cathode as well as the connecting tube were illuminated. Table 1 gives values observed with a cell, the controlling tube of which was about 8 cm long and 2 cm in diameter.

TABLE 1

V	I_d	I_1	ΔI	I_1/I_d
20	1.75	44.75	43.	25.6
30	3.25	55.5	52.25	17.1
40	6.50	71.25	64.75	11.
50	16.50	94.	77.50	5.7
60	31.25	121.	89.75	3.84
80	82.50	180.	97.50	2.18
120	212.	330.	118.	1.55
160	420.	474.	54.	1.13
200	514.	532.	18.	1.04
240	555.	568.	13.	1.02
280	570.	585.	15.	1.02
320	580.	593.	13.	1.02

The first column indicates the potential difference in volts, under the action of which photoelectrons are driven from the cathode bulb, through the transparent glass tube to the anode bulb. The second column gives in arbitrary units the current I_d flowing through the tube, when only the cathode bulb alone is illuminated. The third column gives the current I through the tube, when in addition to the cathode bulb the adjacent tube is also subjected to light, causing an increased current I_1. The increase $\Delta I = I_1 - I_d$ due to illumination of the tube is shown in the fourth column. The fifth column gives the ratio I_1/I_d showing a rapid decrease with increased voltage. So, for instance, for 20 volts the current increases about 25 times when the tube is illuminated, but for 120 volts the increase is only 50 per cent. and for 200 volts only 4 per cent.

The values of I_d and I_1 plotted show two saturation curves one above the other, the one with higher values of the current corresponding to the case when the connecting tube is illuminated. The increase of current due to the latter reaches a maximum for a voltage of 100 volts corresponding to the middle part of the saturation curve. The transparent tube is much more sensitive to variations of illumination than the sensitive layer in the cathode bulb. A shadow 1 millimeter wide cast from a wire across the cathode bulb does not affect the electron current, but the same shadow cast across the transparent tube causes a perceptible decrease of the galvanometer deflection. If the connecting tube is illuminated while the cathode bulb is in darkness, the current is nearly zero. It follows that the inner glass surface contributes very little to the total current. Its action consists in facilitating the passage of electrons from the cathode bulb into the anode bulb. The increase of current due to illumination increases with the length of the transparent tube subjected to light, showing a linear relation between the values of the illuminated area and the increase of current produced by the action of light.

The effect is selective, the increase depending on the wave length as well as on the intensity of the radiating source used for the illumination of the transparent glass tube.

The behavior of the transparent tube remains similar if as a source of electrons produced at the cathode thermions are used instead of photoelectrons. Table 2 gives values for a cell the cathode of which consists of an oxide coated filament 15 mm long heated with a current of 2 amperes.

TABLE 2

V	I_d	I_1	ΔI	I_1/I_d
370	.6	27.	26.4	45.
410	9.4	75.5	66.	7.55
450	55.5	133.	78.5	2.95
490	166.	266.	100.	1.6
535	475.	655.	180.	1.38
575	1182.	1515.	333.	1.28
615	4860.	5340.	480.	1.1

The tube connecting the two bulbs was treated with potassium vapor and then by heating the deposit was removed so that no visible trace of a film was left on the glass. Applying low differences of potential, very few thermions can pass the tube from the heated cathode bulb to the anode bulb. However, when the tube is illuminated the number of electrons reaching the anode increases considerably.

Whether the source of electrons passing the transparent tube is a photoelectric layer activated by light, or a filament activated by heat, in both cases the inner surface of the tube acts like a transparent grid controlling the flow of electrons by means of a radiating source. Several devices based on this principle have been investigated.

The investigation is continued and the influence of different photoelectric substances, of wave length, of the emission of electrons at the cathode, intensity of the controlling radiating source, and the optical properties of the transparent grid is studied.

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SPECIAL ARTICLES

THE BENEFICIAL EFFECT TO PLANT GROWTH OF THE TEMPORARY DEPLETION OF SOME OF THE ESSENTIAL ELEMENTS IN THE SOIL

THE fertility of a soil is reflected in a large measure by the amounts of essential salt elements present in physiologically available form. Available elements in the soil are considered to be those which constitute part of the solutes in the soil solution, or those that may readily become so. Investigators in this field hold that these elements in the soil solution are reflected to a very large degree, if not wholly, in properly obtained aqueous soil extracts. Whether these essential elements in water soluble form are physiologically available or not is, however, a matter outside of the pale of chemical analysis, be it of soil or plant; it is a consideration determinable only by physiological experiments. But whatever may determine the physiological availability of any element, a certain minimum supply thereof is required for any unit yield of product. Whether there is a supply or not is a matter determinable by chemical analysis of the water extract of soils.

In the magnitude of supply of essential elements, or in the rate thereof, as determined by chemical analyses of the water extracts of soils, investigators have found certain important relations that throw light on the crop-producing power of soils. Among these are Hall, Brenchley and Underwood[1] who state that water extracts of soil from the Broadbalk plots varied in direct accordance with their fertilizer treatments and history of the plots. Burd[2] and Stewart,[3] working with California soils, found that the water extracts of soils yielding large crops are not only richer in essential nutrients than are soils yielding much smaller crops, but that the rate at which nutrients are replenished is greater in the more fertile soils than in those of markedly lower productive power. These investigations and those of others that could be cited are proof that so far as marked differences in crop-producing power of soils giving large or small yields are concerned, they are in no small measure accounted for by the relative supply (or rate thereof) of available nutrients in the soil.

But at times, and occurring during the most active part in the growing period of many agronomic plants, the rate of removal of the essential elements in the soil is greater than that of their replenishment. This results in a temporary depletion of some of the available elements. The question arises at this point: Is this temporary depletion of some of these essential salt elements in the soil by the growing plant beneficial or not? Is this depletion a condition that increases the crop-producing power of the soil *per se?*

It appeared to the writer that an answer (or suggestions on this matter) could be most easily obtained from the results of culture solution experiments. The method employed was to arrange experiments where one of the seven elements required by plants and supplied by the soil, namely, K, Ca, Mg, Fe, S, N and P, was lacking for various lengths of time and at different periods in the growth cycle of wheat. A large number of wheat seedlings (200 cultures of 5 plants each) were started in nutrient solutions containing all the essential elements, also an equal number of cultures were set into nutrient solutions lacking in one of each of the seven elements named. At intervals of a month, a number of the cultures grown in the complete nutrient solution were transferred to the several partially complete solutions and those of the latter to the former. Changes were made with different sets at four different periods of growth; stages of one, two, three and four months. Control cultures were those that grew in these different solutions but were not changed in the manner indicated above.

Without going into the discussion of all the results obtained, which will be fully reported in due time,[4] suffice it to say that the most striking results obtained were from those cultures that grew one month in the complete nutrient solutions and were then transferred to the culture solutions devoid of potassium, in which they completed their growth cycle. Six weeks after the transfer was made, these cultures were nearly twice as high as those grown in complete nutrient solutions. The stimulation during this time consisted of a marked increase in vegetative vigor, increase in total weight and in hastened maturity. Very little growth was made by any of the cultures started in the solutions devoid of potassium. It was only after the plants were in contact with solutions containing all the essential elements for their early growth phase that they made exceptionally good growth in this nutrient solution.

These results, unexpected from casual considerations, are, in the opinion of the writer, in accord with what actually happens in soils growing field crops (such as the common cereals), although the relationship is not apparent unless viewed in the light of results obtained in physiological experiments. Referring now to the work of Stewart, the element whose supply was most markedly depleted by the growing barley plants in the 13 soils studied was nitrogen (NO_3). The rate of depletion was much greater in the soils producing large crops than in those produc-

[1] Hall, A. D., Brenchley, W. E. and Underwood, L. M., "The soil solution and the mineral constituents of the soil." *Phil. Trans.*, 204: 179–200, 1914.

[2] Burd, J. S., "Water extraction of soils as criteria of their crop-producing power." *Jour. Agr. Res.*, 12: 297–309, 1918.

[3] Stewart, G. R., "Effect of season and crop growth in modifying the soil extract." *Jour. Agr. Res.*, 12: 311–368, 1918.

[4] The first paper on this subject is to appear in *Botanical Gazette.*

ing small crops. Furthermore, the rate of depletion was much larger in the soils having high concentrations of nitrates at the beginning of the growing period than it was in those soils where the concentration of this element was much lower. In order to understand the significance of the depletion of nitrate as bearing on the relationship above referred to, it is necessary to bear in mind certain results obtained by the writer on the growth of wheat in the simplest culture media that can be devised, namely, combinations of one-salt solutions.[5] In these culture solutions, the plants were in contact with only two elements at any time during the entire growing period, being changed from one solution to another at regular intervals in order to supply the plants with all required elements. These culture solutions experiments showed very clearly that the physiological availability of any ion is largely dependent upon a certain specific ion (or ions, depending on the plant) of opposite charge. The element of opposite charge that predominantly determines the availability of potassium for wheat is nitrate. These two elements must be present together so that either can be most efficiently used and absorbed from the solution. All other elements can be absent from the media without detriment to the availability of these two elements to the wheat plants.[6] With the physiological availability of nitrate or potassium largely dependent upon the supply of one or the other, it follows from these considerations that when nitrates are depleted in any media, water soluble potassium becomes relatively unavailable physiologically. Stewart found that the nitrate content of the 13 soils he investigated was brought to a very low level by barley plants six to eight weeks after planting and kept low for several weeks thereafter. The effect of this depletion of nitrate in soils was to render water soluble potassium relatively unavailable physiologically. This, in essence, then, simulated the experiments herein described with wheat grown in complete nutrient solutions for one month, and then transferred to a solution devoid of potassium.

Study of the results of Stewart in this light brought forth a striking correlation in the differences in the yields of produce and that of the graphs showing the physiologically available potassium for these various soils. These graphs were prepared from the data of the chemical analyses of the water extract of the soils as found at fortnightly intervals. They were constructed by taking for any interval in question the amount of potassium found, if it was less than that of nitrate, to indicate the point (for that interval) of the projected graph. But if nitrate was less than that of potassium, at any interval, then the point for the curve was determined by the amount of potassium that combined as the chemically equivalent quantity with the amount of nitrate found in the soil. As nitrates were found to be practically depleted in most soils 8 to 10 weeks after planting, it follows that this period of growth was usually sufficient to indicate the type of curve for the graph of any kind of soil. While the best curves for these graphs would be those obtained by mathematical treatment, to which the data lend themselves, nevertheless it was found that a fair approximation to these curves could be obtained by drawing a straight line through each graph in such a way as to have equal areas of the segments of each graph above and below the line. This line becomes the hypotenuse of a right angle triangle, of which one leg shows the amount of physiologically available potassium in the soil at different times as indicated on the other leg. The magnitude of yield of barley of the thirteen soils was found to correspond in direct relation to that of the enclosed acute angle indicating the slope of the hypotenuse; the steeper the slope the greater the yield. These relationships even held for small differences in duplicate plots. It is from these striking correlations that the conclusion is drawn that for barley and similarly responding plants the *crop-producing power of soils is determined in a very large measure by the rate and the state of the temporary depletion of some of the essential elements in physiologically available form from a high level by the growing plant,* the soil where this is greatest being generally the most highly productive one.

In no way do these considerations invalidate the doctrine that the difference in crop producing power of soils is in a large measure accounted for by the magnitude of supply of available salt elements they possess; the more productive soils having a larger supply than the less productive ones. But the magnitude of supply is one of the factors that determines the rate of depletion; the other (or others) is concerned in the physiology of the plant. While the removal of salt elements from the soil is a process

[5] A full report of these investigations is being prepared. Brief papers on this subject have appeared. See "On the physiological balance in nutrient solutions." *Amer. Jour. Bot.,* 9: 180–182, 1922. "Water culture experimentation." SCIENCE, 66: 421–422, 1922. "Further notes on growing wheat in one-salt solutions." *Soil Science,* 15: 69–73, 1923.

[6] From investigations now in progress, it appears that potassium and nitrate are not the physiologically paired ions for all plants, or perhaps even for markedly different processes in the same plant. Whether one pair of ions or another is "physiologically paired" or not, appears as a characteristic of groups of plants, rather than of species. Thus potassium and nitrogen (NO_3) are the physiologically paired ions for the common cereals, wheat, barley, oats, etc., but appear not to be in the case of potatoes or sugar beets.

that leads to infertility, *i.e.*, if the rate of removal exceeds that of replenishment, determined over a sufficiently long period of time to take account of the effect of different kinds of cropping and soil management, nevertheless, it also plays a very important beneficial rôle in crop production. It appears as a unique relationship of physiological requirement and soil adjustment.

It appears that these considerations briefly alluded to in this paper are some of the more important factors that bear on the much discussed problem of how to give interpretation in terms of crop production to the chemical analyses of soils. It introduces a new formula—the rate of the temporary depletion of some of the salt elements, as an expression of soil fertility. It is a formula that includes the factor of supply, or rate thereof, whose importance has been generally emphasized by soil investigators since the time of Liebig, and two new factors, that of physiological requirement and soil adjustment.

That the temporary depletion of certain available nutritive elements in the soil by plants—the very process that contains the essence of the conditions that makes for infertility and soil exhaustion—is also one of nature's most important agencies and conditions essential for large crop production, is the conclusion of this paper. The rhythmic cycle of changes in the soil to which plant processes have become adapted is characterized by seasonal accumulations and production of available plant foods. This is a condition necessary for the growth of plants, but as some of these elements become depleted, or nigh so, by plants at certain phases of their growth, the absence of these elements in turn becomes a condition decidedly beneficial to growth. It appears that the failure to recognize and evaluate the physiological significance of these changes, constituted one of the chief obstacles that beclouded an understanding of the relationship of the available nutrients in the soil to crop production.

In a paper to appear elsewhere, the writer will treat the data obtained by Stewart in the light of this formula and discuss its application in the interpretation of chemical analyses of soils in terms of crop-production.

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THE AMERICAN MATHEMATICAL SOCIETY

THE two hundred and thirty-fourth regular meeting of the American Mathematical Society was held at Columbia University, on Saturday, March 1, 1924. This meeting was preceded, on the evening of February 29, by the society's first Josiah Willard Gibbs Lecture, delivered by Professor M. E. Pupin in the Engineering Societies' Building, New York City, before a large and distinguished audience, including, besides members of the society, a number of physicists, chemists and engineers who were present by invitation. Professor Pupin's lecture, entitled "Coordination," dealt in part with certain aspects of Gibbs's work.

At the meeting of the society the attendance included 47 members. The secretary announced the election of five persons to membership.

It was decided to hold a colloquium at Cornell University in the summer of 1925. No summer meeting will be held in 1924.

The following papers were read:

The outer multiplication of integral forms: F. D. MURNAGHAN.

A modification of tensor analysis: G. Y. RAINICH.

On the electromagnetic field in general relativity theory: G. Y. RAINICH.

The remainder in Charlier's integral formulas: R. E. GILMAN.

An existence theorem: EINAR HILLE.

Proof of the instability of the motions of asteroids whose periods are one half that of Jupiter: E. W. BROWN.

Thick rectangular plates: C. A. GARABEDIAN.

Generalization of certain theorems of Bohl: F. H. MURRAY.

Functionals of closed plane curves, invariant under one-parameter groups of transformations of the plane, and generalizations: A. D. MICHAL.

An unusual type of expansion problem: M. H. STONE.

On the order of an analytic function at a singular point: M. H. STONE.

Theorems concerning the division of a plane by continua: J. R. KLINE.

Geometries of paths for which the equations of the paths admit a quadratic first integral: L. P. EISENHART.

On the complete independence of the postulates for betweenness: W. E. VAN DE WALLE.

Equivalent rational substitutions: J. F. RITT.

New proofs of two well known theorems on quadratic forms: J. F. RITT.

A characterization of a bounded continuum which forms the common boundary of two domains in the plane: R. L. MOORE.

On the relation of a bounded continuum to its complement in the plane: R. L. MOORE.

Note on Brouwer's fixed point theorem: J. W. ALEXANDER.

On the dependence of the curvature upon the electromagnetic field: G. Y. RAINICH.

R. G. D. RICHARDSON,
Secretary