SOIL FERTILITY

Its Economic Maintenance and Increase

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DIVISION OF CHEMISTRY

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SOIL FERTILITY

ITS ECONOMIC MAINTENANCE AND INCREASE*

AN ADDRESS TO FARMERS' INSTITUTE WORKERS

BY

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We are again called upon to take part in an education campaign, with the view of increasing the output of our agricultural products. It is in this most practical way, the larger production of foodstuffs, that many a Canadian farmer can, in these troublous times, very materially assist the Empire. It is thus that he can " do his bit " and " serve his King and country."

INCREASED PRODUCTION

In this campaign we are not so anxious to urge upon our farmers an increase in the acreage or area to be put under crop as to obtain a larger yield from the acreage at present under crop. We think that those who are engaged in this campaign should have that point well in view, and we might say with regard to that phase of the question there is plenty of scope for improvement in Canada. We realize, speaking generally, that our crop yields are very much below what is possible, probably in many cases below what is profitable: not merely below the maximum, but below a decent average. There is plenty of margin for improvement in that regard, and I think our energies, at the present time, should be more particularly bent in the direction of urging our farmers to bring up the average of the yield rather than to extend the acreage to be put under crop, although there are places where both may be necessary and desirable.

We have been terribly wasteful of plant food, especially in the Northwest, where farming has been likened to mining, and it is by sounding a note of warning for the future that we should endeavour to get our farmers to maintain and increase the fertility of our soils, and by better, more rational methods, to put a stop to that waste. This warning is necessary in Ontario and Eastern Canada. We must not blame the farmers too much for using methods, if such they can be called, that have impoverished their soil. We have now, however, arrived at that stage where we can change from the extensive to intensive farming. And we must change. It is going to be easier, more profitable, for the farmer to get 60 bushels from one acre than it will be for him to get 30 bushels per acre from two acres; of course this is a very rough and ready illustration, but it will convey the idea I wish to bring forward, viz., that on many farms there will be more profit coming to the farmer from the extra increase in his yield than by putting more land under tillage. Consequently in this present campaign we must place a great deal of emphasis upon this matter of increasing the soil's fertility. We

* The material used in this address has been largely taken from the "Evidence" given by the writer before the Select Standing Committee on Agriculture and Colonization of the House of Commons, 1915. This "Evidence" is not available for general distribution.

must not tell farmers that the yields are absolutely, entirely and exclusively dependent upon, the plant food in the soil, or even upon the available plant food in the soil; there are other factors, the moisture in the soil, the temperature and a number of other conditions which go to make the crop a success or failure. Nevertheless, the amount of plant food in the soil which is available is a prime factor in determining the yield. That is the question to emphasize, we urge our farmers as a fundamental proposition to increase the plant food in the soil by every legitimate, economic means, and we will now discuss some of our teachings in that direction. Thorough tillage, the growing of legumes, more manure and its care and proper application; these are the means at our command.

FARMYARD MANURES

All our work has emphasized the value of farmyard manures as the most effective fertilizer that we can apply. The explanation, we think, is readily found. We make this statement that manure has a greater productive value than can be attributed to it from the plant food that it contains, than is indicated by its percentages of nitrogen, phosphoric acid and potash. Commercial fertilizers are bought, or ought to be bought, on the basis of nitrogen, phosphoric acid and potash that they contain. If we know the percentages of these in the fertilizer, and their availability, and we know the market price of these materials, we can calculate the exact value of the particular brand and say it is worth $25 or $35 a ton. We may take a sample of the manure and analyze it. We ascertain the percentages that are present of these various plant foods, and from them we calculate that at the present time such a sample of barnyard manure should be worth, say, $2.50 a ton. Then this manure has a greater value than can be attributed to it from the amount of its plant food content, that is, over and above $2.50 per ton.

MANURE A SOURCE OF HUMUS

The explanation is that manure furnishes humus-forming material. It is not necessary, perhaps to go into any lengthy definition of humus. Humus, for our purposes, is simply semi-decomposed organic matter, and it is probably the most valuable of all our soil constituents.

HUMUS A SOURCE OF NITROGEN

We find that all our virgin soils of extraordinary richness and fertility are well supplied with this vegetable matter, this humus-forming material, and soils exhausted by cropping and irrational systems of farming have had this material dissipated, destroyed. Moreover, humus is important because it is the storehouse of nitrogen. Nitrogen is an important element of plant food, not merely because it is essential to the life of the plant, but because it is a very expensive form of plant life when we have to buy it for fertilizing purposes, something like three times the price of phosphoric acid and potash, weight for weight. When the humus is burned out of the soil by irrational methods of farming the nitrogen goes with it, for this humus is nature's guardian for this important element. We have, therefore, to consider the humus content of the soil as indicating in a very large measure its relative fertility.

PHYSICAL EFFECTS OF HUMUS

Further, humus has a very remarkable influence upon the mechanical texture of the soil. As we said a moment ago, the fertility of the soil does not depend altogether on the amount and availability of the plant food present;

productiveness depends in a large measure upon the physical or mechanical condition of a soil. It must offer a very comfortable, or convenient and suitable, medium for the germination of the seed and for the growth of the young and tender rootlets and the extension of the root system. It must also be well ærated, and it must hold moisture. Well, in a word this humus material in the soil has all these functions, the bringing of the soil into a right condition of tilth; humus or semi-decayed organic matter makes a soil a comfortable medium for the growth of crops. We have to house our families and our live stock. It is the same with our crops. It is not merely the plant food that is essential, but we must have the soil comfortable for them to live in or they will not thrive.

BIOLOGICAL EFFECTS OF HUMUS

Then there is another matter: humus supports the microscopic life of the soil. We understand now from recent researches that the soil is crowded with micro-organisms, bacteria, and these perform a very useful function. Their prime function is to convert unavailable plant food into available forms for crop use. They feed on this humus-forming material, provided the soil is warm, moist and well ærated. The more vegetable matter (humus) we can give them the more they thrive and develop. It follows that the more available plant food we have in the soil the larger will be our crop yields, speaking roughly, other things being equal. So that it is evident there are many useful functions that this humus material has to perform in the soil. Apart from the purely chemical one of plant food, it has a biological function in supporting the life of the soil, and it has the physical function of improving the tilth. These are the reasons why we say that manure has a greater value than might be indicated, by its percentages of plant food, and that is really the fundamental difference between manure and fertilizer. Manure furnishes a large amount of this humus-forming material; and, more than that, it supplies with it the elements for these soil bacteria to live on and to transform into food useful for farm crops.

MANURES ON MUCK SOILS

Farm manures are teeming with bacterial life, and it is for this reason chiefly, I believe that we have found it a successful practice to apply manure to muck soils. Muck is very largely semi-decayed vegetable matter. It looks like carrying coals to Newcastle to put more organic matter on such soil, but nevertheless we do find that even small amounts of barnyard manure are very useful at the outset in reclaiming these muck soils. Why? Partly because the plant food in the muck is not in an available condition, and there is a certain percentage of plant food in manure in an active, readily soluble and available condition. I believe, further, that the value of manure follows from what we may term an inoculation of the soil, the seeding of that soil with germs, with bacteria, and these cause a further breakdown of the components of the soil that will render the plant food of the muck soil available for crops. Consequently we believe there is a strong line of demarcation to be drawn between manures on the one hand and fertilizers on the other; this knowledge will make plain to our farmers why manure is undoubtedly, and must necessarily be, more effective than fertilizers.

FREQUENCY OF APPLYING MANURE

The next deduction we made from our work was that there is a value in frequency of application. The reason for that is this: There is a natural destruction or dissipation of the organic matter in the soils from the oxidation and chemical reactions following the tilling, the cultivation of the soil, which results in the loss more or less of this organic matter from the manure. We have found, for instance, that when we first till our rich soils in the Northwest, there is for the first five years or so a very heavy destruction of humus material. As we proceed we reach a minimum, or at least a limit, below which the destruction of the humus becomes slower and slower. There is, however, always a loss; good farming methods seek to constantly replenish the soil with humus and plant food. The point is, the richer we have our soils by the addition of manure the larger will be the inevitable loss due to natural farm operations. There is a limit to which we can enrich our soils, and that limit is determined probably by climatic conditions, and partly probably by soil conditions; there is a limit beyond which it would not pay to put plant food in the soil. We believe, therefore, there is a great economy in frequency of application, for thereby we reduce the natural waste of fertility. On light soils there is a greater waste from those natural processes than in heavy soils, heavy soils being more retentive and more conservative than light soils; to put in concrete form, we believe that 5 tons per acre every third year will give a better return than 10 tons every sixth year, simply because there will be less loss. Of course, the question of labour has to be considered in a matter of this kind; but having grasped the principle the farmer will be prepared to plan his work towards carrying it out in some degree at least. We think you may get some idea from this argument as to the reasons for our advice in this matter. It is briefly that comparatively small applications at short intervals are more effective than larger dressings applied less frequently.

POSITION OF MANURE IN THE SOIL

We may now pass on to another point: that is, in regard to the position of manure in the soil. The larger number of the feeding roots of most of our crops lie fairly close to the surface; at least, that is, in humid districts. In arid and semi-arid countries there is a tendency for the roots to go down after moisture, and we may have, as I have seen in certain portions of this country, a dry earth mulch of six or eight inches in which there will be no feeding roots, or practically none. The roots of plants take in their food in the form of a solution, and therefore the roots must go down to water to get their food. Speaking of Eastern Canada, where there is an ample precipitation, usually, and this fairly well distributed throughout the season, we find the larger number of the feeding roots fairly close to the surface, say within the first six inches of soil. If such is the case, we want the food where the feeding roots are, where the moisture is; and consequently, we do not think there is any economy in deeply burying the manure. There will be a larger return from a limited amount of manure by lightly turning it under, or by merely carrying it into the prepared surface, as by discing, than by burying it by deep ploughing. Of course, there are soils which need deepening, and that should be done gradually; and there is no doubt that the deeper the surface soil is the better condition the soil is in to conserve moisture. But we have to consider that we have only a limited amount of manure—and unfortunately it is in all too small quantities on the majority of our farms—and we have to make the most of it. Consequently, we think it is a more profitable practice to keep the manure comparatively near the surface.

FRESH VERSUS ROTTED MANURE

We may now take up the question of fresh versus rotted manure, and we have made very careful and thorough experiments with regard to that phase of the subject. The results at first sight may seem very surprising, and difficult to explain, because we say that, weight by weight, our fresh manure has given yields almost equal to those obtained from rotted manure. It seems a remarkable result, but nevertheless it must be true, because we have tried it over and over again. We do not mask the fact that rotted manure, weight for weight, contains more plant food than fresh manure. That is, a ton of rotted manure will contain more plant food than a ton of fresh manure, and it is very easy to understand why this is the case; yet, nevertheless, when you make a practical field test you find that the yield from a ton of fresh manure is almost equal to the yield from a ton of rotted manure. Now many explanations could be advanced, but I am not quite sure that I could make those explanations altogether satisfactory to you because I do not know that they are altogether satisfactory to myself. I think there are various reasons for the fact, for fact it is. I think that possibly chemistry, biology and physics all play some part in this matter, but as practical farmers all we need is to realize is that this conclusion regarding fresh manure is correct. We do not seek to make our farmers scientific men; all that we want to do is to induce them to work on scientific principles, and to apply those principles discovered by experiment as far as they may be able. We trust they have confidence in our ability and in our rectitude and will accept this fact.

LOSSES FROM MANURE

We have done a considerable amount of work of a very careful character with regard to the changes that take place in the rotting of manure; we have traced the losses which inevitably follow, and we have determined these losses under various conditions. We know very well, as everybody else knows who has done any experimental work on this important problem, that it is impossible to rot manure without some loss, even under the very best conditions. Further, we undertake to say that on the ordinary Canadian farm, and I believe we are conservative in this, where the manure is not at once utilized by being put into the soil, or on to the soil, the farmer is losing one-third of the initial value of that manure. We have studied the various methods of rotting manure, and we have come to the conclusion that the losses are least where the manure is kept compact and protected from rain. These are the indispensable conditions. The more manure is opened up and turned the greater will be the bacterial activity and the greater will be the loss—the loss of organic matter largely and the loss of nitrogen; there are very serious losses in these constituents due to excessive fermentation. On the other hand, where the manure is not protected from rain, we have losses from leaching, and those losses are chiefly in potash and nitrogen. Taking it all in all, we doubt very much whether the farmer who does not spread his manure on his fields as far as may be possible where the weather and the condition of the soil permit, who does not utilize his manure by getting it into the land or on the land as soon as possible, does not lose from one-third to two-thirds of the plant food originally contained in that manure. If he can get his manure on to his fields while still fresh he may return to his soil seven-tenths of the plant food taken from the soil by the growth of his crops. We have never discovered any method which will prevent loss. The changes begin immediately after voiding, especially in the liquid or urine portion, which is highly nitrogenous, and therefore easily susceptible to decomposition. It should be impressed upon our farmers that this liquid portion is much more valuable than the solid part, not merely because its plant food is soluble and immediately available. After the urine has been in the stable for a few hours you may notice that the atmosphere smells strongly, and if you were to examine it you would find it contained ammonia, derived from the decomposition of the urine. Just as soon as the urine is voided, if the conditions are favourable, bacterial life becomes active and ammonia is evolved.

It is not necessary to quote our work exclusively, but referring to the experiments of others who have worked more extensively than ourselves on this problem, it has been found utterly impossible to save all the plant food which is contained in manure, no matter what system of rotting is followed. The sooner, therefore, that it is got into the soil the better. It will be apparent that when the manure is thrown out into the barnyards, and allowed to lie unprotected, the losses must be very large; and I am quite sure that I am well within the limits when I say that under such conditions there is from one-third to two-thirds of its plant food lost, apart from the loss of its humus-forming material by fermentation. So that brings us to the point that manure has no greater value than at the moment of its production; there is no doubt that its initial value represents its maximum value. Of course, we must be prepared to admit that for certain purposes rotted manure is more desirable than fresh manure; these are special cases. On the other hand, there are soils for which fresh manure is better than rotted manure, as for instance a heavy clay soil. But the point we want to emphasize with the farmers in this campaign is, that the manure in ordinary farming is never of any greater value than it is at the moment of its production

NATURE AND COMPOSITION OF MANURE

No farm product is so variable as manure, the composition and value of which depend on a great many factors. Among these are the kind, age, function and food of the animal producing it, the quantity and nature of the litter employed and, last but not least, the care taken in its production and preservation.

The analysis of a large number of samples of fresh horse and cow manure from animals well fed and bedded with sufficient straw to hold all the liquid excreta, gives the following average figures per ton: Nitrogen, 10 pounds; phosphoric acid, 5 pounds; potash, 10 pounds.

The following table states in approximate terms the relative proportions of solid (dung) and liquid (urine) excreta and bedding found in fairly well made manures of the more common farm animals. It also gives the amounts of nitrogen, phosphoric acid and potash in these compounds.

The data express percentages and pounds per ton.

APPROXIMATE AVERAGE COMPOSITION OF MANURE (FRESH) FROM VARIOUS ANIMALS.

Kind of Animal	Relative proportions of solid excrement, liquid excrement and bedding in manure	Lbs. per ton	Nitrogen		Phosphoric Acid		Potash	
			Per cent	Lbs. per ton	Per cent	Lbs. per ton	Per cent	Lbs. per ton
Horse	Solid excrement	1,200	0·55	6·60	0·30	3·60	0·40	4·80
	Liquid excrement (urine)	300	1·35	4·05	tra	ce.	1·25	3·75
	Bedding material	500	0·50	2·50	0·15	0·75	0·60	3·00
	Total mixture	2,000	0·60	13·15	0·22	4·35	0·58	11·55
Cow	Solid excrement	1,260	0·40	5·04	0·20	2·52	0·10	1·26
	Liquid excrement (urine)	540	1·00	5·40	tra	ce.	1·35	7·29
	Bedding material	200	0·50	1·00	0·15	0·30	0·60	1·20
	Total mixture	2,000	0·57	11·44	0·14	2·82	0·49	9·75
Pig	Solid excrement	990	0·55	5·44	0·50	4·95	0·40	3·96
	Liquid excrement (urine)	660	0·40	2·64	0·10	0·66	0·45	2·97
	Bedding material	350	0·50	1·75	0·15	0·42	0·60	2·10
	Total mixture	2,000	0·49	9·83	0·30	6·03	0·45	9·03
Sheep	Solid excrement	1,206	0·75	9·04	0·50	6·03	0·45	5·43
	Liquid excrement (urine)	594	1·35	8·02	0·05	0·30	2·10	12·47
	Bedding material	200	0·50	1·00	0·15	0·30	0·60	1·20
	Total mixture	2,000	0·90	18·06	0·33	6·63	0·95	19·10
Poultry	Solid and liquid excrement	1,900	1·00	19·00	0·80	15·20	0·40	7·60
	Bedding material	100	0·50	0·50	0·15	0·15	0·60	0·60
	Total mixture	2,000	0·97	19·50	0·77	15·35	0·41	8·20

Nearly ninety per cent of the total potash excreted by the cow is to be found in the urine, and this, in addition to the fact that one-half or more of the total nitrogen excreted is also present in the liquid excreta. It thus comes about that, weight for weight, urine has a greater manurial value than the solid excrement, and this not only by reason of its larger percentages of potash and nitrogen, but because these constituents are in a soluble condition and practically at once available for the nutrition of crops.

MANURIAL VALUE OF CLOVER

Looking to the question of increasing the fertility of the soil, it is important that we understand the manurial value of clover. I do not know of any institution that has done the same amount of work in the laboratory and in the field with the legumes as the Experimental Farms, and all our work has been eminently satisfactory. Farmers must be made aware of the unique property of the legumes in that they are able to appropriate the atmospheric nitrogen. This they are not able to do of themselves but through the agency of certain bacteria that live in the tubercles on their roots. We have been able to show that in this way the legumes may furnish and add to the soil, when turned under, from 50 to 150 pounds of nitrogen per acre. This nitrogen is taken from the atmosphere and it is a most valuable addition to the store of plant food in the soil, vastly increasing its productiveness. Even when the crops of alfalfa are cut and used for fodder still the soils will be richer in nitrogen from growing these crops, because of the nitrogen in the root system which is left in the soil, and the larger the root system the larger the manurial value of the soil. Of all farm crops these leguminous crops alone enrich rather than impoverish the soil. All other crops leave the soil poorer in nitrogen. Some soils are without these nitrogen-fixing bacteria, and in these cases we must adopt the practice of inoculating the soil with cultures of these bacteria, which are necessary to the growth of alfalfa or clover or other leguminous crop. Soil from a field growing clover or alfalfa is an excellent inoculating medium and can be used instead of a culture. We have found, however, that in certain cases failure in the growth of clover or alfalfa has not been due so much to the absence of the nitrogen-fixing bacteria in the soil as to the unfavourable conditions of the soil; that is to say, for instance, it has been acid instead of alkaline. In such cases the application of lime or ground limestone has given beneficial results. We have been able to show during the past ten or twenty years that we can enrich the soil to a very large extent not only in nitrogen but in humus by the growing of a legume crop systematically in the rotation. If a comparison can be made (the comparison may not be strictly accurate, very few comparisons are), we think that the growth of clover in a rotation is practically equal to a good dressing of manure of say ten tons per acre of ordinary farmyard manure. I do not wish to be considered as laying that down as a definite and absolute fact, but nevertheless by the introduction of a rotation which includes clover or other legumes in districts in which legumes can be grown luxuriously, we find there is invariably a marked increase in the fertility of the soil; and we have repeatedly found an increase in crop yield therefrom equal to that which can be obtained by the use of 5 to 10 tons of barnyard manure per acre.

MUCKS, MUDS AND SIMILAR DEPOSITS

Among naturally-occurring materials of value for the improvement of soils, may be numbered swamp or black muck, river, pond and marsh muds and similar deposits from both fresh and salt water. Many of these possess a distinct manurial value and applied liberally can frequently be used to advantage in the upkeep of fertility. They are not however to be regarded as in the same class as "fertilizers"—materials furnishing notable and well marked percentages of available nitrogen, phosphoric acid and potash, but rather as amendments, furnishing chiefly semi-decomposed vegetable (organic) matter or carbonate of lime, as the case may be, with small percentages of nitrogen and mineral plant food matter for the physical and chemical improvement of the soil. As a supplier of humus-forming material and nitrogen (largely inert) swamp muck finds its chief functions and value, while the several classes of "muds" are perhaps more particularly useful for their mineral content and their influence on the texture or tilth of the soil to which they may be applied.

COMPOSTS AS A SOURCE OF HUMUS AND NITROGEN

The examination of many types of soil—clays, silts and sands—virgin and cultivated, has furnished evidence of a very emphatic character regarding the fundamental and vital importance of semi-decomposed organic matter (humus) as a soil constituent. It acts mechanically in improving tilth, lightening and mellowing heavy clays and increasing the moisture-holding capacity of all classes of soils. It supports the microscopic life of the soil, the function of which is to prepare plant food for crop use. And lastly, it is the natural storehouse of nitrogen—the most expensive of all plant foods when purchased in the form of fertilizer. One of the chief objects in view in any intelligent, rational method of soil management is the upkeep and if possible the increase of the soil's humus content. Applications of farm manures and the turning under of green crops—clover, buckwheat, rye, etc.—are the principle means of adding humus-forming materials to the soil, and these may be supplemented, cheaply and effectively by composts.

Every farm, every market garden, should have its compost heap, for such affords the most economical (and sanitary) means of utilizing the vegetable and animal refuse, indeed all forms of organic waste. To enumerate some of the materials that can be profitably used in this way: potato tops, cabbage leaves, waste straw, dead leaves, kitchen waste, old sods, the cleanings of ditches, road scrapings, muck and peat, pond and stream deposits; all these materials and many more rich in organic matter may by composting be converted into a forcing manure of very considerable value by reason of its humus content and its store of readily available plant food. In these days it behooves us to abandon our wasteful ways and utilize everything that may make the land more productive. The practice of burning all organic refuse is an exceedingly wasteful one and should only be followed when, by reason of the presence of the eggs, spores and seeds of injurious insects and plants, the composted material would be likely to disseminate disease.

The making of the compost heap is a very simple affair. It can be built up of alternate layers, of say six inches, of refuse (including swamp muck if such is obtainable) and manure, to any convenient height, covering the whole with a few inches of good soil or muck. The heap should be kept moist, that decay may proceed, but not so wet as to cause drainage from the heap. The result, in a few weeks or several months, according to the season of the year, will be a manure of very considerable fertilizing value, capable of improving both clay and sandy loams and especially useful for vegetable and garden crops.

FERTILIZERS

There are many inquiries in regard to fertilizers, their value and function. In Canada up to the present time our knowledge respecting the value of fertilizers is largely fragmentary—incomplete, if we may so term it. The whole subject is comparatively new in Canada. We have not had the length of time to ascertain what their values may be, in any absolute sense, nor have we had the number of acres on various types of soils, with different crops, under experiment with fertilizers to afford the necessary data to arrive at final conclusions. Consequently our deductions in this matter are to be regarded as tentative and provisional. Years of careful, systematic experimentation are necessary before we can hope to speak with authority on the subject. However, we are preparing for it, and we now have experiments going on with fertilizers in widely distant points in the Dominion. These experiments are being conducted, so far as we are able to make them, in a scientific and rational way. There have been experiments in Canada in the use of fertilizers which have been irregular and unsatisfactory. From these it is impossible to say in many instances what profit, if any profit, has resulted from their use.

FERTILIZERS AS SUPPLEMENTS TO MANURE

We have taken the ground that it will never be economically, even if scientifically, possible to maintain soil fertility by the exclusive use of fertilizers. Our belief is that we can use them only as supplemental to, and not as a substitute for, manure. We have obtained, if you look through our records, in many instances a very fair monetary return from the use of certain combinations. It depends partly upon the condition of the soil and crop to be grown and partly upon the combination of fertilizing material and the amounts that we use. For instance, we might find a monetary profit from using 300 pounds, per acre, of a certain fertilizer, whereas an application of 500 pounds might result in a loss. This sounds paradoxical. A farmer sometimes reasons: If a certain amount is good, more is better. Not at all. That is not the way to look at it. The point is not so much increase in the yield as increasing the profit. We have to take into consideration the cost of the fertilizer; 300 pounds of a certain fertilizer will not cost as much as 500 pounds. Now, there might be an increase if 300 pounds were used, and there might be a greater increase if 500 pounds were applied. But the difference between the increase in yield from 300 pounds and that of 500 pounds might not equal in value the difference in the price of 300 pounds and that of 500 pounds. There are many aspects to be considered. Every farmer who decides to use fertilizers should undertake some experimental work to ascertain the needs of his soil. Each experiment should have its check plot for the purpose of comparison.

We want our men to understand the requirements of their crops, to understand something in regard to the nature of their soils, and of fertilizing materials. We want them to understand first of all what rational farming means, namely, the return of a large proportion of the plant food which crops take from the soil, thus keeping up soil fertility without the direct purchase of plant food. There are only two means of doing this, one by producing manure and its right use, and the other by the growth of clovers. This I have already explained. Farmers should be taught that when they use fertilizers it must be as supplemental to all these rational means, rotation of crops, application of manure, proper cultivation of the soil, and so on. Then, we may hope, with a sufficiency of intelligence, to expect from the judicious use of fertilizers a profitable return

ESSENTIAL ELEMENTS IN FERTILIZERS

There are three elements which may be present in compounded fertilizers; when all three elements are present, we term that material a complete fertilizer. Our experiments have included trials with various forms of nitrogen, phosphoric acid, and potash, singly and in all combinations. Looking over the whole field, we conclude that in the larger number of instances where a profit has been obtained it has resulted from the application of a complete fertilizer; that is to say, from the use of a fertilizer that contained all three elements. There seem to be good reasons for such a result. My impression is that the chief function of the fertilizer is to raise the percentage of the very small amount of plant food that is immediately available for use. There is never a very large percentage of this immediately available plant food, and I think the function of the fertilizer is to increase it rather than to add to the total store of plant food in the soil, much of which is unavailable.

THE LAW OF MINIMUM

We also know this fact, that the growth of crops is limited by the percentage of plant food which is present in minimum. If there is an excess of nitrogen, an excess of phosphoric acid, but only a small amount of potash, then the growth is in proportion, and is limited by that minimum percentage of potash which is present. I think that that is probably the chief reason why it is desirable and profitable in the majority of cases to apply a fertilizer which presents all three elements, nitrogen, phosphoric acid and potash. Of course there are cases in which soil conditions or special crop requirements call for nitrogen or for phosphoric acid or for potash. For such we recommend the application that seems desirable—perhaps superphosphate, perhaps nitrate of soda, and so on. But in the majority of instances we advise a complete fertilizer, for experience has taught us that from such there is the greatest expectation of a profitable return.

MINIMUM EXPENDITURE FOR THE MAXIMUM PROFIT

The next point is that the largest profits do not always result from the largest applications. That view is not generally held, especially in the provinces of New Brunswick and Nova Scotia, where in late years fertilizer agents and others have been advocating increasing the amounts of fertilizers, particularly for the potato crop. But, as I have said, it is not a question of yields; it is a question of profits. That is what we use fertilizer for, and we have obtained the best returns, dollar for dollar, from a moderate application of fertilizer. We might say that in the larger number of cases from five hundred pounds of complete fertilizer we have got a better monetary return than from an amount exceeding that, say from eight hundred or one thousand pounds. Some people apply as much as a ton to the acre. They have, of course, increased their yield but frequently not profitably, and that is what the fertilizer is for. That is one of our main arguments in connection with the application of fertilizer. We want the farmers to find out the largest yield from the smallest application; we want them to know what they are putting on the soil, and to be able to compare profits and yields. This knowledge is valuable for their future guidance.

DOMESTIC SOURCES OF POTASH, OTHER THAN MANURE

Wood Ashes as a Potassic Fertilizer

Wood ashes are essentially a potassic fertilizer, ashes of good quality, that is, dry, unmixed with sand, etc., and unleached, containing between 4 per cent and $6\frac{1}{2}$ per cent potash, the average potash content being about $5\frac{1}{2}$ per cent. This potash is in a soluble form and hence immediately available for crop use.

In addition to their potash they contain some 2 per cent phosphoric acid and from 20 to 30 per cent carbonate of lime, enhancing their fertilizing value and making them, in a sense, an all-round fertilizer for supplying the mineral elements required by crops. And, further, they correct acidity, a condition detrimental to the thrift of most farm crops.

From 25 to 50 bushels of wood ashes per acre will furnish from 60 to 120 pounds of potash, the latter an ample dressing for even very light soils. They are not needed on heavy clay loams; indeed their use on such may destroy good tilth and do more harm than good. Their application is best deferred to spring, broadcasting preferably on a quiet damp day on the ploughed land, and incorporating in a thorough harrowing.

For clover, corn and mangels, they will be found very valuable. Especially are they beneficial for orchards and for grapes on sandy loams. For turnips, mixed with one-third to one-half their weight of bone meal, superphosphate or basic slag, they have similarly proved advantageous. But indeed there are few crops on light and gravelly soils, as also on vegetable loams inclined to be sour, for which wood ashes cannot be employed with profit.

Seaweed as a Potassic Fertilizer

Seaweed occurs on both our Atlantic and Pacific coasts (more abundantly probably on the latter) and may be collected in large amounts at little expense on many sea beaches, where it is thrown up by storms in prodigious quantities. It can also be collected in boats from rocks and from floating masses not far from the shore. There are many varieties; some are quite small, others attain large proportions, but all are valuable, though naturally differing somewhat in composition.

Seaweed is essentially a potassic fertilizer, being specially rich in potash, but it also contains notable amounts of nitrogen and other elements of plant food, so that it might be termed a complete fertilizer.

ANALYSIS OF SEAWEEDS COLLECTED ON THE ATLANTIC SEABOARD.

—	Fucus furcatus	Fucus vesiculosus	Ascophyllum nodosum	Porphyra laciniata	Laminaria longicruris
Water	63·49	88·29	75·14	79·42	88·30
Organic matter	27·93	7·61	19·30	15·15	7·15
Ash or mineral matter	8·53	4·10	5·56	5·43	4·55
	100·00	100·00	100·00	100·00	100·00
Nitrogen	0·468	0·182	0·273	0·928	0·251
Phosphoric acid	0·108	0·037	0·070	0·068	0·134
Potash	2·025	0·615	0·619	0·619	1·546

Fresh seaweed is undoubtedly a watery manure, and it is this fact, no doubt—the cartage being a more expensive feature—that limits its use to those living more or less close to the shore. A part of this useless water may be got rid of by piling the seaweed on the beach for a few days before hauling to the farm. But notwithstanding its large percentage of water, seaweed compares very favourably, weight for weight, with barnyard manure, and it has this additional value that it brings to the farm no weed seeds or insect or fungus pests.

The essentially potassic character of seaweeds is well brought out by the analyses given, but it will also be noted that they are specially high in nitrogen. The differences in composition between the varieties may in part be accounted for by the stage of growth or maturity at the time of collection, and in this connection it is interesting to note that, for several varieties, collections made during the winter have shown a higher potash content than samples taken in summer.

The manurial value of seaweed is greatly enhanced by its ready decomposition in the soil; it quickly decays, liberating its constituents in forms available for plant nutrition. It is quite unnecessary to compost it, though little loss would ensue if composting with muck or other vegetable matter which would absorb and hold the decomposition products is resorted to, provided the heap is not exposed to heavy leaching rains. The weathering of seaweed alone is a wasteful process. On the whole, the best plan is to apply the seaweed direct to the soil, with which it will readily become incorporated. It is essentially of the nature of a quick-acting forcing manure.

Seaweed can be employed for all classes of crops, though it will be found most useful for roots, vegetables and those with an abundance of foliage, since it is essentially a nitrogenous and potassic manure. It has given excellent results as a top dressing for grass lands, encouraging the growth of clover more particularly. Its composition suggests that if a more complete fertilizer is desired it should be supplemented by superphosphate, basic slag or bone meal. Seaweed gives its best returns on moderately light loams that are warm and moist, and its poorest on wet, ill-drained, or heavy clays.

Liberators of Potash

There is no substitute for potash in agriculture. It cannot be replaced in the plant's economy by soda or any other compound. But there are certain substances that act as excitants or liberators of the locked-up, inert stores of potash in the soil, and thus may be considered as indirect potash fertilizers. We shall discuss briefly two of these: gypsum and nitrate of soda.

Gypsum, commonly known in the ground form as land plaster, is a naturally occurring sulphate of lime. Although supplying lime it is of no value for the correction of acidity (sourness) of soils, for which purpose lime or ground limestone must be employed. But the furnishing of lime does not constitute its chief manurial value. It has the property of acting on the insoluble potassic compounds of the soil, setting free for plant use a part of their potash. This is its most important function, and it is this property that has made it specially beneficial as a top dressing for clover, a crop that particularly responds to potash. The application of land plaster is usually from 300 to 600 pounds per acre, which may be broadcasted on the prepared land and harrowed in.

Large deposits of gypsum occur in New Brunswick, Nova Scotia and Ontario, and as it is readily quarried and is a comparatively soft material, land plaster may be purchased cheaply—in many districts at a lower price than ground limestone.

Users of superphosphate (acid phosphate) will have no necessity to apply land plaster, since this phosphatic fertilizer contains sulphate of lime as a necessary constituent.

Nitrate of soda is a well known, highly efficient nitrogenous fertilizer. It has been shown that crops "feeding upon a neutral salt like nitrate of soda, take up more of the nitric acid than of the soda." This soda acts chemically upon the stores of insoluble potash compounds, setting free a certain amount of potash, and thus rendering it unnecessary, in a certain measure, to directly apply a potassic fertilizer. It is this liberation of soda within the soil that is the cause of the deleterious action on the tilth or texture of heavy clay loams when large and frequently repeated applications of nitrate of soda are made, for the soda has the property of deflocculating clays, making them sticky when wet and refractory when dry. We should not advise any special application of nitrate of soda to make up for the lack of a potassic fertilizer, but it is obvious from what has been stated that its use to a certain degree obviates the necessity of such an application, especially on heavy loams.

GROUND LIMESTONE, LIME AND MARL

Soils containing free carbonate of lime have for many years been recognized and classed as among the most productive; the presence of this basic material not only furnishes an element required in crop nutrition but in other ways, chemical, physical and biological, enhances soil fertility. Similarly, it has been long known that the application of lime in some form—as quick-lime, slaked lime, ground limestone (essentially carbonate of lime), marl (a naturally occurring carbonate of lime)—increases soil fertility, and especially is this true in the case of so-called sour soils.

Of late years there has been a renewed interest, from both practical and scientific points of view, of this question. Much study has been devoted and a large amount of careful investigation has been carried on towards determining the nature and cause of "sourness" in soils and the manner in which basic lime compounds correct this unfavourable quality. As a result many theories have been put forward to account for soil acidity and its correction. Many attempts, based on these theories, have been made to devise a reliable, accurate laboratory method for determining the "lime requirement" of a soil, but as yet all are more or less empirical and approximate. The fact however remains, that these lime compounds have a beneficial influence on many soils and that they can be profitably employed to increase crop yields. We further know that there are laboratory methods which can be applied to ascertain if a soil is in need of lime and to indicate, within certain limits, the amounts per acre desirable and economic to apply.

The outstanding functions of lime (including the forms slaked lime, ground limestone and marl) may be briefly stated as follows: the correction or neutralization of soil acidity commonly known as sourness—a property more or less injurious to the growth of most farm crops; the furnishing of an important element of plant food; the improvement of the tilth and structure of many types of soils and especially of heavy clay loams, making them more retentive of moisture, better ærated, more easily drained and more easily worked and better adapted to the extension of the crop's root system; the promotion of conditions favourable to the development of those microscopic organisms within the soil which as mentioned before play so important a part in the preparation of crop food from inert soil material—especially in the production of nitrates—and by encouraging the growth of clover which may add available nitrogen to the soil from the free and otherwise unavailable store of that element in the atmosphere.

Our attention has been directed to this matter of soil improvement by "liming" for some years past and it is encouraging to note the ever increasing interest in it by Canadian farmers. The practice of applying lime in one or other of the forms mentioned is extending and a considerable amount of satisfactory evidence is accumulating, especially from the eastern provinces and British Columbia, to show that it has proved beneficial and profitable; especially is this true in districts under humid conditions and in which cultivation and cropping have long been carried on, on soils naturally poor in carbonate of lime.

Our analytical work in this connection has been chiefly in the examination of soils as to "lime requirements" and in the determination of the carbonate of lime content in a number of limestones sent in for a report as to quality. These limestones, if sufficiently pure, were to be used in the preparation of ground limestone.

Marl is found in the larger number of the provinces of the Dominion, but more especially in Eastern Canada. It more commonly occurs as a deposit, varying from a few inches to several feet in thickness, on old lake bottoms and is frequently overlaid by muck—a material also useful as a soil amendment and more especially for loams deficient in organic matter.

Its preparation and application will, as a rule, be simple and comparatively cheap. Frequently it can be obtained at the cost of digging and hauling from a deposit on the farm or in the neighbourhood. Its soft and friable nature when air dried permits it being easily and uniformly applied to the land and when of the best quality its results will be found fully equal to those of ground limestone. Naturally it is variable in composition, due to the association of or admixture with clay, organic matter and foreign matter. Marls have been examined in these laboratories containing in the air-dried condition over 90 per cent carbonate of lime but there are many others of poorer quality and hence the value of a chemical analysis when considering the opening up of a deposit which would first require the removal of any great thickness of superencumbent material—in other words when the deposit of marl lies at a considerable depth below the surface.

Is Lime or Carbonate of Lime Preferable?

In settling this question the character of the soil and the desired rapidity of action should be considered.

On account of their influence in hastening the decomposition of the humus, quick-lime and slaked lime are not so desirable or safe to use on light sandy and gravelly loams as are ground limestone and marl. If lime be applied to these soils it should be in small dressings and at long intervals. Carbonate of lime (limestone and marl) is much milder in its action and an excess can do little or no harm.

For heavy clays or soils rich in organic matter, mucks and peaty loams, lime or slaked lime is to be preferred and may be applied in fairly large amounts. These compounds are gradually converted into carbonate of lime within the soil, but being more vigorous and active from the outset and being in finer powder than ground limestone they pass more readily into solution, thus allowing a more uniform distribution throughout the soil. As a result their influence in flocculating the clay particles and improving tilth will be more rapid. For the same reason the chemical action also of these forms is more vigorous than that of ground limestone and marl.

Acidity or Sourness

Lime and carbonate of lime combine with and neutralize the soil's acids and the excess used renders the soil slightly alkaline, a condition favourable to crop growth.

Wet, low-lying and ill-drained soils are especially apt to become sour. Soils consisting essentially of vegetable organic matter, as mucks and peat loams, are usually, though not invariably, sour. Many light upland soils are slightly acid, presumably by the washing out and leaching away of their original store of carbonate of lime or its withdrawal by many years of cropping.

In all soils, but more especially in sandy and gravelly loams, there is a tendency for the lime compounds to disappear, partly through removal by crops but more particularly by their solution (in water containing carbonic acid) and passage into the strata below the root area.

Method of Testing for Acidity with Litmus Paper

The usual test for soil acidity is blue litmus paper, which may be purchased at any drug store. It should be kept in a clean, dry, preferably wide-mouthed, well-corked bottle. When tearing or cutting off a strip of litmus paper for use, a pair of forceps or scissors should be used, as the paper is sensitive and the fingers may cause its reddening. The following test, if carefully carried out, is reliable:—

Take up, by means of a spade or trowel, a little of the surface soil from, say, half a dozen places on the area to be examined and mix well; do not handle the soil. Take a small quantity (a few ounces) of the sample, put it in a clean cup or tumbler, pour on a little boiled water and stir with a clean piece of stick or spoon until a pasty mass is obtained. Into this " mud " press, by means of a small stick or the back of a knife, a strip of blue litmus paper for about one-half to two-thirds of its length. If on drawing out the paper, at the end of fifteen minutes, the part in contact with the soil has turned red, then the soil is acid.

CONCLUSION

In concluding this review of the chief means whereby we may increase the soil's productiveness, may I say that we should point out on all occasions to our farmers the various means and agencies provided by the governments—Federal and Provincial—for the assistance of the man on the land by information, by advice and by demonstration. There is no country better provided than Canada in this respect. There is a vast amount of educational literature to be obtained for the asking and inquiries relating to agricultural matters are answered at a number of our educational institutions. Every farmer ought to be in touch with one or other of the Farms and Stations of the Dominion Experimental Farms System. If there is an Illustration or Demonstration Station in his district, he should visit it, for there he will find tried out in a very practical way the more important problems affecting the farming of the neighbourhood. Information by printed page or letter may be very valuable, but information gained by actual observation, as at an Experimental Farm, Illustration or Demonstration Station, will, in most cases, be more immediately effective. It has been at a number of these institutions that the largest average yields in Canada have been obtained; these heavy and remunerative yields are the direct result of the application of economic means for the increase of soil productiveness. Let us encourage and advise our farmers to avail themselves of their opportunities, and to adopt, as far as may be practicable, those methods which science and practice have alike shown to be rational and profitable.

PUBLICATIONS ON SOIL FERTILITY

The following publications of the Department of Agriculture relating to Soil Fertility are available on application to the Publications Branch, Department of Agriculture, Ottawa:—

Alkali Soils, Their Nature and Reclamation, Bulletin No. 4. New Series

Western Prairie Soils, Their Nature and Composition, Bulletin No. 22. New Series.

Lime in Agriculture, Bulletin No. 80. Old Series.

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