principle, by careful inquiry of the section committee and others as to the important problems significant to workers in several fields, the outstanding investigators of these problems, the groups that should be invited to cooperate with us to the end that common or borderline problems might be discussed by workers in allied fields. The new policy met with immediate and wide and hearty response.

There were, of course, other efforts by other groups in the same general direction, a breaking down of ever-narrowing barriers, a regrouping and coming together of isolated groups. The Society for Experimental Biology and Medicine has for twenty-six years been bringing together the workers in the manifold fields of experimental medicine and biology. The geneticists are coming together more and more closely each year, and breaking down the artificial walls called zoology, botany, agriculture, etc. The National Academy, the American Philosophical Society, some of the state academies, are but a few illustrations. An interesting example is the union of chemists, physiologists, pathologists and biologists with the surgeons in the Mayo Foundation. The Rockefeller Institute more completely and on a larger scale than ever before (except in war) uses every field, every tool, every facility, and by frequent group meetings attacks the fundamental problems of health and disease. The Carnegie Institution is another illustrious example of coordinated attack on the problems of science. An increasing number of university laboratories, particularly in medical schools as well as industrial laboratories, are being manned and equipped with workers and tools from the allied fields of science. There is a wholesome trend in the same direction in respect to newly organized journals. More and more are the old barriers laid low, regrouping of workers, cooperative use of tools, techniques, cooperation of workers.

In the Cambrian or Precambrian age in which so many of our schools still live, one finds evidences of the ancient separatisms, the old fear of the trespasser, the vicious codes that separate related departments and subdivisions of science, that compel uncorrelated, compartmented, often antagonistic or contradictory facts, methods and results of science.

There are a number of movements making for concerted attacks on important problems by workers in allied fields. There are examples in the drama, in archeology, in exploration, in two or three colleges, in some university laboratories, in many research institutes, in a few grammar and high schools. These are oases surrounded and overwhelmed by the blare of publicity trumpets, proclaiming the polytheism of the sciences, shouting the shibboleths of experiment, project, research, scientific method, integration, survey courses and other fine names for rather poor substitutes of the original article.

When so many ills are believed to be curable not by medicine, but by legislation, we might urge a law like the Food and Drug Act, penalizing institutions of learning which put misleading labels on their wares —a law as unenforceable as many other laws.

May the time come soon when the practitioners of science, individually and collectively as faculties, may more widely and more adequately understand the aims, the methods, the importance of experimental investigation in science, its significance in education, in citizenship. We may then hope that trustees, presidents and heads of government laboratories will cooperate more and more in providing the conditions that will make for better, more thorough methods in teaching science, when emphasis will be transferred increasingly from the search for facts and "laws" to the search for rigorous experimental procedures.

We may then hope for a better understanding of science by larger proportions of our people, expect decreasing influence of faddists and stylists, less opposition and more cooperation from the public that conditions our lives, whether legislature, press, industrial and financial leaders, publicists, medical workers, etc.

We may then hope for a more rapid cure of the ills that the individual and democracy are heir to.

SOME OBSERVATIONS FROM LIMING INVESTIGATIONS[1]

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LIMING to increase crop production has been practiced in various parts of the world from time immemorial. The practice, however, appears to have been somewhat intermittent, and in Europe, as well as in this country, many farmers have never limed. The custom of liming gave rise to some disquieting adages, such as "Liming enriches the father but impoverishes the son" and "Lime and marl without manure make both farm and farmer poor."

Soon after the advent of the agricultural experiment stations liming became a subject of investiga-

[1] Address of the retiring vice-president and chairman of Section O—Agriculture, American Association for the Advancement of Science, Des Moines, December 28, 1929.

tion. The work of the Pennsylvania and Rhode Island stations is especially worthy of mention. At the latter station, studies were made of the effects of liming on the production of both field and garden crops, and of the relation of liming to different fertilizer materials, especially ammonium sulphate in comparison with sodium nitrate. Later the stations began to investigate the effects of liming on various soil components. Crop yields showed that judicious liming was generally beneficial, but it was essential to learn why this was so. It was also essential to discover harmful effects, if such existed. The solution of the problems involved required long-continued chemical investigations, such as have been pursued for nearly twenty-five years at the Tennessee station. Investigations were begun by the writer in 1905. About 1911 they were in large part—especially those relating to the soil reactions with the mineral elements —entrusted to Dr. W. H. MacIntire, the present head of the department of chemistry. Since that time he and his associates have untiringly, and successfully, pursued laboratory studies on the subject in connection with extensive open-air lysimeter equipments. During the progress of the studies it became necessary, as is often the case, to develop dependable quantitative chemical methods. Of the methods worked out in our laboratories, three have been adopted by the Association of Official Agricultural Chemists. The lysimeters have proved of great value in the determination of the outgo of the different elements over extended periods. The importance of time as a factor is too often overlooked. The forces that produce soil changes, like the mills of the gods, grind slowly. Where the subsoil is retentive, it is only by the use of the shallow lysimeter that the outgo of either nitrogen or the basic elements from the surface soil can be determined quantitatively. This apparently simple matter was not easily established. Precedent required tanks with several feet of subsoil. It was only after a detailed study of several years with lysimeter tanks of varying depths that the need and fundamental importance of the shallow tank was fully realized. This study was begun in the earlier years, and the outgo of nitrates following various manurial treatments furnished the conclusive evidence. In the liming investigations, therefore, two sets of lysimeters were used. One set contained only surface soil; the other contained the same amount of surface soil underlaid with a foot of heavy loam subsoil. The results from the two depths were often dissimilar, for even a foot of such a subsoil materially changes the outgo. The findings, though not always revolutionary, have furnished a substantial foundation on which to base explanations of some of the chemical reactions of the soil and have suggested new viewpoints of more than local interest. This paper deals almost entirely with results from the Tennessee station, but without citation to the more than fifty articles published by the station in bulletins and scientific journals.

Certain pioneer teachers maintained that liming with burnt lime had a "burning" effect on soil humus. The question has been a subject of field investigation since 1905, and a report from the first twenty years' study has been made. In addition to field plots, cylinders sunk in the ground and lysimeters have been utilized. In the field experiments, liming with burnt lime was found to accelerate materially the outgo of nitrogen and the oxidation of humus for a few years following the application. A retardation of these processes then set in, so that in the course of eight or ten years little difference was found between the humus content of the unlimed and the limed soil. In fact, the only noticeable final effect was where all crops had been removed without either the return of vegetable matter or the production of clover and grass. In such a case the limed areas were slightly lower in both nitrogen and humus.

The study with cylinders placed in the open showed that neither the oxide nor the hydroxide of calcium exercised any determinable chemical disintegration of the humus matter of the soil prior to carbonation or silication, even when heavy applications of eight tons per acre were made. In the case of an application of two tons per acre of burnt lime, maximum carbonation took place within five days and complete silication within ten days. Magnesium carbonate was converted to silicate even more rapidly than calcium carbonate.

One of the discoveries made in the earlier part of the work was the readiness with which silica, a supposedly inert substance, reacted with carbonate of lime—CO_2 being lost and calcium silicate produced. The general conclusion was drawn that the effects of an ordinary liming with burnt lime are derived primarily from silicates. It was concluded that, for soils formed *in situ* under humid conditions, magnesium was almost non-existent except in the silicate form. It was shown also that any toxicity induced by applications of the pulverulent magnesium carbonate was necessarily short-lived. In some of the earlier studies it was found that the silicates of calcium and magnesium produced greater clover crops than their corresponding carbonates—a finding that has since been verified at several other places. Silica additions were successfully used for tobacco as a "buffer" and to eliminate toxicity induced by heavy additions of magnesia.

Soil sulphur, along with soil nitrogen, is an element in plant nutrition that may undergo oxidation, and may, therefore, be influenced by any material modification of the soil reaction or its supply of available calcium or magnesium. The effects of additions of these elements in each of several forms and at widely varying rates were thoroughly investigated over a fifteen-year period. Materially different effects were produced. The light applications of lime in all forms accelerated the outgo of sulphates. The acceleration was the greatest for the first year or two but continued in evidence throughout the period. On the other hand, the very heavy burnt lime applications retarded the outgo, not only through partial sterilization of the soil, but also by a fixation of the sulphate radical derived from both soil and rainwater. Magnesia increased the outgo at all rates of application. The increase was much the greatest at the heavy rates, and under this condition far surpassed that from lime in any form and at any rate. The experiments were carried out with two sets of lysimeters. One set contained about 7 inches of surface soil only, and the other the same amount of surface soil underlaid with a foot of a heavy loam subsoil. For a number of years the amount of sulphates leached from the surface soil alone was very much greater than that which came from the tanks containing the surface soil underlaid with the subsoil. The latter exerted a decidedly retardative effect on the outgo wherever burnt lime was applied. The same was true of the light applications of magnesia but not of the heavy applications, in which case the percolates soon became heavily impregnated with magnesium sulphate. Although the data show that liming increases the outgo of sulphates and that this increased outgo is still apparent after fifteen years, the final outcome can only be surmised. Reasoning from the effects of liming on the nitrogen outgo during twenty years of the cowpea-wheat experiments, there could be expected in the course of time a reduction of outgo due to the diminished supply of oxidizable sulphur. The data obtained are sufficient, however, to warrant the consideration of a possible sulphur shortage for plant nutrient purposes wherever liming is long practiced without sulphur additions from fertilizer or other sources. As a matter of interest and warning it may be stated that the percolation results would have been inconclusive, if not misleading, had not determination been made of the sulphate radical as well as calcium, magnesium and potassium brought by the rainfall.

The findings relative to sulphur as found naturally in the soil were amplified by a similar study for twelve years following additions of ferrous sulphate, pyrite and flour of sulphur. Where ferrous sulphate was applied to the soil, both burnt lime and magnesia increased the outgo of sulphates. Where pyrite was applied, the liming materials tended to depress the outgo. Where elemental sulphur was applied, both burnt lime and magnesia in the lighter applications and magnesia in the heavy applications accelerated the outgo. It is probable that the increased sulphur outgo produced by the liming of a humid soil comes as a result of increased oxidation of organic sulphur.

The literature of the past makes frequent reference to the supposed liberation of soil potash by liming. This appears to have been largely a surmise based on the mass-action effect that was observed when acid soils were suspended in solutions of neutral calcium salts. Plot results were available for each of several widely different types of soil on which liming experiments had been continued from seven to twenty years. The crop yields on the twenty-year field had long shown a greater potash deficiency for the limed areas. It was a question, however, whether this was entirely due to the heavier drafts on the soil potash as a result of the larger crops produced in the earlier years by the liming or in part to reduced availability of the potash. The answer to this question was furnished by the lysimeter studies. It should be stressed that in these studies no crops were grown, hence the quantity of potash in the percolates showed the influence of the various additions of calcic and magnesic materials upon the availability of the soil potash. Ten years ago the Tennessee station published the results from five years of these lysimeter experiments, which showed that in none of the soils used, with a single exception, did liming liberate potash. The exception was where enormous amounts of calcium hydroxide persisted for over two years as the result of 100-ton calcium oxide additions, and even in this case there was only a small and temporary liberation of potash. Ordinary applications of both lime and magnesia repressed the potash content of the soil leachings. The repressive effect of liming upon the solubility of native supplies of potash was likewise observed where potash was added through incorporations of red clover.

The Tennessee station's findings relative to the repressive action of liming on the availability of soil potash have recently been verified by reports from several other stations which showed a lower potash content for plants grown on limed soils. The evidence, as a whole, may be said to show that liming forces potash back into the soil, and not out of the soil as some German investigators have asserted.

The outgo of calcium and magnesium as influenced by different liming materials has been considered in lysimeter experiments for a period of fifteen years. According to the law of mass action it might be expected that calcium would displace magnesium, and *vice versa,* and it was long assumed that this is what took place. The experimental results can be very briefly stated, and are quite at variance with the displacement theory. Liming with burnt lime and high calcic limestone appreciably increased the calcium outgo and depressed the magnesium outgo. In a similar manner applications of magnesium, either as oxide or as carbonate, increased the magnesium outgo and very markedly depressed the calcium outgo. The result from liming with dolomite—a double carbonate of calcium and magnesium—is of special interest. It was found that in spite of calcium enrichment supplied by this material there followed a decreased outgo of calcium and an increased outgo of magnesium. It should be borne in mind that the sum of the enhanced outgo of calcium and magnesium was found to be nearly constant. These findings have an especial interest in explaining the detrimental effect that high-calcic limes may exert upon such a magnesia-loving crop as tobacco. They throw a new light upon many of the interpretations given to the older studies of lime-magnesia ratios.

Study of the accumulated data for calcium and magnesium outgo from economic liming in the lysimeter experiments shows that the loss of lime is too small to account for the decreasing benefit to legumes of high lime requirement. A need for reliming is therefore apparently due to changes in the form or state of the large residual fraction of added lime rather than to extensive outgo in those soils that possess good fixing capacity. It has been demonstrated to our satisfaction that after added lime is absorbed by the soil the absorption product undergoes a progressive decrease in availability. This phenomenon may be a simple "aging," using the term in the chemical sense, for which there are many analogies in the formation of precipitates that in time become increasingly less soluble.

Much has been said relative to base-interchange—a phenomenon that is of great importance in the genesis and subsequent make-up of dyke-reclaimed soils and those of arid regions. Under humid conditions Tennessee soils do not show base-interchange reactions in the zone of incorporation of calcic and magnesic materials, even in the presence of high concentrations of a neutral calcium or magnesium salt; but on the contrary they show a repressive action. On the other hand, the percolates from lime- or magnesia-treated surface soil do exert a base-interchange effect in the subsoil where the action of sulphates, nitrates and chlorides comes into play beyond the zone of contact between the soil and additions.

The writer has reserved for the close of this paper a brief discussion of a most interesting and important soil reaction which explains certain soil phenomena and also has other and unexpected applications as an important analytical procedure both in the soils laboratory and in industry. That is the formation of the ternary systems, $CaO–Fe_2O_3–CaSO_4$ and $CaO–Al_2O_3–CaSO_4$. These compounds and the reactions involved were new to soil chemistry, and their discovery is one of the more interesting achievements of the station's researches.

In connection with certain lysimeter experiments it was observed that very heavy liming—100 tons of CaO per acre—practically inhibited the outgo of sulphates for a year or two, but that this effect was not permanent. The phenomenon was studied from various angles, and finally by means of a synthetic study with pure gels, the formation of compounds of both iron and aluminum united with CaO and $CaSO_4$ was found to be the explanation. These compounds are of low solubility as long as the system is alkaline, but are readily soluble in either neutral or acid media. Further investigation showed that aqueous solution of calcium hydroxide and calcium sulphate readily attacked aluminum complexes in the soil, with the formation of the ternary compound. Afterward the reaction was utilized as the basis of a chemical method of determining the amount of reactive alumina and silica and promises much as a useful yardstick in the measurement of the colloidal properties of a soil. Industrially the discovery is valuable because an explanation is given for the disintegration of concrete under certain conditions, which had previously not been understood, and furnishes the necessary information for the avoidance of such trouble in the future.

In conclusion, the fact may well be emphasized that the soil solution is the source of all the nutrients taken up by the roots of plants. As Brazeale has said, "The plant deals with the soil solution and with the soil solution only." It is this solution that is obtained by means of lysimeters. Lysimeter findings may therefore be studied to advantage by plant physiologists and others who are interested in learning what effects manurial treatments may be expected to exert upon crop-nutrient assimilation and plant-ash content.

A DEVELOPING VIEW-POINT IN OCEANOGRAPHY

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AT the Princeton meeting of the National Academy of Sciences on November 18 last, its committee on oceanography, consisting of W. Bowie, E. G. Conklin, B. M. Duggar, J. C. Merriam, T. W. Vaughan and F. R. Lillie (*chairman*), with H. B. Bigelow, *secretary*, submitted a report on its study of the scope, economic