MINNESOTA PEAT SOILS.

A Thesis Submitted to the Faculty of the
Graduate School of the
University of Minnesota

by

De Forest Hungerford

In partial fulfillment of the requirements for
the degree of Master of Science.

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REPORT

of

COMMITTEE ON THESIS

THE undersigned, acting as a committee of the Graduate School, have read the accompanying thesis submitted by Mr. De Forest Hungerford for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

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PREFACE.

The work, the results of which are embodied in this thesis, was begun in 1910 at the suggestion of Professor Ralph Hoagland, formerly Chief of the Division of Agricultural Chemistry and Soils and has since been continued at intervals, by the writer, as his time has permitted.

The writer is indebted to Mr. George W. Walker for the determination of potash in six samples; to Mr. P. R. McMillar for determining the potash in ten samples, and to Miss Esther Rosen for assistance with the analysis of the samples from Grand Rapids.

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INTRODUCTION.

The Definition of Peat. Various definitions have been made for peat and peat soil, all of which agree in stating that they contain a large amount of organic matter. There is lack of agreement, however, as to the lower limit of organic matter content and the distinction between peat and muck. The geological definition as given by Chamberlin and Salisbury[1] is as follows: "Peat is the dark brown residuum arising from the partial decomposition of mosses and vegetable tissue in marshes and wet places". J. A. Bonsteel[2] of the Bureau of Soils, U. S. Dept of Agri., describes peat as soil derived from vegetation in which the original form of the material is to some extent retained, whereas in muck a more advanced stage of disintegration has been reached. The Bureau of Soils does not classify as peat or muck any deposit of less than eight inches in depth. C. A. Davis,[3] the Peat Expert for the Bureau of Mines, U. S. Dept. of the Int., uses the term peat to include muck which he defines as: "the name given to dark colored, thoroughly decomposed peat in which there is a considerable mixture of mineral matter, but as this is very variable in quan-

tity, there is no sharp distinction to be made between peat and muck, as all peat contains some mineral matter which appears as ash when the peat is burned". It is this broad use of the term that is adopted in this theses, any soil containing a large amount of organic matter and more than eight inches in depth being called peat.

Institutions for the Investigation of Peat. The first Experiment Station[4] devoted to the study of peat soils was the Mooversuchstation, established by the German government at Bremen, in 1877. The second government Experiment Station to be established was the Königlich Bayerische Moorkulturanstalk, which maintains five experimental farms. Another government which has taken up the study of peat soils is that of Austriawhich in 1901 established a department for the study of the utilisation of peat soils, Abteilung für Moorkultur und Torfverwertung der K. K. lander Versuchs-station.

Investigational work is also carried on in different European countries under the supervision of peat societies which are subsidized by the governments. The oldest of these is the Verein zur Förderungder Moorkultur in Deutscher Reiche organized in 1883. The Svenska Mosskulturforeninger was founded in 1886 by Carl von Feilitzer, at Jönköping. It maintains chemical and botanical laboratories as well

as two experimental farms. Other European peat societies are the Danske Hedeselskab which took up the cultivation of peat bogs in 1888, the Deutsch-Oesterreichischer Moorverein, founded in 1900, the Finska Mosskulturföreningen, organized in 1895, the Norske Myrselskap organized in 1902, and the Baltischer Moorverein founded in 1910 at Dorpat, Russia.

The American Peat Society and the Canadian Peat Society have been organized to study the utilization of peat bogs for fuel and power, but as yet they have done nothing to further their Agricultural development.

Peat Soils of Germany. The German peat soils are classified by Tacke[5] Director of the Bremen Moorversuchstation, according to the vegetation from which they were formed and the amount of lime they contain. He states that in most cases, it is an easy matter to decide whether we have to do with a grass-peat, a so called "low moor", or with a moss peat, called a "high moor". As the result of numerous analyses of the Peat Experiment Station it has been shown that the former are richer in lime than the latter. For the upper limit of the amount of this constituent the moss peat 0.50 percent of the dry substance is accepted while the lower limit for the grass peat is

2.50 percent. Between these two distinct kinds are found numerous intermediate stages, and it is possible that in the same moor through the change of vegetation conditions, grass moor and moss moor strata, have originated in alternating layers. Between the moss moors and the grass moors are formations to which a great number of the south German moors, the most of the mountain moors as well as those of the Swedish provi nce, Smaland, belong, showing as a rule a much higher lime and nitrogen content as well as a far more decomposed state than the typical moss moors.

The average chemical composition of a large number of German peat soils, as quoted by Tacke[5] from a treatise by Dr. M. Fleischer, and recalculated to pounds per acre foot, is shown in table 1.

Table 1. COMPOSITION OF GERMAN PEAT SOILS IN POUNDS PER ACRE FOOT.

	N	K_2O	P_2O_5	CaO
Heath Humus	3.370	117	230	98
Moss turf	1.696	58	105	526
Grass moor	14.625	585	292	23,400
Transition moor	8.424	84	211	4,212

Peat Soils of Austria. A comparison of the peat soils of Austria with those of Germany is made by Bersch[6] who states : "Whilst in Germany moors frequently form enormous uninterupted tracts of waste largely state property, Austria possesses a large number of small extent, almost all of which either belong to private persons particularly needy small-holders, or are common land.....Our moors show no essential difference in chemical composition and botanical origin from those of other lands as has been shown by numerous investigations.....It is true that many of the Austrian moors on the primary rocks show a somewhat higher potash content, but the total amount is small and it occurs in a form soluable with extreme difficulty, so that - as with phosphoric acid - potash in the form of artificial fertilizer must be applied. As regards nitrogen content, our moors are in agreement with those of other countries. The true moss moors are generally very poor in this nutrient material and consequently always require nitrogen fertilizing, while the fens (low moors) are generally richer and contain the nitrogen in a more readily soluable form, so that they can frequently do without any addition of nitrogen. There are however exceptions: many fens, especially before the peat is much decomposed form such small quantities of

assimilable nitrogen, that their full cropping capacity cannot be reached; such fens at any rate in the first few years of cultivation, respond well to nitrogenous dressings."

Regarding the importance of lime in peat soils Bersch states: "One of the numerous differences between the fens and the moors is that the former are mostly rich in lime and decompose quickly after drainage, with its consequent aeration, and regular working, while the moors with their low lime content only slowly take on the crumb structure. The decomposition of moss peat is greatly helped by a single application of lime as quick lime, marl or carbonate of lime, provided this material is thoroughly mixed with the cultivable soil. Under north German conditions sufficient liming has been found to be 1800 pounds of quick lime or its equivalent in marl for arable land and 2700 to 3600 pounds for grass land per acre of moor; heavier dressings generally do damage to the crops. In the Alps and also in Bavaria, though such dressings have no harmful results, the same effect is produced by smaller amounts, about half, always provided the soil is very thoroughly worked.....The average yield of good artificial meadows on moor soil may according to all experience be set down as 56 cwt. of first class hay per acre but it frequently

reaches much higher figures, especially on fens (low moors) even 80 cwt. or more.....Thus while moor peat in its original condition gives practically no yields, it can be permenantly improved with normally small expenditurs, and the moor soil then forms the best and kindliest cultivated soil we possess.....Whilst, as far as climate allows almost any moor can be used as arable land yet the production of fodder is the most profitable use to which moor land can be put."

Peat Investigations in the United States. Fertilizer experiments[7] conducted by the Purdue Univ. Exp. Sta. indicate that most of the Indiana peat soils are in need of fertilization with potash fertilizers and in one trial phosphorous was the limiting element. Six experiments with corn, three of which were one year tests, two were two year tests and one extending over four years gave increased yields with potash on all except one field where a two year test gave a decided indication of the need for phosphorus. The analyses of three of the soils are given in table 2, number 3 being the soil which responded to phosphorus fertilizer.

TABLE 2. INDIANA PEAT SOILS.

		Soil No. 1.	Soil No. 2.	Soil No. 3.
Volatile Matter,	%	83.16	84.55	81.16
Total Nitrogen,	%	3.82	3.76	3.51
Phosphoric Acid,	%	0.36	0.29	0.40
Lime,	%	1.86	2.02	3.89
Total Potash,	%	0.34	0.20	0.26
Lime Requirement,	lbs.	1940	2200	360

Illinois Peat. The analysis of a sample of Illinois deep peat[8] gives as follows the pounds of plant food in one million pounds of soil, which is stated to be the weight of an acre to the depth of seven inches: Total nitrogen, 34,880, total phosphorus 2940, total potassium 2930, "limestone rarely required."[9] Fertilizer tests with corn on the deep peat of Tampico Field during 1902-3 and 4, showed a decided increase when potash was applied, nothing being produced on any but the potash treated plots. An experiment conducted on the Momence Field since 1902, in which thirty plots were used showed that potassium was the limiting element and could be used with profit although this was less during the last four years than during the first four of its use. Nitrogen and phosphorus have also shown beneficial effects especially during the last years and the latter in the form of bone meal is used at a profit.

Pennsylvania Peat Soils. No very extensive beds of peat are found in Pennsylvania[10] but there are deposits from a few square rods to many acres. The soil tends to be acid, has a great water holding capacity (sometimes thirteen times its dry weight) is cold, lacks aeration, and is defficient in nitrifying bacteria and mineral plant food. Table 3 gives the composition of some Pennsylvania peat soils.

Table 3. COMPOSITION OF PENNSYLVANIA PEAT SOILS.

Soil No.	Volatile Matter	Ash %	Nitrogen %	Potash %	Phosphoric Acid,%	Lime %
1.	75.57	24.43	3.42	0.74	0.89	5.67
2.	77.76	22.24	3.17	0.61	0.47	10.01
3.	68.26	31.74	2.52	0.67	0.58	11.62
4.	38.30	61.70	0.67	0.79	0.67	1.19
5.	62.02	37.98	1.30	1.30	0.51	0.95
6.	28.42	71.58	0.69	1.59	0.67	0.87
7.*	4.46	95.54	0.12	1.96	0.24	0.88
8.	32.56	67.44	1.00	0.66	0.56	3.56
9.	76.38	23.62	2.40	1.18	0.34	5.17
10.	85.33	14.67	2.54	0.25	0.40	5.68
11.	63.61	36.39	1.60	0.61	0.35	4.68
12.	70.20	29.80	1.02	0.40	0.10	2.85
13.	94.69	5.31	1.30	0.05	0.19	----

* Sample No. 7 contains such a low percentage of volatile matter that it would not be considered peat, but is so classed by the author quoted.

Wisconsin Peat Soils. There are areas of peat soil in this state but in the publications of the Wisconsin Agr. Exp. Sta. a sharp distinction is not made between peat and marsh soils, which would include any poorly drained land. Fertilizer tests[11] have been conducted on marsh soils some of which are called peat or peaty marsh and these indicated that fertilizers were needed.

Objects and Scope, of this Investigation. The objects of this study were (a) to determine the general chemical composition of Minnesota peat soils as related to the important elements of plant food; (b) to determine from field observations their productivity without fertilizers, and the effects of different fertilizers and soil amendments.

The chemical analyses included determinations of volatile matter, ash, lime, phosphoric acid, potash, and nitrogen in 32 samples, and determinations of only volatile matter, ash, and lime in 16 other samples. The 48 samples were collected from various parts of the state, fifteen counties and 22 localities being represented. While every important peat bog had not been sampled and some counties containing large areas of peat, for example Carlton and Pine, are not represented, the samples analyzed are so well distributed over the State that a general idea of the composition of Minnesota peat soils may be obtained

from them.

Cooperative fertilizer experiments were conducted in a number of places, to determine the plant food requirements of peat soils. On the whole the fertilizer tests were unsatisfactory. Much difficulty was met in getting the farmers to harvest the crops separately and report the yields, they assigning as a reason unfavorable weather conditions and poor drainage.

INVESTIGATION OF MINNESOTA PEAT SOILS.

Distribution of Peat in Minnesota. The peat soils of Minnesota are distributed quite generally over the State. Few if any of the counties are entirely free from deposits of one sort or another, but the most extensive areas are found in the region north and northwest of Red Lake including the northern part of Beltrami County, eastern Marshall County and parts of both eastern and western Roseau County. Somewhat smaller areas are found in southwestern St. Louis County, and eastern Aitkin County.

Minnesota peat soils are of two general types - moss peat and grass peat. The former is commonly called "muskeg" and is usually but not always timbered. The latter is called "meadow" because it is

always covered with grass even in timbered regions. The muskegs correspond in a general way to the "high bogs" or "high moors" of European countries, while the grass peat soils are similar to the fens of England and the low moors of continental Europe.

Where trees occur in Minnesota peat bogs they usually consist of tamarack and spruce. Cedar (arbor vitae) and balsam fir are sometimes but less frequently found. Elm and black ash which are reported by Davis[12] as growing on the peat soils of Michigan, occur but seldom or not at all on such soils in Minnesota. Often the trees occur in dense thickets, through which it is difficult for one to make his way, while in other cases there are only a few scattered here and there. It is possible that in a region of comparatively few trees fires have passed over and destroyed them. Figure 2 shows a dense growth of spruce on peat soil. Under such conditions the trees seldom attain any very great size, the largest seen by the writer being only six or eight inches in diameter. Figure 3 shows an area that was burned over several years ago, practically all the trees being killed. Under such conditions Labrador teavery frequently comes in and the sphagnum moss, having a better chance, grows more luxuriantly.

Description of Samples. Sample 1 was taken two miles north of Kimberly in Aitkin County near where the road crosses a State ditch, in an uncleared tamarack swamp. The surface four inches consists of a thick mat of sphagnum moss. Below the moss the peat is well decomposed but contains many roots. It is 27 inches in depth and beneath it is found a very plastic blue clay. The water table was one foot from the surface. The sample was taken to the depth of one foot after the moss had been removed.

Sample 2was taken near Skibo Junction in St. Louis County in township 58, range 13. This is an uncleared and undrained spruce and tamarack swamp with an undergrowth of sphagum moss forming a layer about four inches deep. Underneath the moss the soil is dark brown, well decomposed peat six feet in depth. No subsoil could be found, the peat apparently resting upon a mass of boulders. In sampling the moss was removed and the sample then taken to the depth of one foot.

Sample 3 and 4 were taken from the Island Farm, at Island in St. Louis County, on the northwest quarter of section 22, township 52, range 21. The Island Farm is located about in the center of the swampy district mentioned above. The sample was taken from an experimental field of seven acres. The peat has a dark brown color

and appears to have been formed chiefly from sphagnum moss. In the field sampled it is five feet deep in the deepest place and three and a half feet in the shallowest spot. Under the peat the subsoil is a sandy clay carrying concretions of yellow iron oxide. Southwest of this field the peat was found to be nine feet deep and it was reported to be fifteen feet in places. The native vegetation is tamarack and sphagnum moss. In some of the open places wire grass is found. The sample was taken to a depth of one foot. Sample 5 was also taken from the same farm but was sent in by Mr. John H. Black, manager of the Island Farm.

Samples 6 to 12 inclusive, were taken from the Demonstration farm of the Duluth & Iron Range railroad at Meadowlands in St. Louis County. The field had been cleared of trees and moss, tile drained, broken up, and used for experimental purposes by the land department of the railroad in cooperation with the Minnesota Experiment Station. This bog is also in the same swampy district as Island and Wallace. The soil was formed chiefly from sphagnum moss and decayed wood. After the moss was removed, the peat was from 18 to 30 inches deep where the samples were taken. Below the peat the subsoil is very plastic, drab-colored clay. Sample 6 was sent in by the manager of the farm and was taken

from near the center of the field. He reported the peat to be four and a half feet at that place. Samples 9, 10, 11 and12 were taken from a series of 1/20 acre fertilizer plots. Samples 7 and 8 were taken from a series of plots belonging to the Agricultural Division. Sample 7 has received lime and complete fertilizer while 8 was untreated.

Sample 13 was taken seven miles northwest of Kelliher in Beltrami County, from section 9, township 152, range 30. The peat was formed from sphagnum moss and decayed wood. It has a very dark brown color, much darker than that found near Bemidji. The vegetation is a mixture of cedar (arbor vitae) and balsam fir, with sphagnum moss underneath. The peat is eighteen inches to two feet in depth and underlying it is a sandy clay.

Sample 14 was taken half a mile from sample 13. The only difference to be observed is that the vegetation consists chiefly of tamarack and sphagnum moss and that the peat is from three to four feet in depth.

Samples 15 to 25 inclusive were taken from the Grand Rapids Experiment Farm. The peat was six feet deep where samples 15 to 21 were obtained and two feet deep where samples 22 to 25 were taken. The sketch on page 55 shows the location of the test pits.

Sample 26 was taken from near Gun Lake about six miles north of Kimberly in Aitkin County on the southwest quarter of section 11, township 48, range 25. The vegetation is chiefly wire grass. The first three feet of soil is a light brown fibrous peat. Underneath the peat the sub-soil consists of a blue clay very similar to that found under the Kimberly swamp. The peat was six feet deep and the sample was taken to a depth of twelve inches.

Sample 27 was taken near the R. R. station at Wallace in St. Louis County, from the southeast quarter of section 34, township 35, range 18. The bog from which the sample was taken is part of a swampy district covering about 26 townships, the approximate boundaries of which are townships 56 on the north and 51 on the south, range 16 on the east and 22 on the west. The Whiteface, St. Louis and Floodwood rivers flow through the area but owing to the flat topography the natural drainage is poor, resulting in the formation of large areas of peat. At Wallace the peat is nine feet deep. Beneath the peat is a heavy blue clay. The vegetation is chiefly wire grass, but there are a few small spruce trees from six to ten feet high. About half a mile west of the station the peat is from 12 to 18 inches in depth and tamarack and spruce are abundant.

Sample 28 was taken from the farm of W. G. Schroeder four miles west of Bemidji in Beltrami county. The peat occurs in a depression about thirty acres in extent which evidently was at one time a shallow lake. In the center the peat is five feet deep. It was formed from grass stems and roots, is brown in color, and was not difficult to break up and seed to grass. The native vegetation at present is wire grass, but it is stated that until a few years ago it grew excellent crops of red top. The sub soil below the peat is clay, almost white near the edges but blue or drab in the center.

Sample 29 was taken eight and a half miles northwest of Bemidji in Beltrami County from the northeast quarter of section 13, township 147, range 34. The exact size of this swamp could not be learned, but it has an irregular outline and extends for several miles to the west and south with occasional patches of open water. The peat is of grass formation and has a color and texture similar to that of sample 28. The depth varies considerably but the deepest at the place sampled is five feet. Below the peat is sandmixed with organic matter and very little silt. The native vegetation is wire grass.

Sample 30 was taken about three miles southwest of Bemidji from the farm of Henry Bachle on the southeast quarter of the northwest

quarter of section 24, township 146, range 34. The peat occurs in a depression about forty acres in extent and is very similar to that found on Mr. Schroeder's farm. The general appearance is shown by figure 16. The depth of the peat and the character of the underlying subsoil were not determined.

Sample 31 was taken seven miles east of Middle River in Marshall County on sections 13 and 14, township 157, range 42. This region is part of the large swampy district in eastern Marshall County, not all of which is covered with peat, but a large portion of the country has from a few inches to three feet of peat. At the place sampled the peat was two feet deep and the subsoil underneath was clay. The native vegetation is wire grass and red top. The sample was taken to a depth of one foot.

Sample 32 was sent in by W. H. Frederick, of the Thief River Land Co. No information was sent with the sample except that it is Marshall County soil.

Sample 33 was taken two miles northwest of Greenbush near a large drainage ditch. The exact location could not be learned. The soil and vegetation are very similar to thatat Middle River. The sample was taken to the depth of one foot which is the depth of the peat at the

place sampled. The subsoil under the peatis clay.

Sample 34 is from fifteen miles northeast of Bronson, Kittson County, on the northwest quarter of section 18, township 162, range 45. The only diference to be seen between this region and that at Middle River and Greenbush is the presence of boulders in the subsoil under the peat. In some places the boulders are very abundant.

Sample 35.was taken near Lowry, Pope County, from the southeast quarter of section 24, township 126, range 39. The area consists of an old lake bed covering about fifty acres. The peat is from two to two and one-half feet deep, almost black in color, thoroughly decomposed and works up mellow when plowed. A great many small shells are mixed with the peat. The field was drained with an open ditch in 1906, after which it was possible to cut the native grass for hay. In 1911 a part was plowed and seeded to flax which yielded thirteen bushels per acre. Another part was manured and seeded to barley and oats. The barley yielded sixty bushels per acre and the oats forty bushels. In 1912 the clover that had been seeded with the oats and barley produced two tons of hay to the acre.

Sample 36 was taken on the south side of the Minnesota River, about three miles aboveMendota, Dakota County. The soil is very dark

brown in color, is well decomposed and when broken works up very quickly into good condition. Small shells are abundant and during dry seasons a white incrustation of calcium carbonate forms on the surface. Where the sample was taken the peat is five feet deep. Underneath the peat there is a layer of sand and gravel and below that, solid rock, said to be limestone by the owner of the land.

Sample 37 was obtained on the farm of John Crowe, near Dassel, Meeker County. The bog covered 22 acres of peat on this farm, occurring in an old lake bed. The peat is dark brown in color, well decomposed and formed chiefly from grass. It is ten feet deep at the place sampled and under the peat the subsoil is fine sand. The field was plowed in the fall of 1910, yielding 11 bushels of flax per acre in 1911, and 14 in 1912. Part of the field in the latter year gave a yield of corn, which however, was not measured.

Sample 38 was sent in by George W. Leasman, Hector, Renville County. The bog covers ten acres and had been tile drained. It was broken in 1910 and seeded to flax. The owner states that the flax did well but grasshoppers caused a low yield. In 1911 corn was planted but this was ruined by an early frost.

Sample 39 was taken from the farm of J. M. Turner, St. Peter,

Nicollet County. The bog covers about ten acres that is not perceptibly lower than the surrounding soil. It is about three and one-half feet deep, dark brown in color and works up mellow when plowed. Clay is found underneath the peat. The peat was formed from grass and is mixed with sediment.

Sample 40 was taken from the farm of E. C. Gale, St. Bonifacius, Hennepin County. The peat is brown in color, formed from grass and three feet deep where the sample was taken. The subsoil under the peat is sandy clay.

Samples 41 and 42 were sent in by the owner of the land from Stacy, Minnesota. The land is drained with open ditches. The original vegetation was wire grass.

Sample 43 was taken eight and a half miles northeast of Laporte in Hubbard County, from the north half of the southwest quarter of section 4, township 144, range 32. The peat is only about twelve inches deep and seems to be a mixture of decayed grass and other vegetable matter and sediment deposited by a near-by stream. The soil has a very dark brown color and is well decomposed. Under the peat is a layer of clay about three inches thick and beneath this is pure sand.

Samples 44 to 48 inclusive were taken by Mr. G. R. McDole from an area mapped as peat by the U. S. Bureau of Soils.(13) No. 44 was taken from near the center of section 13, No. 45 from the southeast corner of section 16, and number 46 from the southwest corner of section 17. The peat varies in depth from six inches to twenty - two inches and is covered in some places with two or three inches of sediment.

Fig. 1. Map Showing Location of Samples.

Table 4. LOCATIONS AND DESCRIPTION OF SAMPLES.

Reference No.	Lab. No.	County	Nearest Railroad Station	Sec.	Twp.	Range	Depth of Peat Ft.	Vegetation	Drainage	Years Cultivated
			Muskeg Peat.							
1	350	Aitkin	Kimberly				27	Tamarack & Moss	Ditch	Virgin
2	354	St.Louis	Skibo		58	13	6	"	None	"
3	359	" "	Island	22	52	21	(3½to	"		Several
4	506	" "	"	22	52	21	(5	"	Ditch	"
5	391	" "	"		52	21		"	"	Virgin
6	392	" "	Meadowlands	-	-	-	4½	"	Tile	Two
7	486	" "	"	"	"	"	(	"	"	"
8	487	" "	"	"	"	"	(2	"	"	"
9	495	" "	"	"	"	"	(to	"	"	"
10	496	" "	"	"	"	"	(2½	"	"	"
11	498	" "	"	"	"	"	(	"	"	"
12	500	" "	"	"	"	"	(	"	"	"
13	369	Beltrami	Kelliher	9	152	30	2	Cedar	Ditch	Virgin
14	371	"	"	"	"	"	4	Tamarack	"	"
15	1	Itasca	Grand Rapids	15	25	55	6)		Tile	"
16	2	"	" "	"	"	"	")	Tamarack	"	"
17	3	"	" "	"	"	"	")	Spruce	"	"
18	4	"	" "	"	"	"	")	and	"	"
19	5	"	" "	"	"	"	")	Moss	"	"
20	6	"	" "	"	"	"	")		"	"
21	7	"	" "	"	"	"	")		"	"
22	8	"	" "	"	"	"	")		"	"
23	9	"	" "	"	"	"	")		"	"
24	10	"	" "	"	"	"	")		"	"
25	11	"	" "	"	"	"	")		"	"
			Grass Peat.							
26	352	Aitkin	Kimberly	11	48	25	6	Grass	Ditch	Virgin
27	357	St.Louis	Wallace	38	35	18	9	"	"	"
28	365	Beltrami	Bemidji	-	146	34	5	"	"	Three
29	367	"	"	13	147	34	5	"	"	Virgin
30	479	"	"	24	146	34	-	"	"	"
31	380	Marshall	Middle River	(13 (14	157	42	2	"	"	"
32	507	"		-	-	-	-	"	-	One
33	382	Roseau	Greenbush	-	-	-	1	"	"	Virgin
34	384	Kittson	Bronson	18	162	45	2	"	"	"
35	478	Pope	Lowry	24	126	39	2½	"	"	Three
36	477	Dakota	Mendota	-	-	-	5	"	Tile	Several
37	481	Meeker	Dassel	-	-	-	10	"	"	Four
38	501	Renville	Hector	-	-	-	-	"	"	"
39	511	Nicollet	St. Peter	-	-	-	3½	"	"	Several
40	390	Hennepin	St.Bonifacius	-	-	-	3	"	Ditch	Virgin
41	483	Anoka	Stacy	-	-	-	-	-	"	Two
42	484	"	"	-	-	-	-	-	"	"
43	362	Hubbard	Laporte	4	144	32	3 in to 1 ft.	"	"	Virgin
44	12	Polk	Beltrami	13	147	47	1	"	-	-
45	13	"	"	15	"	"	1½	"	-	-
46	14	"	"	15	"	"	2	"	-	-
47	15	"	"	16	"	"	3/4	"	-	-
48	16	"	"	17	"	"	½	"	-	-

Method of Sampling. Most of the samples analyzed were collected by the writer. Others were taken according to the writer's directions by farmers living upon the land. Nearly all were taken to the depth of one foot. Each is a composite of three or more individual samples from different places in the bog. A section about a foot square was dug out with a spade, broken up and mixed by hand on a piece of canvass, about five pounds being taken to another part of the field where another five pound sample was obtained in the same manner. This was repeated as often as was thought to be necessary--usually three times. A composite was then made by mixing the individual samples, 10 to 15 pounds of the moist soil being placed in a sack and shipped by express to the University Farm.

Different methods of sampling were followed at Meadowlands and at Grand Rapids. At Meadowlands a single sample was taken from each of seven 1/20 acre plots to the depth of ten inches. As the moss had been removed previously the soil was smapled to the depth of ten inches instead of one foot. At Grand Rapids, where it was considered desirable to learn the variation in the composition of the soil at different depths, six pits were dug. Each was about three feet deep. Samples were taken in three inch sections and in the others in six

inch sections. Samples for the determination of the weight per cubic foot were also taken from these pits. For this purpose a cube exactly twelve inches each way was cut from the top of one side of the pit. Figure24 shows one of the pits and the method of obtaining the cubic foot sections.

The Field Weight of Peat Soils. Since peat soils are composed chiefly of vegetable matter, they have much lower specific gravity thanmineral soils, and this fact should be borne in mind when comparisons are being made between their plant food content. The usual manner of expressing the chemical composition of soils is in percent of dry matter, but peat soils, being only one-eighth to one-seventh as heavy as mineral soils, would contain a great deal less plant food in an acre foot than a mineral soil, having the same chemical composition.

Field weight determinations in duplicate were made by the method described above, at four places on the 12 acre muskeg at Grand Rapids, the results of which are shown in table. 5.

TABLE 5. FIELD WEIGHT OF PEAT SOIL AT GRAND RAPIDS, MINN.

Pit No.	Sample No.	Weight per cu.ft. lbs.	Weight per A. ft. tons aver.	Apparent sp.gr. average
1	a	8.78	213	.15+
	b	10.78		
2	c	8.79	200	.15-
	d	9.66		
3	e	9.85	215	.15+
	f	9.88		
4	g	12.28	257	.19-
	h	11.27		
Average		10.16	221	.16

The Chemical Composition of the Samples. To prepare the samples for analysis, they were dried in shallow pans in an oven at 70 to 75° C for about a week, ground in a power mill, quartered and passed through a 1 mm. sieve. It was usually necessary to pulverize a part of the soil with a mortar and pestle in order to get it to pass through the sieve. In those instances where the sample contained considerable quantities of large roots, sticks, or fresh blades of grass, these were removed before the sample was ground.

Method of Analysis. The volatile matter and ash were determined by igniting 5 gms. of air dry peat in a porcelain dish, first over a very low flame until volatile material ceased to be evolved, then in a Hoskins electric muffle to dull red heat until all carbonaceous matter was destroyed. It usually required about forty-five minutes to insure complete incineration. The percentages of ash, volatile matter, and all other constituents were calculated on the basis of water-free soil. In the case of soils from Grand Rapids and Beltrami, a few slight modifications were introduced, platinum dishes being used instead of porcelain . They were placed in the muffle without previous ignition over a low gas flame. For the determination of lime the ash was digested in a small covered porcelain dish on a steam bath,

for four hours, with 30 cc. of concentrated hydrochloric acid and two or three cc. of concentrated nitric acid. At the end of that time more acid was added if all had evaporated, the solution boiled a few minutes, evaporated to dryness on a steam bath, the soluble portion taken up with a little hot water and one or two cc. of concentrated hydrochloric acid, transferred to 250 cc. flask, cooled to room temperature and made up to volume, allowed to stand over night and freed from silica by filtration. Lime was determined in eight of the samples by the gravimetric method adopted by the Association of Official Agricultural Chemists[14], using 100 cc. portions of the solution. In the other samples lime was determined by the volumetric method, treating with potassium permanganate.

Phosphorus was determined in sixteen of the samples by the gravimetric method of the A.O.A.C.[15] using a separate portion of the solution prepared as above described. In the case of the other samples I used a volumetric method, the ammonium phospho-molybdate precipitate being dissolved with a measured quantity of standard potassium hydroxide and the excess determined by titration against standard nitric acid.

Nitrogen was determined in a two gram portion by the ordinary Kjeldahl method.

The acidity was determined by the Hopkins method. Fifty grams of the soil were shaken for three hours with 250 cc. normal potassium nitrate. After it had stood over night 125 cc. of the clear supernatant liquid was drawn off, boiled ten minutes to remove carbon dioxide, cooled, titrated with standard sodium hydroxide, the acidity calculated and expressed in percent of calcium carbonate required by the soil. The result was multiplied by two and one-half since it has been found[16] that if the soil is treated with successive portions of potassium nitrate the total acidity is about two and one-half times the amount obtained by the first titration.

Fixed carbon was determined by igniting a sample in a closely covered platinum crucible as in the usual method [17] of coal analysis.

Table 6. CHEMICAL COMPOSITION OF MINNESOTA PEAT SOILS.

Reference No.	Nearest Railroad Station.	Depth of Peat	Ash %	Volatile Matter %	Total N %	P_2O_5 %	K_2O %	CaO %
			Muskeg Peat Soils.					
1	Kimberly	27 in.	10.43	89.57	2.115	.395	.128	2.53
2	Skibo	6 ft.	10.53	89.47	1.634	.145-	..165	1.41
3	Island	(3 ½ to	16.41	83.59	2.181	.301	.130	1.66
4	"	(5 ft.	14.86	85.14	2.250	.336	.113	2.45
5	"		12.22	87.78	2.07	.333	.086	0.72
6	Meadowlands	4½ ft.	8.28	91.72	1.75	.195	.101	0.91
7)	"		17.88	82.12	1.60	.343	.076	1.38
8)	"		9.80	90.20	1.54	.357	.072	0.84
9)	"	2 ft.	8.52	91.48	1.39	.223	.083	0.73
10)	"	to	9.06	90.94	1.68	.348	.074	0.86
11)	"	2½ ft.	10.66	89.34	1.54	.275	.084	0.84
12)	"		12.60	87.40	1.56	.267	.115	0.82
13	Kelliher	2 ft.	34.02	65.98	1.601	.274	.124	4.38
14	"	4 ft.	14.72	85.28	2.060	.329	.166	5.97
15	Grand Rapids	1" - 6"	7.16	92.84	-	-	-	0.38
16	" "	7" - 12"	8.51	91.49	-	-	-	0.37
17	" "	13" - 24"	5.40	94.60	-	-	-	0.38
18	" "	25" - 36"	4.82	95.18	-	-	-	0.41
19	" "	37" - 48"	4.93	95.07	-	-	-	0.27
20	" "	49" - 60"	17.42	82.58	-	-	-	0.35
21	" "	61" - 66"	28.64	71.36	-	-	-	0.25
22	" "	1" - 6"	13.36	86.64	-	-	-	0.80
23	" "	7" - 12"	10.70	89.30	-	-	-	0.80
24	" "	13" - 18"	9.65	90.35	-	-	-	0.80
	" "	19" - 24"	28.45	71.55	-	-	-	0.65
Average			13.16	86.84	1.784	.294	.108	1.237

Table 6 Cont. CHEMICAL COMPOSITION OF MINNESOTA PEAT SOILS.

Reference No.	Nearest Railroad Station.	Depth of Peat	Ash %	Volatile Matter %	Total N %	P_2O_5 %	K_2O %	CaO %
			Grass Peat.					
26	Kimberly	6 ft.	11.24	88.76	2.874	0.450	0.095	1.49
27	Wallace	9 ft.	14.10	85.90	2.274	0.217	0.082	1.74
28	Bemidji	4 ft.	10.40	89.60	2.860	0.290	0.079	2.52
29	"	5 ft.	6.78	93.22	2.820	0.270	0.105	2.38
30	"	-	9.97	90.03	2.790	0.273	0.139	2.93
31	Middle River	2 ft.	10.48	89.56	2.693	0.285	0.104	2.80
32	" "	-	29.07	70.93	-	0.349	0.094	7.06
33	Greenbush	1 ft.	15.91	84.09	2.901	0.369	0.103	2.66
34	Bronson	1½ ft.	13.03	86.97	2.312	0.332	0.087	3.23
35	Lowry	2½ ft.	43.83	56.17	2.060	0.302	0.079	2.17
36	Mendota	5 ft.	23.96	76.04	2.530	0.378	0.118	14.36
37	Dassel	10 ft.	14.48	85.52	-	0.295	0.096	1.92
38	Hector	-	41.23	58.77	1.860	0.318	0.234	1.03
39	St. Peter	3½ ft.	43.08	56.92	-	0.266	0.326	3.10
40	St. Bonifacius	3 ft.	17.73	82.27	2.755	0.323	0.071	2.17
41	Stacy	-	26.99	73.01	2.770	0.370	0.077	2.55
42	"	-	29.56	70.34	2.740	0.310	0.094	1.85
43	Laporte	3/4ft.	52.45	47.55	2.295	0.557	0.076	1.43
44	Beltrami	1 ft.	53.22	46.78	-	-	-	3.36
45	"	1½ ft.	29.59	70.41	-	-	-	2.41
46	"	2 ft.	18.06	81.94	-	-	-	3.26
47	"	3/4 ft.	51.12	48.88	-	-	-	6.46
48	"	1/2 ft.	38.35	61.65	-	-	-	4.28
Average			26.29	73.71	2.569	0.331	0.114	3.35

Table 7. CHEMICAL COMPOSITION OF MINNESOTA PEAT SOIL.

Reference No.	Nearest Railroad Station	Total N %	P_2O_5 %	K_2O %	CaO %
		Muskeg Peat			
1	Kimberly	10,575	1975	640	12,650
2	Skibo	8,170	725	825	7,050
3	Island	10,905	1505	650	8,300
4	"	11,250	1680	565	12,250
5	"	10,350	1665	430	3,600
6	Meadowlands	8,750	975	505	4,550
7	"	8,000	1715	380	6,900
8	"	7,700	1780	360	4,200
9	"	6,950	1115	415	3,650
10	"	8,400	1740	370	4,300
11	"	7,700	1375	420	4,200
12	"	7,800	1335	525	4,100
13	Kelliher	8,005	1370	620	21,900
14	"	10,300	1645	830	29,850
15	Grand Rapids	-	-	-	1,900
16	" "	-	-	-	1,850
Average		8,918	1471	538	8,203
		Grass Peat			
26	Kimberly	14370	2250	475	7,450
27	Wallace	11,370	1085	410	8,700
28	Bemidji	14,300	1450	395	12,600
29	"	14,100	1350	525	11,900
30	"	13,950	1365	695	14,650
31	Middle River	13,465	1425	520	14,000
32	" "	-	1745	470	35,300
33	Greenbush	14,505	1845	515	13,300
34	Bronson	11,560	1660	435	16,150
35	Lowry	10,300	1510	395	10,850
36	Mendota	12,650	1890	590	71,800
37	Dassel	-	1475	480	9,600
38	Hector	9,300	1590	1170	5,150
39	St. Peter	-	1330	1630	15,500
40	St. Bonifacius	13,775	1615	355	10,850
41	Stacy	13,850	1850	385	12,750
42	"	13,700	1550	470	9,250
43	Laporte	11,475	2785	380	7,150
44	Beltrami	-	-	-	16,800
45	"	-	-	-	12,050
46	"	-	-	-	16,300
47	"	-	-	-	32,300
48	"	-	-	-	21,400
Average		12,845	1654	572	16,774

The chemical composition of the peat samples is given in tables 6 and 7. For the sake of convenience and to show the differences in composition between the two types, the analyses of the muskeg peat and the grass peat are grouped separately. A description of each sample is found on pages 13 to 22 and a summary giving location, depth of peat, drainage and vegetation of each sample is found in table 4. Since the samples were taken from a great many different areas in widely separated localities, the data should give a general idea of the composition of Minnesota peat soils.

The volatile matter, which in the case of peat soils consists chiefly of organic substances is above fifty percent in practically every case, and the ash content is the difference between one hundred percent and the percent of volatile matter. The highest percentage, 95.07, is in the sample taken at Grand Rapids, 16 to 18 inches from the surface. The largest amount of volatile matter among the surface samples, 93.22 percent, is in one of the Bemidji soils. Although the surface soil containing the highest percent of volatile matter is a grass peat, those of the muskeg type generally contain the more. Only one of the sixteen surface samples of muskeg contains less than 80 percent of volatile matter, while twelve of the twenty-four samples of

grass peat contain less than this proportion.

When the nitrogen content is expressed on the percentage basis there appears to be a much larger amount present than is found in mineral soils. For example, the average nitrogen content of seventy-three Minnesota surface soils, as reported by Prof. Snyder[18] is 0.20% while the smallest amount found in the peat soils is 1.39 per cent, which is nearly seven times greater. When one considers however, that the weight of one acre foot of mineral soil is four million* pounds while an acre foot of peat weighs only one-half million (500,000) pounds, which is one-eighth as great, the apparent difference in the nitrogen content disappears.

The average nitrogen content of thirty-two samples of peat soil is 10,949 pounds per acre foot, the average of seventy-two samples of mineral soil is 8,000 pounds per acre foot, and the average nitrogen content of six samples of mineral soil from the Red River Valley[19] is 16,000 pounds per acre foot.

The phosphoric acid content of peat soils varies from 0.145 per cent to 0.557 per cent, which is equivalent to 725 and 2,785 pounds per acre foot, respectively. The average phosphoric acid content is

* In the absence of other data the field weight of the Grand Rapids samples is used in all of the calculations.

1,528 pounds per acre foot with 1,471 pounds as the average for the muskeg type and 1,654 as the average for the grass peat. Apparently, therefore, the grass peat is richer in phosphorous than the muskeg peat. An examination of table 6 shows however that the difference is produced by four samples, two of which are grass peat and are unusually high while two samples of muskeg are unusually low in phosphoric acid. With the exception of these four samples, the phosphoric acid content in the grass peat and in the muskeg is quite uniform.

Compared with mineral soils the phosphoric acid content, even in the richest peat soils, is very low. The average percent in 73 Minnesota mineral soils is 0.20 %[20] or 8,000 pounds per acre foot, which is over five times as much as is contained in the average of the thirty two peat samples. Hilgard[22] places the lower limit of adequacy for crop production without the addition of commercial phosphates, at 0.05 percent or 2,000 pounds per acre foot. If this figure holds for peat soils as well as for mineral soils, only two of the soils analyzed contain sufficient phosphoric acid to supply the needs of crops, without fertilization, and of these two, one, number 43 belongs to that intermediate shallow type, containing over fifty percent of mineral matter.

In regard to their content ofpotash, peat soils show a great similarity being uniformly defficient in that element. The average content of potash expressed as K_2O as shown by table 6 is 556 pounds per acre foot and is practically the same in the two types, grass and muskeg peat. Two of the samples, numbers 38 and 39 contain considerably more than the others but, as will be shown, even they are decidedly defficient.

The average acid-soluable potash content of Minnesota mineral soils as reported by Prof. Snyder[21] is 0.43 percent K_2O or 17,200 pounds per acre foot, which is thirty-one times as much as is found in the average of the peat samples. The lower limit of adequacy for potash is placed at 0.25 or 10,000 pounds per acre foot, by Hilgard[22] which is 18 times the amount present in the peat soils.

A 65 bushel crop of corn requires 55 pounds of potash (K_2O) for its production. If all the potash in an acre foot of peat were made available there would be only enough for ten crops of corn. Since only a very small percentage of the plant food in a soil is made available at any one time it is evident that potash will need to be supplied to all peat soils.

The greatest variation is found in their lime content, which European investigators consider a reliable indication of their agricultural character. In general the muskegs contain less lime than the grass peat soils, altho there are several exceptions. For example numbers 13 and 14 contain 4.38 percent and 5.97 percent respectively which exceed all but three of the samples of grass peat. None of the grass peats contain less than one percentof lime and only three contain less than 1.5 percent, whereas only five muskeg peat sdls contain more than 1.5 percent.

Three of the muskegs contain more than 2.5 percent which would throw them into the grass peat class according to the German classification. (See page 3 amd 4) They bear, however, the characteristic muskeg vegetations, sphagnum moss, tamarack and spruce, except number 13 which bears sphagnum moss, and arbor vitae. Of the others, only those from Grand Rapids contain less than 0.5 percent, which would place them in the "high moor" class, the remainder being in the intermediate group between 0.5percent and 2.5 percent. Thirteen of the twenty three samples of grass peat contain more than 2.5 percent and none is below the 0.5 percent limit.

These results show that in general, the muskegs of Minnesota do not conform exactly to the "high moors" of Europe as defined by the German investigations. It is probably, however, that a classification based upon the lime content will be found more useful than one based upon the vegetation that happens to be growing upon the surface at the present time, since it is well known that the surface vegetation varies from time to time because of temporary conditions such as water supply and fires.

Acidity of Peat Soils. The acidity of 19 samples of peat soil was determined by the method outlined on page 29, the results of which are shown in table No. 8. The lime content is included in the table to show the relation between lime content and acidity.

At present there is no method, that is generally accepted, for the quantitative determination of soil acidity. The results however show that at least a qualitative relationship exists between the lime content and the acidity. For example those soils containing less than 1. per cent of lime are decidedly acid, while those containing from 4. to 5. per cent are practically neutral. Considerable disagreement between the lime content and the acidity is found in the intermediate soils. The method indicates which soils are strongly acid and which are neutral, but it is not a reliable indicator of the lime requirement of the intermediate soils.

Table 8. Acidity of Peat Soils.

No.	CaO %	Acidity %	Lime Required lbs.
		Muskeg Peat.	
1	2.53	.085	1,696
2	1.41	.082	1,632
3	1,66	.052	1,040
5	0.72	1.556	31,120
6	0.91	1.320	26,400
13	4.38	Alk.	none.
14	5.97	.022	440
15	0.37	2,272	45,440
27	1.74	.047	936
		Grass Peat.	
26	1.49	.089	1,780
28	2.52	.059	1,184
29	2.38	.040	792
31	2.80	.044	880
33	2.66	.041	808
34	3.23	.043	848
40	2.17	.065	1,304
43	1.43	.039	784

Fertilizer Experiments. In order to determine the fertilizer needs of peat soils, cooperative tests were conducted during the years 1911, 1912, and 1913. Although the details were varied in many of the tests, the scheme followed in general was as follows: Six 1/4 acre plots were staked off and treated, respectively, with nitrate of soda, sulphate of potash, acid phosphate, ground limestone, a complete fertilizer - either Swift's Grain Grower or a mixture of nitrate of soda, acid phosphate, and sulphate of potash,- and one plot was left untreated as a check.

In 1911 cooperative fertilizer tests were started at the following places:

Middle River, Marshall Co. A. W. Clark, In charge.
Askov, Pine Co., Pedersen and Gravesen, In charge.
Elk River, Anoka Co., Walter E. Whipple, In charge.
Bemidji, Beltrami Co., W. G. Schroeder, In charge.

The plots at Askov were the only ones from which a report of the yields could be obtained. The land was plowed in 1910 to the depth of 3 inches, but a fire late in the summer burned the peat to the depth it had been plowed. An open ditch was dug along one side of the field to provide drainage. The depth of peat varies from about 1 foot to 2-1/2 feet, and is underlaid with sand.

A frost in June injured the crop so severely that it failed to mature; so the oats were cut for hay, the yield on the various plots being as follows:

Table 9.	Fertilizer	Yield per acre.
Plot 1.	Nitrate of soda	1,920 Lbs.
" 2.	Sulphate of potash	1,320 "
"" 3.	Acid phosphate	840 "
" 4.	Ground limestone	1,320 "
" 5.	All of above	2,200 "
" 6.	None	720 "

At Middle River flax was seeded on peat that is from 12 to 18 inches in depth where the plots were laid out. The same treatment was given the plots as at Askov with two other plots added, which received, respectively, manure and peat ashes from a burned over swamp. The plots were cut separately, but the owner was unable to secure a threshing machine so the grain was not threshed. He stated that the manure plots looked the best, the phosphorus plots next, and that the others showed no distinct difference.

At Bemidji the fertilizer was applied as a top dressing to winter wheat. A drainage ditch through the center of the series favored two plots more than the others, and produced a greater

effect than the fertilizer. The plots were not harvested separately.

At Elk River flax was seeded on a similar set of plots. No difference could be seen in the plots at any time during the season. When the flax was in bloom a wind and rain storm beat it down to the ground so that it could not be harvested.

In 1912 the experiments were continued at Askov and Elk River, and in addition the following sets of plots were started:

Mendota, Dakota Co., C. Larson, In charge.
Freeborn, Freeborn Co., Sidney Seath, In charge.
Hector, Renville Co., George W. Leasman, In charge.
St. Peter, Nicollet Co., Herman Turner, In charge.
Dassel, Meeker Co., John Crowe, In charge.
Meadowlands, St. Louis Co., W. A. Dickinson, In charge.

Results were obtained only from the plots at Freeborn and St. Peter. The following is the report sent in by Sidney Seath giving the result of the test at Freeborn:

"Location - Sec. 26, Twp. 104, Range 23.
Depth of peat - 5 feet.
Original vegetation - wire grass.
1908 crop - Hay 2 tons per acre.
1909 crop - " " " " "
1910 crop - Flax 5 bushels per acre.
1911 crop - Fodder corn.

The plots were plowed May 20, dragged twice, planted to corn May 29, in drills 8 inches apart in the row. June 5, four and one-half tons

"well-rotted horse manure was applied to one plot. June 6, fertilizers were applied according to directions, with the exception that on plot 5 Swift's complete fertilizer was applied instead of a mixture of sulphate of potash and acid phosphate. The fertilizer was cultivated in and harrowed. On July 4, there was a striking difference in the plots, acid phosphate being the most vigorous, with manure a close second. August 1, the manure had caught up and was passing the acid phosphate plot. October 4, the middle row of each plot was snapped in a one and one-half bushel basket because the corn was too green to husk and it was necessary to harvest the plots before leaving for the University Farm School".

Table 10.

Plot No.	Fertilizer	Height of Stalks	Number of Baskets	Yield per Acre.
1	Nitrate of soda	6 - 7 ft.	7	35 bu.
2	Sulphate of potash	6-7-1/2 ft.	8	40 "
3	Acid phosphate	6-1/2-7 ft.	9	45 "
4	Manure	7 - 8 ft.	11	55 "
5	Complete fertilizer	6 - 7 ft.	8	40 "
6	Check	5 - 7 ft.	5-1/3	27 "

The soil upon which the test was conducted at St. Peter is described as sample No. 39, pages 20-21. Table No. 11 gives results obtained as reported by Mr. Herman Turner:

Table 11.

Plot	Fertilizer	Yield per Acre.	Increase
1	Nitrate of soda	18 bu.	Loss
2	Sulphate of potash	19 "	"
3	Acid phosphate	37 "	7.4 bu.
4	Ground limestone	28 "	Loss
5	All of above	37 "	8 bu.
6	Check	29 "	

Results were not obtained at Askov and Elk River because the land was too wet. At Renville, an early frost injured the corn and caused it to mature unevenly, so the plots were not harvested separately. No difference could be noted in the different plots. At Meadowlands a fire burned over the field, killing the crop. At Dassel no differences could be seen in the flax growing on the plots so they were not harvested separately.

At Mendota the farm was sold and the purchaserout the corn on the plots before the writer had been notified. He had visited them however, just before the corn reached the roasting ear stage and could see no differences as the result of the fertilizers. When

the corn was harvested a difference of opinion was expressed in regard to the effect of the fertilizer, the owner stating he could see no differences while the hired man maintained there was a difference in the plots. The need of the soil for plant food however, was shown very strikingly on the potato crop. A part of one field was manured, and a part left unmanured. One hundred paces were stepped on both the manured and the unmanured parts, and 4 rows of potatoes were dug from each. The manured portion yielded 13 bushels, while the unmanured part yielded 5 bushels. Figure 34 shows the potatoes from each plot.

The composition of this sample, which is No. 36, is shown in Table 6, page 30. It will be noted that the soil is very calcareous, it contains afairly high percentage of phosphoric acid, but is very low in potash. It would seem therefore, that the beneficial effect of the manure was due to its potash content.

In 1913 the experiment at St. Peter* was continued, but was modified by discontinuing the use of nitrate of soda and ground limestone, and substituting bone meal for acid phosphate. New plots were started at Corona, Carlton County, in charge of N. A. Houck, and at Germantown, Marshall Co., in charge of E. M. Hinchman.

*The plots were not harvested separately at St. Peter in 1913 because of lack of time on the part of the owner.

At Corona four 1/4 acre plots were seeded to winter rye and fertilized as follows:

Plot 1. Air slaked lime, 250 lbs.
" 2. " " " " " ; sulphate of potash 50 lbs.
" 3. " " " " " ; bone meal 70 lbs.
" 4. Check.

Mr. Houck reported "We got three and a half bushels off of each of the three treated plots - practically no difference in the yield. On the fourth plot which received no lime or fertilizer, nothing grew".

At Germantown five 1/4 acre plots were seeded to flax. Table 12 gives the treatment each plot received and the yield:

Table 12.

Plot	Fertilizer	Yield per Acre
1.	Sulphate of potash and bone meal	440 lbs.
2.	Sulphate of potash	320 "
3.	Bone meal	440 "
4.	Manure	820 "
5.	None	600 "

Five similar plots were started using barley instead of flax, but the crop was a failure due to the undrained condition of the land.

The following statement by the owner explains why the unfertilized plots produced more than the fertilized plots: "The weights of the production of the plots do not show true uniform results, as the plot without fertilizer shows a greater yield than those fertilized. This is due to the fact that plots 4 and 5 were on peat about 8 inches deep (the others were on peat 18 inches deep) and being dry enough for thorough working and having rotted more than the others a good seed bed was secured".

While the fertilizer tests are not conclusive, they indicate that most of the Minnesota peat soils will respond to fertilizers, even when practically virgin; that some need lime; and that some respond to nitrogen fertilizers even though there is present a very large amount of this element. The experiments indicate a more immediate need for phosphorus than for potassium.

Peat Soil Studies at Grand Rapids. The North Central Experiment Farm which was called the Northeast Experiment Farm until 1912, is located on the west bank of the Prairie River, two miles east of Grand Rapids, in Itasca County. The farm contains about 450 acres. There are several areas of peat soil, the largest of

which is about 12 acres in extent and is of the muskeg type.

Considerable interest was shown in the development of this muskeg from the beginning. In 1898[23] open ditches had been dug to remove the surface water from two of the areas of peat soil. These were found to be unsuccessful because the soil caved in filling the ditches. In 1899[24] a cribbing was built of tamarack poles to support the sides of the ditches, which gave the surface water a chance to run off. The layer of moss was then stripped off from a portion of the soil, which the next year[25] was seeded to oats and grass. No report of the results of this test was found but it was probably unsuccessful, since in 1903[26] Mr. H. H. Chapman, superintendent of the farm stated "The experiment farm has worked for 7 years upon a small muskeg, 10 acres in extent. A portion of the swamp has been drained since 1896 and another piece since 1898. On both pieces the moss was stripped off after failing to get rid of it by burning. A horse and three-pronged hook was used to tear up the tough bunches of moss and shrubs and haul them off. The ground was left to rot, but after rotting 3 and 5 years respectively, the swamp has not been

gotten into tame meadow".

Chemical analyses[27] were made by Professor Harry Snyder of 10 samples of the muskeg soil collected in 1902 by Superintendent Chapman. The method of analysis is not given in the report, but it is more than likely that the ordinary method of soil analysis in use at that time was employed. This method consists in digesting the soil with hydrochloric acid (sp. gr. 1.115) and the determination of the various mineral constituents in the solution. The volatile matter was determined by burning a portion in a muffle furnace. The composition of the 10 samples as reported by Professor Snyder is given in Table 13.

Samples 1 to 6 inclusive were taken from the large muskeg and 7 to 10 from the small muskeg. On the large muskeg samples 1 and 2 were from that part which had been stripped of moss and the stumps removed. Samples 3 to 5 were from the muskeg in the natural state. Sample 6 was from a portion which had been cleared of moss in 1899, plowed and drained. On the small muskeg the peat was not over 30 inches deep. It had been drained and blue joint was growing vigorously where the samples were taken.

Table 13. Composition of Grand Rapids Muskeg soil in 1902.

Soil No.	Location	Volatile Matter %	N %	CaO %	P_2O_5 %	K_2O %
1	Large muskeg	92.25	2.91	.41	.22	.15
2	" "	93.78	2.36	.22	.02	.19
3	" "	94.04	2.45	.47	.19	.32
4	" "	95.13	1.50	.25	.00	.26
5	" "	91.69	2.49	.40	.24	.41
6	" "	90.14	2.43	.29	.13	.27
7	Small "	85.31	1.98	.18	.03	.32
8	" "	86.40	2.76	.29	.03	.23
9	" "	46.16	1.36	.26	.05	.27
10	" "	8.59	.19	.37	.04	.28

Apparently no further attempts were made to subdue the muskeg until 1910. At least a 37-page report of the Northeast Experiment Farm by Superintendent A. J. McGuire, published in 1909 made no mention of muskeg soils, nor do any of the intervening reports mention them. In 1910 a part of the farm including a portion of the peat soil was under drained with tile. Professor John T. Stewart[28] states regarding the peat as follows: "Approximately 12 acres of peat land, varying from 8 to 20 feet in the depth of the peat deposit, was under drained; the object to determine the effects of tile on land of this character, and later to determine their value for agricultural purposes, by planting them to various crops".

In the spring of 1911 a fertilizer experiment planned by members of the Agricultural Division and Professor Ralph Hoagland, was started on the peat soil that had been drained the year before. The original plans of the experiment called for a 4-course rotation consisting of corn, oats, potatoes, and barley, each crop to be represented each year on a series of six 1/10 acre plots. When the time came to lay out the plots however, it was found that insuffi-

cient land had been prepared, so, rather than reduce the number of plots which would interfere with the rotation, the size of the plots was reduced. The sketch on page 55 shows the location of the fertilizer plots with reference to the remainder of the muskeg, while that on page 56 shows their arrangement and the treatment each received.

On June 20, 1911 Superintendent A. J. McGuire made the following report on the general appearance of the crop, expressed in percentage of an average crop:

Table 14.

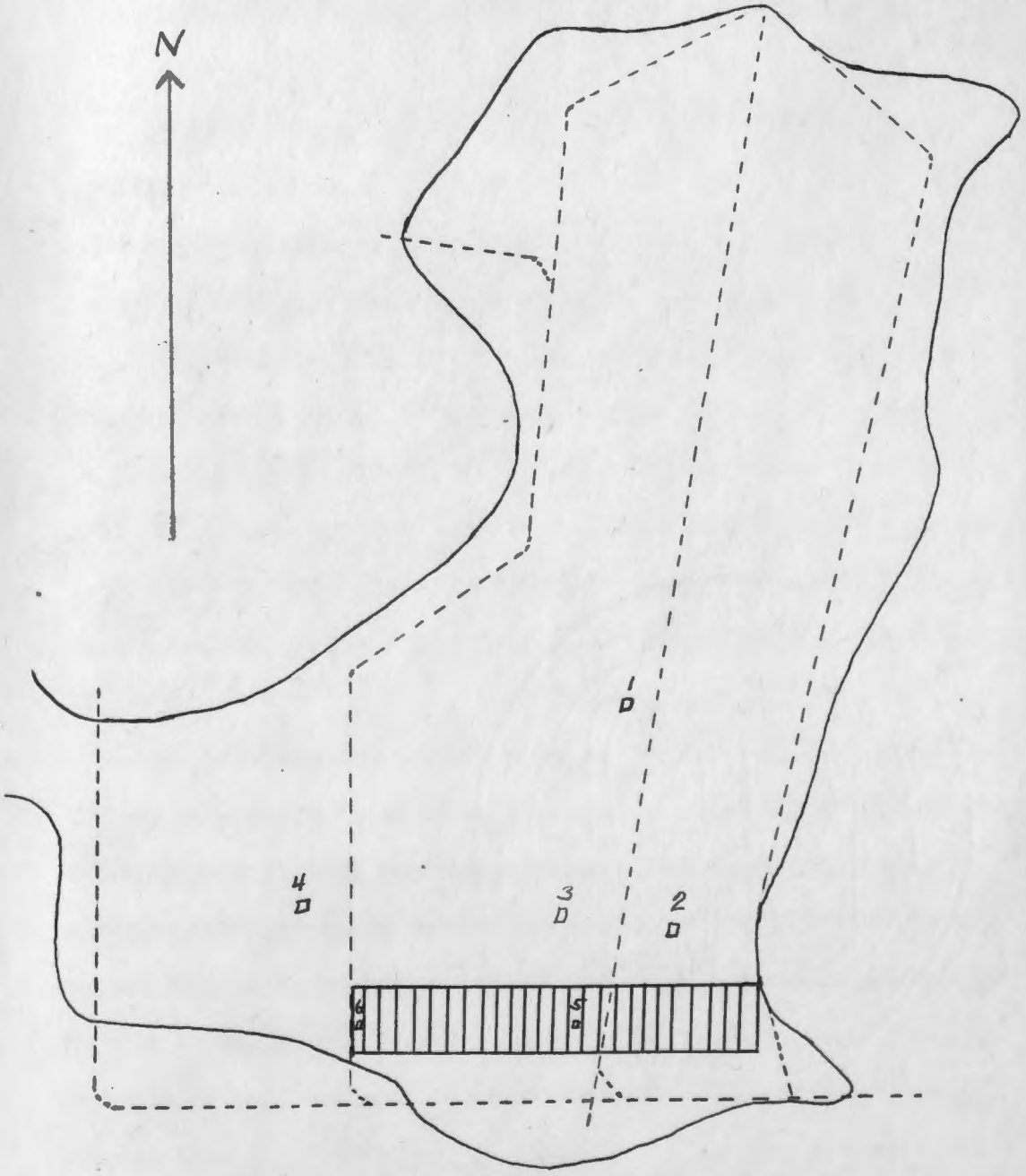
Plot	Fertilizer	Corn %	Oats %	Barley %	Potatoes %
1	Nitrate of soda	100	100	65	
2	Acid phosphate	90	70	45	
3	Sulphate of potash	95	80	45	
4	Ground limestone	95	95	50	(Not reported)
5	Manure	97	90	75	
6	Check	85	60	30	

The crops were not harvested because the wet condition of the soil made it impossible to get on the land with teams.

The experiment which was continued in 1912 gave no results

because the land was too wet for crops in the early part of the spring, and potatoes were substituted on all of the plots, which were killed by frost on July 19. The fertilizers were applied on May 18, by Superintendent McGuire, ground limestone being omitted.

In 1913 no fertilizer was applied, but all of the plots were seeded to oats. August 20, the plots were examined and a very marked residual effect from the application of ground limestone could be seen. The lime plots and the manure plots were the only ones upon which the oats were doing well, and the manure plots were much better on the side next to those which had been treated with lime, suggesting the possibility that the wind had carried some of the powdered limestone over on to them while it was being applied. On the remaining plots smartweed was more abundant than the oats. The pictures figs. 26 and 27 give a fair idea of the effect of the different treatments upon the growing oats. The crop failed to ripen and was not harvested.



Peat Soil at Grand Rapids Showing Fertilizer Plots ~ Test Pits and Tile Drains

Moisture Content of Peat Soil. Peat soils have a much greater capacity for holding water than other types of soil. In the case of the Grand Rapids peat as shown by samples 14 and 15, in table 15, more than nine times the weight in water is sometimes held by peat. That this water is held very tenaciously is evidenced by the many unsuccessful attempts [29] to drain the bog by means of open ditches. On plot 11, samples were taken (Nos. 34 to 39) about 20 feet from a tile drain (see page 55), and the soil found to contain nearly six times its weight (596 per cent) of water at 12 inches from the surface and almost eight times its weight (775 per cent) between 19 and 21 inches.

The water content was not so great in plot 24, containing only 250 per cent at 13 to 18 inches, and 276 per cent at 19 to 24 inches. The samplesom plot 24 were taken about 8 feet from a tile which might explain the difference in water content, or it might be due to the fact that on plot 24 the peat is only 24 inches deep, while on plot 11 it is much deeper. The difference in the water holding capacity of peat and clay is shown very strikingly in the set of samples taken from plot 24, (Nos. 40 to 47). In the peat, as shown

in table 15, the water content of the peat which was not saturated, contained from 200 to 276 per cent, while the clay was saturated at 29.2 per cent.

In the virgin peat, samples were taken every three inches down to the clay in Pit No. 1, and every six inches down to three feet in Pit No. 4. Five samples were taken the evening of August 20. That night a heavy rain fell, and August 21, a new set of samples was taken. Both sets are shown in table 15. All of the water which fell the previous night was held in the first six inches of peat, although it had had ten hours to drain. Considerable variation was found in the moisture content at various depths. At a depth of between 7 and 27 inches, the soil was only moist, from 28 to 48 inches it was almost saturated, below which there was less moisture except for a wet layer at from 58 to 60 inches. These variations are caused by differences in the structure of the peat. At from 34 to 39 inches, where the moisture content jumps from 770% to 873% in six inches, there is an abrupt change in the appearance of the peat. It becomes lighter in color and the grass and roots are much less decomposed. At 49 to 51 inches, where the moisture

content drops over 100% in three inches, the soil changes from grass peat to moss peat. The next layer, at 58 to 60 inches, had the moss formation, but was less thoroughly decomposed.

In Pit No. 4 the moss was formed at 30 inches and the moisture content is greater at that point, which differs from the condition in Pit No. 1, in which case the peat having the same depth as in Pit No. 4, moss formed at 48 inches caused the water content to decrease.

On August 23, three days after the pit was dug, there was no water in the pit, nor had there been any water standing in it previously, showing that the water table was below six feet from the surface. Likewise in Pit No. 6 the water table was below the peat. At the places where the other pits were dug however, the case was different.

Table 15. MOISTURE IN FIELD SAMPLES OF GRAND RAPIDS PEAT.

Depth in Inches	Pit No. 1 ** Virgin August 21,		Pit No. 1 Virgin August 20,		Pit No. 4 Virgin August 20,		Pit No. 5 Oats August 20,		Pit No. 6 Oats August 20,	
	Soil No.	Water %	Soil No.	Water %	Soil No.	Water %	Soil No.	Water %	Soil No.	Water %
1 - 3	1	822	23	597	28	467.6	34	382	40	200
4 - 6	2	833	24	704	-	-	-	-	-	-
7 - 9	3	566	25	577	29	485.9	35	506	41	232
10 - 12	4	580	26	504	-	-	36	596	-	-
13 - 15	5	610	27	521	30	502.9	37	676	42	250
16 - 18	6	630	-	-	-	-	38	713	-	-
19 - 21	7	603	-	-	31	671.3	39	775	43	276
22 - 24	8	590	-	-	-	-	-	-	-	-
25 - 27	9	624	-	-	32	705.7	-	-	-	-
28 - 30	10	746	-	-	-	-	-	-	44 *	20.0
31 - 33	11	770	-	-	33	830.1	-	-	-	-
34 - 36	12	834	-	-	-	-	-	-	-	-
37 - 39	13	873	-	-	-	-	-	-	-	-
40 - 42	14	942	-	-	-	-	-	-	45*	29.2
43 - 45	15	915	-	-	-	-	-	-	-	-
46 - 48	16	860	-	-	-	-	-	-	-	-
49 - 51	17	705	-	-	-	-	-	-	-	-
52 - 54	18	729	-	-	-	-	-	-	46*	30.7
55 - 57	19	712	-	-	-	-	-	-	-	-
58 - 60	20	832	-	-	-	-	-	-	-	-
61 - 63	21	725	-	-	-	-	-	-	-	-
64 - 66	22	521	-	-	-	-	-	-	47*	25.6
67 - 72	-	-	-	-	-	-	-	-	-	-

* Samples 44 to 47 inclusive, are clay subsoil.

** The samples from Pit No. 1 were taken the day after a heavy rain. No rain had fallen for several days when the other samples were taken.

The moisture content of the samples of Beltrami peat at the time they were taken is shown in Table 16.

Table 16. MOISTURE IN FIELD SAMPLES OF PEAT SOIL FROM BELTRAMI, POLK CO., MINN.***

Location	Depth Inches	Water Content %
Set I. Center Sec. 13	1 - 12	131.4
	13 - 16	39.1*
	17 - 28	19.6*
Set II. SE. Corner Sec. 15,	1 - 12	233.1
	13 - 16	189.1
	17 - 28	41.4*
Set III. SW. Corner Sec. 15,	1 - 3	60.2**
	4 - 15	369.3
	16 - 22	404.3
	23 - 34	46.5*
Set IV. SW. Corner Sec. 16,	1 - 2	146.8
	3 - 9	167.2
	10 - 21	40.1*
Set V. SW. Corner Sec. 17,	1 - 2	171.1
	3 - 6	199.5
	7 - 18	33.7*
	19 - 30	29.5*
	31 - 42	30.2*

* Underlying clay.
** Sediment of clay deposited on the peat.
*** All samples were taken from virgin peat November 14, 1913.

These samples show clearly the difference in the water holding capacity of peat and clay. The peat covers from three to ten times as much water as the clay immediately beneath it.

The Beltrami peat contains about the same amount of water as that from Pit No. 6 at Grand Rapids where the peat is 24 inches deep, but very much less than is found in the deep peat at Grand Rapids. This coincidence tends to indicate that shallow peat soils are less likely to be water logged than the deep peat soils.

SUMMARY AND CONCLUSIONS.

Forty-eight samples of peat soil, twenty-five of which were from the muskeg type, and twenty-three from the grass peat type, were collected and analyzed. On most of the samples, determinations were made of volatile matter, ash, nitrogen, phosphoric acid, potash, and lime, while the acidity was determined on eighteen samples.

Muskeg peat, as a rule, contains a larger per cent of volatile matter than the grass peat, averaging 86.84 per cent in the former and 73.71 per cent in the latter.

The nitrogen content is higher in the grass peat than in the muskeg, the former containing 1.874 per cent on the average and the latter 2.569 per cent.

The phosphoric acid and potash content are also somewhat higher in the grass peat than in the muskeg, but both are so low as to indicate an almost immediate need of fertilization with those substances.

The greatest difference in composition between the muskeg and the grass peat is found in their lime content, although there is considerable variation in the amount present in different samples of both types. The muskeg peat contains on the average, 1.237 per cent of lime but different samples vary from 0.25 per cent to 5.97 per cent. The grass peat contains 3.35 per cent as an average, and varies from 1.03 per cent to 14.36 per cent.

The analyses indicate that Minnesota peat soils resemble, but do not agree exactly in composition with those of European countries.

The fertilizer trials did not give conclusive results but indicate the need of fertilization.

In their natural state peat soils contain from two to nine times their weight of water.

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29. See 24, 25, 26, 27.

Fig. 2. An uncleared muskeg swamp near Deer River, Itasca County, Minnesota.

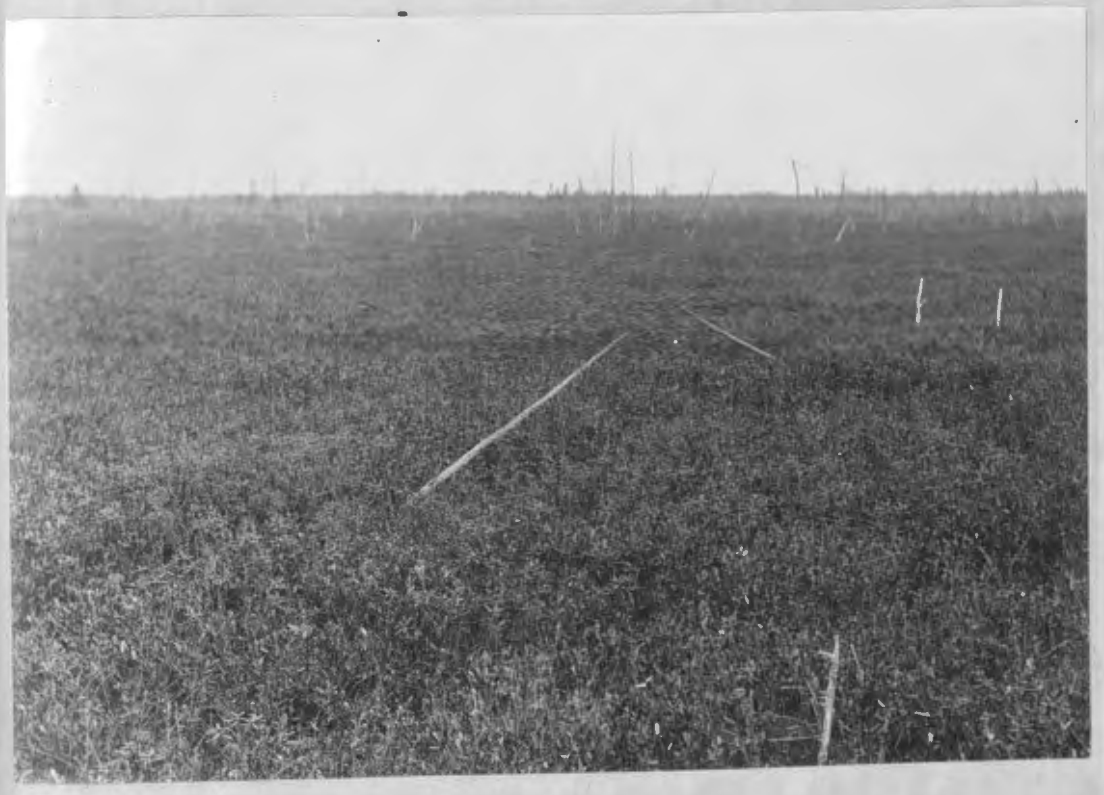

Fig. 3. A burned-over muskeg at Island, St. Louis County, Minn.

Fig. 4. An upturned tamarack from muskeg near Deer River, Itasca County, Minnesota, showing the horizontal root growth.

Fig. 5. View of a partially cleared muskeg on the D&IR. Ry. Demonstration Farm at Meadowlands, Minn.

Fig. 6. View of the muskeg on the D&IR. Ry. Demonstration Farm at Meadowlands, Minn., from which the trees, stumps, and moss have been removed.

Fig. 7. Appearance of a muskeg at Meadowlands, Minn., after the brush has been piled and a part of the roots and stumps taken out.

Fig. 8. Appearance of the vegetation along a drainage ditch at Island, St. Louis County, Minn.

Fig. 9. Appearance of muskeg after plowing with a disk plow, at Island, St. Louis County, Minn.

Fig. 10. A vegetable garden on muskeg at Meadowlands, St. Louis County, Minn.

Fig. 11. Growing celery at Meadowlands, St. Louis County, Minn.
Photograph taken August 12, 1912.

Fig. 12. Muskeg peat at Nemadji, Carlton County, Minn., after a fire had killed the trees and moss.

Fig. 13. Crop of timothy and clover hay taken from the fifteen-acre muskeg shown in Fig. 12.

Fig. 14. Corn on the small muskeg at the Grand Rapids Experiment Farm. The blighted condition of the leaves was caused by a recent frost. Photograph taken August 10, 1912.

Fig. 15. Rutabagas on muskeg, at Island, St. Louis County, Minn.

Fig. 16. View of a virgin grass peat meadow at Bemidji, Beltrami County, Minn.

Fig. 17. Barley on grass peat at Lowry, Pope County, Minn. The land was broken in 1910, manured in 1911, and seeded to oats and barley, yielding 40 bushels of oats and 60 bushels of barley per acre. Photograph taken August 18, 1912.

Fig. 18. Oats on grass peat at Lowry, Pope County, Minn. For treatment and yield see Fig. 17.

Fig. 19. Clover meadow on grass peat at Lowry, Pope County, Minn.
For treatment see Fig. 17.

Fig. 20. Flax on grass peat at Elk River, Anoka County, Minn. The crop failed to mature.

Fig. 21. Flax on grass peat at Frazee, Becker County, Minn.
The crop failed to mature.

Fig. 22. Vegetable and flower garden on grass peat, Southeast Minneapolis, Minn. The soil is very calcareous and contains 75 percent volatile matter.

Fig. 23. View of the twelve-acre muskeg at the Grand Rapids Experiment Farm, upon which fertilizer trials were conducted. The muskeg is shown in the virgin condition after the trees and stumps had been removed.

Fig. 24. Method of obtaining field weight samples from the muskeg at Grand Rapids Experiment Farm.

Fig. 25. View of the fertilizer plots on the Grand Rapids Experiment Farm upon which potatoes had been planted. Photograph taken August 13, 1912, about two weeks after a severe frost had killed all the potato vines.

Fig. 26. Oats on the fertilizer plots at the Grand Rapids Experiment Farm.

Fig. 27. Oats on the fertilizer plots at the Grand Rapids Experiment Farm.

Fig. 28. Oats on the fertilizer plots at St. Peter, Nicollet County, Minn. Results of 1912.

Fig. 29. Oats on the fertilizer plots at St. Peter, Nicollet County, Minn. Results of 1912.

Fig. 30. Barley on the fertilizer plots at St. Peter, Nicollet County, Minn. Experiment of 1913.

Fig. 31. Barley on the fertilizer plots at St. Peter, Nicollet County, Minn. Experiment of 1913.

Fig. 32. Oats on grass peat at Elk River, Anoka County, Minn. The figure on the left was unmanured, and the one on the right shows the effect of a light dressing of manure.

Fig. 33. Spring rye on muskeg on the D&IR. Ry. Demonstration Farm at Meadowlands, St. Louis County, Minn. The view on the left shows the unfertilized plot and the one on the right shows the plot which received lime and a complete fertilizer.

Fig. 34. Potatoes on grass peat showing the effect of manure.