X.—Fertilizers on Sandy Soil.—By Prof. H. W. Smith, B. Sc., *Provincial Agricultural School, Truro, N. S.*

The soil of the farm for the Provincial School of Agriculture possesses a very fine texture and is of the same constant character throughout the entire farm. It is formed from the red sandstone and was evidently made up in the same way as any sand bank at the side of the mouth of a river opening into the Bay of Fundy. The soil varies from five to thirty feet deep and has underlying it at least one hundred feet of red sandstone rock. How much more is not known. The sub-soil is of the same character as the soil. This sandy soil is very fine, almost an impalpable powder. It is easily tilled, fairly fertile, yielding about twenty bushels of barley cr two hundred and twenty-nine of potatoes per acre, in each case without manure.

We propose to make a careful investigation of this soil and its relations to plant growth. These investigations will be conducted by some of the students of the School under my directions. At present they are pursued as follows: the analysis of the soil and the effects of fertilizers upon it, by Mr. Trueman, and the relations of plants to the soil by Mr. Moore. It is hoped that by the next session of the Institute a report of progress in this work can be made. In the present paper we will try to point out lines along which our work will lie and some experiments which will enable us to work more intelligently.

Many experiments have been conducted by investigators upon the characters of soils and their relations to fertilizers and plants. But our conditions are so different that they afford us only general information and on many points none. With a climate approaching that of England in rain-fall but very much colder, the valuable experiments of Lawes and Gilbert are scarcely applicable here. Again their experiments were conducted on very fertile soil. Most of our soil would not compare with it. In the same manner, it could be shown that other experiments are not applicable for similar reasons.

This paper then will form a preface to further contributions.

PART I.

THE PHYSICAL AND CHEMICAL PROPERTIES OF THE SOIL—ITS RELATION TO MANURE.

Johnson classifies the physical properties of the soil as follows: 1. Weight of soil; 2. State of division; 3. Hygroscopic capacity; 4. Power of condensing gases; 5. Power of fixing solids from solution; 6. Capillary power; 7. Change of bulk on drying; 8. Adhesiveness; 9. Relations to heat.

These properties of our soil are now under investigation. We may point out certain peculiarities, however. It is very fine silicious sand, so fine that it is scarcely gritty. When crops are suffering from drought on other soils in the same locality, those on our soil do not seem affected to such a degree. Not much change of bulk takes place on drying. (?) It is not adhesive and is a very warm soil. Although we have had the farm only two years, it shows marked effects the second year from the application of fertilizers the first. These are the indications as to the physical characters of the soil; they may be considerably modified by analysis.

The chemical composition of the soil cannot now be discussed further than to call attention to facts directly used in this paper, discarding the so-called inert material of the soil for the present.

Nitrogen is found in soils in the form of ammonia, nitrates and insoluble organic compounds. The ammonia usually exists in the soil either as double salts with insoluble bases or as double silicates. A small amount always exists in solution, as it is during the warmer season constantly being formed, or absorbed.

Nitrates probably exist in the soil in the form of nitrates of potash, ammonia, soda, lime and magnesia. The insoluble forms of Nitrogen are in most cases not available unless converted into ammonia or nitrates.

Nitrates are not fixed by the soil like the ammonia, but exist there for the most part as freely soluble.

Phosphoric acid, although so important to the plant, occurs very sparingly in the soil. It is there in the form of lime, iron, magnesia, and aluminium phosphates, all more or less insoluble.

Potassium occurs in the form of silicates, especially hydrated silicates. It is not abundant.

A discussion of the other constitutents is not required in this paper.

" From a great number of experiments made by Way, Liebig, and many others, it seems to be established as a general fact that all tillable fields are able to decompose salts of the alkalies and alkali-earths in a state of solution in such a manner as to retain the base together with phosphoric and silicic acids, while the hydrochloric, nitric and sulphuric acids remain dissolved in union with some other base besides the one with which they were originally dissolved."

This power varies in regard to the time required, the completeness of the absorption, and the quantity absorbed. It is increased by adding bases to the soil and diminished by treating the soil with acids. It is probably due to hydrated double silicates. It is a part of good farming to increase them. We find them very abundant in the rocks around the Bay of Fundy and possibly they may in a measure account for the fertility of our marsh lands.

It may also be added that when one base is introduced into a soil it usually, more or less, displaces some other base, but it has not been shown that this invariably follows. Ammonia is least readily displaced and potassium follows next.

Phosphates are probably retained by the soil by the production of insoluble double phosphates.

Bases may be retained by the formation of double salts, especially with iron hydrates.

THE EFFECT OF FERTILIZERS AND MANURE UPON THE SOIL.

The probable effect of the application of ammonia salts to the soil would be to slightly increase its absorptive power. This would be still more marked with potassium compounds and sodium nitrate—the only form in which we apply nitrates. Most of the ammonia from manure is converted into nitrates, but how far this is true of ammonia salts is not known. Phosphates would in a short time become insoluble double phosphates. With manure the case is different. All our manure is applied before fermentation begins. It contains no ammonia, but presumably ammonia is formed in the soil from the soluble nitrogen compounds it contains. The conditions which would tend to cause this change would be such as would favor nitrification, and the ammonia would immediately be converted into nitric acid. These conditions are decaying organic matter in contact with the soil containing nitrifying ferments. When ammonia salts as a fertilizer are applied, such is not the case, and the salts, if applied in any considerable quantities, would retard the action of the ferments, or might even kill them. This is only a surmise till we have investigated it more fully; but whatever the cause, ammonia salts, as will be shown, appear actually iujurious to most of our crops, especially potatoes. This we suggest as an explanation till we have found out what is the truth. Phosphates, whether in manure or not, soon become precipitated into insoluble phosphates. These are dependent on what bases are most abundant in the soil. In manure the phosphates are, like all the other constituents, very finely divided, and the decomposition of products of the manure tend to hold the phosphates longer in solution or to dissolve those freshly precipitated. This would not be the case with phosphates of fertilizers, for they have no organic decaying matter in close proximity to them unless we except fine ground bone, and that class of fertilizers. The potassium is present first as carbonate, then as rapidly as nitric acid forms it would be combined with it and with the other organic acids present. Its tendency would be to pass over into the zeolites in a short time.

PART II.

PLANTS:—THEIR COMPOSITION AND RELATION TO THE SOIL.

The elements essential to agricultural plants are potassium, calcium, magnesium, phosphorus and sulphur. Besides there are constantly found in plants, iron, chlorine, sodium and silicon. Iron undoubtedly is indispensible to the growth of plants. Chlorine might possibly be added also. In regard to sodium and silicon the case is different, and we will take time to point out that probably these are not required for plants, —especially as it is often erroneously taught that plants require them, particularly the latter, to strengthen their stalks. It appears from experiments that sodium cannot be wholly excluded from plants on account of its universality, but that in so far as it is or can be excluded, the plants do not suffer for it. Silicon is always present in the plant when grown under natural conditions. It occurs in largest proportions in the outer portions of the plant, especially the bark and leaves, and in the parts surrounding the seeds. It varies very much in the same and in different plants. The amount present depends on the amount of it soluble in the soil. Sachs has shown that the amount in the ash of the Indian corn could readily be reduced from 18% to 7½% without injuring the growth in the least. Knop grew a maize plant with 140 ripe kernels in a medium so free from silicon that there was only a trace of it found in the root, but half a milligram in the stem, only 22 milligrams in the leaves, and none in the seed. Knop thought that the little that he found was due to dust and was not present in the tissues. He says, "I believe that silica is not to be classed among the nutritive elements of the Gramineæ, since I have made similar observations in the analysis of barley." In experiments conducted by Sachs, Knop, Nobbe, and Siegert, Stohmann, Raute, Rautenberg and Kuhn, Birner and Lucarius, Leydbecker, Wolff and Hampe, it was, as far as possible, excluded from the food of plants grown in glass vessels, without any injurious effects to the plants. A number of plants of different species have been grown to full development without an appreciable amount of it being present.

Davy supposed that the function of silicon was to serve as a support to the plant as bones do to the body of an animal. But we find that the proportion of silicon is not greatest in those parts which require the greatest strength. The analysis of the oat shows that the upper part of the stem and leaves contain more silicon than the lower part of the stem, which certainly requires to be the strongest. In the experiments above, the stem was not weakened in the least when grown without this element. A sample of wheat straw was brought to our attention from New Annan, Colchester County, and the farmer complained that just at harvest time the straw, especially wheat, broke off just below the head, and that he lost a considerable amount of grain from this cause. When the straw was analysed it was found to contain a large percentage of silicon in the upper internode just below the head where it broke. Again the wood of our various trees is surely strong, but it possesses scarcely any ash, and of this ash only a small part is Silicon. The bark, however, which is so brittle and weak often possesses a large percentage.

Of the volatile parts of the plant only a word is required. Plants obtain their nitrogen from the compounds in the soil. It is possible that the clover may obtain a little from sources that are not available to other plants, but it is not necessary to discuss the point here. The most of our cultivated plants depend on nitrates and ammonia, and can possibly use one or two of the other forms of combined nitrogen in the soil.

Of all the constituents of the plants mentioned above, only three are usually in such small quantities or in such insoluble forms in the soil that the plant cannot obtain them. In order to be unavailable to the plant, they must be locked up in quite insoluble forms, for the plant is able in a measure to make its own solution. It can undoubtedly dissolve out bases from the hydrated silicates, and, probably, also put double salts containing potassium or ammonia in solution. Double phosphates containing alkalies are probably often soluble to the roots.

Our soil is a sandy soil. These are held in bad favor by popular opinion. They are called leachy. They are said to possess all that a soil should not have, and none of those properties which a soil should have. Fortunately their reputation is worse than they are. The effect of the application of fertilizers to them would be in the highest degree to increase the absorptive power for valuable constituents except nitrates. These it might be expected would be washed out of sandy soils more rapidly than from other soils. Every application of fertilizers would increase its absorptive power for other constituents. As to how far these plant foods are likely to be washed out again, is a subject for investigation, They should be in a very available condition for the plant. Manure, when applied to such soils, would increase their retentive power for water, and by its decay in the soil might improve their physical and chemical properties immensely.

PART III.

What does our Soil Require?

The problems that presented themselves to us on taking possession of the farm for the School in the late fall of 1888 contained among others the following questions: —

What plant foods are there in the soil?

How abundant, and how accessible to the plant?

Is the difference in demand made by the different crops shown by application of fertilizers?

In order to answer these questions, some experiments were undertaken as soon as we obtained possession of the farm. These were confined to Nitrogen, Phosphorus and Potassium. In each application of fertilizer a slight excess over what it was thought would be required for the plant was used. The same amount of each was used when used together. Forty-two separate trials were made during the past two years, the results of which are recorded in this paper. Instead of giving the amount of the different yields, I have reduced the increased yield to per cent. of increase over the unmanured plots. This enables us to compare the results one with another much more readily.

The table gives the year, the crop, the fertilizer applied, and the per cent. increase. In each set of experiments the plots were treated exactly alike in every other respect. It will be observed that each ingredient increased the yield when applied alone, that as a rule, when two were applied together the inerease was greater than when a single ingredient was applied, but not double that of either, finally, that when three were applied, the increase was often over three times that caused by a single ingredient. The results from manure on potatoes are worthy of notice.

The Nitrogen was applied as Sodium Nitrate and as Ammonium Sulphate, Potassium as Potassium Sulphate and Chloride, Phosphorus as Mono-, Di- and Tricalcic Phosphates.

TABLE I.

Showing the per cent. of Increase of each Crop from the Application of different Fertilizers.

Fertilizer.	Crop.	Year.	Per Cent. Increase.	Average.	
$NaNO_3$	Potatoes	1889	12.2		
"	"	1890	6.3		
"	Grass	1889	7.6	17.4	
"	"	1890	43.5		
$[NH_4]_2SO_4$	"	1889	9.		
"	"	1890	38.	14.4	20.8
"	Potatoes	1890	3.9 Dec.		
" $NaNO_3$	Oats	1889	30.8	30.8	
K_2SO_4	"	1889	21.5		
"	Grass	1889	2.3		
"	"	1890	.33	11.2	
"	Potatoes	1889	24.		
"	"	1890	7.9		
$Ca_3P_2O_8$	"	1889	30.7		
"	Oats	1889	10.1		
$CaH_4P_2O_8$	"	1889	14.3		
"	Potatoes	1889	21.1	24.9	
"	"	1890	20.		
"	Grass	1889	32.		
"	"	1890	45.4		
$NaNO_3$ and K_2SO_4	Potatoes	1890	31.7		
" "	Barley	1890	16.7	20.7	
" "	Oats	1889	13.7		
" and $CaH_4P_2O_8$	Potatoes	1890	20.		
" "	Oats	1889	37.9	—	
$(NH_4)_2SO_4$ and "	Potatoes	1890	11.2	11.2	
" and K_2SO_4	"	1890	4.2	4.2	
$NaNO_3$ and $Ca_3P_2O_8$	"	1889	5.		
" and $CaH_4P_2O_8$	Barley	1890	14.4		
" "	"	1890	50.		
K_2SO_4	Oats	1889	21.5		
" "	Barley	1880	56.	48.1	
" "	"	1880	66.9		

Fertilizer.	Crop.	Year.	Per Cent. Increase.	Average
K_2SO_4 and $NaNO_3$	Grass	1889	65.3	
" "	"	1890	155.8	
" "	Potatoes	1889	23.	
" "	"	1890	61.2	75.6
" "	Oats	1889	43.3	
" "	Barley	1890	73.1	
" "	"	1890	107.7	
" $(NH_4)_2SO_4$	"	1890	81.1	
" "	Potatoes	1890	8.	36.7
Farm manure	"	1889	65.5	
" "	"	1880	38.7	52.1

Table I shows that the increase from

Nitrates used alone	averaged	17.4
Ammonia "	"	14.4
Nitrates and Ammonia	"	20.8
Potash	"	14.2
Phosphates	"	24.9
Nitrates and Potash	"	20.7
" " Phosphates	"	25.4
Ammonia and Potash	"	4.2
" " Phosphates	"	11.2
Potash and Phosphates	"	48.1
Nitrates, Potash and Phosphates	"	75.6
Ammonia, " "	"	36.7
Farm Yard Manure	"	52.1

Of the three constituents, Phosphates gave the largest yield when used alone, Phosphates and Nitrates the largest yield of the two combined on potatoes, and Phosphates and Potash the largest yield on grains.

Nitrates gave better results than Ammonia, either alone or in combination with the other fertilizers.

These experiments have extended over about twenty-five acres of the farm, and have been repeated a number of times.

They seem to indicate that—

Our soil has a similar composition over the entire farm;

All the above constituents when applied increase its fertility;

Phosphates appear the most useful;

Nitrates are more valuable than ammonia

It depends upon the crops as to the proportion of the different constituents to apply.

Further tests are required to show—

What constituents the respective crops require;

The effect of continued application of the three different fertilizers to the same soil;

To confirm or correct indications.

Nothing has been said of the relative profit of these fertilizers, as that has nothing to do with the problem before us. Some of them were, however, extremely profitable.