THE RELATION BETWEEN THE CHEMICAL COMPOSITION OF THE SOIL AND ITS PRODUCTIVITY

THESIS FOR DEGREE OF M. S.

OSCAR EDWIN HARRINGTON

1916

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Soils
Agricultural Chemistry

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Table of Contents.

Introduction.

There has been a considerable amount of discussion during the past few years as to the value of a chemical analysis of a soil as a means of studying its producing power.Many opinions have been ventured,a limited amount of data has been compiled,and conclusions have been drawn which vary between two extremes:the one held in the past by the United States Bureau of Soils that the productivity of soil is mainly dependent upon its physical condition,water supply,etc.,(23) the chemical condition as related to plants being essentially the same in all soils;the other held by Hilgard(6),late of California,Hopkins,etal,maintaining that the productivity of a soil is almost directly proportional to the amount of plant that it contains.

The effect of cropping upon the chemical composition of a soilis also of considerable interest to both the theoretical and applied phases of soil investigations. To what extent the total ampunt,as well as the amount of readily available,nitrogen,phosphorous,potassium,sulfur and calcium are decreased or increased by cropping and in what way,if in any,the acidity of a soil is affected by cropping ,are questions of interest and practical value. Each of these questions has been dealt with in this paper.

There has also been an effort made to touch upon the variations in the relation between composition and productivity ,caused by differences in type.Certain more or less arbitrary standards have been suggested by various workers,notably that of Maerckerof Halle Station,Germany, and that of Hilgard.These standards are of a limited value, however,because of their failure to take into proper consideration variations in composition,texture,and structur e due entirely to type.

Itis hoped that this paper may throw some additional light,of interest and value,upon this phase of the work.

The work reported in this paper includes both field and laboratory studies of the soils under consideration. It was realized at the beginning that laboratory studies would be of little or no significance ,unless as exhaustive knowledge as possible was obtained concerning the field conditions.

The field studies include a consideration of the climate,geology,physiography,cropping systems,and soil management in all of the areas sampled,as these factors all have a direct bearing upon the solubility of the plant food and consequent loss by percolation,removal by erosion, crops,and the like.They also include a careful consideration of the physical conditions of the soil as affecting bacterial and chemical activity and plant growth.

The laboratory studies include a determination of the total amount of nitrogen,phosphorous,potassium, sulfur,and calcium supplemented by a determination of the readily available phosphorous and potassium in at least one sample of each type.The lime requirement of each soil was also determined.

Finally,an effort has been made to correlate these laboratory and field studies,and to compare them with the producing power of the soil. It is believed that such a correlation is the most important part of a line of work of this nature,and as such correlations have not

been extensively reported in the literature, it is hoped that they may prove to be of a certain interest and value.

Review of Literature.

For purposes of review, the literature has been divided into three groups: that dealing with soil depletion by cropping, the factors affecting the availability and solubility of plant food, and finally miscellaneous articles.

The literature which bears directly upon the matter of soil depletion by cropping is rather limited. In 1892 Snyder (1) reported the results of his investigations upon some soils of Minnesota. He determined the amount of nitrogen, phosphorous, potassium, sulfur, and calcium, and the readily available phosphorous in both cropped and uncropped soils. The greatest decrease was in the nitrogen content which was about 40% during the period of cropping. Similar but smaller decreases were found in all the other elements. The amount of soluble phosphorous was noticeable in the presence of a large amount of organic matter. There was often a slight gain of calcium in the sub-soil of the cropped soil, due to percolation. The length of time the soils were cropped was not given.

VanSlyke discusses in his text (2) various sources of loss of plant food from the soil, and gives in the following table the approximate amounts of nitrogen, potassium, and phosphorous removed per acre by corn, wheat, and oats when yielding 25 bu. each per acre:

Crop	Lbs.N.	Lbs.P.	Lbs.K
Corn	39.2	13.8	27.6
Wheat	42.5	16.6	21.0
Oats	24.0	9.0	20.4

He summarizes the factors governing the loss by leaching as rainfall,adsorbing and holding power of the soil,organic matter,and tne form of the plant food,

King reports (3) in 1905 the results of some pot experiments conducted to show the depletion of plant food by cropping;he found the available potash and humus to be depleted the most rapidly. In 1911 Hart and Peterson (4) reported the results of their ivvestigations into the relation of sulfur to crop production and its loss from the soil due to cropping.They found that the cereals and grasses remove about 2/3 as much sulfur from the soil as phosphorous and that legumes remove more sulfur than phosphorous. They also found that continuous cropping for a period of fifty or sixty years reduced the sulfur content by about 40%. From these results they concluded that the sulfur content of the soil ,the same as that of phosphorous,might become dangerously low,and might become an important factor in soil fertility work.A similar work was reported in 1913 by Shedd (5).He had worked on some Kentucky soils which showed the sulfur content to have been depleted as much as the phosphorous.The per cent loss of the sulfur varied from 3% to 40%,and that of the phosphorous from 5% to 40%.

An important of each of the two last named articles is the high loss of sulfur noted.This point will be dealt with more extensively later.

The literature having to do with the various factors and conditions which affect the solubility of the mineral plant food is somewhat more extensive.One of the earliest investigations is that of Hilgard (6).His work was general and very extensive,and he drew the following conclusions: 1.All virgin soils having high per cents of plant are highly productive unless physical conditions are adverse. 2.The reverse is not always true because some soils having low amounts of planf food are highly productive and are lasting.Therefore analysis alone cannot be relied upon to determine crop production.3.The coarse textured soils seem to be able to produce with lower amounts of plant food than the finer textured ones.This he believes to be due to the fact that in coarse textured soils the plants could develope a more extensive root system than in the fine soils and therefore come in contact with more plant f od. 4. He believes that lime is often a controlling factor in the producing power of a soil;that in very sandy soils o.1% is often enough,while in heavy clays o.6% is often inadequate.

A very considerable amount of work has been done on the factors influencing the solubility of phosphatic compounds.Most of the studies have been on phosphatic rocks which are used as fertilizers,but the facts thus obtained should a ply well tothe phosphatic minerals of the soil. Joffre (7) in 1898 tested the solubility of tricalcium phosphate and apatite in pure water and in water charged with carbon dioxide. He found that the water charged with carbon dioxide dissolved on an average of fifteen times as much of the tricalcium phosphate and eight times as much of the apatite as the pure water,thus emphasizing the role of carbon dioxide in the soil in connection with the availability of phosphatic minerals. Statstrom (8) in 1904 Obtained results with humus, sour milk, etc., which also point to the solvent action of carbondioxide when dissolved in water. In 1907 Cameron and Bell (9) published what was largely a review of much of the work previously done on the solubility of phosphates. This included the work of Maley and Donath, Warrington, Erlenmeyer, Terril, and others. All of the results by the authors in this paper, like the ones mentioned above, bring out clearly the value of carbon dioxide as a solvent of soil minerals. Perotti (11) concludes from his investigations with different soil organisms in culture media containing nitrogen as asparagin, tartrates, sulphates, and urea, that in media containing a physiologically acid salt there is a uniformly important solution of the phosphates. Likewise, Sackett, Patten, and Brown (12) concluded in 1908 that when bacterial growth is accompanied by acid formation, there is a decided solution of the insoluble phosphates and that the presence of carbohydrates increases the solvent action because of the increase in the amount of carbon dioxide formed.

Prianishnikov (13) found in 1909 that the presence of calcium carbonate in the solvent had a decidely depressing effect upon the solubility of tricalcium phosphate, due to the presence of the common ion, Ca, in both the solvent and solute. Mitscherlich and Simmermacher (14) found in 1913 that the same principal holds true when any calcium salt is present; but that the presence of other salts as ammonium sulphate, ammonium chloride, sodium sulphate, and magnesium sulphate, increased the solubility of the phosphate

In1913, Jordan (15) reported that the solubility of rock phosphate increased with the fineness of the material and Peck (16) found the same thing to be true with bone meal. It would seem that the same principals should hold true with the phosphate minerals of the soil, assuming that the composition of the minerals is the same.

In 1913 Truog (18) reported results obtained by composting raw rock with manure and grass. He found that there was slight, if any, solvent action of the fermenting material. This he thought to be due to the fact that the water charged with carbon dioxide had became saturated with the phosphates and that if it could be removed, as under field conditions, the results would show a greater solvent action. In 1913 Tottingham and Hoffman (19) reported results very similar to those of Troug. They carried their work further, however, and found that the phosphorous in the cell material of the bacteria was in an insoluble form, and concluded that the consumption of the phosphorous by the bacteria after it had become soluble rendered it once more insoluble. It is very possible that, had their results been taken after a longer period of time, giving the bacterial cells time to become broken down again, that they would have been different. McDowell (10) obtained results similar to these in 1908.

The work just reviewed all deals with the solubility of phosphorous; the principals should, however, apply more or less directly to all the mineral constituents of the soil. The next work to be reviewed treats of the availability of an organic constituent of the soil, nitrogen. Winter and Robson (20) made investigations along this line

and concluded that organic compounds of nitrogen decompose and become available more intensely in sands than in clays and loams when the water content is low, but if the water content is high the difference is much less marked.

Thus it will be seen that the factors which influence the solubility of the mineral constituents of the soil have been rather extensively studied; the exact reason for the relative insolubility of these constituents has received much less attention, however. It is taken for granted usually, that it is due to the chemical composition of the minerals in which the elements occur. The next work deals with this subject. In 1913 appeared the results (21) of Fry,s work on the condition of the insoluble phosphorous. He offered two hypotheses as possible explanations of the insoluble condition of the phosphorous and worked on these. First he suggested that the phosphorous might be in insoluble compounds; but upon investigation he found that these insoluble compounds occur in only small amounts, not enough to account for all the insoluble phosphorous present. He next suggested that it might be present in soluble compoun s but protected in some way from the solvent action of the acids. This he found to be true. Large quantities of phosphatic minerals were protected by insoluble quartz grains.

A work somewhat similar in nature was reported in 1915 by Plummer (22). He carried on investigations on the relation between the mineral composition of some typical soils and their fertilizer requirements. After mineral analysis of the soils and corresponding fertilizer treatment

he decided that there is a definite relation between the mineral composition and the fertilizer requirements.

Other literature more or less miscellaneous,but having a bearing upon the problems of this paper,will be taken up at this point.In 1913 Whitney and Cameron (23) published results of very extensive studies and research upon the relation of the chemistry of the soil to its productivity,and they concluded that but very little can be determnied concerning the productivity of a soil by its chemical composition.They concluded that all soils contain enough plant food and are practically inexhaustable: and that the greatest limiting factor,next to temperature, is water supply.They consider that texture is a very important factor due to its close relation to water holding power.

Alimited amount of valuable and significant work has been done on the relation which sulfur bears to soil fertility,and some of that work will be reviewed here. Hopkins (25) believes that sulfur is of much less importance in soil fertility than many other workers have believe He contends that in as much as there is a considerable amount of sulfur addes to the soil each year by rainfall,there is but slight possibility that it will ever become a limiting factor in crop production.He seems,however, to have neglected in his criticisms the fact,as established by the Rothamsted workers,that more is lost in drainage water than is added by precipitation. Shedd (26) has carried on pot experiments in an effort to determine whether or not sulfur is an important element in plant food.He found that it increased the yield of certain of the legumes but not of clover.He could find no relation between the protein content of the plant and the sulfur content.

Kossovitch (26) has made extensive studies on the sulfur cycle in soils and concludes that the amount added by rainfall will not replace all that is removed by plants and percolation.This leads him to believe that sulfur may in time become as important a factor in soil fertility as phosphorous.Peterson (28) in 1914,reported that he found an increase in sulfur in plant tissues,with an increase in the soil.Hart and Tottingham (29) carried on a similar work and found that the beneficial results with sulfur seemed to be with plants high in protein.Brown and Kellogg (30) made several analyses and found about half as much sulfur as phosphorous and concluded that it might in time become a limiting factor.

Ruprecht (30) did work on the toxic effect of iron and aluminum salts on clover seedlings.This is a different phase of the question of the relation between chemical composition and productivity,but is of more or less importance.He found ferrous sulphate to be toxic if present in as small amounts as four parts per million, and aluminum sulphate to be toxic if present in as small amounts as forty parts per million.He found that this toxic action could be overcome to a great extent by the addition of calciumcarbonate.

Description of the Areas Studied.

The soils used in this work were taken from two separate areas in Michigan:The Wexford County Area and the Allegan County Area.Both of these areas have been surveyed by the United States Bureau of Soils.

The Wexford County Area is located in north western Michigan,at approximately latitude 44 deg. 30 min. N.It is about twenty-five miles from the Lake Michigan shore and consequently is not materially affected by it.The climate is rather cool,ranging from 18 deg.F to 68 deg.F in August;the mean for the year is 42 deg.F. The rainfall is fairly well distributed throughout the year and is sufficient for good agriculture;the mean for the year is 32.4 in.The greater part of the area has good natural drainage ,and most of it is level to gently rolling,although there are some very hilly sections.The soils are of glacial origin and were originally derived from the breaking down of igneous and metamorphic rocks.

The soil is nearly of the Coloma series;there is a small amount of Dunkirk and Clyde.

The oldest parts,agriculturally,have been under cultivation only about twenty-five or thirty years; other parts ten to fifteen years,and a large amount of the area is still unimproved.The chief crops grown are potatoes,corn,some oats,rye,wheat,and hay.No very definite system of crop rotation or soil management is followed except in a few isolated cases.Originallr very good crops of potatoes could be raised,but continued cropping has greatly reduced the yield.

The Allegan County Area is located in south western Michigan, about latitude 42 deg. 30 min. N. It borders Lake Michigan and consequently the climate, especially that of the western part is modified. The mean annual temperature is somewhat higher here than in the Wexford Area, being 47.6 deg. F. The mean annual precipitation is 30 in. and is fairly well distributed throughout the year. The surface is rolling to hilly in some parts. There are considerable areas of poorly drained land, including mucks and soils of the Clyde series. Some of the upland soils are characterized by numerous kettle-holes.

The soil is of glacial origin and has been altered to some extent by water action. The soils are quite varied and the largest areas are of the Miami and Clyde sreies. The area has for the most part been under cultivation for forty to sixty years. The chief crops are fruit and general farm crops in the western part and wheat, corn, hay, oats, and some truck in the eastern part.

In many parts of the county very good systems of crop rotation and soil management are in use; in other parts but very little effort is being made along thar line.

Description of Samples Used.

The next few pages will be devoted to a description of the soils used. This description will include source, type, length of time cropped, chief crops grown, and any other points of value that could be learned

More or less difficulty was experienced in getting a reliable history, especially in the Wexford Area, as most of the farmers had been on their farm but a short time or had kept little or no account of the management. Only those soils are included, however, of which the history is considered fairly reliable. Less dificulty was met with in this respect in Allegan County, and perfect confidence is felt in the information obtained.

In the numbers which are used in the description the letter is the initial letter of the county from which the soil was taken, the number in the hundreds place indicates the series to which the sample belongs, and the rest of the number indicates the number of the soil in the order of taking. The 1 hundred series is Miami, the 2 hundred series is Clyde, the 3 hundred series is muck, and the 5 hundred series is Coloma. For example, W510 is a Coloma soil taken in Wexford County. The s following any number indicates that it is a sub-soil; A205S is the sub-soil of A205.

W510(1) Taken from Sec. 16 Slagel Twp. It has been farmed about ten years with no treatment. The rotation used is corn, oats, beans, and timothy. The crops are rather poor. A medium sand about 6 in. deep, very open.

W510S. (2). A yellow sand to a depth of 24 in.

W511. (3).Avirgin soil comparable to W510. Covered with hard-wood timber.

W513. (4) Taken from Sec. 26 Boon Twp. It has been farmed about thirty years with no treatment.It laid idle for four years and was planted to rye in the fall of 1914.The straw is large but the heads are very small;it will probably yield about fifteen bushels per acre.The surface is a medium sandabout 8 in. deep, open.Beneath this is a compact layer 4 in. thick.

W513S. (5).Medium sand;light yellow to 36 in.

W514. (6).Virgin of W513;covered with hard-wood timber.

W515. (7).Taken in SEc.6 Cherry Twp.Farmed for twenty years with no treatment.The rotation used is corn or potatoes,oats,clover and timothy fot two years;will yield about 25 bu. of corn per acre.An open, medium sand,8 in. deep.

W515S. (8).Light yellow to 24 in.

W516. (9).Virgin of W515.Hard-wood land.

A101. (10).Taken from Sec. 29 Gunplains Twp. Farmed for sixty years with a wheat-clover rotation and no treatment.The crops at present are almost a complete failure,but it would originally produce 40 to 50 bu. of wheat per acre.A medium sand 8 in. deep and very open.

A101S. (11).Light yellow to 24 in. then a hard pan of loosely cemented gravel with quite a large number of large stones just beneath the plow furrow.

A102. (12).Virgin of A101 and covered with an oak forest.The surface soil is 12 in. deep and dark gray.

A102S. (13).Similar to A101S.

A103. (14).Similar to A101 and of the same virgin conditions.

A103S. (15).Similar to A101S.

A104. (16).Similar to A101 and A 103.

A106. (17).Taken from Sec. 30 Martin Twp.. Farmed for sixty years,chiefly to wheat with some corn and clover.Originally produced about 45 bu. of wheat per acre,but will produce neither wheat nor clover at present.Rye will now yield about 10 bu. per acre.Avery open medium sand,8 in, deep.

A106S. (18).Alight yellow,medium sand.Some cement ed gravel at 24 in. and much of it at 6 ft.

A107. (19).Virgin of A106.Surface soil is dark gray in color and 8 in. deep;covered with oak timber.

A107S. (20).Similar to A106S.

A108. (21).Taken from Sec. 8 Martin Twp.A heavy,stony,fine sandy loam.Surface 10 to 12 in. deep. Has been cropped for about sixty years,chiefly wheat and clover,with no treatment.It originally produced 40 to 50 bu. of wheat and 2 T. of clover per acre;now it will produce about 25 bu. of wheat and 1 T. of clover per acre.In only fair tilth.

A108S. (22). A light yellow,gravelly loam to 36 in.

A109. (23).Virgin of A108.Covered with maple, beech,and some hicory.Rather compact.

A110. (24).Virgin of A111,and simolar to A109.

A111.(25). History and type similar to A108.

A112. (26).Taken from Sec. 30 Wayland Twp. Adark colored clay loam,12 in. deep.Cropped to wheat, corn,oats,and hay for fifty years with no treatment. Originally produced 40 bu. of wheat per acre; now about 10 bu.Very compact and in poor tilth.

A112S. (27).Light yellow to gray for 30 in.; very compact.

A113. (28).Virgin of A112.Very compact;covered with hicory,oak,and elm.

A113S. (29).Similar to A112S.

A114. (30).Taken from Sec. 14 Allegan Twp. Agravelly,medium sand.Cropped to wheat,corn,and potaoes for fifty years.Will produce about 25 bu. of corn at present.

A114S. (31).Light yellow in color;gravelly and compact for 30 in.

A115. (32).Virgin of A114;compact;covered with oak.

A115S. (33).Similar to A114S.

A116. (34).Taken from Sec.1 Trowbridge Twp. Amedium sand,6 to 8 in. deep,and very open.Cropped to wheat,corn,and a little clover for 40 years.Originally produced 35 to 40 bu. of wheat and 40 bu. of corn per acre;now no wheat is grown and only about 25 bu. of corn or 10 bu. of rye can be grown per acre.

A116S. (35).Light yellow in color,and unusually open to 36 in.

A117. (36).Virgin of A116;5in.deep;covered with oak.

A117S. (37).Similar to A116s.

A118. (38).Taken from Sec. 5 Trowbridge Twp. A poorly drained clay loam about 6 in. deep.Cropped for fifty years to wheat,oats,corn,and clover,with no treatment.Originally produced large crops,but now only about 25 bu. of oats,and 25 to 30 bu. of corn per acre.

A118S. (39).A compact,impervious,clay.Light colored to 24 in. then darker and a blue clay at 30 in.

A119. (40).Virgin of A118.6in. deep;covered with poplar,willow,soft maple and basswood.

A119S. (41).Similar to A118s.

A120. (42).Taken from Sec. 16 Trowbridge Twp. Cropped to oats,clover,and corn,for fifty years with no treatment.Adark colored clay loam,about 5 in. deep. In poor tilth.

A120S. (43).Clay,light gray to yellow in color, compact.

A122. (44).Virgin of A120.

A123. (45).Taken from Sec. 17 Trowbridge Twp. A medium sand,reddish in color,6 in. deep.Spots of this soil are scattered throughout what is otherwise a very productive field.The corn grows only to a height of 6 to 8 in.,and is red in color.No virgin sample of this soil could be obtained but one was taken about twenty feet from it in a productive spot.

A123S. (46).Ared sand to 20 in. then a white water sand.The water table is 30 in. below the surface. A small amount of blue clay is mixed with the sand and forms a loose hard pan.

A124. (47).Taken about twenty feet from A124; Dark gray in color and 8 in. deep.The corn here is very luxuriant.

A124S. (48).Light gray in color to 14 in. then a white water sand;did not strike the water table.

A125. (50).Taken from Sec. 14 Casco Twp.A gray medium sand,6 in. deep.Cropped to beans,corn,and rye for thirty years,with no treatment.Originally produced 20 bu. of beans,40 bu. of corn,or 20 bu. of rye per acre.Now about one-half these amounts.

A125S. (51).The color is gray to 14 in.,then white to 20 in.,then yellow to 36 in.Compact.

A126. (52).Originally covered with hemlock, maple,and beech.

A126S. (53).Similar to A125S.

A527. (54).Taken from Sec. 14 Casco Twp.A medium sand,gray to yellow in color,8 in. deep.Farmed forty years with no treatment.When new produced 25 bu. of corn or 15 bu. of rye per acre;now only 10 bu. of and 5 to 10 bu. of rye.Very open.

A527S. (55).A perfectly open,yellow sand with no variations for several feet.

A528. (56).Virgin of A527;covered with pine, hemlock,white ash,and cherry.

A528S.Similar to A527S.

A529. (57).Taken from Sec.2 Lee Twp. A light gray,medium sand,6 in. deep.Cropped thirty years to corn,beans,and rye,with no treatment.Originally produced 20 bu. of corn or 15 bu. of rye;now about one-half that amount; very open.

A529S. (58).Yellow and very coarse to a great depth;very open.

A530. (59).Virgin of A529.Covered with beech and maple.and a few pine.

A530S. (60).Similar to A529S.

A204. (61).Taken from Sec. 17 Trowbridge Twp. A clay loam 10 in. deep.Cropped 50 years to potatoes, corn,and oats,with no treatment.At present will produce about 35 bu. of corn or 25 bu. of oats which is only one-half the original yield.

A204S. (62).A heavy,compact clay;gray to 24 in. than yellowish gray to 36 in.

A205. (63).virgin of A204.Covered with elm, willow,and sycamore.

A205S. (64).Similar to A204S.

A206. (65).Taken from sec.16 Allegan Twp.A clay loam,about 14 in. deep.Farmed forty years to corn, oats,wheat,clover,and timothy,with no treatment.At present it produces about 20 bu. of wheat,and 35 to 40 bu. of corn per acre, which is only about one-half the yield of similar virgin fields.

A206S. (66).A heavy,dark colored clay to 20 in. then a light gray clay to 30 in.

A207. (67).Virgin of A206;covered with elm, oak,and maple.

A207S. (68).Similar to A206S.

A208. (69).Taken from Sec. 16 Casco Twp.A grayish brown sand,10 in. deep.There are patches of this soil scattered throughout the Clyde area of this part of the county.It will produce nothing; other parts of the field are very productive.It has been farmed about forty years.

A208S. (70).The first 10 in. is dark brown in color,then it becomes lighter,and from 18 in. to 36 in. it is white.Water table at 36 in.

A209. (71).Taken from See. 18 Lee Twp.A medium sand,dark gray to red in color,14 in. deep.
Farmed twenty-five years to corn,oats,potatoes,and hay with no treatment.The crops are a complete failure.

A209S. (72).A medium sand; hard,wet,yellow in color,and impervious.

A210. (73).Virgin of A209.Covered with poplar, elm,soft maple,and white ash.

A210S. (74).Similar to A209S.

Experimental

The samples obtained in the field were taken into the laboratory, thoroughly mixed, and a small sample of about 35 gms. taken. This sample was ground until fine enough to pass through a sieve of 100 meshes per square inch.

The first work done was to determine the total amount of phosphorous, nitrogen, sulfur, potassium, and calcium in each sample. The nitrogen was determined according to the Gunning method for total nitrogen; the phosphorous was determined according to the official method for total phosphorous; the calcium by the method used in the laboratory of the University of Illinois, as recorded in the appendix of "Soil Fertility and Permanent Agriculture" by Hopkins; and the sulfur by the method used in the University of Wisconsin, as recorded in Wis. Res. Bull. 14. The potassium was determined by the Lawrence Smith method.

The results are recorded in Table I.

Table I.Giving the Total Am

the Lime Requirement of Each Sampl

Sample No.	Virgin of	% N	% P
1		0.060	0.0
2		0.055	0.0
3	1	0.09[illegible]	0.0
4		0.1.25	0.0
5		0.04[illegible]	0.0
6	4	0.140	0.0
7		0.[illegible]	0.0
8		0.04[illegible]	0.0
9	7	0.0[illegible]4	0.0
10		0.079	0.0
12	14,10	0.161	0.0
13		0.076	0.0
14		0.105	0.0
15		0.0[illegible]	0.[illegible]
17		0.066	0.0
18		0.071	0.0
19	17	0.17[illegible]	0.[illegible]
20		0.067	0.[illegible]
21		0.1[illegible]	0.[illegible]
22		0.075	0.[illegible]
23	21	0.224	0.[illegible]
24	25	0.470	0.[illegible]
25		0.240	0.[illegible]
26		0.1[illegible]	0.[illegible]
27		0.100	0.[illegible]
28	26	0.2[illegible]6	0.[illegible]

Table I. (continued).

Sample No.	Virgin of	% N	% P (
29		0.140	0.1
30		0.09[illegible]	0.1
31		0.039	0.0
32	30	0.107	0.1
33		0.072	0.0
34		0.084	0.1
35		0.039	0.0
36	34	0.115	0.1
37		0.075	0.0
38		0.165	0.0
39		0.038	0.0
40	38	0.300	0.0
41		0.096	0.0
42		0.135	0.0
43		0.075	0.0
44	42	0.185	0.0
45		0.142	0.0
46		0.063	0.0
47		0.145	0.0
48		0.058	0.0
50		0.104	0.0
51		0.029	0.0
52	50	0.187	0.0
53		0.030	0.0
54		0.072	0.
55		0.075	0.0
56	54	0.109	0.0

Table I. (Continued)

Sample of	Virgin of	% N	% P
57		0.105	0.07
58		0.065	0.06
59	57	0.193	0.08
60		0.074	0/08
61		0.255	0.03
62		0.97	0.06
63	61	0.669	0.17
64		0.096	0.0
65		0.304	0.12
66		0.152	0.10
67	65	0.417	0.09
68		0.162	0.0
69		0.161	0.0
70		0.071	0.0
71		0.141	0.0
72		0.019	0.0
73	71	0.153	0.07
74		0.051	0.03

A comparison between the per cents of the vafious plant food elements,and total plant food of productive and unproductive soils,of the same and of different types,brings out some very interesting points.

First a comparison might be made between soils 12 and 25.The former is a virgin medium sand and will produce from 40 to 50 bu. of wheat per acre,and other general farm crops in proportion.It contains fairly large ampunts of all the various food elements with the exception of phosphorous; in this it is deficient.It has a total of 1.965% of plant food. 25 is a cropped fine sandy loam which will produce only 20 to 25 bu. of wheat and other farm crops in proportion.It contains large amounts of all the plant food elements ,and a total of 3.431% of plant food,or nearly twice as much as 12,fet will produce only about half as much.That is to say o.161% N,0.037% P,1.391% K,0.067% S,and 0.259% Ca will produce as large a crop in a virgin medium sand as 0.240% N,0.156% P,2.231% K, 0.0103% S, and 0.611% CaO in a cropped fine sandy loam.

We have a similar condition in the relation between soils 19 and 38.19 is a virgin medium sand which will produce 40 bu. of wheat per acre;it is low in no essential element with the exception of phosphorous.It has a total of 1.868% of plant food.38 is a cropped clay loam which will produce about half a normal crop.It is very deficient in phosphorous but in no other element,and has a total of 2.434% of plant food.Or in other words o.165% N, 0.051% P, 1.752% K, 0.040% S, 0.426% CaO,is producing about one-half as much in a cropped clay loam as 0.178% N,0.086% P,1.365% K, 0.059% S, and 0.380% CaO, in a medium virgin sand.

Other similar comparisons might be made; 32, a virgin medium sand with a total of 1.646% of plant food, produces more than 21, a cropped fine sandy loam, with 2.203% of plant food. 50, a virgin medium sand with a total of 1.851% of plant food, produces more than 26, a cropped clay loam with a total of 2.2358% of plant food.

Thus we have a series of comparisons between productive and unproductive soils of different types. It would also be of value to compare productive soils of one type with productive soils of another type. Soil 12, with a total of 1.965% of plant food, 19, with a total of 1.868% of plant food, are productive medium sands; 23 with a total of 2.751% of plant food, 24, with a total of 4.550% of plant food, are productive fine sandy loams; 28, with a total of 3.879% of plant food, 40, with a total of 3.655% of plant food, and 44 with a total of 2.862% of plant food, are productive clay loams. Here we have a series of soils of very nearly equal productivity, buy of different types, and varying in total amount of plant food from 1.916% in medium sand to an average of 3.430% in the heavy loams.

To make the comparison complete two or three more soils should be mentionedwhich are virgin and contain fair amounts of plant food, but which are not productive. 56 and 59 are medium sands, uncropped, and with a total of 2.282% 2.310% of plant food respectively. This is considerably above the average for the productive sands mentioned above. 73 is a medium sand with 1.803% of plant food, only a trifle under the average for the sands but is very unproductive.

We now have comparative data on productive and unproductive soils of the same and different types. One of the most obvious facts brought out by these data is the great difference in the relation between composition and productivity ,due at least apparently,to type. A much lower amount of plant food is needed in a sandy soil to produce a given crop than is needed in a finer,loam soil. This might be due to a difference in the availability of the nutrient salts present,or to a difference in the physical conditions. Poor tilth and drainage might easily account for the difference between 19 and 38. Much of the organic has been removed from 38,leaving a poor condition of tilth and the drainage is poor. Both of these conditions are dertrmental to aeration and bacterial activity,and consequently the plant food might become available more slowly,and the roots of the plants might be hindered in their development. Poor tilth might also explain the differences between 50 and 26. It would not,however explain the difference between 12 and 25 or 32 and 21. The possibility of availability being the determining factor will be discussed later;but it is very probable that the difference is due in a large measure to type and consequent differences in texture. As pointed out by Hilgars,the coarser textured soils are more easily penetrated and allow a more extensive root development,and thus the roots may come in contact to with a larger amount of plantfood.

One further comparison of variations within the class should be made. 12 has already been discussed;56,59,and 3 are of the same class as 12. The type is different;12 is a Miami medium sand and 56,59,and 3 are Coloma medium sands.

The three latter are coarser,more open,and are underlaid with a coarse and very open sub-soil.These physical characteristics of the Coloma soils coupled with a probable difference in their geological origin and mineral composition so reduce their water holding capacity that their pdoductivity is very low.

As a result,then, of a comparison of the producing capacity of various soils we find that an interpretation of such analyses must be modified by a considereation of the class,drainage,sub-soil,organic matter content,and all other conditions which may in any way affect the bacterial conditions and the availability of the plant food.

This brings up the question of the relation between the amount of avaioable plant food and the producing power of the soil.Owing to the limited amount of time available for the work,only one sample of each type was used,and only the available phosphorous and potassium were determined.

The digestions were made with N/5 HCl and the determinations made according to the official method.

Table II gives the results obtained.The soils are arranged according to type and the results given in parts per million (ppm)

Table II .Showing the ppm. of Available K_2O and P_2O_5 in the Various Types of Soil.

Sample No.	Class	Virgin of	ppm. K_2O	ppm. P_2O_5
1.	Medium S		170	103
3	"	1	130	100
54	"		93	167
56	"	56	190	174
12	"	14	130	397
14	"		160	360
45	"		240	76
47	"		270	166
71	"		120	267
73	"	71	100	179
24	Fine S L	25	290	210
25	"		120	370
38	Clay L		220	61
40	"	38	290	80
42	"		120	43
44	"	42	190	64
65	"		250	263
67	"	65	330	232

Areview of this table will show that it is more or less difficult to draw from it any conclusions concerning the availability of phosphorous and potassium in relation to productivity.

It is not certain that the quantities indicated in the table really indicate the amounts actually in the soil because considerable quantities of each of these elements might go into solution,but be readsorbed by the soil;in this case the filtrate would contain less after filtering than had previously been in solution.This would be especially true of the finer types of soil.

Using the results given in the table as a basis for discussion,it would seem that in no case should the amount of soluble material be a limiting factor except in the case of the phosphorous of the clay loams and 45.

But the mere fact that certainamounts of these elements are soluble in weak acid,doesn,t necessarily mean that they will be available to the plants under the conditions as they actually exist in the field.For example in the soils 12 and 14,the former virgin and very productive,the latter cropped and very unproductive,the amount of soluble phosphorous and potash has not been changed enough to cause such a marked difference in productivity.But the organic matter in 14 is so much lower than it was originally that the water holding capacity has beenbgreatly reduced and one would not expect to find so much of the nutrient salts actually in the soil solution as in 12,although it might be in a soluble form.

Also there may be enough soluble plant food in the soil for good plant growth,yet the structure of the soil and other conditions of tilth be such that the root system cannot come in contact with sufficient quantities of it to give the best results.Thus,in 25 and 12,we find only a small difference in the amount of soluble material present,yet soil 12 is much more productive.It is more open and permits of a better root development and consequently the soluble ma material may be more compleyely utilized.

Another factor not brought out in the table,but which might partially explain the lack of correlation between the dissolved material and the amount of plant growth supported,is the availability of the nitrogen.If the conclusions of Winter and Robson (20) be correct,that nitrogenous compounds become available more rapidly in sands than in finer classes of soil,then a smaller amount of nitrogen in a sand would produce better results than a laregr amount in a loam soil due to its greater activity.It is also conceded that the nitrogen of a virgin soil is more active than that of a cropped soil;consequently,although there might be a large amount of nitrogen in a cropped soil,as in 25,than in a virgin soil like 12,yet its inactivity might be a limiting factor.

Thus we find difficulty in interpreting results obtained in availability studies withoutna careful consideration of all other limiting factors.

The ohter phase of the subject,the effect of cropping upon the chemical composition, will next be taken up. The cropped soils have been arranged in Table III according to type,and the per cent loss of nitrogen,phosphorous,potassium, sulfur,and calcium recorded,together with the number of years of cropping.

Table III. Showing the Per Cent Loss of the Various Food Elements and the Number of Years Cropped.

Sample	Type	N Loss	P Loss	K Loss	S Loss	Ca Loss	Cropped
1	M.S.	38.7 %	33.3 %	2.60 %	39.0 %	23.4 %	25 years
4	"	11.4 %	12.2 %	9.20 %	58.6 %		30 "
7	"	10.6 %	28.8 %		14.4 %		20 "
10	"	50.9 %	20.6 %	7.60 %	31.3 %		60 "
14	"	34.1 %	20.6 %	10.8 %	59.6 %		60 "
17	"	62.9 %	13.9 %	14.8 %	54.2 %	4.7 %	50 "
30	"	8.4 %	22.6 %	4.6 %	6.6 %	33.6 %	50 "
34	"	26.9%	23.6 %	8.50 %	33.3 %	16.0 %	40 "
50	"	44.3%	20.0 %	5.70 %	27.1 %	30.2 %	30 "
54	"	33.9 %	10.0 %	12.3 %	14.0 %	12.3 %	40 "
57	"	45.6 %	15.1 %	6.30 %	33.8 %	9.0 %	30 "
71	"	10.7 %	45.8 %	7.30 %	12.4 %	20.0 %	25 "
21	F.SL	18.8 %	18.1 %	24.4	15.5 %	11.1 %	60 "
25	"	49.3 %	31.9 %	20.1 %	20.1 %	25.1 %	60 "
26	CL	41.5 %	6.40 %	41.20 %		29.8 %	50 "
38	"	45.0 %	40.6 %	11.30 %	40.2 %	65.4 %	50 "
42	"	27.0 %	21.7 %	5.60 %	3.30 %	8.30 %	50 "
65	"	27.1 %	gain	6.80 %	11.4 %	1.60 %	40 "

Only discussions of a rather general nature will be possible of Table III for the following reasons:certain losses have ocurred inthe virgin soils during the time which the corresponding cropped soils have been under cultivation ; consequently it is impossible to know the exact original composition of the cropped soil. Also it has been entirely impossible to determine the exact number of the various crops that have been removed from the soil during the period of cropping;and as there is so great a variation in the composition of the crops removed it is impossible to more than approximate the amount removed by the crops.

The losses from the soil are brought about through percolation,surface washing,some loss of nitrogen into the air,and by the removal of crops.All of these losses are of course greater in cropped than in uncropped soil,although there are some losses from the uncropped soil due to percolation.

The highest per cent of loss seems to be in the case of nitrogen.In practically all cases,judging from the length of time cropped,the loss of nitrogen is greater by far than that brought about by the removal of plants alone.This is especially true of the sands.Although there is no great difference in the average loss in the sands and the loams it must be kept in mind that the amount of material really removed by cropping from the sands is much less.Soil 10 has been cropped the same length of time as 21 or 38 and originally produced as much, yet during the last half or more of the fifty or sixty years of cropping the production on the sands has been far behind that on the heavier types and at present practically nothing is being taken from the sands,and the loams,especially 21,are still producing crops that mean a distinct loss in plant food.

Thus the loss in other ways must be greater in the sands.Soils 10,14,17,and 30,are open soils and consequently the oxidation of the organic matter would take place very rapidly,and although the sub-soils are not excessively open, yet the loss by percolation would be great during cropping. Oxidation would be much slower in the loams.

In the soils,1,4,7,34,54,and 57,we have not only a very open surface soil but a perfectly pervious sub-soil, both of which conditions greatly promote the loss of nitrogen Consequently,although none of these soils have produced a large aggregate of crops yet the nitrogen loss is comparatively,high,considering the time of cultivation.

The loss of phosphorous averages considerably than that of nitrogen.This is probably due to the fact that plants remove less as food and that there is less loss by percolation, due to its insoluble form in the soil.It is noticeable that the losses are somewhat higher in the loam soils than in the sands,due to the fact,no doubt,that the removal by cropping is much greater and the possible loss by percolation is small.65 and 71 are striking exceptions to the above statement.It is impossible to explain the great loss of phosphorous from71 without further study into the form in which it occurs as this is an unusual soil.The gain in 65 is undoubtedly due to imperfect sampling.

The losses of potash,in percents,are considerably lower than those of phosphorous or nitrogen.This is because of the much larger amount of potash in the soil,and the actual loss in pounds per acre is greater.

There is a somewhat greater loss in the loams than in the sands due, as in the case of phosphorous, to the greater total amount of production by the loams and the comparatively small loss due to percolation.

In a consideration of the loss of sulfur, two points are of especial interest. The first of these is the fact that there is a decided loss of sulfur from the soil due to cultivation. This fact is worthy of notice at this time because of the discussion in recent literature as to the improtance of sulfur as a factor in soil fertility. These results correspond very favorably to those obtained at other station And in as much as sulfur is considered a necessary element of plant food and is a constituent of all protein compounds, it would seem that sulfur should be considered a factor in fertility problems.

The second point of interest is the relation between sulfur and nitrogen. Although it cannot be said that there is a distinct relation between total sulfur and total nitrogen, yet it is evident from Table I that there is some relation and those soils that are especially highin nitrogen are likewise high in sulfur. The reverse of this, however, isnot always true but the striking relation between the two elements is that of the losses due to cropping. It will be seen from Table III that with but two or three exceptions a high loss in nitrogen is accompanied with a high loss in sulfur, and a loss in nitrogen by a low loss in sulfur. This might be accounted for by the close association of each element with the protein compounds. Plants which are high in protein of course take up large amounts of nitrogen and the same thing has been found to be true with sulfur(29). Thus a large removal of nitrogen by plants should be accompanied by a large removal of sulfur.Likewise when the plant tissues in the so l decay and break down into soluble compounds the nitrogen and sulfur will be associated in the accompanying loss by percolation.

The last element to be considered in connection with its loss due to cropping is calcium.A considerable difficulty was met with in gettigg consistent data on calcium content and loss due,probably,to sampling in the field,as it has been found that a much larger number of samples is necessary to make up a representative composite than is the case with the other elements.The loss is in all cases,of course,far beyond that which could be caused by cropping alone.The loss by percolation depends upon the nature of the compounds in which the calcium occurs.The highest losses recorded o cur in the loam soils in which the calcium is probably in the form of a carbonate.

One of the most interesting and practical phases of soil depletion by cropping,is the difference in the lasting powers of thebdifferent types of soil;that is the difference in the length of time which the various types of soil will produce profitable crops.This subject,with the relation t the original vegetation,will bebtaken up at this point.

Soils 12,19,23,24,56,59,and 67 will be used in the comparisons.12 and 19 are Miami sands covered with oak timber. These soils are at present producing no profitable crops, and have not for the past twenty years.Soils 23 and 24 are Miami loams covered with hard-wood timber including beech maple,and some hicory.There has been only a gradual decrease in the productivity of these soils,and even at present,after fifty years of continuous cropping,they are producing crops at a profit,even though it is small.56 is a Coloma medium sand,covered chiefly with pine,with some hemlock and cherry. 59 is essentially the same type,but is in a region of transition between the Coloma and Miami series,and is covered with small maple and beech timber.These soils produced fairly good cropd for the first two to five years,then decreased very rapidly in productivity,and no profitable crops can be grown after ten years.67 is a Clyde loam covered with elm,maple,and a great deal of oak.Its productivity,like that of 23 and 24,has decreased gradually and it will still produce a somewhat profitable crop.

Thus we find that the upland,oak soils are much less lasting than the low land oak soils,or the up land typical maple and beech soils.The pine up lands are much less lasting than the hard-wood up-lands:this is duevery largely to their coarse texture and open structure,which decreases their water holding capacity and increases oxidation to a great extent.

As a summary of this point,it is apparent that oak lands,if low,are very lasting in productivity;and if high are only moderately so.The maple and beech up lands campare very favorably with the oak low lands in this respect.The least valuable from the standpoint of ability to produce profitable crops over a series of years,are the Coloma pine soils.

The next and final phase of the work to be discussed is the changes in the acidity of the soils due to cropping. The Veitch method was used in making the lime requirement determinations.

The results are recorded in Table IV.

Table IV. Showing Changes in Lime Requirement. No sign before the Number in the Last Column Indicates the Change to have Been an Increase. A - sign indicates a Decrease.

Sample	Virgin of	CaO Requirement	Change
1		2500 Lbs. per A	2500 Lbs.
3	1	None	
4		2000 " "	2000 "
6	4	None	
7		2000 " "	500 "
9	7	1500 " " "	no change
10		1000 " " "	" "
14		1000 " " "	
12	14	1000 " " "	
17		600 " " "	-1640 "
19	17	2240 " " "	
21		1600 " " "	-800 "
23	21	2400 " " "	
26		1100 " " "	-3300 "
28	26	4400 " " "	
30		None	no change
32	30	"	
34		1300 " " "	-500 Lbs.
36	34	1800 " " "	
38		2700 " " "	2500 "
40	38	None	
42		"	-800 "
44	42	800 " " "	
50		3000 " " "	-3000 "
52	50	6000 " " "	

Table IV. (Continued)

Sample	Virgin of	CaO Requirement	Change
54		2000Lbs.per A	300 Lbs.
56	54	1700 " " "	
58		3400 " " "	-5600"
59	58	9000 " " "	
61		None	no change
63	61	"	
65		"	" "
67	65	"	
71		4200 " " "	2850 Lbs.
73		1350 " " "	

In making an attempt to discuss or explain the results gimen in Table IV it must be kept in mind that our knowledge of the exact nature of soil acidity, the factors which produce it and which correct it, are more or less limited, and that the methods of determining the lime requirement are somewhat arbitrary and may not be accurate.

For purposes of dixcussion, the acidity will br considered as positive and negative. The positive acidity being due to the actual presence of acid and the negative acidity being due to the lack of sufficient bases to satisfy the adsorptive power of the soil for bases. An accumulation of organic matter, poor drainage, or other conditions detrimental to oxidation, would undoubtedly increase the positive acidity, and anything that would increase the oxidation or improve the drainage would have a tendency to decrease it. Any factor which removed the basic material of the soil would undoubtedly increase the negative acidity.

In five of the cropped soils studied, three sands and two loams, neither an increase non a decrease in the acidity is noticeable. These are 10, 14, 30, 60, and 65. 12 is the virgin of 10 and 14, and 32 is the virgin of 30. These virgin soils especially 12, contain a considerable amount of organic matter and were covered with quite a large accumulation of leaf mold etc. Although this accumulation was entirely removed before sampling, it no doubt has had a marked effect on the acidity beneath. This material has been very largely oxidized in the corresponding cropped soils. Thus any increase in negative acidity which has been brought about by a removal of bases in the cropped soil has been counterbalanced by the decrease in positive acidity. The negative acidity would also be somewhat decreased by the oxidation of the organic colloids, thus reducing the total adsorbing surface.

In soils 61 and 65, the original basic content was great enough to enable the soil to retain its basic reaction for a considerable number of years.

In four sandy soils, 17, 34, 50, and 58, and two loams, 21 and 42, there has been an actual decrease in the lime requirement. This is no doubt due to the same causes mentioned in the preceding discussion but the oxidation of the acids and the organic colloids has been more complete. The virgins of 21 and 42 are very high in organic matter which has been quite extensively oxidized in the cropped soils.

In five sands, 1.4.7.52, and 71, and in one loam, 33, the lime requirement is increased. In the first four soils mentioned the amount of acidity lost by cultivation has been more than counterbalanced by the increase due to the removal of bases and we have an increase in the lime requirement as a result. 71 is a special case and there is a strong possibility that the acidity is due in part to an acid ferrous salt, as there is a large amount of iron in the soil. This cannot be lost by percolation because of the impervious subsoil. 38 is in very poor tilth and consequently there is a chance for the accumulation of acids.

Thus we find that contrary to the rather general opinion that cropping increases acidity, it as often decreases it as it does increase it. This is at least true in so far as our present methods are reliable.

It was hoped that same relation might be worked out between acidity and crop production,but owing to the large number of other factors that are present to influence the yields,it is impossible to draw any conclusions along that line.Some of the soils that have decreased the most in productivity have no greater lime requirement than they had when virgin,as judged by the uncropped soil;and some soils which have an increased acidity have shown the least decrease in producing capacity.

Summary

Probably few if any, entirely new facts have been brought out by the work reported in this paper. Certain facts, however have been emphasized by the data presented here, and our knowledge of Michigan soils has been greatly increase

I. Effect of chemical composition upon productivity.

1. The most valuable point brought out by the data on this phase of the subject is great variation in productivity due apparently to type.

2. The same amount of plant food will produce much better results in a sandy soil than in loam soil.

3. The same amount of plant food in a virgin soil will produce better results than in an old soil.

4. The same amount of readily soluble plant food will give better results in a sandy soil than in a loam soil.

5. in some soils the availability of the plant food is increased by cropping, and in some soils it is decreased. The type and physical condition of the soil has a great deal to do with this.

II. The effect of cropping upon the chemical composition.

1. All food elements are lost in greater quantities than could be caused by cropping alone.

2. The greatest loss is in nitrogen, due to large amounts taken up by plants and the oxidation of organic matter and the subsequent loss by percolation.

3. Smaller amounts of phosphorous and potash are lost by percolation, consequently their decrease is not so great.

4. There is a close relation between the loss of

nitrogen and that of sulfur, due probably to their associaiton in protein compounds.

5. Cropping, under certain conditions increases acidity and under other conditions decreases it. The effect is determined in a great measure, no doubt, by the cause of the acidity.

III. Lasting powers of soils.

1. The Clyde oak lands and the Miami maple and beech lands are much more lasting than the Miami oak lands.

2. The Coloma pine lands are the least valuable of all types from this point of view.

General Conclusions

It seems quite apparent that the mere chemical composition of the soil is only one factor in determining its productivity. The solubility of the mineral constituents is determined to a great extent by the physical conditions of the soil, and the use which the plant can make of these constituents after they become soluble is also governed quite largely by physical conditions.

Thus it is of but little use to study the chemical conditions of the soil in the hope of arriving at some definite conclusion concerning its producing power without an equally exhaustive study of its physical conditions.

It is planned to take up this phaseof the work more extensively late on.

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