
25- 36	.042	.059	.050	.048	.081	.064	.065	.057	.061	.052	.052	.052	.055	.071	.063	.058
Average 1 - 36	.166	.219	.192	.161	.188	.174	.201	.187	.194	.169	.174	.171	.204	.203	.203	.187
2. Late Wisconsin																
1 - 6	.444	.427	.437	.343	.389	.366	.274	.356	.315	.317	.312	.314	.370	.402	.386	.364
7 - 12	.382	.376	.379	.204	.217	.210	.162	.382	.272	.279	.249	.264	.294	.237	.265	.278
13- 24	.230	.238	.234	.133	.216	.174	.088	.175	.131	.143	.137	.140	.166	.121	.143	.164
25- 36	.104	.063	.083	.067	.040	.053	.037	.090	.063	.062	.068	.065	.077	.059	.068	.066
Average 1 - 36	.249	.234	.242	.158	.186	.172	.114	.211	.162	.168	.162	.165	.192	.166	.179	.184

Table 54.

Nitrogen in the different sections from the five fields on Fargo silt loam.

Depth Inches	Field I Set 1 %	Field I Set 2 %	Field I Av. %	Field II Set I %	Field II Set 2 %	Field II Av. %	Field III Set I %	Field III Set 2 %	Field III Av. %	Field IV Set I %	Field IV Set 2 %	Field IV Av. %	Field V. Set I %	Field V. Set 2 %	Field V. Av. %	Av. for 5 fields %
I. Kansan																
1 - 6	.813	.889	.855	- -	.505	.505	.669	.542	.605	1.010	1.014	1.012	1.096	.815	.955	.786
7 - 12	.520	.517	.518	.477	.478	.477	.432	.370	.401	.363	.431	.397	.625	.452	.538	.466
13- 24	.175	.156	.165	.154	.125	.139	.185	.149	.167	.132	.130	.131	.184	.131	.157	.152
25- 36	.050	.034	.042	.060	.041	.050	.063	.053	.058	.029	.028	.028	.040	.047	.043	.044
Average 1 - 36	.297	.298	.298	-	.236	.227	.266	.219	.242	.282	.293	.288	.361	.270	.315	.274
2. Late Wisconsin																
1 - 6	.631	.419	.525	.484	.371	.427	.422	.371	.396	.371	.411	.391	.448	.521	.484	.445
7 - 12	.402	.238	.320	.216	.209	.212	.456	.358	.407	.233	.290	.261	.312	.337	.324	.305
13- 24	.138	.077	.107	.091	.080	.085	.335	.298	.316	.101	.103	.102	.094	.163	.128	.148
25- 36	.050	.044	.047	.037	.030	.034	.120	.166	.143	.052	.068	.060	.039	.042	.040	.065
Average 1 - 36	.235	.150	.192	.159	.133	.146	.298	.276	.287	.152	.174	.163	.171	.211	.191	.196

Table 55.

Nitrogen in the different sections from the five fields of Carrington loam.

Depth Inches	Field I Set I %	Set 2 %	Av. %	Field II Set I %	Set 2 %	Av. %	Field III Set 1 %	Set 2 %	Av. %	Field IV Set I %	Set 2 %	Av. %	Field V * Set 1 %	Set 2 %	Av. %	Av. for 5 fields %
I. Kansan																
1 - 6	.328	.224	.276	.220	.265	.242	.222	.239	.230	.294	.225	.259	.163	.258	.210	.243
7 - 12	.214	.170	.192	.066	.100	.083	.130	.113	.121	.140	.130	.135	.067	.094	.080	.122
13- 24	.163	.103	.133	.040	.051	.045	.060	.059	.059	.061	.066	.063	.046	.079	.062	.072
25- 36	.090	.036	.062	.031	.055	.043	.021	.032	.027	.033	.033	.033	.031	.031	.031	.039
Average 1 - 36	.175	.112	.143	.071	.096	.083	.086	.089	.087	.104	.092	.098	.064	.095	.079	.098
2. Late Wisconsin																
1 - 6	.330	.378	.354	.171	.134	.152	.280	.295	.287	.172	.195	.183	.233	.447	.340	.263
7 - 12	.150	.153	.151	.056	.061	.058	.150	.126	.138	.066	.069	.067	.126	.220	.173	.117
13- 24	.083	.085	.084	.037	.044	.040	.103	.149	.126	.057	.063	.060	.098	.120	.109	.084
25- 36	.043	.054	.048	.031	.037	.034	.056	.044	.050	.044	.038	.041	.041	.054	.047	.044
Average 1 - 36	.122	.135	.128	.060	.059	.060	.125	.134	.129	.073	.078	.075	.106	.169	.137	.106

the two drifts.

Marshall loam. The three forested fields I, II and III show little variation within the same field but a wider one from field to field (table 56). In the amounts present these resemble the fields on the Carrington loam, a forest type.

The cleared fields, IV and V, resemble the prairie types in both the amounts of nitrogen and its distribution.

Discussion. The averages for the five fields on the different types are shown in table 57. Both the Carrington silt loam and Carrington loam are very similar on the two drifts. The latter shows the lowest percentage of all four types but this is to be explained by the fact that the areas sampled were all forested while prairie conditions prevailed on the other types, with the exception of three fields on the Marshall loam.

With the Fargo silt loam the two upper sections are much richer in nitrogen on the Kansan than on the Late Wisconsin, the former being 76 per cent the higher in the first 6-inch section and 52 per cent in the second. This is to be explained by the fact that the Late Wisconsin glaciation obstructed the drainage on the Kansan and thus increased the accumulation of eroded surface material rich in organic matter. The averages for the second and third foot sections on this type are very similar.

The average for the three feet on the Marshall loam is quite similar to both of those on the Carrington loam, the difference being due to the relatively large amounts found in the two cleared fields on the former.

Table 56.

Nitrogen in the different sections from the five fields on Marshall loam.

Depth Inches	Field I Set 1 %	Field I Set 2 %	Field I Av. %	Field II Set 1 %	Field II Set 2 %	Field II Av. %	Field III Set 1 %	Field III Set 2 %	Field III Av. %	Field IV Set 1 %	Field IV Set 2 %	Field IV Av. %	Field V Set 1 %	Field V Set 2 %	Field V Av. %	Av. for 5 fields Av.
I. Kansan																
1 - 6	.119	.122	.120	.194	.203	.198	.161	.183	.172	.354	.409	.381	.452	.351	.401	.254
7 - 12	.043	.048	.045	.087	.104	.095	.114	.123	.118	.229	.394	.311	.241	.353	.297	.173
13- 24	.033	.050	.041	.047	.053	.050	.040	.133	.086	.098	.234	.166	.182	.221	.201	.109
25- 36	.018	.030	.024	.038	.033	.035	.039	.033	.036	.051	.061	.056	.172	.096	.134	.057
Average 1 - 36	.044	.055	.049	.075	.080	.077	.072	.106	.089	.147	.232	.189	.233	.223	.228	.126

Table 57.

Nitrogen in the different sections. The data are averages for the five fields reported in tables to .

Depth Inches	Carrington silt loam Kansan percent	Carrington silt loam Late Wis. percent	Fargo silt loam Kansan percent	Fargo silt loam Late Wis. percent	Carrington loam Kansan percent	Carrington loam Late Wis. percent	Marshall loam percent
1 - 6	.383	.364	.786	.445	.243	.263	.254
7 - 12	.292	.278	.466	.305	.122	.117	.173
13- 24	.166	.164	.152	.148	.072	.084	.109
25- 36	.058	.066	.044	.065	.039	.044	.057
Average: 1 - 36	.187	.184	.274	.196	.098	.106	.126

E. Color.

A comparison was made of the color of the samples of the two sets from each field. For this purpose 25 gram portions of soil, which had passed the 2mm. seive, were placed in porcelain dishes of 100 cc. capacity, moistened, allowed to temper for an hour or so and then arranged in order of their color, the darkest being placed at one end and the lightest colored at the other.

It was found possible to differentiate the soils into eight groups (tables 58 to 61) the shades of color of which were fairly distinct. The gradation of one group into another, however, was not abrupt nor did every member of any group possess the exact shade of all the others. While eight shades of color were distinguishable, the basic colors were black, white, and red, so that those in group 1, the darkest soils, and in group 2, the next darkest, were black to black with a brownish tint, in group 3, brownish black to dark brown, in 4, dark brown, in 5, dark reddish brown, in 6, light reddish brown, in 7, brownish red and in 8, light gray to brownish grey. The color of subsoils is not dependent, as has recently been pointed out, (1, p. 253) upon the amount of organic matter, but is due in large part to other coloring material. The degree of oxidation of the iron would naturally affect this. For instance the soils of groups 7 and 8 have relatively the same intensity of color but the former has the more pronounced reddish shade because of a higher degree of oxidation of the iron present.

<u>Carrington silt loam</u>. There is considerable variation in color between sets within the same field and from field, this being as great on one drift as on the other (table 58).

On the Late Wisconsin the soils in the first 6-inch section have in general a relatively darker color than those in the corresponding section on the older formation. On the latter the averages for the three foot-sections in the individual fields are the same, while on the Late Wisconsin the range is greater, varying from 2 to 5. There is quite a marked difference in the shade of color between the soils from the third foot level on the two drifts, those on the Kansan having a distinctly reddish tint while on the younger drift browns, grays, and grayish browns predominate. This would indicate that the oxidation of the iron has not proceded as far on the latter. The averages for the five fields, with

Table 58.

Relative shade of color of the soils on Carrington silt loam.
1. indicates the darkest and 8 the lightest colored.

Depth	Field I			Field II			Field III			Field IV			Field V			Av. for
Inches	Set 1	Set 2	Av.	Set 1	Set 2	Av.	Set 1	Set 2	Av.	Set 1	Set 2	Av.	Set 1	Set 2	Av.	5 fields
1. Kansan																
1 - 6	2	1	2	2	2	2	1	2	1	2	2	2	1	1	1	2
7 - 12	2	1	2	3	1	2	1	1	1	2	2	2	1	1	1	2
13- 24	5	2	3	3	3	3	3	4	3	4	5	5	3	2	3	3
25- 36	7	5	6	7	5	6	6	6	6	7	7	7	7	7	7	6
Average 1 - 36	5	3	4	4	3	4	3	4	3	4	5	5	4	3	4	4
2. Late Wisconsin																
1 - 6	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1
7 - 12	1	1	1	3	2	3	3	1	2	1	2	2	1	2	2	2
13- 24	1	1	1	4	4	4	5	3	4	2	4	3	3	5	4	3
25- 36	4	4	4	8	8	8	8	4	6	5	5	5	5	8	6	6
Average 1 - 36	2	2	2	5	5	5	5	3	4	3	4	3	3	5	4	4

he exception of the first six inches are the same.

argo silt loam. With the exception of fields I and II on the Late Wisconsin, there is little variation between the two sets within the same field (table 59). As with the arrington silt loam, the averages for the three foot-sections on the Kansan are the ame, while a wider variation is shown on the Late Wisconsin. On the latter the color f the soils in the second and third foot-sections is relatively darker. With this type he grays characterize the third foot-section on the Kansan, being absent from a majority f the fields on the Late Wisconsin, a condition just the opposite to what prevailed for he Carrington silt loam. This may be attributed to the obstructed drainage, mentioned bove (page 96), on the older drift, the water table being relative close to the surface his excluding the air and preventing any considerable oxidation of the iron compounds, while on the younger formation this type is confined to more or less narrow bands (page 96) round the lower lying areas and consequently does not have the water table as near to the urface.

arrington loam. The same remarkable similarity characteristic of the soils from this ype on the two drifts is to be observed with the color also (table 60). With the xception of field I on the Kansan there is little variation within the individual fields, rom field to field, or from drift to drift.

arshall loam. There is little variation in the color between the soils from the two sets within the same field (table 61) but here, as in other instances, there is a marked ifference between the three forested fields, I, II and III and the cleared ones IV and V. n the latter the effect of the accumulation of organic matter has reached as far as the hird foot, causing a darker brown shade than is found in the corresponding level in the orested fields.

iscussion. The averages for the five fields on the different types on the two drifts re shown in table 62. There is little difference in intensity of coloring between the oils on any one type on either drift and none at all if we except the surface 6 inches n the Carrington silt loam and in the second and third foot-sections on the Fargo silt oam. In the case of these exceptions the color of the soils on the Late Wisconsin is relatively darker, indicating a condition just opposite to that observed by Burke & Kolbe (11, p. 21) who state that "the Kansan drift has generally a darker color than the Wisconsin".

Table 59.

Relative shade of color of the soils on Fargo silt loam.
1. indicates the darkest and 8 the lightest colored.

Depth Inches	Field I Set 1	Set 2	Av.	Field II Set 1	Set 2	Av.	Field III Set 1	Set 2	Av.	Field IV Set 1	Set 2	Av.	Field V Set 1	Set 2	Av.	Av. for 5 fields
1. Kansan																
1 - 6	1	1	1	-	1	1	1	1	1	1	1	1	1	1	1	1
7 - 12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13- 24	2	3	2	2	2	2	2	3	3	3	3	3	2	3	3	3
25- 36	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Average 1 - 36	4	4	4	-	4	4	4	4	4	4	4	4	4	4	4	4
2. Late Wisconsin																
1 - 6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7 - 12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13- 24	2	3	3	1	3	3	1	1	1	2	2	2	2	1	2	2
25- 36	4	8	6	4	8	6	2	2	2	4	4	4	4	3	4	4
Average 1 - 36	2	4	3	2	4	3	1	1	1	2	2	2	2	2	2	2

Table 60.

Relative shade of color of the soils on Carrington loam.
1. indicates the darkest and 8 the lightest colored.

Depth Inches	Field I Set 1	Field I Set 2	Field I Av.	Field II Set 1	Field II Set 2	Field II Av.	Field III Set 1	Field III Set 2	Field III Av.	Field IV Set 1	Field IV Set 2	Field IV Av.	Field V Set 1	Field V Set 2	Field V Av.	Av. for 5 fields
1. Kansan																
1 - 6	1	1	2	4	3	3	3	4	4	3	3	3	4	3	3	3
7 - 12	2	3	3	6	5	5	5	5	5	4	4	4	6	5	5	4
13- 24	3	5	4	7	6	7	7	7	7	5	5	5	7	7	7	6
25- 36	5	7	6	7	7	7	7	7	7	7	7	7	7	7	7	7
Average 1 - 36	3	5	4	6	6	6	6	6	6	5	5	5	6	6	6	5
2. Late Wisconsin																
1 - 6	2	2	2	4	4	4	3	3	3	4	4	4	3	2	3	3
7 - 12	4	4	4	6	6	6	4	4	4	5	5	5	4	3	3	4
13- 24	5	5	5	7	7	7	5	5	5	6	6	6	6	5	5	6
25- 36	7	7	7	7	7	7	6	7	7	6	7	7	6	6	6	7
Average 1 - 36	5	5	5	6	6	6	5	5	5	5	6	6	5	5	5	5

Table 61.

Relative shade of color of the soils on Marshall loam.
1. Indicates the darkest and 8 the lightest colored.

Depth Inches	Field I Set 1	Set 2	Av.	Field II Set 1	Set 2	Av.	Field III Set 1	Set 2	Av.	Field IV Set 1	Set 2	Av.	Field V Set 1	Set 2	Av.	Av. for 5 fields
1. Kansan																
1 - 6	5	4	5	4	4	4	4	4	4	2	2	2	2	2	2	3
7 - 12	6	6	6	5	5	5	6	6	6	4	2	3	3	2	3	5
13- 24	7	7	7	7	7	7	7	7	7	5	3	4	4	3	4	6
25- 36	7	7	7	7	7	7	7	7	7	7	5	6	6	5	5	6
Average: 1 - 36	6	6	6	6	6	6	6	6	6	5	3	4	4	3	4	5

Table 62.

Relative shade of color. The data are the averages for the five fields reported in tables to .

Depth Inches	Carrington silt loam Kansan	Carrington silt loam Late Wis.	Fargo silt loam Kansan	Fargo silt loam Late Wis.	Carrington loam Kansan	Carrington loam Late Wis.	Marshall loam
1 - 6	2	1	1	1	3	3	3
7 - 12	2	2	1	1	4	4	5
13- 24	3	[illegible]	3	2	6	6	6
25- 36	6	6	8	4	7	7	6
Average 1 - 36	4	4	4	2	5	5	5

SUMMARY.

The thesis represents a study of the relation of the chemical composition and the physical properties of glacial soils to the age of the drift upon which they have been developed. The site chosen was Rice County, Minnesota, part of which is occupied by the latest drift, the Late Wisconsin, and the remainder by the earliest glaciation exposed in Minnesota, the Kansan. The two drifts were derived from practically the same sources and both were originally highly calcareous from the surface downward. For this county detailed glacial and soil surveys were available and the southern tip of the deciduous forest, the Big Woods of Minnesota, extended into it on both sides of the dividing line between the two drift sheets.

Ten virgin fields, or tracts, on each of three types, the loam and the silt loam of the Carrington series and the silt loam of the Fargo series, were samples, the three types representing, respectively, forest, upland grassland and lowland grassland. In the case of each type, five of the fields were on the Late Wisconsin and five on the Kansan.

The Fargo silt loam has developed under such poor natural drainage conditions that on many of the fields of this type there is little or no leaching to be expected, but all the fields on the other types are so situated as to have been fully exposed to the leaching effect of the portion of the precipitation passing from the surface into the deeper subsoil.

The samples were taken to a depth of three feet, and these in four sections, the first six inches, the second six inches, the second foot, and the third foot. In each field two sets of samples were taken being composites from ten borings, and these two sets being combined formed the field samples. Complete analysis were made of the composites of the corresponding sections from the five fields of the same type and on the same drift, determinations of phosphoric acid and carbon dioxide on all field samples and of moisture equivalent, proportion of coarser rock fragments, nitrogen, color and reaction by various methods on all the set samples.

Five fields on a fourth soil type, Marshall silt loam, developed only upon the loess overlying the Kansan till, were included in the study and treated similarly in so far as part of the analyses, etc., are concerned. Three of these were still in virgin forest and two were remnants of the original prairie.

The texture of the fine earth of each type, expressed as the moisture equivalent, is very similar on both drifts, but the proportion of coarser fragments is higher in the soils on the Kansan than in those on the Late Wisconsin. On the older formation, the original fragments of the softer rocks (limestones, shales, and cherts), have almost entirely given way to the processes of weathering throughout a depth greater than three feet.

A general relation was found to exist between the carcareousness and the texture, the finest textured soils retaining the most carbonate and the coarsest the least.

With the two members of the Carrington series the degree of acidity, as indicated by three different methods, the litmus, the Truog and the ammonia, is the more pronounced on the Kansan. With the loam the carbon dioxide content is alike on both drifts, carbonates having been removed to a depth in excess of three feet, but with the silt loam, while the leaching has been as extensive on the Kansan, considerable amounts of carbonate still remain in the third foot on the Late Wisconsin. On the fields of Fargo type little appears to have been removed in the case of either drift, the reaction being less frequently acid on the Kansan than on the younger drift.

The comparison of the indications of acidity obtained by the different methods for the individual samples shows a very close agreement between the litmus and Truog methods, but the degree of acidity which is shown by only the latter of the two does not agree closely with the results obtained by the ammonium method.

The total lime on the two types is fairly uniformly distributed on both drifts but in the third foot of the Carrington silt loam, it is more than 100 per cent the higher on the younger formation. On the Kansan both of the Carrington series have lost the more readily soluble lime compounds to a depth of more than three feet, while on the Late Wisconsin, the silt loam still retains a considerable amount in the third foot, but with the loam the leaching has been as extensive as on the Kansan. The poorly drained condition of the Fargo silt loam has prevented any serious leaching.

The lime other than that in the form of carbonate is similar both in amount and distribution on the two Carrington types, but in the first two feet in the Fargo silt loam, is considerable higher on the Kansan.

The magnesia for each type is very similar from drift to drift, but is considerably higher in the Fargo silt loam than in the other types.

The ratio of total lime to magnesia is slightly higher on the Late Wisconsin, this being due to the greater amount of calcium carbonate on the two of the types on the latter. The ratio of lime in the form of silicate to magnesia is very similar for each type from drift to drift, except with the Fargo silt loam where it is the lower on the younger formation.

The phosphoric acid is the higher on the Kansan, this being true for each of the three types. The amounts were determined in all ten fields on each type and with every type the individual fields on the Kansan showed an amount higher or practically equal to that in the field on the Late Wisconsin showing the highest content. On the two prairie types this constituent shows a decrease from the surface downward, while with the forest type the vertical distribution is irregular.

Both potash and soda are very similar in corresponding sections from the two drifts except that in the Carrington loam on the later glaciation the potash is slightly the higher and the soda distinctly the lower.

In volatile matter the corresponding sections from the two drifts are very similar except that the Fargo silt loam in the surface six-inch section shows nearly twice as much on the Kansan, an apparently anomalous condition which really can be explained by the difference in age of the two drifts.

The nitrogen in both amount and distribution is very similar on both drifts, with each of the two Carrington types, but with the Fargo silt loam in the first two sections it is the higher on the Kansan, in this resembling the volatile matter. The forested fields show lower percentages than those on the grassland.

In relative darkness of color, there is no difference between the drifts in the case of any soil type except in the surface six-inch section on the Carrington loam and the two and three foot sections on the Fargo silt loam, with these the soil on the Late Wisconsin being somewhat the darker colored.

In general the first three feet of soil on the well-drained areas, originally similar in topography and profile and later covered by the same type of vegetation, are surprisingly alike on the two drifts, which would suggest that the age of the most recent glaciation is so great as to have permitted the uniformity in climate and in vegetative cover, which has prevailed on the two sides of the dividing line in Rice County, to almost completely mask the effects of the great difference in age. Moreover, it appears probable that the previously reported marked differences in composition between the soil on the Kansan and the Des Moines Lobe of the Late Wisconsin are to be attributed to the effects of the differences in climate and vegetation that appear when we employ data from large sections extending far to the east and to the west, respectively, of the contact line of the surface exposures of the two glacial sheets. It is also probable that the differences within the area of any one glaciation which have been induced by differences in precipitation and vegetation may be found to far exceed those attributable only to differences in the age of glaciation.

LITERATURE CITED.

(1) Alway, F. J. and Blish, M. J.
1916. The loess soils of the Nebraska portion of the transition region: II. Humus, humus-nitrogen and color. In Soil Sci. v. 1, no. 3, p.239-258, 4 fig.

(2) Alway, F. J. and McDole, G. R.
1916. The loess soils of the Nebraska portion of the transition region: I. Hygroscopicity, nitrogen, and organic carbon. In Soil Sci., v. 1, no. 3, p. 197-238, 2 fig., 3 pl.

(3) Alway, F. J. and Rost, C. O.
1916. The vertical distribution of phosphorus in the surface soil of prairies. In Soil Sci., v. 2, no. 5, p. 493-497.

(4) Alway, F. J. and Rost, C. O.
1916. The loess soils of the Nebraska portion of the transition region: IV. Mechanical composition and inorganic constituents. In Soil Sci., v. 1, no. 5, p. 405-436, 2 fig.

(5) Alway, F. J. and Russel, J. C.
1916. Use of the moisture equivalent for the indirect determination of the hygroscopic coefficient. In Jour. Agr. Research, v. 6, no. 22, p.833-846.

(6) Briggs, L. J. and McLane, J. W.
1907. The moisture equivalents of soils. U. S. Dept. Agr. Bur. Soils Bul.45, 23 p., 1 fig., 1 pl.

(7) Briggs, L. J. and McLane, J. W.
1910. Moisture equivalent determinations and their application. In Proc. Amer. Soc. Agron., v. 2, p. 138-147, 6 pl.

(8) Briggs, L. J. and Shantz, H. L.
1912. The wilting coefficient for different plants and its indirect determination. U. S. Dept. Agr. Bur. Plant Indus. Bul. 230, 83 p., 9 fig., 2 pl.

(9) Brown, P. E.
1914. The fertility in Iowa soils. Iowa Agr. Exp. Sta. Bul. 150, p. 151.

(10) Buchanan, H.
1807. Journey from Madras through Mysore, Canara, and Malabar. Vol. II.

(11) Burke, R. T. A. and Kolbe, L. A.
1911. Soil survey of Rice county, Minnesota. Advance sheets from field operations, 1909, 39 p., 1 Fig., 1 map.

(12) Bureau of Soils.
1913. Soils of the United States. U. S. Dept. Agr. Bur. Soils Bul. 96, p. 791, 13 fig., 2 pl.

(13) Chamberlin, T. C. and Salisbury, R. D.
1907. Geology. Vol. III. 624 p. 576 figs. Holt & Co. New York.

(14) Dokutschajew, V. V.
1883. Russian chernozem. St. Petersburg.

(15) Glikka, K.
1915. Pedologie (Russ) Petrograd.

(16) Glinka, K.
1914. Die typen der Bodenbildungen. p. 358, 65 fig., map. Berlin.

(17) Hilgard, E. W.
1892. A report on the relation of soils to climate. U. S. Dept. Agr. Weather Bur. Bul. 3.

(18) Hilgard, E. W.
1895. Origin, value, and reclamation of alkali lands. In yearbook of U. S. Dppt. Agr. p. 103.

(19) Hillebrand, W. F.
1910. The analysis of silicate and carbonate rocks. U. S. Geol. Survey Bul. 422, 239 p., 27 fig.

(20) Hopkins, C. G. and Pettit J. H.
1908. The fertility in Illinois soils. Ill. Agr. Exp. Sta. Bul. 123, p. 187-294, 8 pl.

(21) Kossowitsch, P.
1912. Die Swartzerde (Tschernosiom). In Internat. Mitt. Bodenk. Bd. 1, p. 199-354.

(22) Leverett, Frank
1910. Comparison of North American and European glacial deposits. In Zeitschrift für Gletscherkunde. v. 14, p. 241-316, 5 fig. 5 maps.

(23) Leverett, Frank and Sardeson, F. W.
1917. Surface formations and agricultural conditions of northeastern Minnesota. Minnesota Geological Survey Bul. 13, p. 72, 15 fig. 15 pl.

(24) Loew, Oscar.
1901. The relation of lime and magnesia to plant growth.
I. Liming of soils from a physiological standpoint. In U. S. Dept. Agr. Bur. Plant Indus. Bul. 1, p. 1 - 35.

(25) McMiller, P. R.
1915. A study of the glacial and loessial soils of the most southerly tier of counties in Minnesota. Thesis, University of Minnesota.

(26) May, D. W.
1901. The relation of lime and magnesia to plant growth.
II. Experimental study of the relation of lime and magnesia to plant growth. In U. S. Dept. Agr. Bur. Plant Indus. Bul. 1, p. 37-53, 3 pl.

(27) Ramann, E.
1911. Bodenkunde, ed. 3, p. 619, 63 fig.

(28) Rost, Clayton O.
1917. The determination of soil phosphorus. In Soil Sci., v. 4, no. 4, p. 295-311.

(29) Smith, J. Lawrence.
1871. On the determination of the alkalies in silicates ignited with carbonate of lime and sal ammoniac. In Am. Jour. Sci., 2nd ser., vol. 50, p. 269.

(30) Truog, E.
1915. A new test for soil acidity. Wisconsin Agr. Exp. Sta. Bul. 294, 15 p., 3 fig., 1 ch.

(31) Warth, F. J.
1903. The composition of Indian laterite. In Geological Magazine, v. 4, no. 10, p. 154-159.

(32) Washington, H. S.
1910. Manual of Chemical analysis of rocks. Ed. 2, 200 p. New York.

(33) Wheeler, H. J., Hartwell, B. L. and Sargent, C. L.
1899. Chemical methods for ascertaining the lime requirement of soils. Rhode Island Agr. Exp. Sta. Bul. 62.